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MILDOS - A Computer Program for Calculating Environmental Radiation Doses from Uranium Recovery Operations

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PREFACE

The computer program MILDOS was designed as a primary licensing and evaluation tool and is expected to provide basic input to critical licensing, regulatory and policy decisions. The current version of MILDOS was developed from version IV of the Argonne National Laboratory (ANL) computer program UDAD, (Uranium Dispersion And Dosimetry). Version IX of UDAD is documented as NUREG/CR-0553 (Momeni et al. 1979). The preparation of MILDOS was performed by staff of the Nuclear Regulatory Commission under the direction of Giorgio Gnugnoli and Dan Martin. The models and assumptions on which the MILDOS program is based are described in the U.S. Nuclear Regulatory Commission Draft Regulatory Guide RH 802-4 (USNRC 1979) and portions of the UDAD document. The user is encouraged to be familiar with the mathematical models to aid in preparation of input as detailed in Section 2.

A copy of the MILDOS program can be obtained from USNRC using the request form provided on page v, accompanied with a blank computer tape. The tape will be returned containing the MILDOS program and a sample problem. A listing of the code, and sample problem input and output will also be included.

This form should be mailed along with the reel of tape to:

James A. Shields
Mail Stop P-624
U.S. Nuclear Regulatory Commission
Washington, DC 20555

The MILDOS computer code has been prepared as an account of work sponsored or performed by the United States Government. Neither the United States nor the Nuclear Regulatory Commission, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

REQUEST FOR THE MILDOS CODE

This form should be used to request a copy of the U.S. Nuclear Regulatory Commission's MILDOS computer code for radiological impact evaluation. Please provide the following information in order to facilitate distribution:

Requestor: _____

Organization: _____

Requestor's Address: _____

Date of Request: _____

This request must be accompanied by a 2400-foot reel of magnetic tape. Unless otherwise requested, the tape will be written as follows:

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ABSTRACT

The MILDOS Computer Code estimates impacts from radioactive emissions from uranium milling facilities. These impacts are presented as dose commitments to individuals and the regional population within an 80 km radius of the facility. Only airborne releases of radioactive materials are considered: releases to surface water and to groundwater are not addressed in MILDOS. This code is multi-purposed and can be used to evaluate population doses for NEPA assessments, maximum individual doses for predictive 40 CFR 190 compliance evaluations, or maximum offsite air concentrations for predictive evaluations of 10 CFR 20 compliance.

Emissions of radioactive materials from fixed point source locations and from area sources are modeled using a sector-averaged Gaussian plume dispersion model, which utilizes user-provided wind frequency data. Mechanisms such as deposition of particulates, resuspension, radioactive decay and ingrowth of daughter radionuclides are included in the transport model. Annual average air concentrations are computed, from which subsequent impacts to humans through various pathways are computed. Ground surface concentrations are estimated from deposition buildup and ingrowth of radioactive daughters. The surface concentrations are modified by radioactive decay, weathering and other environmental processes. The MILDOS Computer Code allows the user to vary the emission sources as a step function of time by adjusting the emission rates, which includes shutting them off completely. Thus the results of a computer run can be made to reflect changing processes throughout the facility's operational lifetime.

The pathways considered for individual dose commitments and for population impacts are:

- Inhalation
- External exposure from ground concentrations
- External exposure from cloud immersion
- Ingestion of vegetables
- Ingestion of meat
- Ingestion of milk.

Dose commitments are calculated using dose conversion factors, which are ultimately based on recommendations of the International Commission on Radiological Protection (ICRP). These factors are fixed internally in the code, and are not part of the input option.

Dose commitments which are available from the code are as follows:

- Individual dose commitments for use in predictive 40 CFR 190 compliance evaluations (Radon and short-lived daughters are excluded)

- Total individual dose commitments (impacts from all available radionuclides are considered)

- Annual population dose commitments (regional, extraregional, total and cummulative).

This model is primarily designed for uranium mill facilities, and should not be used for operations with different radionuclides or processes.

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1.0 INTRODUCTION

This report describes the use of the computer program MILDOS for the purpose of calculating doses to humans resulting from uranium milling activities. It is used by the staff of the Nuclear Regulatory Commission to perform routine radiological impact and compliance evaluations for various uranium recovery operations. The present MILDOS code was developed as an outgrowth of the staff's work with version IV of the Uranium Dispersion and Dosimetry (UDAD) code developed by Argonne National Laboratory. An expanded version of the code, version IX of UDAD, is documented as NUREG/CR-0553 (Momeni et al. 1979). MILDOS uses the dispersion models of UDAD IV to determine the incremental normalized concentrations due to each source and radionuclide as a function of the meteorology. The total concentrations and dose determinations have been rewritten from that of UDAD IV to reflect the NRC's requirements.

Models are included in MILDOS to consider both point sources (stacks, vents) and area sources (ore pads, tailings areas). Release of particulates are limited to consideration of ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb. Other radionuclides are implicitly accounted for under the secular equilibrium assumption. Gaseous releases are limited to consideration of ^{222}Rn plus ingrowth of daughters. Exposure pathways of concern are assumed to be inhalation of airborne radioactive material, ingestion of vegetables, meat and milk contaminated via deposition, and external exposure to radiation emitted by airborne activity and activity deposited on ground surfaces. Liquid exposure pathways are not treated by the MILDOS code.

The dose to exposed individuals is calculated for comparison with requirements of both 40 CFR Part 190 and 10 CFR Part 20.

The Environmental Protection Agency (EPA) regulation, 40 CFR Part 190, addresses individual radiation doses from all pathways and all nuclear fuel cycle facilities combined, except exposure from radon and its daughters is excluded. The regulation 10 CFR Part 20 states that all radiation exposure be kept "as low as reasonably achievable" (ALARA). For ALARA evaluations all releases, including radon and its daughters, are considered for calculation of population doses as well as individual doses. Population doses are calculated for the region (within 80 km) of the mill center, and for the continental U.S. (from radon and its daughters only). A summary of the models and doses considered by MILDOS are described in Section 2.

The remainder of the report gives information on the computer program including input preparation, a sample problem and program design information.

2.0 PROGRAM DESCRIPTION

This section describes the purpose of the computer program MILDOS and the mathematical models used. The program calculates radiation exposure to individual and the population from releases of particulates and gases from uranium milling operations.

The physical description of the mill site includes a grid of twelve concentric distance intervals (within 80 km) and sixteen angular intervals based on the sixteen compass directions (N, NNE, etc.). Figure 2.0-1 illustrates the grid system and nomenclature. The mill center is at the center of the grid. Source and receptor locations are defined relative to the mill center by specifying distances on a cartesian grid with east represented by the positive abscissa and north by the positive ordinate. The elevation with reference to the mill center is also defined.

2.1 Source Description

Sources can be defined by the user to represent each significant radionuclide release point for the mill under consideration. The locations of the radiation sources are defined relative to the mill center on the cartesian grid system mentioned above. Typical sources include yellowcake stacks, crushers, grinders, conveyers, rod mills, fine ore blending, tailings areas and ore pads. Radionuclide releases are defined for each source for particulates and radon gas. The ^{238}U decay chain is assumed to be the only significant source of radiation for uranium milling operations. The contribution from the ^{235}U chains is less than 5% of that from the ^{238}U chain. Particulate releases are defined to include the radionuclides ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb. The gaseous releases are defined for ^{222}Rn with ingrowth of short-lived daughter products also considered. 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 equilbrium.

The time history of release for each source is defined for the life of the mill and post operational periods. 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 releases from tailings areas can be limited by wetting the piles to inhibit air suspension by wind action. Upon completion of the actual milling operation, the tailings pile is normally allowed to dry by natural evaporation until it is ready for stabilization. During this period there are essentially no releases from the ore pad or the mill. However, as the tailings pile dries radon and particulate releases from this source may increase, reaching a maximum prior to stabilization. After stabilization and reclamation of the tailings area, there should be no further particulate releases. However, small quantities of radon may continue to be released to the atmosphere for long periods.

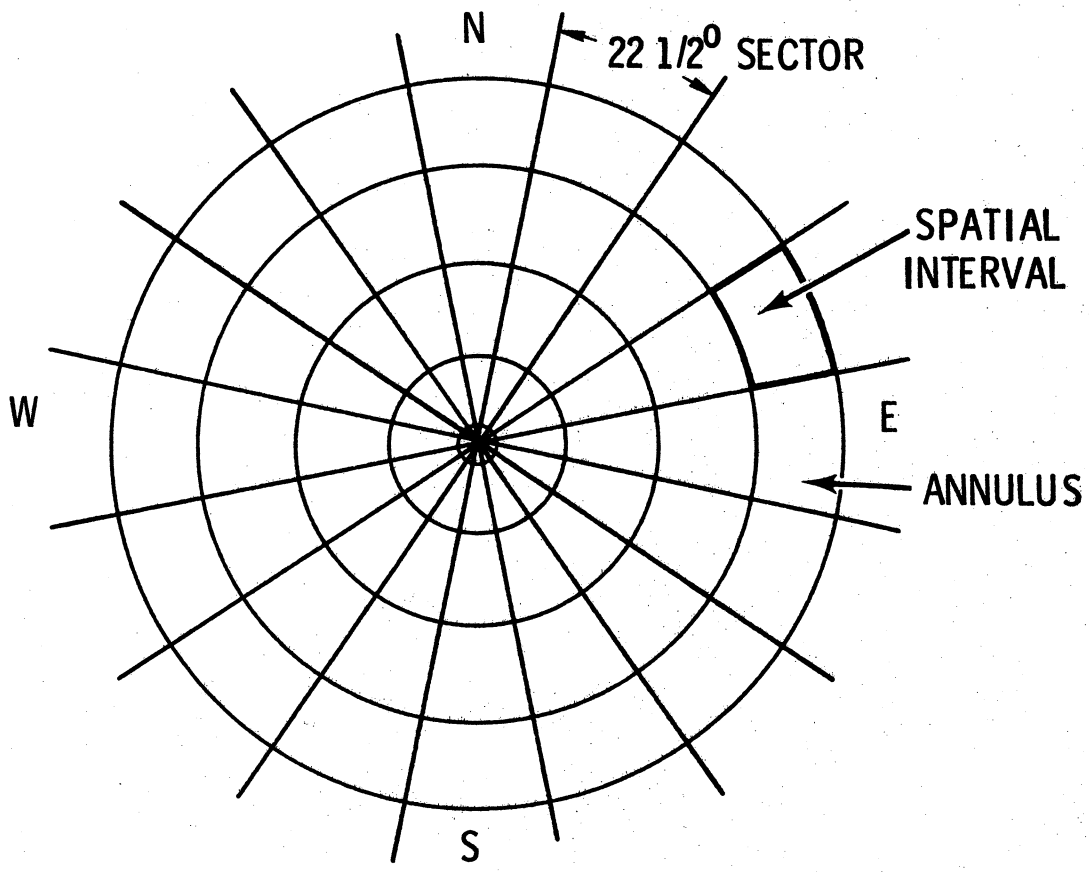


FIGURE 2.0-1 Population Dose Grid System Definition

2.2 Atmospheric Transport and Diffusion

Models for dispersion, transport, deposition and resuspension of particulates and gases in the atmosphere are given in this section. Wind suspension of tailings dust is considered as a potential source of airborne contamination. The vertical flux rate from area sources is calculated by MILDOS using the UDAD model. This model calculates the vertical flux as a function of windspeed, surface roughness, tailings density, average tailing grain diameter and tailings water content.

