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ASSESSMENT OF ATMOSPHERICALLY-RELEASED RADIONUCLIDES USING THE COMPUTERIZED RADIOLOGICAL RISK INVESTIGATION SYSTEM

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1. INTRODUCTION

In 1978, the U.S. Environmental Protection Agency initiated an agreement with the U.S. Department of Energy authorizing Oak Ridge National Laboratory to develop a comprehensive methodology for assessing atmospheric releases of radioactive materials. This methodology, called the Computerized Radiological Risk Investigation System (CRRIS) (Baes et al., 1985) provides technical support for regulatory decisions necessitated by the Clean Air Act Amendments of 1977.

The standards which the CRRIS supports differ from those used for many chemical pollutants covered by that legislation. First, for pollutants such as SO_2, NO_x, and others the regulations are written in terms of short-term air concentrations over one-hour, three-hour, or twenty-four-hour time periods. Furthermore, the concentration of concern is generally a highest, second-highest, etc. value for the source regardless of its physical location with respect to the location of members of the general public. For radionuclides, however, the standards are in terms of an annual dose, and the regulations require assurance that no member of the general public receives a dose in excess of that standard (USEPA, 1985). Thus, spatial variations in the population around an emmission source must be considered. Furthermore, for most chemical pollutants the standards are written in terms of an air concentration while for radionuclides other pathways of exposure, e.g. uptake of the airborne emissions by terrestrial food chains must also be considered. The remainder of this paper discusses the computer codes that make up the CRRIS and how they are used to perform an assessment of the health impacts on man of radionuclides released to the atmosphere.

2. CRRIS ASSESSMENTS

The CRRIS begins with the calculation of environmental radionuclide concentrations following an extended period of facility operation. The time period selected for facility operation and environmental buildup of nuclides differs for assessments of individual vs. population health effects. For an assessment of the risk to an individual, this period is the expected life of the facility. If the expected facility life is unknown, then a period is chosen that is sufficient to produce equilibrium in the environmental concentrations, e. g. 100 y. The estimated concentrations are computed for the end of the assessed time period and are not a time-average. Population doses are the sum of the individual doses at each assessed location times the associated population. Normally in computing a collective dose, 100 years is used as the time period for facility operation and environmental buildup. The total population dose represents the total expected 70-year dose commitment to all persons from an annual release. This dose is calculated for intakes or exposures which may occur at any time up to 100 years from the time of the initial release.

Doses and risks to individuals are calculated from the intakes or exposures using appropriate radiological dose and health risk factors (Dunning, Leggett, and Yalcintas, 1980; Sullivan et al., 1981). The internal dose factors (inhalation and ingestion) are for a 70-year dose commitment. The lifetime fatal cancer risk factors are calculated for a cohort of 100,000 newborns with 1970 lifetable mortality and assuming constant, lifelong intake or exposure. The assessed location providing the greatest individual lifetime risk is generally selected for a detailed dose assessment.

Collective fatal cancer risks are calculated as the total number of premature deaths per year expected within the assessment area. The population is presumed to have the stationary age distribution which would be obtained from a constant birthrate, the age dependent mortality of the 1970 lifetable, and no external migration. Under these circumstances, the total number of premature deaths per unit intake is the same as the number of expected deaths per unit intake for the cohort used to determine the individual lifetime risk. This means that the collective risk can be interpreted as either (1) the fatal cancer risk (premature deaths per year) that would result in a population at equilibrium, exposed to the calculated environmental concentrations or (2) the risk per unit release, where the intakes and exposures associated with the release are committed during the environmental accumulation period.

3. THE CRRIS CODES

The CRRIS contains eight integrated program modules, including both a long-range trajectory atmospheric dispersion model, RETADD-II, and a shorter range Gaussian plume dispersion model, ANEMOS. Shown in Fig. 1 are all the codes that comprise the CRRIS and their interrelationships. The remainder of this article will briefly examine each of the CRRIS codes and discuss their use in performing nuclear risk assessments.

