MILDOS-AREA Computer Code

NATURE OF PROBLEM SOLVED

The MILDOS Computer code calculates the dose commitments received by individuals and the general population within an 80 km radius of an operating uranium recovery facility. In addition air and ground concentrations are presented for individual locations, as well as for a generalized population grid. Extra-regional population doses resulting from transport of radon and export of agricultural produce are also estimated. The transport of radiological emissions from point and different area sources is predicted by using a sector-averaged Gaussian plume dispersion model. Mechanism such as radioactive decay, plume depletion by deposition, ingrowth of daughter products and resuspension of deposited radionuclides are included in the transport model. Alterations in operation throughout the facility's lifetime can be accounted for in the input stream. The pathways considered are: inhalation; external exposure from groundshine and cloud immersion; and ingestion of vegetables, meat and milk. Dose commitments are calculated primarily on the basis of the recommendations of the International Commission on Radiological Protection (ICRP). 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.

The MILDOS/MILDOS-AREA Computer code was designed as a primary licensing and evaluation tool and is expected to provide basic input to critical licensing, regulatory and policy decisions. It is used by the staff of the Nuclear Regulatory Commission to perform routine radiological impact and compliance evaluations for various uranium recovery operations. This code is designed for uranium mill facilities, and should not be used for operations with different radionuclides or processes. Over the years MILDOS computer code has gone through many changes. The 1981 version of MILDOS was designed for mainframe computer. Latest 1998 version of MILDOS-AREA has graphic user interface uses the Windows 3.x (and Window 95) operating system and runs on personal computers.

PATHWAYS

The pathways considered for individual and population impacts are:

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

DOSE COVERSION FACTORS

Doses 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 options.

SITE DESCRITION

The physical description of the mill site includes a grid of twelve concentric distance intervals (within 80 km) and sixteen angular intervals based on sixteen compass directions (N, NNE, NE, etc.). The mill center is assumed to be 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.

SOURCE DESCRITION

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 yellow-cake stacks, crushers, grinders, conveyors, rod mills, fine ore blending, tailings areas, ore pads etc. Radionuclide releases are defined for each source for particulates and radon gas. The U-238 decay chain is assumed to be the only significant source of radiation for uranium milling operations. The contribution from the U-235 chins is less than 5% of that from the U-238 chain. Particulate releases are defined to include the radionuclides U-238, Th-230, Ra-226, and Pb-210. The gaseous releases are defined for Rn-222 with ingrowth of short-lived daughter products also considered. These Rn-222 daughters include Po-218, Pb-214, Bi-214, Pb-210, and Po-210. The dosimetry model accounts for releases and ingrowth of other radionuclides using assumption of secular equilibrium.

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.

ATMOSPHERIC TRANSPORT AND DIFFUSION

Emissions of radioactive materials from different sources are modeled using a sector-averaged Gaussian plume dispersion model, which utilizes user-provided wind frequency data. Mechanism 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 life.

POPULATION DOSES BEYOND 80 KM

Population doses to the North American continent from Rn-222 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

MILDOS has the precalculated population dose estimates for 1000 Ci releases from these four sites during the calendar year 1978. These dose factors are defined in subroutine POPDOS as the array parameter RADPOP. TABLE 1 has these dose factors.

TABLE 1 Population Doses Resulting From 1 KCi Release of Rn-222 During 1978, in organ-rem

Release Site	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 population dose to persons beyond 80 km radius is estimated from radon releases characterized by the nearest of these four sites. The array FRADON is used to select the radon release characteristics for one of the above sites or as a geographic average of the above sites.

Moreover, the population dose calculations beyond 80 km are based on total U.S. population growth relative to the year 1978. The array PAJUST gives relative population during each time step compared to the 1978 populations. A value for PAJUST must be given for each of the NSTEP (maximum allowed is 10) time steps in order. These values are used to obtain the proper continental population doses as a function of the time of exposure.

HISTORY

Over the years MILDOS computer code has gone through many changes. In 1981 MILDOS (NUREG/CR-2011) 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. The models and assumptions on which the MILDOS program was based are described in the U.S. Nuclear Regulatory Commission Draft Regulatory Guide RH 802-4 and portions of the UDAD document. Models were included in MILDOS to consider both point sources (stacks, vents) and area sources (ore pads, tailing areas). Release of particulates are limited to U-238, Th-230, Ra-226, and Pb-210. Other radionuclides are implicitly accounted for under the secular equilibrium assumption. Gaseous releases were limited to consideration of Rn-222 plus ingrowth of daughters. The dose to exposed individuals is calculated for comparison with requirements of both 40 CFR 190 and 10 CFR Part 20. Version of MILDOS developed in 1981 allowed the user to define a maximum of twenty source terms, ten time steps, and forty eight individual receptor locations. For the calculations ingestion dose conversion factors were based on ICRP Publication 2 and 10 A's ingestion models, inhalation dose conversion factors were calculated by UDAD computer code in accordance with the Task Group on Lung Dynamics (TGLM) lung model of ICRP (ICRP 1966 and 1972), and the external dose conversion factors were directly taken from Hones and Soldat (1977)[1].