The equations for calculation of wind suspension of tailings material are as follows, where the vertical and horizontal flux are for particles smaller than 20 μm in diameter.

$$q_v = q_h \left(\frac{C_v}{C_h}\right) \frac{1}{u_{*t}^3} \left[\left(\frac{U^*}{U_{*t}}\right)^{(p/3)} - 1 \right] \qquad (2.2\text{-}1)$$

where

q_v • vertical flux of particulate material, gm $m^{-2} sec^{-1}$

q_h • horizontal flux of particulate material, gm $m^{-1} sec^{-1}$

C_v • coefficient of proportionality for vertical flux, 2×10^{-6} gm $m^{-2} sec^{-1}$

C_h • empirical constant to relate shear velocity to horizontal flux, 10^2 gm $m^{-4} sec^2$

u^* • shear velocity, m sec^{-1}

u_{*t} • threshold shear velocity, m sec^{-1}

p • percent of tailing mass that has a diameter smaller than 20 μm

The values of C_v and C_h are those given by Gillette (1973). The wind velocity profile near the surface is described by Bagnold (1941) as:

$$u_z = 2.5\, u_* \ln \left(\frac{z}{z_o}\right) \qquad (2.2\text{-}2)$$

where

u_z • wind velocity at height z, m sec^{-1}
z • height at which wind is measured, m
z_o • characteristics surface roughness height, m

In calculating the shear velocity u*, the ratio (z/z_o) is assumed to be constant and equal to 100.

The threshold shear velocity for the initiation of saltation is given by the following expression (Bagnold, 1941) as modified by Belly (1964) to consider the influence of moisture.

$$u_{*t} = C_t \sqrt{\frac{\rho_s - \rho}{\rho} g d} \,(1.8 + 0.6 \log_{10} W) \qquad (2.2\text{-}3)$$

where

C_t • dimensionless coefficient of 0.1 in value

ρ_s • density of particle, gm m^{-3}

ρ • density of air, gm m^{-3}

g • gravitational acceleration, m sec^{-2}

d • average diameter of saltating particle, m

W • water content expressed in weight percent

The horizontal flux is calculated by the following equation proposed by Lettan and reported by Gillette (1973)

$$q_h = C_h u_*^2 (u_* - u_{*t}) \qquad (2.2\text{-}4)$$

For u_* less than u_{*t}, the horizontal flux is taken to be zero.

The radioactivity of radionuclide i released from the tailings surface, E_i (pCi per year), is dependent on the wind speeds, their frequency of occurrence, and the total tailings area:

$$E_i = A \sum_u f_u q_v(u) \frac{I_{20}}{F_{20}} \left(3.156 \times 10^7 \frac{sec}{yr}\right) \qquad (2.2\text{-}5)$$

where

A • tailings area, m^2

f_u • frequency of wind speed u

$q_v(u)$ • vertical flux for wind speed, u, gm m^{-2} sec^{-1}

I_{20} • specific activity of radionuclide i with diameter less than 20 μm, pCi gm^{-1}

F_{20} • activity fraction of suspended particulates less than 20 μm in diameter

The specific activity for particles with diameter less than 20 μm is obtained from the bulk specific activity for all particles times an activity ratio factor, which MILDOS assumes to be 2.5.

The parameter values for estimating particulate flux from tailings piles are given in Table 2.2-1.

TABLE 2.2-1. Particulate Release Rate Parameters

Parameter	Value Used
z_o	1 cm
ρ_s	2.4 gm cm^{-3}
d	0.03 cm
W	0.1
p	3.0
F_{20}	0.5

The specific activity, I_{20}, is computed based on inputed values of bulk specific activity for each radionucide and an activity ratio of 2.5.

Atmospheric dispersion of effluents is modeled using the straight line crosswind-integrated Gaussian dispersion model. The ground level air concentration at a receptor which is downwind a distance x and crosswind a distance y for a pollutant i from a source j is given by:

$$\chi(x,y,i,j,s) = \frac{Q(i,j,y,s)}{\sqrt{\pi/2}\ \sigma_z \bar{u}\ (\pi x/8)} \exp\left(-\frac{h^2}{2\ \sigma_z^2}\right) \qquad (2.2\text{-}6)$$

where

$\chi(x,y,i,j,s)$ • ground level air concentration, Ci m^{-3}

x • downwind distance, m

y • crosswind distance, m

i • pollutant i

j • source j

s • particle size

Q(i,j,y,s) • emission rate, Ci sec-1

σ_z • vertical standard deviation of plume concentration, m

$\bar{u}$ • average windspeed, m sec^{-1}

h • effective height of plume centerline, m

$\pi x/8$ • sector width at distance x, m

The vertical dispersion, σ_z, as a function of downwind distance x is calculated using the following empirical expression (Briggs 1974; Gifford 1976).

$$\sigma_z = (ax)\ (1 + bx)^c \qquad (2.2\text{-}7)$$

The constants, a, b, and c are given in Table 2.2-2 as a function of atmospheric stability. For distances less than 100 meters from source to receptor the value of σ_z at 100 meters is used.

The effect of mixing layer height on dispersion is considered only for unstable and neutral conditions (Pasquill A-D), as stable conditions limit the plume dispersion in the vertical direction. Equation 2.2-7 is used to calculate vertical dispersion out to a downwind distance x_L, at which $\sigma_z = 0.47L$, where L is the vertical distance from the ground to the base of the stable atmosphere layer (mixing layer height). At the base of the stable layer, the concentration of the radionuclide will be one-tenth of that at the plume centerline, for the distance x_L. At distances between x_L and $2x_L$, the concentration (for non-stable conditions) is determined by a linear interpolation between Equation 2.2-6 and Equation 2.2-8.

$$\chi(x,i,j) = \frac{Q(i,j)}{\frac{\pi}{8} \times L\,\bar{u}} \qquad (2.2\text{-}8)$$

where

L • mixing layer height.

TABLE 2.2-2. Stability Class Parameters for Equation 2.2-7

Stability Class	Pasquill Type	a	b	c
1 Extremely unstable	A	0.20	0.0	1.0
2 Moderately unstable	B	0.12	0.0	1.0
3 Slightly unstable	C	0.08	0.0002	-0.5
4 Neutral	D	0.06	0.0015	-0.5
5 Moderately stable	E	0.03	0.0003	-1.0
6 Very stable	F	0.016	0.0003	-1.0

The mixing layer height L varies greatly with the season, day to day, and also diurnally. An estimate of mixing height for a given location can be made from figures presented in Holsworth 1972. The annual average height for the mixing layer L can be estimated from:

$$\frac{1}{L} = \frac{1}{2}\left(\frac{1}{L_{AM}} + \frac{1}{L_{PM}}\right) \qquad (2.2\text{-}9)$$

where

L_{AM} • mean annual morning mixing height, m

L_{PM} • mean annual afternoon mixing height, m

The average annual mixing layer is provided by the user or a default value of 1000 meters is used. For downwind distances greater than $2x_L$, Equation 2.2-8 is used to calculate concentrations.

The six wind speed categories have the following averages in miles per hour: 1.5, 5.5, 10.0, 15.5, 21.5, and 28.0.

The effective plume height, h, takes into account plume rise due to effluent momentum from a stack or vent and also vertical movement due to particle settling. The rise due to momentum is based on the model of Holland (1953):

$$h_m = 1.5 \frac{VD}{\bar{u}} \qquad (2.2\text{-}10)$$

where

V • effluent exit velocity, m sec^{-1}

D • inside diameter of stack, m

$\bar{u}$ • average windspeed, m sec^{-1}

The vertical settling is based on a "tilted plume model" where the downward movement of the plume is given by:

$$h_v = \frac{x\ V_s}{\bar{u}} \qquad (2.2\text{-}11)$$

where V_s is the settling velocity and is calculated from:

$$V_s(m/s) = 3x10^{-5}\ \rho_s d^2 \qquad (2.2\text{-}12)$$

where

d • particle diameter, m

ρ_s • density of particle, gm cm^{-3}

For settling velocities less than 0.01 meter per second, the vertical settling is ignored. The effective plume height is thus:

$$h = h_s + h_m - h_v - h_r \qquad (2.2\text{-}13)$$

where

h_s • stack height above mill center, m

h_r • elevation of receptor above mill center (negative if below mill center), m

For population exposure calculations within 80 km, the concentrations are evaluated at the midpoint of each spatial interval, and applies to all points within that sector, see Figure 2.0-1. However for individual receptor locations the concentration is weighted by the distance from the midline of the sector. This is calculated by adjusting the source strength to be:

$$Q(i,j,y) = \frac{(\frac{\pi}{8}\,x - y)}{\frac{\pi}{8}\,x}\,Q(i,j,o) \qquad (2.2\text{-}14)$$

Thus any receptor within 22-1/2° (one sector width) in either direction from the centerline of the wind direction sector receives some concentration. All other receptors receive zero. Area sources are given an additional lateral dispersion by using a "virtual point source" method. The size of the area source is provided by the user in km^2 and is then converted to a square source of equivalent area. The distance to the "virtual point", taken upwind from the area source is calculated by:

$$X_{vp} = \frac{8}{\pi}\,S \qquad (2.2\text{-}15)$$

where

S • length of the side of an equivalent square source

This distance is added to the downwind distance when calculating the sector width, see Figure 2.2-1. It is recommended by the NRC that area sources larger than 0.1 km^2 be partitioned into area sources of size less than or equal 0.1 km^2. This limits the virtual point source distance to 0.8 km or less.

For receptors that cannot "see" the entire area source, a correction factor is applied. This factor is the ratio of that portion of the square source area within the 22.5 degree sector located upwind from the receptor (assuming the receptor is on the centerline of the sector) to that of the total source area, see Figure 2.2-1.

Multiplying the concentrations by the fractional joint frequency of occurrence of wind speed, wind direction, and atmospheric stability factors in the meteorology at the site, the annual average concentration at receptor k for pollutant i from all sources j is calculated from:

$$<\chi(i,k)> = \sum_{j} \sum_{f} f\chi(x,y,i,j) \qquad (2.2\text{-}16)$$

where

f • fractional joint frequency of occurrence by wind speed, wind direction, and atmospheric stability

Plume depletion due to ground deposition is also incorporated in the calculations. This deposition is estimated using an effective deposition velocity for each particle size class. The deposition rate has been empirically defined by Chamberlain (1953) as:

$$\dot{w}_s = <\chi(s)> V_d(s) \qquad (2.2\text{-}17)$$

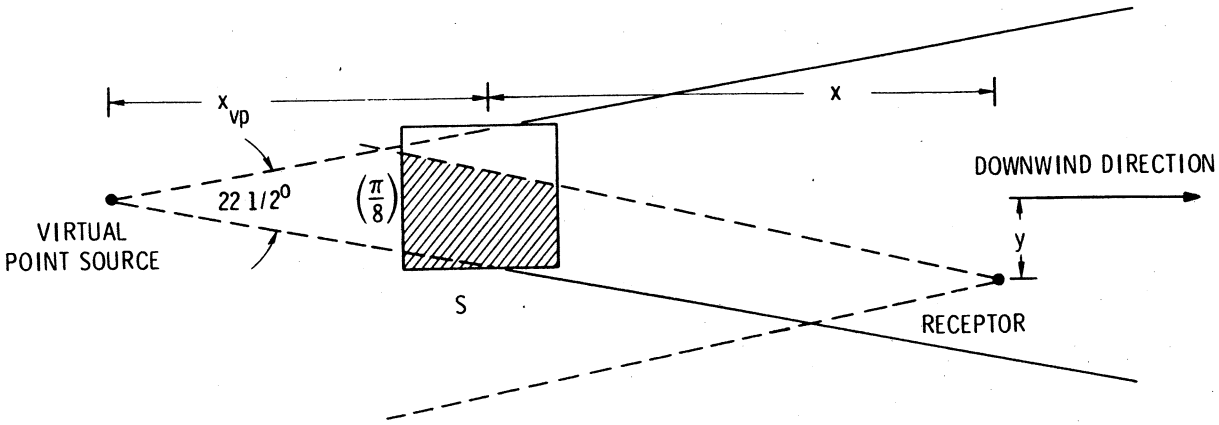
where

$\dot{w}_s$ • deposition rate, Ci $m^{-2} sec^{-1}$

$<\chi(s)>$ • average air concentration of particles of size s, Ci m^{-3}

$V_d(s)$ • deposition velocity for particles of size s, m sec^{-1}

For particles with settling velocities less than 0.01 m sec^{-1}, the deposition velocity is set to 0.01 m sec^{-1}. For particles with settling velocities greater than 0.01 m sec^{-1}, the deposition velocity is assumed equal to the calculated settling velocity, see Equation 2.2-12. Table 2.2-3 defines the particle size categories used in MILDOS and indicates the radionuclide particle size combinations for which air concentrations are explicitly computed.