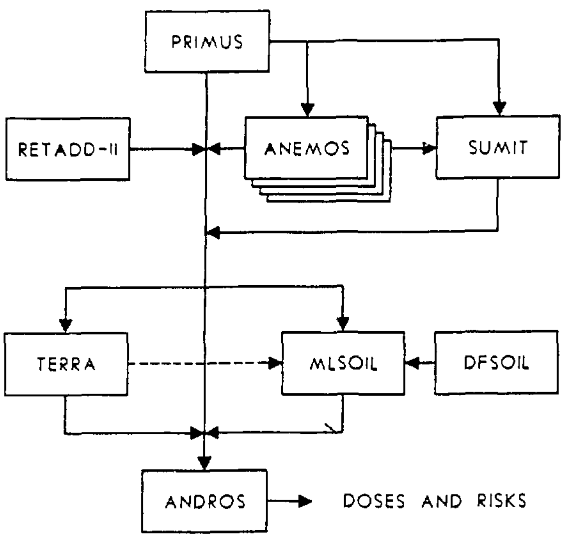

Fig. 1. The computer codes which comprise the CRRIS system and the various pathways of interaction among them.

3.1 PRIMUS

The PRIMUS code (Herman et al., 1984) is generally the first code run each time a new set of released radionuclides (source term) is evaluated using CRRIS. This is a program for the Preparation of Radionuclide Ingrowth Matrices from User-specified Sources. Based on the radionuclides in the source term supplied as input by the user, the PRIMUS code sets up matrices of decay constants for the calculation of daughter ingrowth by accessing a documented radionuclide decay data base (Kocher, 1981). The parent decay and daughter buildup calculations are not handled directly in PRIMUS. Instead, the other CRRIS codes use the PRIMUS data files to make these calculations via appropriate subroutines.

3.2 ANEMOS

The purpose of the ANEMOS code (Miller et al., 1986) is to estimate concentrations in air and ground deposition rates for Atmospheric Nuclides Emitted from Multiple Operating Sources. ANEMOS calculates the average concentrations around a source for releases that occur over an extended period of time, such as a year.

The calculations made in ANEMOS are based on the use of a modified point-source, straight-line, 22.5-degree sector-averaged, Gaussian-plume atmospheric dispersion model (Slade, 1968). The emission source for an ANEMOS calculation may also be a finite area with the computational grid centered on the centroid of the assumed circular area. Basically, air concentrations and ground deposition rates for an area source are calculated by interchanging the source and the receptor points and approximating the effect of a point source (receptor) on a sector (area source). For a windblown source, a model developed by Mills, Dahlman, and Olson (1975) is used to calculate the radionuclide release rates.

ANEMOS requires as basic meteorological data a joint frequency distribution of wind direction, wind speed class, and atmospheric stability class over the time period of interest in each run. The basic set of dispersion parameters used in ANEMOS is that developed by Smith (1972). These parameters may be modified by the user to account for building wake effects (Huber and Snyder, 1976). Also, radionuclides may be removed from the plume during transport by dry and wet deposition processes.

3.3 SUMIT

ANEMOS makes calculations for only one release point in a given run and does not account for contributions from other nearby sources. The purpose of SUMIT (Begovich et al., 1984) is to provide for the Systematic Unification of Multiple Input Tables that have been generated by individual runs of ANEMOS. SUMIT combines the results of these individual runs onto a master grid.

The grid system used in ANEMOS is generally set up for computational convenience. This may not, however, be the desired grid from an assessment point of view. As a result, provision has been made in SUMIT to interpolate an ANEMOS output to other locations. These other locations may be [1] a rectangular grid of specified dimensions, [2] a different circular grid of specified dimensions, or [3] specific locations within the original assessment area as designated by the user, e.g., site boundaries.

3.4 RETADD-II

For downwind distances on a regional or continental scale, a REgional Trajectory And Diffusion-Deposition model, RETADD-II (Murphy, Ohr, and Begovich, 1984), has been incorporated into CRRIS. RETADD-II is intended for the estimation of average dispersion over a time period not shorter than a month. RETADD-II operates by calculating tropospheric wind trajectories which advect or carry material away from the source of emission. Superimposed on these trajectories are the vertical and horizontal diffusion rates of the advected material which are a function of travel time. Loss of material by deposition on the ground is also accounted for in RETADD-II, as is radioactive decay and ingrowth of daughter species. Also, both wet and dry plume depletion effects may be considered. The source of emission may be either at ground level or elevated. This option allows for realistic treatment of plume depletion from elevated sources during the initial part of the advection and diffusion process. RETADD-II could also be used to examine individual trajectories.