In 1989, Argonne National Laboratory developed the MILDOS-AREA code (ANL/ES-161) by modifying the MILDOS code developed in 1981. The changes were intended to provide enhanced capability to compute doses from large-area sources and to incorporate changes in methods for dosimetry calculations (ICRP 1979). The revised program was designed for use on IBM or IBM-compatible personal computers. This version of MILDOS-AREA allowed the user to define a maximum of 10 sources (point or area), 48 individual receptors, and 10 time steps. The number of sources were reduced from 20 allowed in MILDOS code because in the revised code a large-area source is considered as a single source rather than as two or more virtual-point sources[2]. MILDOS-AREA considers the same radionuclides as MILDOS. MILDOS computer code could only be used on a mainframe computer, MILDOS-AREA was designed for use on an IBM or IBM-compatible personal computer. MILDOS-AREA was easier to use; more flexible in handling the large amount of printer output; and although slower in execution , usually

[1] Hoenes, G.R. and J.K. Soldat, 1977, "Age Specific Radiation Dose Conversion Factors for a One-Year Chronic Intake", NUREG-0172, U.S. Nuclear Regulatory Commission, Washington, D.C.

[2] In MILDOS a "virtual point source" method was used to describe dispersion from area sources and it was recommended that the area sources larger than 0.1 km2 should be broken down to smaller area source.

exhibited a better net turnaround time than MILDOS. A validation study of MILDOS-AREA was conducted using measured Rn-222 concentration and flux data from the Monticello, Utah uranium mill tailings impoundment. The results of this study demonstrated that use of MILDOS-AREA can result in generally good agreement between model-generated and measured Rn-222 concentrations.

In 1997, MILDOS-AREA computer code was further updated by ANL. The 1989 version of MILDOS-AREA computer code incorporated dose conversion factors derived by the ICRP recommendations of 1978. The annual average air concentrations were compared to the maximum permissible concentrations (MPCs) in the Nuclear Regulatory Commission's *Standards for Protection Against Radiation* (10 CFR Part 20). On January 1, 1994, a revision to 10 CFR Part 20 (revised Part 20) went into effect. The revised Part 20 updated its dosimetry to the ICRP 1978 recommendations. The dose limit to the general public also changed. The changes led to a revision of the calculated allowable concentrations for unrestricted areas. The changes led to a revision of the calculated allowable concentrations (ALC) for unrestricted areas, with MPC being replaced by the term "effluent concentrations." In addition, a new method of recovering uranium gained popularity in the late 1980s, and majority of operating licensees started using the in-situ leach (ISL) method.

In 1997 MILDOS-AREA computer code was updated keeping two objectives in mind, first objective was to update the code's data structures and terminology to meet the needs of the revised Part 20, the second objective was to create an example problem for in-situ leach facilities. These two objectives resulted in the creation of a patch program that updated the 1989 version to the 1997 version of MILDOS-AREA computer code.

In 1998, ANL is again updating MILDOS-AREA computer code. The MILDOS-AREA computer code as currently designed (till 1997) lacked user-friendly features. To run the code, a user must first separately develop an input file, which is an ASCII file containing all of the pertinent values that are required by the code. The code is then executed to produce the output file, which contains results of the calculations. The latest version of MILDOS-AREA code has a user-friendly software interface incorporated to the 1997 version of MILDOS-AREA computer code. This graphical user interface (GUI) is simple and easy to use and allows MILDOS-AREA to run under the Windows operating system. The interface contains sufficient information so that the user clearly understands where to input each parameter needed for the calculations. The GUI follows standard Windows 3.x (and Windows 95) structures. The GUI allows the creation, retrieval, and editing of MILDOS-AREA input files. In the various editing windows, the GUI provides information to clearly indicate where each parameter value should be input and what units should be used for each parameter. The GUI allows the results of the MILDOS-AREA calculations (the output file) to be viewed, the results file to be saved, the information from the results to be moved into other software applications, and the results files from previous runs to be retrieved.

The GUI is implemented with standard Windows 3.x (and Windows 95) usage of menus, windows, buttons, and other Windows functions. All user actions in the GUI are accessible through keystrokes and keystroke combinations as well as a pointing device (mouse). The GUI contains an online help system that uses Windows-standard protocols and include information from the user's manual and other basic operating information.

This 1998 GUI version of MILDOS-AREA computer code runs on a baseline PC, configured with a 486/66 MHz CPU, with 8 MB RAM, that uses the Windows 3.x (and Windows 95) operating system.

MILDOS/MILDOS-AREA PARAMETERS

The MILDOS/MILDOS-AREA parameters can be classified into seven categories as follows:

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

<u>Job Control Parameters</u>

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. The array JC controls selection of calculational options and report selections.

<u>Source Term Parameters</u>

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) 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. For characterizing fixed particulate release rates for area sources (corresponding to the three isotopic composition mixes) array FAS is used. The code would generate the wind-erosion source term for particulate releases if FAS < 0.0. Similarly array SRNS defines the radon release rates.

The population dose to persons beyond the 80 km radius is estimated from radon releases characterized by the nearest of the following four 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 above sites or as a geographic weighted average of the above sites. The release rate during each time period is defined by the array QAJUST and this array 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.

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.

Meteorological Parameters

Average meteorological data characteristics 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 0-3, 4-7, 8-12, 13-18, 19-24, >24 mph; in 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. In addition to the joint frequency array, the annual average morning (DMM) and afternoon (DMA) mixing heights are provided.

Food 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 parameter 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 feed requirements that are provided as locally grown stored hay for the individual doses and the 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.

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. 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 for the meteorological parameter FREQ.

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.

Receptor Location Parameters

The parameter IADD gives the number of individual receptor locations to be considered and the array XRECEP gives coordinates defining the locations.

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 length of each timestep is given in array TSTEP.

REGULATIONS

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 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).