S^2 • AREA SOURCE (km^2)

x_{vp} • DISTANCE FROM CENTER OF AREA SOURCE TO VIRTUAL POINT SOURCE

x • DOWNWIND DISTANCE TO RECEPTOR

y • CROSSWING DISTANCE TO RECEPTOR

Figure 2.2-1. Area Source as "Seen" by Receptor

The decrease in source strength due to deposition is calculated using Chamberlain (1953). For unstable and neutral atmospheric stability the calculations are divided into the same distance intervals as the concentration calculations, Equation 2.2-6 and 2.2-8.

$$Q(x) = Q(o) \exp \left[\left(- \frac{V_d}{\bar{u}} \right) F_1(o,x) \right] \quad \text{for } x \leq x_1 \tag{2.2-18}$$

$$Q(x) = Q(o) \exp \left\{ \left(- \frac{V_d}{\bar{u}} \right) \left[F_1(o,x_L) + F_2(x_L, x) + \frac{(x-x_L)^2}{2x_L L} \right] \right\}$$

$$\text{for } x_L < x \leq 2x_L \tag{2.2-19}$$

$$Q(x) = Q(o) \exp \left\{ \left(- \frac{V_d}{\bar{u}} \right) \left[F_1(o,x_L) + F_2(x_L, 2x_L) + \frac{X_L}{2L} + \frac{x-2x_L}{L} \right] \right\}$$

$$\text{for } x > 2x_L \tag{2.2-20}$$

where

$$F_1(x_1,x_2) = \int_{x_1}^{x_2} \frac{\exp \left[- \frac{1}{2} \left(\frac{h}{\sigma_z} \right)^2 \right]}{\sigma_z} dx \tag{2.2-21}$$

TABLE 2.2-3. Particle Size Category Characteristics and Isotope-Particle Size Combinations for Which Air Concentrations are Explicitly Computed

Particle Size Category (p)*	Diameter Range, μm	Mean Diameter, μm	Density gm cm^{-3}
1	--	1.0	8.9
2	--	1.0	2.4
3	1 to 10	5.0	2.4
4	10 to 80	35.0	2.4
5	--	--	--

Isotope-Particle Size Combinations**

i	Isotope (i)	p = 1	p = 2	p = 3	p = 4	p = 5
1	U-238	CE	CE	CE	CE	--
2	Th-234	se	se	se	se	--
3	Pa-234	se	se	se	se	--
4	U-234	se	se	se	se	--
5	Th-230	CE	CE	CE	CE	--
6	Ra-226	CE	CE	CE	CE	--
7	Rn-222***	se	se	se	se	--
8	Po-218	se	se	se	se	CE
9	Pb-214	se	se	se	se	CE
10	Bi-214	se	se	s3	se	CE
11	Po-214	se	se	se	se	se
12	Pb-210	CE	CE	CE	CE	CE
13	Bi-210	se	se	se	se	CE
14	Po-210	se	se	se	se	CE

* In this analysis particle size groups are assigned to effluents as follows: p=1 for yellowcake dust; p=2 for fugitive ore dust; p=3 (30 percent) and p=4 (70 percent) for fugitive tailings dust; and p=5 for air ingrowth concentrations of Rn-222 particulate daughters.

** The entry "CE" denotes "calculated explicitly." The entry "se" denotes "secular equilibrium"in which case the air concentration of the indicated isotope, in the particular size category, is assumed to be identical to that of the first parent for which it is explicitly calculated.

*** The air concentration of Rn-222 is also computed; Rn-222 is an inert gas and no particle size is assigned.

$$F_2(x_1,x_2) = \int_{x_1}^{x_2} \frac{(2x_L - x)}{\sigma_z x_L} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right] dx \qquad (2.2\text{-}22)$$

and

$Q(o)$ • source strength at x = o

$Q(x)$ • source strength at x

For stable conditions equation 2.2-18 is used to calculate the effective source strength. The integrals F_1 and F_2 are evaluated numerically using the fourth Newton-Cotes closed integration formula (see Section A.3.3).

With suspension of previously deposited material (resuspension) is considered as a potentially significant exposure pathway. The air concentration due to resuspension is calculated using a time dependent and particle dependent resuspension factor, which, for deposits of age t years, is defined by:

$$R_s(t) = \left(\frac{0.01}{V_d(s)}\right) 10^{-5} \exp(-\lambda_R t) \text{ for } t \leq 1.82 \text{ yr} \qquad (2.2\text{-}23)$$

$$R_s(t) = \left(\frac{0.01}{V_d(s)}\right) 10^{-9} \text{ for } t > 1.82 \text{ yr} \qquad (2.2\text{-}24)$$

where

$R_s(t)$ • ratio of the resuspended air concentration to the ground concentration, at t years after deposition, m^{-1}

$\frac{0.01}{V_d(s)}$ • ratio of minimum deposition velocity, 0.01 m sec^{-1} to deposition velocity of particle size s

10^{-5} • initial resuspension value, m^{-1}

λ_R • assumed decay constant of resuspension factor, 5.06 yr^{-1} (equivalent to a weathering half-time of 50 days)

10^{-9} • final resuspension value, m^{-1}

The annual average resuspended air concentration is given by:

$$\chi_R(x,y,i,j,s) = \chi(s)10^{-7} \left\{ \frac{1-\exp\left[-(\lambda_i^* + \lambda_R)t\right]}{(\lambda_i^* + \lambda_R)} \right\} (3.156 \times 10^7)$$

for $t \leq 1.82$ yr (2.2-25)

$$\chi_R(x,y,i,j,s) = \chi(s)\ (0.01) \left\{ 10^{-5} \left[\frac{1-\exp\left[-(\lambda_i^*+\lambda_R)(1.82)\right]}{(\lambda_i^* + \lambda_R)} \right] + 10^{-9} \left[\frac{\exp(-1.82\lambda_i^*) - \exp(-\lambda_i^* t)}{\lambda_i^*} \right] \right\} (3.156\times10^7)$$

for $t > 1.82$ yr (2.2-26)

where

λ_i^* • the effective removal constant for radionuclide i on soil, yr^{-1}

3.156×10^7 • sec yr^{-1}

Particulate daughters of ^{222}Rn (particle size 5 in Table 2.2-3) are assumed not to be depleted because of deposition and are also assumed not to be resuspended. In order to compute inhalation doses, the total air concentration of each radionuclide at each receptor (as a function of particle size) is computed as the sum of the air concentration from all sources and the resuspended air concentration.

$$\chi_T = \chi + \chi_R \quad (2.2\text{-}27)$$

Since radon has a half-life of 3.82 days, its decay during transport in the atmosphere is important. The radon source strength is corrected for radioactive decay by:

$$Q\ (\text{radon},j,x) = Q\ (\text{radon},j,o)\ \exp\ (-\lambda_r \tau) \quad (2.2\text{-}28)$$

where

Q(radon,j,o) • source strength of radon, Ci

τ • transit time = $\frac{x}{u}$, sec

λ_r • decay rate = $\frac{\ln 2}{T_r}$, sec^{-1}

T_r • half-life of radon, sec

x • downwind distance, m

The concentration of radon daughters in the air is given by:

$$\chi_n = \chi_1 \left(\prod_{i=2}^{n} \lambda_i \right) \left\{ \sum_{i=1}^{n} \left[\frac{\exp(-\lambda_i \tau)}{\prod_{\substack{j=1 \\ j \neq i}}^{n} (\lambda_j - \lambda_i)} \right] \right\} \qquad (2.2\text{-}29)$$

$$n = 2, \ldots 7$$

where

χ_1 • concentration of radon, Ci m^{-3}

λ_i • decay rate = $\frac{\ln 2}{T_i}$, sec^{-1}

T_i • half-life of i^{th} daughter, sec

n • the daughters of radon (see Table 2.2-3, p=5)

Since the half-life of ^{214}Po is so short, it is not included.

2.3 Exposure Pathways

The air and ground concentrations at each location of interest are used to calculate radiation doses to individuals and the population for the pathways shown in Figure 2.3-1 (USNRC 1979). Pathways shown in this Figure result from airborne releases of radioactivity: liquid exposure pathways are not considered because there are usually no discharges to surface waters from uranium recovery operations. A detailed description of the environmental pathway models and equations follow. Suggested parameter values are provided in reference USNRC 1979.

Material deposited on the ground is assumed to contribute to external radiation exposure and ingestion exposure from intake of contaminated food products. Inhalation of resuspended material is also included through the total air concentration term. The ground concentration is assumed to increase from the constant deposition source terms and to decrease from environmental loss of availability processes such as downward migration in soil and chemical bonding. The concentrations of radionuclide i due to constant deposition over time interval t is calculated as

$$\chi_g(i,t) = \frac{1 - \exp\left[-(\lambda_i + \lambda_e)t\right]}{\lambda_i + \lambda_e} \sum_s \chi(i,s)\, V_d(s) \qquad (2.3\text{-}1)$$