The calculation of wind trajectories uses a data base of historical upper-air wind data. The premise behind this approach is that a climatology which is typical for the assessment run is chosen from the historical record and used in the simulation. For instance, to predict dispersion patterns during a given time period with RETADD-II, one would use upper-air wind data for that month, season, or year of interest.

3.5 TERRA

The computer code TERRA (Baes et al., 1984a) is used to calculate the Transport of Environmentally Released Radionuclides through Agriculture. TERRA calculates the buildup of radionuclides on the ground surface and in the root zone of irrigated and nonirrigated agricultural soils. From root-zone soil concentrations, TERRA calculates root uptake of radionuclides into food and feed crops. Deposition of radionuclides on exposed surfaces of food and feed crops is calculated by using the ground deposition rate and vegetation-specific interception fractions. Finally, the transport of nuclides to beef and cow's milk from ingested feeds is calculated from feed concentrations. During transport, consideration is made for leaching of nuclides from root-zone soil, variation in plant physiology and structure, site-specific cattle management practices, and resuspension of ground surface-deposited material.

3.6 SITE DATA BASE

The environmental transport codes used in CRRIS rely heavily on a variety of transfer factors for estimating the movement of radionuclides between various environmental compartments. It is preferable to have site-specific data for these parameters, but this is seldom possible. As a result, a major effort has been made to acquire a data base of geographically-dependent default parameters describing agricultural production and productivity, climate, and other considerations across the conterminous United States. These parameters are available on a 1/2 x 1/2-degree longitude-latitude basis and are part of a data base of Specific Information on the Terrestrial Environment, called SITE (Baes et al., 1984b). For a given location, as specified by a longitude-latitude coordinate, TERRA simulates terrestrial transport by incorporating 20 of the SITE parameters into its calculations. The remaining 14 parameters not used by the TERRA code are either used by or are available for use by the other codes of CRRIS.

The agricultural parameters in SITE were derived from the United States county-averaged values given in the report by Shor, Baes, and Sharp (1982) which analyzes the 1974 Census of Agriculture. Climatological parameters were interpolated from long-term averages recorded by U.S. weather stations. Demographic parameters describing the fraction of the population in various urbanization categories were available from the 1970 U.S. Census and the population estimate was taken from the 1980 U.S. Census.

3.7 MLSOIL AND DFSOIL

The MLSOIL (Multiple Layer SOIL model) code (Sjoreen et al., 1984) is used to calculate an equivalent ground-surface concentration to be used in computation of external doses. This effective ground-surface concentration is equal to (the computed dose in air from the concentration in the soil layers) divided by (the dose-rate factor for computing dose in air from a plane concentration). MLSOIL uses a five-compartment linear-transfer model to calculate the time-dependent concentrations of radionuclides in the soil resulting from deposition on the ground surface. The model considers leaching through the soil as well as radioactive decay and build-up. The element-specific transfer coefficients used in this model are a function of the soil-water distribution coefficient and environmental parameters. The DFSOIL (Dose conversion Factors for radionuclides in SOIL) code calculates dose-rate factors to determine the dose in air per unit concentration at 1 m above the ground for each of the five soil layers used in MLSOIL and the dose per unit concentration from a surface plane source. MLSOIL and DFSOIL used together produce a soil concentration that can be used in ANDROS as an alternative to the soil concentration computed in TERRA.

3.8 ANDROS

The ANDROS computer code (Begovich et al., 1986) is used for the Assessment of Nuclide Doses and Risks with Option Selection. ANDROS couples radionuclide concentrations generated by the other codes in CRRIS with human intake factors and dose and risk factors to arrive at individual or collective doses and health risks.

4. CONCLUSIONS

Because of its modular construction the CRRIS codes provide an alternative to assessment codes which incorporate all calculations into a single program. Each code of CRRIS contains well-documented default parameters for ease of operation, but all defaults may be readily overridden. Additionally, numerous options for transport, dose, and risk calculations and for output display in all codes make CRRIS a very versatile system for performing nuclear assessments. However, the data and models used in the CRRIS are designed for estimating the risk associated with long-term radionuclide releases. The CRRIS is not intended to be used for assessing the impact of accidental radionuclide releases, or for determining compliance with short-term Clean Air Act standards for other potentially-hazardous materials.

5. ACKNOWLEDGEMENT

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