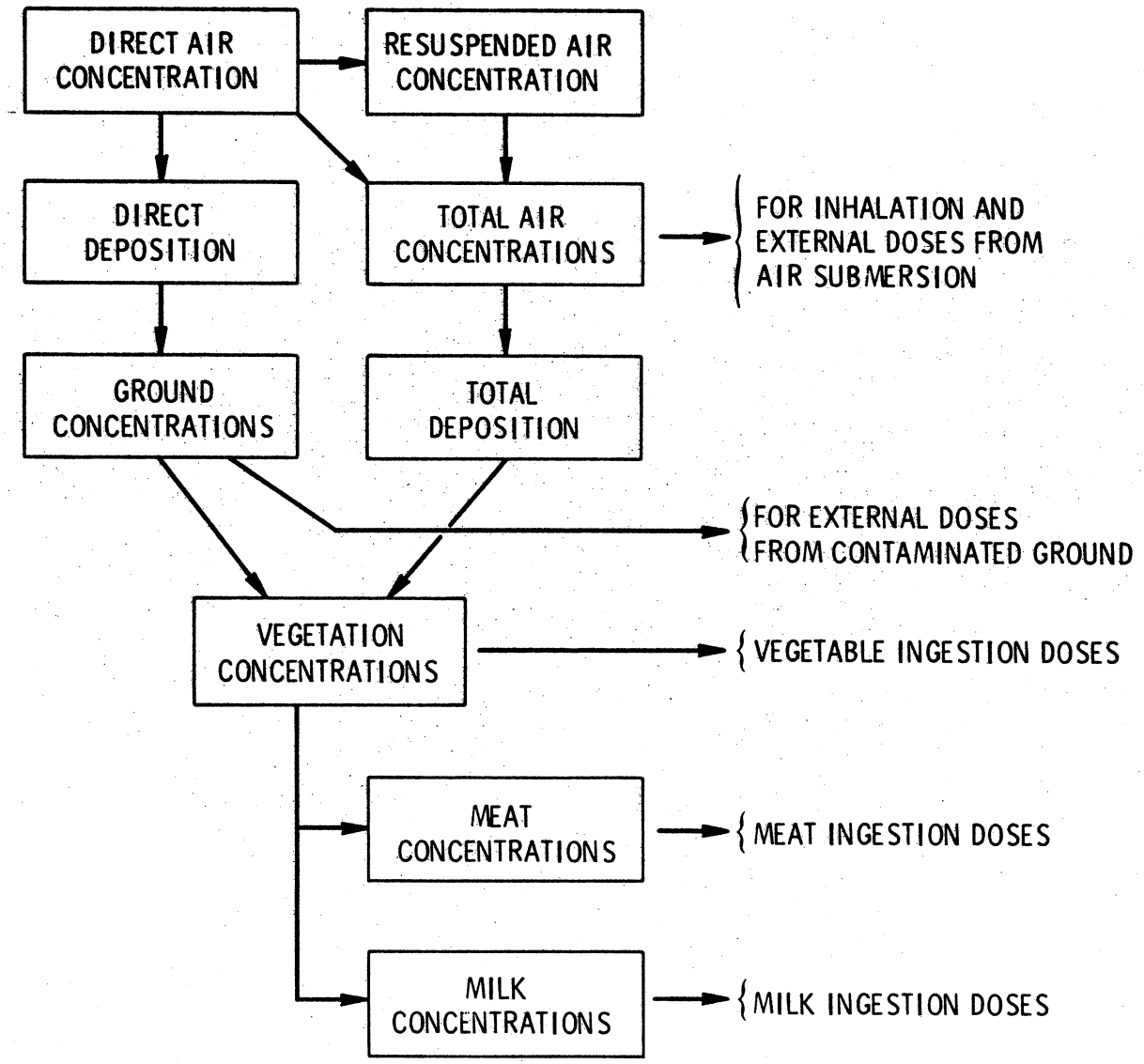


FIGURE 2.3-1 MILDOS Exposure Pathway Diagram

where

$\chi_g(i,t)$ • ground surface concentration of radionuclide i at time t, (pCi m^{-2}),

t • time interval over which deposition has occurred, sec,

λ_e • assumed rate constant for environmental loss, sec^{-1},

λ_i • radioactive decay constant, sec^{-1},

$\chi(i,s)$ • direct annual average air concentration of radionuclide i associated with particle size fraction s, pCi m^{-3},

V_d • deposition velocity of particle size fraction s, m/sec.

Environmental losses are described by a rate constant corresponding to a fifty year half-time. Resuspension is not treated as a loss term. Ground concentrations are calculated for ^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb. The incremental ingrowth of ^{210}Pb from ^{226}Ra, $\Delta\chi_g$, on the ground is calculated from:

$$\Delta\chi_g(^{210}Pb, t) = \frac{\lambda_{Pb}}{\lambda^*_{Ra}} \left\{\sum_s \chi(^{226}Ra, s)\, V_d(s)\right\} \cdot \left\{\frac{1 - e^{-\lambda^*_{Pb}t}}{\lambda^*_{Pb}} + \frac{e^{-\lambda^*_{Pb}t} - e^{-\lambda^*_{Ra}t}}{\lambda^*_{Pb} - \lambda^*_{Ra}}\right\} \qquad (2.3\text{-}2)$$

where

λ_{Pb} • decay rate of ^{210}Pb, sec^{-1},

λ^*_{Ra} • effective rate constant for loss by radioactive decay and migration of ground-deposited radium and is equal to $\lambda_{Ra} + \lambda_e$, sec^{-1}, where λ_{Ra} is the decay rate of radium and λ_e corresponds to a 50-year half-life for loss of environmental availability,

$\chi(^{226}Ra, s)$ • direct annual average air concentration of radium associated with particle size fraction s, pCi m^{-3},

λ^*_{Pb} • equals $\lambda_{Pb} + \lambda_e$, sec^{-1}, and parallels the explanation of λ^*_{Ra}.

Exposure to contaminated ground results in dose from external radiations. An occupancy factor of 100% is assumed for this external exposure pathway.

Inhalation doses are calculated from the total annual average air concentration; direct air concentration (Equation 2.2-6) plus resuspended air concentration (Equation 2.2-25 or 2.2-26).

The concentration of radionuclides in vegetation is calculated from total air concentrations and ground concentrations for five categories of plants:

- edible above-ground vegetables
- potatoes
- other edible below-ground vegetables
- pasture grass
- hay

} for meat and milk ingestion pathway only

The total deposition rate to plants for determining plant concentrations is given by Equation 2.2-17.

Vegetation concentrations are calculated as follows.

$$C_v(i) = \dot{w}_s F_r E_v \left[\frac{1 - e^{-\lambda_w t_v}}{Y_v \lambda_w} \right] + \chi_{g(i)} \frac{B_v(i)}{\rho_p} \qquad (2.3\text{-}3)$$

where

$C_v(i)$ • concentration of radionuclide i in vegetation v (pCi kg^{-1}),

F_r • fraction of the total deposition retained on plant surfaces, 0.2 (dimensionless),

E_v • fraction of foliar deposition reaching edible portions of vegetation v (dimensionless),

λ_w • decay constant accounting for weathering losses (assumed to have a 14 day half-time), (sec^{-1}),

t_v • duration of exposure while growing of vegetation v (sec).

Y_v • yield density of vegetation v (kg m^{-2})

$B_v(i)$ • soil-to-plant transfer coefficient for radionuclide i and vegetation v (dimensionless),

ρ_p • soil areal density for plowing (240 kg m^{-2}).

The value of E_v is assumed to be 1.0 for all above ground vegetation and 0.1 for all below-ground vegetables. The value of t_v is taken to be 60 days, except for pasture grass where a value of 30 days is assumed. The yield density, Y_v, is assumed to be 2 kg m^{-2}, except for pasture grass where a value of 0.75 kg m^{-2} is used.

The radionuclide concentrations in meat (beef) and milk are calculated from pasture grass and hay (stored feed) concentrations using feed-to-meat and feed-to-milk transfer factors. Consideration is also given to the fraction of the animals total intake satisfied by each feed type (grazing and stored feed). These fractions are defined by the user for calculation of both individual doses and population doses.

The equation used to estimate radionuclide concentrations in meat is

$$C_b(i) = QF_b(i) \left[F_{pg} C_{pg}(i) + F_h C_h(i) \right] \qquad (2.3\text{-}4)$$

where

$C_b(i)$ • average concentration of radionuclide i in meat (pCi kg^{-1}),

$C_h(i)$ • concentration of radionuclide i in hay (or other stored feed), (pCi kg^{-1}),

$C_{pg}(i)$ • concentration of radionuclide i in pasture grass (pCi kg^{-1}),

$F_b(i)$ • feed-to-meat transfer coefficient for radionuclide i (pCi kg^{-1} per pCi day^{-1} ingested),

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

Q • feed ingestion rate, 50 kg day^{-1}

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

$$C_m(i) = QF_m(i) \left[F_{pg} C_{pg}(i) + F_h C_h(i) \right] \qquad (2.3\text{-}5)$$

where

$C_m(i)$ • average concentration of radionuclide i in milk (in pCi ℓ^{-1}),

$F_m(i)$ • feed-to-milk transfer coefficient for radionuclide i (pCi ℓ^{-1} per pCi day^{-1} ingested).

To estimate the average media concentrations during the final year of mill operation, the value of the time parameter t in Equations 2.2-26 and 2.3-1 is set to T_o year where T_o is the operational lifetime. This gives concentration values for the end of the final year. During the final

prereclamation year exposure results from postoperational releases and residual contamination due to releases during the period of mill operation. Because there are no direct air releases during the prereclamation period, contamination results only from residual ground and resuspended air concentrations. Ground concentrations at the end of the mill operation period are calculted using Equation 2.3-1 with the value of t set to T_o, the operational lifetime. The ground concentration at the end of the final prereclamation year is then calculated as:

$$\chi_g(i,T_d) = \chi_g(i,T_o) \exp\left[-\lambda_i^* T_d\right] \qquad (2.3\text{-}6)$$

where

$\chi_g(i,T_o)$ • ground concentration of radionuclide i at the time of mill shutdown (pCi m^{-2}),

$\chi_g(i,T_d)$ • residual ground concentration of radionuclide i resulting from operational releases at the end of the T_o year drying period (pCi m^{-2}),

T_d • duration of time required to dry the tailings pile prior to reclamation (yr).

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

$$\chi_R(x,y,i,j,s,T_d) = 0.01\,\chi(s,i)\,10^{-9}(\exp -\lambda_i^* T_d)\left[\frac{1-\exp(-\lambda_i^* T_o)}{\lambda_i^*}\right](3.156 \times 10^7) \qquad (2.3\text{-}7)$$

where

$\chi(s,i)$ • direct air concentration of radionuclide i in particle size s at location (x,j) resulting from operational releases (pCi m^{-3}),

$\chi_R(x,y,i,j,s,T_d)$ • residual resuspended air concentration of radionuclide i in particle size s resulting from operational releases at the end of the T_d -year drying period (pCi m^{-3}).

2.4 Dose Calculations

Radiation doses are calculated by MILDOS for evaluating:

- compliance with 40 CFR Part 190, EPA Radiation Protection Standard
- compliance with 10 CFR Part 20, NRC Radiation Protection Standard
- overall environmental impact required by the National Environmental Policy Act (NEPA).

Doses to maximum exposed individuals are calculated to determine compliance with the CFR criteria. The NEPA evaluation also requires calculation of exposure of populations. All dose calculations consider the exposure pathways described above with one exception: the 40 CFR Part 190 evaluation excludes doses from radon and its daughters. However radon daughters (^{210}Pb specifically) produced after release of radon parents are included when significant.

Doses are calculated from air, ground and food concentrations using dose conversion factors (provided internal to the program in Block Data). The doses at a given location are calculated by multiplying the media concentration by the appropriate dose conversion factor and summing over all radionuclides of importance. Population doses are calculated as the sum of population times dose for each spatial interval. The dose conversion factors are listed in Figure C.2-1, output pages 5 and 6.

Internal dose conversion factors give the 50 year dose commitment from one year of uptake normalized to unit air concentration, (mrem year^{-1} per Ci m^{-3}). For inhalation doses, the conversion factors are calculated by the Argonne National Laboratory computer program UDAD (Momeni 1979) in accordance with the Task Group on Lung Dynamics lung model (TGLM) of the International Commission on Raidological Protection (ICRP 1966; ICRP 1972). Inhalation dose conversion factors for the lung are weighted averages over the nasopharyngeal, tracheobronchial, lymph and pulmonary regions as defined for the TGLM. Dose conversion factors are provided as a function of particle size and organ for the radionuclides ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po. For ^{222}Rn and short-lived daughters the dose to the bronchial epithelium is also calculated.

Inhalation doses are computed by the equation:

$$d_\ell(inh) = \sum_s \sum_i x(s,i)\ DCF_{i\ell s}(inh) \qquad (2.4\text{-}1)$$

where

$d_\ell(inh)$ • inhalation dose to organ ℓ, at location (x,j), (mrem yr^{-1}),

$DCF_{i\ell s}(inh)$ • inhalation dose conversion factor for radionuclide i, organ ℓ, and particle size s (mrem yr^{-1} per pCi m^{-3}).

Ingestion dose conversion factors (Hoenes and Soldat 1977) are provided for four age groups and several organs for the radionuclides ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po. These dose conversion factors are based on the ICRP Publication 2 (1959) ingestion model. The dose conversion factor for ^{226}Ra (Fletcher and Dotson 1971) is based on models recommended in ICRP Publication 10A (1971). The calculation of ingestion doses from consumption of vegetables includes a factor of 0.5 to account for loss of contamination during food preparation.

The annual radionuclide intake via ingestion is calculated as

$$I_{ik} = U_{mk}C_m(i) + U_{bk}C_b(i) + 0.5 \sum_v U_{vk}C_v(i) \quad (2.4\text{-}2)$$

where

I_{ik} • activity ingestion rate of radionuclide i by an individual in age group k (pCi yr^{-1}),

U_{mk}, U_{bk} • milk (ℓ yr^{-1}) and meat (kg yr^{-1}) ingestion rates for age group k,

U_{vk} • ingestion rate of vegetable category v for age group (kg yr^{-1}),

0.5 • the fraction of vegetable activity remaining after food preparation (dimensionless).

Ingestion doses are then computed by

$$d_{\ell k}(ing) = \sum_i I_{ik}DCF_{i\ell k}(ing) \quad (2.4\text{-}3)$$

where

$d_{\ell k}(ing)$ • ingestion dose for organ ℓ, age group k (mrem yr^{-1}),

$DCF_{i\ell k}(ing)$ • ingestion dose conversion factor for radionuclide i, organ ℓ, and age group k (mrem pCi^{-1} ingested).

The dose from external exposure to contaminated ground is calculated assuming 100 percent occupancy at a given receptor location. A structural shielding factor of 0.825 is applied to account for indoor occupancy 14 hours per day at a shielding factor of 0.7.

The external dose to an individual is given by:

$$d_\ell(ext) = 0.825 \sum_i \left[\chi_g(i)DCF_{i\ell}(gnd) + DCF_{i\ell}(cld) \ \chi_T \right] \quad (2.4\text{-}4)$$

where

χ_T • total air concentration of radionuclide i in size fraction s at given location

$d_\ell(ext)$ • external dose to organ ℓ (mrem yr^{-1}),

$DCF_{i\ell}(cld)$ • dose conversion factor for external exposure to the cloud for radionuclide i and organ ℓ (mrem yr^{-1} pCi^{-1} m^3)

$DCF_{i\ell}(gnd)$ • dose conversion factor for ground exposure for radionuclide i and organ ℓ (mrem yr^{-1} per pCi m^{-2}),

0.825 • effective reduction factor of structural shielding for indoor exposure periods.

Individual doses are calculated at each receptor location defined by the user. These locations are normally defined to represent locations where high exposures are likely. The maximum doses to individuals are usually calculated for the last year of mill operation and for the last year of tailings pile drying prior to stabilization. However, doses can be computed for any time period.

Two types of population doses may be calculated at the option of the user: the annual population dose commitment or the 100 year environmental dose commitment. The annual population dose commitment gives the dose received by the population from one year of exposure and consumption with a 50 year dose commitment period (for the material in the body from the first year's consumption). The environmental dose commitment (EDC) concept of EPA (1974) considers future exposure and consumption of residual environmental contamination. The two types of population doses are calculated in a similar manner except that total uptake for the annual population dose is calculated for one year and the total uptake for the EDC are calculated for a period of one hundred years. The radiological impacts from a given release are integrated over a period of 100 years following the release.

Population doses are calculated for the region (within the 80 km grid) for the mill operation time period and the tailings drying period (post-operational, prestabilization). These doses include contributions from particulate releases and ^{222}Rn releases. Annual population doses from transcontinental transport of ^{222}Rn are evaluated for all three mill-life-cycle time periods (above plus post stabilization).

Inhalation and external doses to the regional population are calculated by the following procedures.

- For each spatial interval of the grid doses to the average individual are calculated (based on air and ground concentrations at the interval midpoint)

- Individual doses are multiplied by the population within the spatial interval
- The total dose is then calculated as the sum over all spatial intervals.

The population dose from inhalation and external exposure in the site region is calculated by the following equations.

$$M_{\ell}\,(inh + ext) = 10^{-3} \sum_{a} P_a\left[d_{\ell}\,(inh) + d_{\ell}(ext)\right] \qquad (2.4\text{-}5)$$

where

$M_{\ell}(inh + ext)$ • population doses from inhalation and external pathways (person-rem-yr^{-1})

P_a • population residing in spatial interval a (at location, see Figure 2.0-1)

a • indicates summation at over all spatial intervals

10^{-3} • conversion from mrem to rem

The total population dose from ingestion pathways is calculated on the basis of the regional agricultural productivity rather than population. This is because the total activity in the food determines the doses rather than the number of people exposed. Ingestion population doses are calculated by the following procedure.

- The productivity rate (kg yr^{-1} per m^2) of each food category is assigned (vegetables, meat and milk) by the user.
- For each spatial interval the activity concentrations in each food type are calculated and multiplied by the production rate and the interval area to find the total activity in each food for the spatial interval.
- The total activity for the region is determined by summing over all spatial intervals.
- Population doses are determined assuming all food produced in the region is consumed by a population with the same age distribution as the U.S. population.

The population doses from ingestion is calculated by the following equations. First the gross activity in each food type is calculated by:

$$Q_{fi} = \sum_{a} G_{fa}\, A_a\, C_{fa}(i) \qquad (2.4\text{-}6)$$

where

A_a • area of spatial interval a (km^2)

$C_{fa}(i)$ • concentration of radionuclide i in spatial interval a in food type f where f represents m for milk, b for meat and v for vegetables (Ci kg^{-1} or Ci ℓ^{-1})

G_{fa} • production rate of food type f in spatial interval a (kg yr^{-1} km^{-2} or ℓ yr^{-1} km^{-2})

Q_{fi} • gross activity content of radionuclide i in food f (pCi yr^{-1})

The consumption by each age group in the population is calculated using weighting factors F_{fk} defined as follows (see Table 3.3-8).

$$F_{fk} = \frac{F_{pk}\, U_{fk}}{\sum_k F_{pk}\, U_{fk}} \qquad (2.4\text{-}7)$$

where

F_{fk} • fraction of the production of food type f ingested by individual in age group k (dimensionless)

F_{pk} • fraction of the regional population belonging to age group k (dimensionless)

U_{fk} • average consumption rate of food type f for an individual in age group k(kg yr^{-1} or ℓ yr^{-1}).

The region population ingestion dose from all food categories is calculated by:

$$M_\ell(\text{ing}) = 10^{-3} \sum_f \sum_i \sum_k E_f Q_{fi} F_{fk} DCF_{i\ell k}(\text{ing}) \qquad (2.4\text{-}8)$$

where

E_f • fraction of activity remaining on food type f after preparation for eating (dimensionless)

$M_\ell(\text{ing})$ • regional population dose to organ ℓ from ingestion (person rem yr^{-1})

Population doses to the North American continent from ^{222}Rn are calculated using estimates of population dose resulting from 1000 Ci releases from four specific locations in the western United States:

- Casper, Wyoming
- Falls City, Texas
- Grants, New Mexico
- Wellpinit, Washington

Data is contained within MILDOS for each of these sites giving the continental population dose that would result from release during the calendar year 1978. The user may select any one of the four sites as representative of the site under study or a weighted average of the four sites may be used. For projected releases in future years doses are assumed to be proportional to the U.S. population increase. The user supplies population increase factors (relative to 1978) for each time period of interest.

The regional and continental population doses are calculated on an annual basis for milling, 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 duration and summing. The total population dose to the regional and continental population is calculated by

$$M_\ell = M_\ell\,(inh + ext) + M_\ell(ing) + M_\ell(Rn) \qquad (2.4\text{-}9)$$

where

M_ℓ • total population dose to organ ℓ (person rem yr^{-1})

$M_\ell(Rn)$ • continental population dose to organ ℓ from radon (person rem yr^{-1})

A technical review of the dispersion and dose models used in MILDOS has been performed by Horst and Soldat (1981). In their document the models are evaluated to determine if they represent adequate application of the state-of-the-art in predicting environmental impacts.

3.0 PROGRAM CONSIDERATIONS

This section describes details of the computer program useful to users such as program limitations and execution time estimates. Details of the program structure are given in Appendix A. Computer specific requirements are given in Appendix C.

3.1 Program Limitations

Three major features of the calculations performed by MILDOS rely on definitions made by the user. These are definition of:

- source terms for significant releases,
- time steps for describing the mill life-cycle,
- individual receptor locations

The current version of MILDOS allows the user to define a maximum of twenty source terms, ten timesteps and forty-eight individual receptor locations.

The radionuclides considered by MILDOS are those in the uranium-238 decay series: ^{235}U, ^{234}U, ^{230}Th, ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{210}Pb and ^{210}Po. The user does not have the option to include additional radionuclides through input parameters.

3.2 Execution Time

The MILDOS program runs rapidly with typical execution times of less than 1 minute. The sample problem described in Appendix C requires about 46 seconds on the CDC 7600 computer at Brookhaven National Laboratory.

The execution time depends mainly on the type and number of sources specified and on the fraction of non-zero values given in the meteorological data set (see array FREQ in Section 4.2). Other parameters having a minor effect on execution time include the number of time steps, the number of individual receptors and output report requests. Three types of sources are generally defined in using MILDOS:

- point source with particulate release only
- point source with particulate and ^{222}Rn release
- area source with particulate and ^{222}Rn release

TABLE 3.2-1. MILDOS Execution Time Tests

Source Types							
Point, Particulate P_p	Point, Radon/ Particulate P	Area, Radon/ Particulate A	Met. Data Fraction F	Number of Timesteps	Number of Receptors	Execution Time Estimate	Execution Time Actual
1	--	--	0.49	1	1	3.4	3.31
--	1	--	0.49	1	1	7.4	7.53
--	--	1	0.49	1	1	9.8	10.16
1	--	--	0.49	6	1	3.4	4.93
1	--	--	0.49	1	6	3.4	3.64
1	2	--	0.49	3	3	18.1	16.31
--	1	--	1.0	1	5	15.0	17.40
1	1	3	0.49	3	30	40.2	37.30
1	2	3	0.49	1	1	47.5	41.96
1	2	3	0.49	6	6	47.5	45.87

Several test runs were performed to determine the effect of input parameters on execution time. Results of these tests are indicated in Table 3.2-1. This table also indicates the calculated execution times based on the following equation.

$$T = F\ (7\ P_p + 15\ P + 20A)$$

where

- T • execution time, seconds
- P_p • number of points sources with particulate releases only,
- P • number of point sources with particulate and radon releases
- A • number of area sources with particulate and radon releases,
- F • fraction of meteorological data set entries that are non-zero.

This equation gives an approximate execution time that will be within 50% (high or low) for most cases.

3.3 Data Constants

Parameters are initialized in MILDOS using a block data procedure labeled FRESH and specification statements in several subroutines. This section lists the initial values given to parameters of interest to the user. These parameters include input variables and constants used in several of the models.

The input parameters are initialized to values indicated in Table 3.3-1. This table lists the parameters which can be defined by the user through the NAMELIST input data set INDATA (see Section 4.2).

The atmospheric transport model for particulates used by MILDOS requires data on the particle size distribution and density. Table 3.3-2 lists values assumed by MILDOS for these parameters.

The exposure pathway model requires radionuclide transfer factors for vegetables, meat and milk. The vegetable ingestion pathway uses the soil-to-plant transfer factor (dimensionless). The meat and milk ingestion pathways use feed-to-meat and feed-to-milk transfer factors which relate animal intake to animal product (meat or milk) contamination levels. Values used for these parameters are defined in Table 3.3-3 (USNRC 1980).

Dose conversion factors are defined for inhalation, ingestion and external exposure pathways. Dose conversion factors are set in block data FRESH. Values for these factors are defined in Tables 3.3-4 thru 3.3-6 (USNRC 1980).

TABLE 3.3-1. Values assumed by MILDOS for NAMELIST INDATA Parameters

Parameter	Type	Initial Value in Block Data FRESH
Job Control		
IFTODO	Integer	0 (10 values)
IRTYPE	Integer	-1 (48 values)
JC	Integer	0 (10 values)
Source Terms		
FRADON	Real	0.0 (4 values)
IPACT	Integer	Not Set
NSORCE	Integer	0
PACT	Real	0.0 (12 values)
QAJUST	Real	0.0 (400 values)
SORCE	Real	0.0 (240 values)
Meteorology		
DM	Real	1000. meters
FREQ	Real	0.0 (576 values)
Food Pathway Parameters		
FFORI	Real	0.5 dimensionless
FFORP	Real	0.5 dimensionless
FHAYI	Real	0.5 dimensionless
FHAYP	Real	0.5 dimensionless
FPR	Real	0.0 (3 values)
Population Distribution		
IPOP	Integer	0 (192 values)
PAJUST	Real	1.0 dimensionless (10 values)
Individual Receptors		
IADD	Integer	0
XRECEP	Real	0.0 (144 values)
Time History		
NSTEP	Integer	0
TSTART	Real	Not Set
TSTEP	Real	5.0 years (10 values)

TABLE 3.3-2. Particle Size Parameter Values

Particulate Group	Density, gm/cm^3 PDEN	Particle Size Fraction PTS7FC Particle size (μm) 1.0	1.0	5.0	35.0
1	8.9	1.0	0.0	0.0	0.0
2	2.4	0.0	1.0	0.0	0.0
3	2.4	0.0	0.0	0.3	0.7

Intake of radionuclides by individuals via ingestion is dependent on food consumption rates. The vegetable, meat and milk consumption rates used in MILDOS (for individual dose calculations) are listed in Table 3.3-7 for four age groups: infant, child, teen and adult. Data in Table 3.3-7 is stored internally in the data array UOF in labeled common block FDATA.

For population doses the total vegetable consumption is assumed to be 78.3% from above ground vegetables, 19.6% from potatoes and 2.1% from other below ground vegetables (parameter FGBVT defined in subroutine POPDOS, Appendix B).

In estimating the fraction of the regional food production that is consumed within the region, MILDOS uses the age dependent food consumption rates shown in Table 3.3-8. The total per capita consumption values are defined in subroutine POPDOS as parameter array PCCR. The fraction of the regional production eaten by each age group for each food type is given in Table 3.3-9 (USNRC 1977). Data is defined in subroutine POPDOS as parameter array FIK.

The population dose to the North American continent from ^{222}Rn releases is based on precalculated dose estimates for 1000 Ci releases from four sites. (See section 2.4). These dose factors are given in Table 3.3-10 (USRNC 1979) and are defined in subroutine POPDOS as the array parameter RADPOP.

3.4 Error Handling

There are no tests performed on input parameters in MILDOS. The user is required to provide valid data within defined ranges for necessary parameters. An output report is prepared giving values for input parameters as read by the computer. The user should check these reports carefully to ensure that the input data was interpreted correctly. Improper definition of parameters may or may not be apparent in the results. Some errors will cause abnormal run termination while others may not be noticeable.

TABLE 3.3-3. Food Pathway Transfer Coefficients

Pathway	Transfer Coefficients by Element U	Th	Ra	Pb
Soil-to-Plant (BIV)				
Above Ground Vegetables	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 Vegetables	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	2.5×10^{-3}	4.2×10^{-3}	8.2×10^{-2}	3.6×10^{-2}
Feed-to-Beef (FBI) (pCi/kg per PCi/day)	3.4×10^{-4}	2.0×10^{-4}	5.1×10^{-4}	7.1×10^{-4}
Feed-to-Milk (FMI) (pCi/ℓ per pCi/day)	6.1×10^{-4}	5.0×10^{-6}	5.9×10^{-4}	1.2 x 10-4

TABLE 3.3-4. Ingestion Dose Conversion Factors

Age Group	Organ	Internal Dose Conversion Factors by Organ and Age, mrem per pCi ingested							
		238U	234U	234Th	230Th	226RA*	210PB	210BI	210PO
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	8.01E-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	4.90E-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 Ra-226 have been obtained from Momeni et al. (1979) and are based on applicable models and data from ICRP (1966). Ra-226 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 Hoenes and Soldat (1977). All other dose conversion factors are from Hoenes and Soldat (1977) directly.

TABLE 3.3-5. Inhalation Dose Conversion Factors

	mrem/yr per pci/m^3					
Particle Size = 0.3 Microns	PB210	PO210				
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				
Particle Size = 1.0 Microns Density = 8.9 g/cm^3	U238	U234	TH230	RA226	PB210	PO210
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
Particle Size = 1.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	PO210
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
Particle Size = 5.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	PO210
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
Particle Size = 35.0 Microns Density = 2.4 g/cm^3	U238	U234	TH230	RA226	PB210	PO210
Whole Body	7.92E-01	9.02E-01	5.77E+01	3.90E+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

TABLE 3.3-6. Dose Conversion Factors for External Exposure

Dose Factors for External Doses from Air Concentrations, mrem/yr per pCi/m^3	
Isotope	Whole Body*
U238**	1.23E-04
TH230	3.59E-06
RA226	4.90E-05
RN222	2.83E-06
PO218	6.34E-07
PB214	1.67E-03
BI214	1.16E-02
PB210	1.43E-05

Dose Factors for External Doses from Ground Concentrations, mrem/yr per pCi/m^3	
Isotope	Whole Body*
U238**	3.70E-06
TH230	6.12E-07
Ra226	9.47E-07
RN222	5.03E-08
PO-218	1.10E-08
PB214	3.16E-05
BI214	1.85E-04
PB210	2.27E-06

* Doses to internal body organs are assumed to be the same as computed for the whole body

** Dose factors for ^{238}U include contributions from daughters ^{234}Th, ^{234m}Pa and ^{234}U

TABLE 3.3-7. Food Consumption Rates

	Ingestion Rates by Age Group			
Food Type	Infant	Child	Teen	Adult
Vegetables (kg/yr)	--	47.8	76.1	105.
Meat (kg/yr)	--	27.6	44.8	78.3
Milk (l/yr)	208.	208.	246.	130.

TABLE 3.3-8. Age Distribution of Population, Average and Per Capita Consumption Rates and Fractions

Age Group	Fraction of Population[a]	Average Total Consumption Rates, kg/yr[b]		
		Vegetables	Meat	Milk
Infants	0.0179	0.	0.	207.6
Children	0.1647	238.1	48.7	234.8
Teenagers	0.1957	306.4	78.0	291.4
Adults	0.6217	285.5	127.9	176.3
Per Capita Average:[c]		276.7	102.8	209.0

[a]Age fractions given reflect average values for the entire U.S. population indicated by 1970 census data, as reported in EPA (1973).

[b]Consumption rates given are average values taken from Fletcher and Dotson (1971) and are not appropriate to use for the calculation of maximum individual doses.

[c]Per capita consumption rates shown are weighted averages over all age groups. They are used for determining the fractions of regional food production potentially consumed by the regional population.

TABLE 3.3-9. Food Consumption by Age Group

Age Group	Fraction of Regional Production Ingested by Each Age Group		
	Vegetables	Meat	Milk
Infants	0.0	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

TABLE 3.3-10. Continental Population Dose Factors

Release Site	Population Doses 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.

The sample problem input deck in Section C.1 results in five system generated diagnostic messages related to the NAMELIST input procedure. The messages are not significant. They are caused by specifying a parameter name on one card without giving any constants on the same card. The diagnostics are not shown in the sample problem output listing in Section C.2.

4.0 DATA INPUT PREPARATION

To execute the computer program MILDOS the user must supply two card sets: a NAMELIST INDATA set followed by a title card set. All integer and floating point data is given in the NAMELIST set while the title card set contains the alphanumeric labels. The FORTRAN NAMELIST statement provides a simplified means of supplying input data to a computer program. Use of the NAMELIST procedure permits the reading of input without the need of format specification. A general description of the NAMELIST input procedure is given in Section 4.1. Details of the NAMELIST INDATA parameters are given in Section 4.2. The title card set is described in Section 4.3.

4.1 Use of NAMELIST

The NAMELIST data input procedure is available with FORTRAN compilers on most large computing systems. The description which follows is thought to be generally applicable to most systems. For detailed information on specific systems the user is referred to system FORTRAN reference manuals.

The use of the NAMELIST procedure can best be described by the following set of usage rules.

1. The first column, and only the first column, of each NAMELIST card is not read by NAMELIST. This column can be used as a label to indicate the order of the cards or it can be left blank.

2. The first card of the set must begin with a blank in column one and a dollar sign, "$", in column two followed by the set name. For MILDOS the set name is INDATA and the first card contains $INDATA in columns 2-8. The next column must be blank (column 9 for MILDOS).

3. The data set is ended by "$END". On many systems just the dollar sign is sufficient.

4. Data entries are made by giving the parameter name, an equal sign and the data value to be assigned to the named parameter. Allowable forms of parameter specification are as follows:

   a. Name = constant
   b. Array Name = set of constants
   c. Array Name (subscripts) = set of constants

   An example of the first form would be to set the parameter NSORCE equal to 8:

   NSORCE = 8,

The second and third forms are used to set data into arrays. Note that for these forms, data values cannot be skipped. The set of constants consists of one or more data values separated by commas. As an example consider the array IRTYPE with the first 15 (dimensioned 48) values to be set as follows:

Positions 1-5 set to 1
Positions 6-10 set to 10
Positions 11-15 set to 1

The entry would be as follows:

```
IRTYPE = 1,1,1,1,1,10,10,10,10,10,1,1,1,1,1,33*0,
```

or,

```
IRTYPE(1) = 5*1, 5*10, 5*1, 33*0,
```

Both of the examples have the same effect.

The repeat form 33*0 indicates that the value 0 is to be entered 33 times. In the example this fills the remaining array positions with zero. This repeat form can be used with both forms of array specifications. The third form (with a named subscript) is generally used only when the data specification does not start with the first element of the array. For example, IRTYPE (6) = 5*10 set positions 6-10 of array IRTYPE to 10.

The number of data values in the set of constants must be less than or equal to the size of the array. When the third form is used the number of data values must be less than or equal to the space between the named element and the end of the array. For example only 33 values can be specified when the array name is given as:

IRTYPE(16)

because this array is dimensioned 48.

5. Every data value must be followed by a comma, and no data values may be skipped, except at the beginning or end of the array.

6. Variables can be specified in any order.

7. The order of element entry for multiple dimensioned arrays follows the FORTRAN array convention wherein the first subscript is varied most rapidly followed by the second subscript. For a double dimensioned array B(I,J) where I and J represent the array dimensions the position of element B(i,j) is given by

$$i + (j-1)I$$

Thus, B(3,4) is in position 18 for I = 5 and J = 5.

For a triple dimensioned array A(I,J,K) the position of element A (i,j,k) is given by

$$i + (j-1)I + (k-1)IJ$$

As an example consider the NAMELIST variable FREQ(16,6,6) for MILDOS. The position of element FREQ(i,j,k) is given by

$$i + (j-1)\ 16 + (k-1)\ 96$$

8. Parameters not named in the input set are left unchanged; therefore, the initial values of Table 3.3-1 are invoked.

4.2 Definition of NAMELIST Parameters

The MILDOS parameters supplied through the NAMELIST data set INDATA can be classified into seven categories as follows:

Data Category	NAMELIST Parameter Names
Job Control	IFTODO, IRTYPE, JC
Source Terms	FRADON, IPACT, NSORCE, PACT, QAJUST, SORCE
Meteorology	DM, FREQ
Food Pathway Parameters	FFORI, FFORP, FHAYI, FHAYP, FPR
Population Distribution	IPOP, PAJUST
Individual Receptors	IADD, XRECEP
Time History	NSTEP, TSTART, TSTEP

Parameters for each of these categories are described in the following sections.

4.2.1 Job Control Parameters

Three job control integer arrays are used by MILDOS; IFTODO, IRTYPE and JC. The array IFTODO is used in conjunction with the time history data and controls calculation and printing of doses for each time step. The array IRTYPE requests output reports for each individual receptor location (see Section 4.2.6). The array JC controls selection of calculational options and report selections. Usage of these arrays is described in Table 4.2-1. The user is reminded that the value for JC(7) must be 1 if any element of the array IRTYPE is set to 10. Element JC(4) selects printing of population doses. Doses are printed for the pathways and organs indicated in Table 4.2-2.

4.2.2 Source Term Parameters

Multiple release points may be defined as input to the MILDOS program. The number defined for a run is specified by the parameter NSORCE. The location, rate of release and characteristics of each release are defined in the array SORCE. Additional data is defined for area sources such as tailings piles where wind suspension is the main driving force for entry to the atmosphere. The sample area source isotopic composition mixes (specific activity in pCi gm^{-1}) are defined in array PACT. Three composition mixes may be defined to represent different ore mixes. The array IPACT then assigns these composition mixes to represent each area source as appropriate. Area sources are indicated by a value of SORCE(10,i) greater than 2000 for a source i. A "virtual point source" method is used to describe dispersion from area sources. Area sources larger than 0.1 km^2 should be broken down to smaller area source.

The population dose to persons beyond the 80 km radius is estimated from radon releases characterized by the nearest of the following sites:

Casper, Wyoming
Falls City, Texas
Grants, New Mexico
Wellpinit, Washington

The array FRADON is used to select the radon release characteristics for one of the above sites or as a geographic weighted average of the above sites.

TABLE 4.2-1. Job Control Parameters

(Dimension) Parameter	Type	Description
IFTODO(10)	Integer	This array controls calculation and printing of doses for each of NSTEP time steps. When IFTODO(i) = 1 doses will be calculated and printed for time step i.
IRTYPE(48)	Integer	This array of control integers is used to specify the output reports requested for each of the IADD locations. For a given receptor location i: IRTYPE(i) < 0, suppresses printing IRTYPE(i) = 0, perform a 10 CFR 20 check on air concentrations and print a report IRTYPE(i) = 1, print doses totaled over all exposure pathways. IRTYPE(i) = 10, print doses for each exposure pathway and total doses If IRTYPE(i) has any positive value other than 0, 1 or 10, a default value of 1 is used. If no value is specified IRTYPE is set to -1 to suppress printing. When IRTYPE(i) is set to 1 or 10 reports are printed for total dose commitments and for 40 CFR 190 dose commitments.
JC(10)	Integer	Job control integer array to select options for the current calculation. An option is selected by setting the appropriate value to 1. Usage is as follows: JC(1)=1, use the internal dusting rate algorithm (subroutine TAILPS), utilizing the input array FREQ for all sources j having SORCE(10,j) greater than or equal to 2000. If JC(1)=0, then default values are used for sources with SORCE (10, j) $\geq$ 2000. JC(2)=1, compute the 100 year environmental dose commitments. If JC(2) = 0, the annual population dose commitments are computed. JC(3)=1, print total air concentrations (pCi m^{-3}), ground concentrations (pCi m^{-2}), and total deposition rates (pCi m^{-2} sec^{-1}) for each spatial interval (see Figure 2.0-1).

TABLE 4.2-1. (Cont'd)

(Dimension) Parameter	Type	Description
		JC(4)=1, print annual population doses for each spatial interval. Reports are printed for each pathway and organ listed in Table 4.2-2. If JC(4) ≠ 1 then only a summary table is printed for the 80 km population and the extra-regional population. JC(5)=1, print the normalized dispersion factor (X/Q) arrays. The outputs include the air concentration normalized by the release rate of ^{238}U for each source, receptor and particle size; and for ^{222}Rn and 6 daughters for each source and receptor. Units are: $$\frac{\text{pCi m}^{-3}\ \text{(air concentration)}}{\text{pCi sec}^{-1}\ \text{(release rate)}}$$ This option will generate lengthy output when several sources and receptor locations are specified. JC(6)=1, print a table of dose conversion factors for various pathways, organs and isotopes. Other information printed includes particle sizes, density, age groups, environmental concentration factors and time step dependent variables. JC(7)=1, print total dose commitments (mrem/yr) and 40 CFR Part 190 dose commitments by age group, pathway and organ for each receptor location and timestep. If JC(7) ≠ 1, then the pathway data are not printed; only total dose commitments are printed for each location. This parameter overrides report requests made through the parameter IRTYPE(i). If a full dose printout for any location is desired, then JC(7) must be set to 1. JC(8)=1, include the milk pathway in calculation of doses at receptor locations. If JC(8) ≠ 1, then the milk pathway is not included or printed.

TABLE 4.2-1. (Cont'd)

(Dimension) Parameter	Type	Description
		JC(9)=1, print the particulate concentrations for air (pCi m^{-3}) and ground (pCi m^{-2}) at each individual receptor location. Also printed are particle size data for particulates (^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb) concentrations for radon and daughters (^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{210}Pb, ^{210}Bi and ^{210}Po) and ground concentrations from radon daughters (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{210}Pb).
		JC(10), not currently in use.

TABLE 4.2-2. Population Dose Tables for JC(4)=1

Exposure Pathway	Organ of Interest
Inhalation	Whole Body Bone Mass Average Lung Bronchial Epithelium
Ground Exposure	Whole Body
Cloud Exposure	Whole Body
Vegetable Ingestion	Whole Body Bone
Meat Ingestion	Whole Body Bone
Milk Ingestion	Whole Body Bone

The release rate during each time period (see Section 4.2.7) is defined by the array QAJUST which is used to adjust the release data in the SORCE array. This flexibility in source term specification is necessary over the lifetime of a uranium mill to account for transitions in operations. For example, as one tailings trench is filled, stabilized and reclaimed, the source strength should be adjusted accordingly.

Particle size distribution data is used in the atmospheric transport calculation by MILDOS. Three particle size distribution sets are available as internal data in MILDOS. The element SORCE(11,i) selects one of these sets to represent each source i. Characteristics of each set are given in Table 4.2-3. (Default values are given in Table 3.3-2).

TABLE 4.2-3. Particle Size Distribution Set Characteristics

Set Number	Density g/cm^3	Percent of Material by Particle Size (μm) 1.0	5.0	35.0	Source Types
1	8.9	100	0.0	0.0	Yellowcake dryer packaging
2	2.4	100	0.0	0.0	Crushers, grinders rod mills, conveyers, fine ore blending and other mill process sources
3	2.4	0.0	30	70	Tailings, ore storage piles

The element SORCE(12,i) gives the product of exit velocity times stack diameter for source i. Stacks, vents and blending areas have exit velocities while ore pads and tailings area do not.

Detailed descriptions of each parameter in the source term set is provided in Table 4.2-4.

4.2.3 Meteorological Parameters

Average meteorological data characteristic at the mill center is required as input to MILDOS. The data array FREQ is used to provide the annual average fractional frequency of occurrence of windspeed, wind direction and atmospheric stability. Data is supplied for

- sixteen wind directions in the order
  N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW.

- six wind speed classifications in the order
  0-13, 4-6, 7-10, 11-16, 17-21, > 21 (knots)
  0-13, 4-7, 8-12, 13-18, 19-24, > 24 (mph)
  .67, 2.5, 4.5, 6.9, 9.6, 12.5 (average m sec^{-1})

The average wind speed values (m sec^{-1}) are provided in array UU in block data FRESH.

- six Pasquill atmospheric stability categories in the order
  A - extremely unstable
  B - moderately unstable
  C - slightly unstable
  D - neutral
  E - moderately stable
  F - very stable

The wind direction is the direction the wind is from. These data are available from the National Weather Service for locations with meteorological towers and stations.

In addition to the joint frequency array, the annual average mixing height, DM, is also given. Table 4.2-5 describes the meteorological parameters.

TABLE 4.2-4. Source Term Parameters

Parameter (Dimensions)	Type	Description
FRADON(4)	Real	The fraction of radon releases attributable to each of the following sites: FRADON(1) - Casper, Wyoming FRADON(2) - Falls City, Texas FRADON(3) - Grants, New Mexico FRADON(4) - Wellpinit, Washington Each value must be between zero and one and the four values must sum to exactly one. This array is used to determine impact to populations outside the 80 km radius. See Figure 4.2-1 for the geographical location of the above sites.
IPACT(20)	Integer	This array assigns mixes defined by PACT (i,k) to each area source j. A value of IPACT(j) = i causes mix i to be used for material in area source j. IPACT must have non-negative integer values ≤ 3.
NSORCE	Integer	The number of effluent sources to be defined for the current case. $1 \leq$ NSORCE ≤ 20. (Maximum of 20).
PACT(3,4)	Real	Defines up to three isotopic composition mixes for characterizing of area source particulate releases. The values given for PACT(i,k) represents the specific activity (in pico curies gm^{-1}) for radionuclide k in mix i where k=1 for ^{238}U k=2 for ^{230}Th k=3 for ^{226}Ra k=4 for ^{210}Pb
QAJUST (10,2,20)	Real	Adjustment factors for particulate and radon emissions for each source and timestep. Usage is as follows: QAJUST(i,1,j), adjustment factor for the particulate activities defined for source j that are released during timestep i (see SORCE), QAJUST(i,2,j), adjustment factor for radon activity defined for source j that is released during timestep i.

TABLE 4.2-4. (Cont'd)

Parameter (Dimensions)	Type	Description
SORCE(12,20)	Real	Data defined for each effluent sorce term j:
		SORCE(1,j) = x coordinate for source j, kilometers. A positive value indicates east and a negative value indicates west of the mill center.
		SORCE(2,j) = y coordinate for source j, kilometers. A positive value indicates north and a negative value indicates south of the mill center.
		SORCE(3,j) = elevation of source j, meters, above or below (negative values) the mill center.
		SORCE(4,j) = areas of source j in square kilometers. A value of zero should be used for point sources such as stacks.
		SORCE(5,j) = annual average release rate of ^{238}U for source j, curies/year.
		SORCE(6,j) = annual average release rate of ^{230}Th for source j, curies/year.
		SORCE(7,j) = annual average release rate of ^{226}Ra for source j, curies/year.
		SORCE(8,j) = annual average release rate of ^{210}Pb for source j, curies/year.
		SORCE(9,j) = annual average release rate of ^{222}Rn gas from source j, curies/year.

TABLE 4.2-4. (Cont'd)

Parameter (Dimensions)	Type	Description
		SORCE(10,j) = identification number for source j. A value of SORCE(10,j) $\geq$ 2000 causes the code to generate source terms for particulate releases (^{238}U, ^{230}Th, ^{226}Ra and ^{210}Pb) for source j (subroutine TAILPS). This option is generally used for area sources. Values for ^{222}Rn gas must always be supplied by the user. For SORCE(10,j) $\geq$2000, any user supplied numbers for SORCE(5-8,j) will be ignored.
		SORCE(11,j) = assigned particle size distribution set number for source j. The valid values are 1, 2 or 3. Table 4.2-3 summarizes the characteristics of each particle size distribution.
		SORCE(12,j) = product of stack inside diameter(m) and effluent exit velocity ($m\ sec^{-1}$) for source j, $m^2\ sec^{-1}$. Area sources should have SORCE (12,j) set to zero.

All default values for SORCE array are 0.0.

TABLE 4.2-5. Meteorological Parameters

Parameter (Dimensions)	Type	Description
FREQ(16,6,6)	Real	Fractional joint frequency of occurrence of wind direction (16), windspeed class (6) and atmospheric stability class (6), dimensionless. FREQ(i,j,k) $\geq$ 0, $\sum_{i,j,k}$ FREQ(i,j,k) $\approx$ 1.00
DM	Real	Annual average mixing height, meters. (If not specificied by user, program uses default value of 1000 meters).

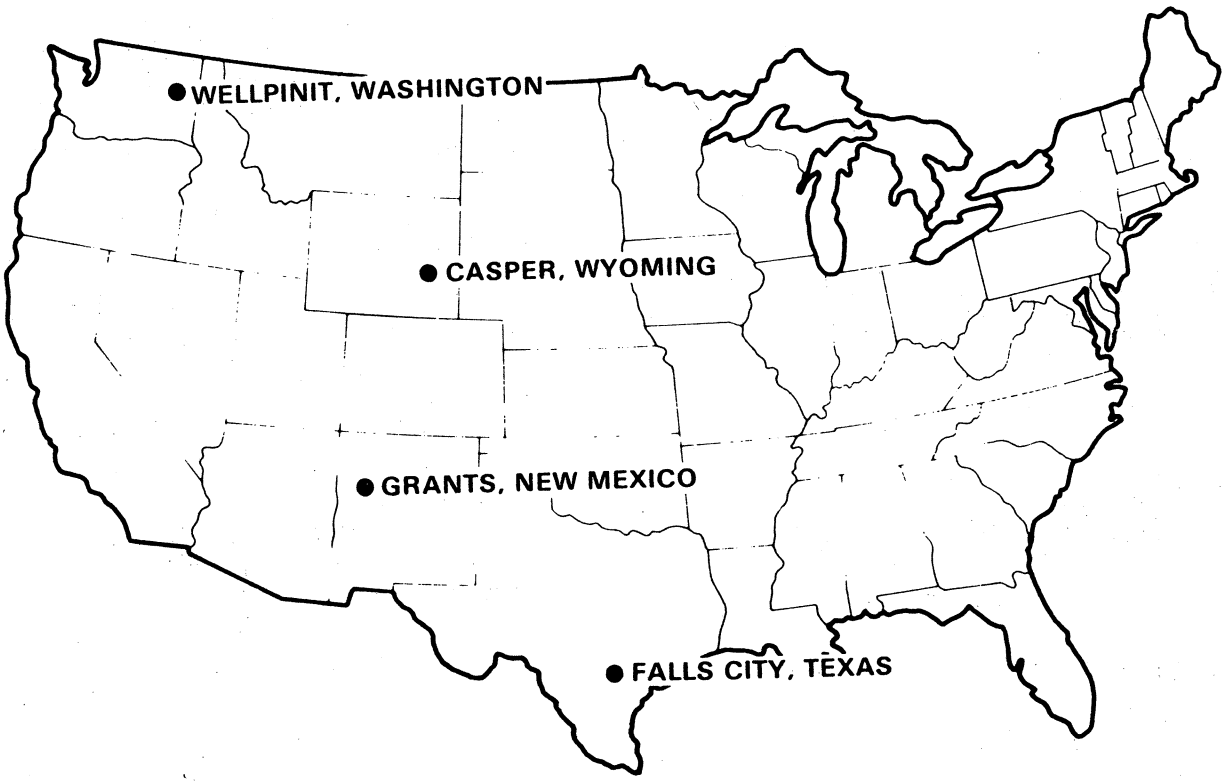


FIGURE 4.2-1. Geographical Locations of Reference Radon Release Sites for Continental Population Doses

4.2.4 Pathway Parameters

Several parameters used in the food pathway model are to be supplied by the user. Four parameters are required for the animal product pathway describing the feeding habits of livestock near the mill site. The parameters FFORI and FFORP give the fraction of total annual feed requirements that are provided as pasture grass for the individual doses and population doses, respectively. The parameters FHAYI and FHAYP give the fraction of total annual food requirements that are provided as locally grown stored hay for the individual doses and population doses, respectively. These numbers are fractions that must be entered as non-negative real numbers between zero and one. A default value of 0.5 is used for any of the above parameters that are not supplied in the input set. Further restrictions on the parameters are

$$FFORI + FHAYI \leq 1.0$$

and

$$FFORP + FHAYP \leq 1.0$$

The array parameter FPR gives the food production rate for the region for three food types: vegetables, meat and milk. These rates may be selected from Table 4.2-6 which gives food production rates for various states where mining and milling operations are prevalent.

The food pathway parameters are presented in Table 4.2-7.

4.2.5 Population Distribution Parameters

The population distribution within 80 km of the mill center is provided by the integer array IPOP. This array gives the number of people living in each of twelve distance intervals in sixteen downwind directions (see Figure 2.0-1). The distance intervals are (km):1-2, 2-3, 3-4, 4-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-80. The direction representations are the same as those defined for the meteorological parameter FREQ (i.e., beginning with the north sector).

The population dose calculations beyond 80 km are based on total U.S. population growth relative to the year 1978. The array PAJUST gives the relative population during each time step compared to the 1978 population. Projected populations of the U.S. are given in Table 4.2-8 as taken from USNRC (1979). Population distribution parameters are described in Table 4.2-9.

TABLE 4.2-6. 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 an NRC staff survey.

4.2.6 Individual Receptor Location Parameters

The user may define up to a maximum of thirty locations where doses to individuals will be calculated such as non-restricted locations subject to 10 CFR 20 air concentration limits. The parameter IADD gives the number of individual receptor locations to be considered and the array XRECEP gives coordinates defining the locations. These parameters are described in Table 4.2-10.

TABLE 4.2-7. Food Pathway Parameters

Parameter (Dimensions)	Type	Description
FFORI	Real	Fraction of total annual feed requirements assumed to be satisfied by pasture grass used for calculation of individual doses. Default value is 0.5
FFORP	Real	Fraction of total annual feed requirements assumed to be satisfied by pasture grass, used for calculation of population doses. Default value is 0.5.
FHAYI	Real	Fraction of total annual feed requirements assumed to be satisfied by locally grown stored feed, used for calculating individual doses. Default value is 0.5.
FHAYP	Real	Fraction of total annual feed requirements assumed to be satisfied by locally grown stored feed, used for calculation of population doses. Default value is 0.5.
FPR(3)	Real	Areal food production rate for 1) vegetables, 2) meat and 3) milk in the region of the mill site. (Suggested values are given in Table 4.2-6).

TABLE 4.2-8. 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		

TABLE 4.2-9. Population Distribution Parameters

Parameter (Dimensions)	Type	Description
IPOP(12,16)	Integer	Population distribution data. IPOP(i,j) gives the population in the spatial interval defined by the i-th distance interval and the j-th direction, where j = 1 indicates north.
PAJUST(10)	Real	Ratio of the U.S. population during each time step to that during the year 1978. A value must be given for each of the NSTEP timesteps in order. These values are used to obtain the proper continental population doses as a function of the time of exposure.

TABLE 4.2-10. Individual Receptor Location Parameters

Parameter (Dimensions)	Type	Description
IADD	Integer	This parameter specifies the number of location for which individual doses will be calculated $1 \leq$ IADD ≤ 48.
XRECEP(3,48)	Real	This array gives coordinates of each individual receptor location. For each receptor i, the data is entered as follows: XRECEP(i,i), distance in kilometers to the east (positive value) or west (negative value) of the mill center. XRECEP(2,i), distance in kilometers to the north (positive value) or south (negative value) of the mill center. XRECEP(3,i), elevation of the receptor in meters above (positive value) or below (negative value) the mill center elevation.

4.2.7 Time History Parameters

This data set describes the time history of the mill operation. The year of initial release is given by parameter TSTART. The mill lifetime is divided into timesteps based on transition points in the mill life and tailings management plans, such as changing from a dry grinding to a semi-autogenous grinding. Up to 10 timesteps can be defined. The

number of timesteps is specified by NSTEP and the length of each timestep is given in array TSTEP. A minimum value of 2 years is allowed for each defined timestep to accommodate mechanisms such as resuspension. The time history parameters are described in Table 4.2-11.

Remember to insert a "$END" (starting in the 2nd column) card at the end of the NAMELIST parameter cards.

4.3 Title Cards

The NAMELIST card set is followed by a set of title cards which contain descriptive labels used on output reports. The title card set contains four types of label information as follows:

- identification of the region and meteorological data
- source identification
- identification of individual receptor locations
- timestep identification

The region and meteological data information is contained on one card with the following format.

Name	Columns	Format	Description
REGION(6)	1-24	6A4	Region identification
METSET(4)	31-46	4A4	Meteorological data identification

TABLE 4.2-11. Time History Parameters

Parameter (Dimensions)	Type	Description
NSTEP	Integer	Number of timesteps used to define the mill lifetime. $1 \leq$ NSTEP ≤ 10. (maximum of 10).
TSTART	Real	Year of initial effluent release in years A.D. Fractional values (non-integer) are used to account for startup during a year i.e. 1980.5 would indicate startup at the beginning of July 1980.
TSTEP(10)	Real	The length of each timestep in years. The number of values to be given is equal to NSTEP (see below). A minimum value of 2 years is assumed, i.e., if a smaller value is given it will be set to 2 years.

The variable NSORCE defines the number of sources to be considered. The labels for each of the NSORCE sources are read one per card on the next NSORCE cards with the following format:

Name	Columns	Format	Description
QNAME(5,j)	1-20	5A4	Label for source j.

Exactly NSORCE cards must be given or there will be confusion in headings and labels throughout the output.

The number of individual receptor locations to be considered is given by the NAMELIST variable IADD. Identification of the individual receptor locations is given one per card on the next IADD cards. The format is:

Name	Columns	Format	Description
XNAME(5,i)	1-20	5A4	Label for individual receptor location i

The number of these cards must be exactly IADD or confusion in output headings will result.

The number of timesteps is given by the NAMELIST variable NSTEP. Descriptive labels for each timestep are provided on the next NSTEP cards, one label per card, with the following format:

Name	Columns	Format	Description
TNAME(5,k)	1-20	5A4	Timestep k identification label

There must be exactly NSTEP of these cards.

The order of the labels within each of the last three sets must coincide with the order in which each item was defined: the source labels must agree with array SORCE; the receptor labels must agree with array XRECEP; and the timestep data must agree with array TSTEP. Labels exceeding the column limitations are truncated (i.e., extra characters are ignored). The title card set completes the input for MILDOS. Some type of end-of-data card may be required at the end of the data set depending on requirements of the computer system being used.

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