DOSE PROJECTION CONSIDERATIONS FOR EMERGENCY CONDITIONS AT NUCLEAR POWER PLANTS

A. E. Desrosiers
Hydro Nuclear Services, Inc.
Richland, WA, USA

In recent years, the objectives and scope of dose projection considerations for emergency conditions at nuclear power reactor facilities have changed dramatically. Previously, dose projection procedures were a major basis for categorizing reactor emergencies.

Presently, the condition of the major reactor safety systems has become the major basis for categorizing the degree of seriousness of a reactor accident. Operating organizations have implemented emergency action levels which allow classification of a wider range of accident sequence types. The primary role of offsite dosimetry is to determine the extent of required protective actions or to support an analysis that no action is required. Preplanned offsite protective actions may obviate the need to complete dosimetry calculations prior to recommending actions to offsite government officials.

Nevertheless, regulatory guidance for offsite dosimetry under accident conditions stresses meteorological forecasts, rapid data collection and analysis, and explicit representation of terrain effects. Current guidance also emphasizes calculations to 16 or 80 km distances, consideration of ingestion doses pathways, and a capability to simulate short-term variations in wind trajectory, wind speed, and diffusion class.

There are some technical difficulties associated with these advances. Lapse rate measurements are recognized to be potentially inaccurate for some daytime conditions if the data averaging period is shorter than one hour. The accuracy and precision of atmospheric dispersion estimates are, in general, degraded as the time interval of for the analysis is reduced.

Emphasis on rapid release scenarios requires consideration of short-lived fission products as well as competence by all shift staffs in completing dosimetry procedures. Emergency dosimetry analysts must also be able to consider the expected duration of releases and atmospheric conditions in order to estimate projected dose integrals. The time required to attain protective response dose limits must be compared to the time required to notify, warn, or evacuate members of the general public.

These changes of emphasis are reflected in two dosimetry computer codes that have recently been developed for the U.S. Nuclear Regulatory Commission (NRC): IRDAM (NUREG/CR-3012) and MESORAD (PNL-4753). The former was designed as a rapid, versatile, user-friendly model that will operate with preliminary source term estimates or refined data, as the situation demands. IRDAM requires minimal user training and contains extensive programmed default values of important parameters. IRDAM also supports the NRC's need for rapid emergency deployment to reactor sites. The program is implemented on a portable microcomputer that is also programmed to emulate a terminal of the more sophisticated MESORAD system.

MESORAD is, in essence, a variant of the MESOI puff-adversion dispersion code that has been enhanced extensively by addition of dosimetry subroutines. MESORAD normally requires a meteorologist and a dosimetrist for operation. An associated source term code (TACT) requires a nuclear engineer, in addition. The computer environment, dual Data General MV-6000 processors, requires a system manager. MESORAD is intended for use in a national or regional emergency operations centers, or a well established site team, by a cadre of trained analysts.

Source Term Estimates

IRDAM provides source term estimates by allowing the user to input isotopic release rates, gross release rates, or to specify a containment leakage problem. The containment leakage options provide estimates of source term according to the equilibrium core inventory, estimated or default leakage rates, and default core release fractions for fuel melt, void space activity, and coolant concentration. The program includes a typical relationship between the containment area radiation monitor and airborne radioactivity concentration for the major types of containments.

MESORAD has no source term capabilities and requires a separate code, TACT, for source term calculations. TACT contains default core release fractions for coolant, void space, and fuel matrix activity. In addition, it allows the analyst to model transfer rates, filtration efficiencies, plateout rates, source quantity, concentration and dose rates for a network of user-defined modes. Isotopic release rates are stored in a data base for later reference or as input to MESORAD. The source term capabilities of TACT greatly exceed those of IRDAM. However, both codes allow estimates of source terms based on descriptions of reactor safety system failures and therefore support the need to calculate projected releases and doses. These codes also assist the emergency response analyst in modifying preplanned protective action recommendations according to actual conditions of time of release, filtration effectiveness, meteorological conditions, etc. The major difference between these models is that IRDAM is a Class A model, as defined in NUREG-0654, while TACT/MESORAD is a Class B model. These distinctions are further discussed in NUREG/CR-3011.

Atmospheric Dispersion

Enhanced dispersion analysis is absent from IRDAM because the need for implementation on a microcomputer precludes inclusion of extensive site specific data bases and because meteorological forecasts are assumed to be unavailable in the short time period where IRDAM would be effective. In contrast, MESORAD accommodates files of observed and forecast meteorological parameters for 30 measurement locations for periods as short as 15 minutes. Site specific data bases contain topographic information. A subroutine simulates the effect of topography on the wind filed vectors. MESORAD requires the user to explicitly specify the stability classification.

Several alternative parameterizations of the diffusion coefficients are contained in the code. IRDAM classifies the dispersion conditions according to lapse rate, horizontal variance in the wind vector, or the user's specification.

MESORAD calculates dispersion data by simulating the transport and diffusion of individuals puffs of released material and summing the current and cumulative contributions of each puff during each 15 minute time step. IRDAM contains tables of Xu/Q at fixed distances (0.5, 1, 2, 3, 8, 20 km). These tables are reasonably accurate if the meteorological conditions are constant during the period of the release and downwind transport. Distances closer than 0.5 km are not included because IRDAM does not model building wake effects. The data necessary for building wake correction is not presumed to be available immediately following an accident and the inclusion of wake effects increases the necessary training level of the dosimetry analyst.

Also building wake corrections are not significant at distances of 0.5 km and beyond.

Dosimetry

MESORAD provides the user with a plethora of output options: relative concentration, daughter concentration, depleted plume, thyroid dose, lung dose, total whole body dose, external plume dose, deposition dose, inhalation dose, (ICRP 26/30 method), and semi infinite cloud (SIC). All options include current dose rate or cumulative dose and tabular or graphic output. There is a total 51 output options. IRDAM calculates thyroid and whole body dose rates and projected doses.

External irradiation from plumes of radioactive material is modeled in MESORAD by averaging the plume concentration over finite volume elements and summing the contribution from each element. The accuracy of this method compares favorably with the rigorous point kernel integration method and the amount of calculational processing is significantly lower. This approach allows real-time analysis of short-term variations in source term or meteorological conditions while maintaining the accuracy of a finite plume simulation model. MESORAD performs finite plume calculations for elevated or ground level releases, unless the user specifices the SIC approximation. The SIC method is not necessarily conservative when a puff advection dispersion model calculates concentrations because the matrix elements that are specified as locations for dosimetry calculations do not, in general, lie along the centerlines of each puff's trajectory.

IRDAM, by comparison, calculates plume exposure from ground level releases according to the SIC model. The code's documentation includes a table of finite plume correction factors for a range of photon energies and stability dosses. Matrices of this type are difficult to program into a computer code because the effective energy of the released photons is a function of the emitter-receptor geometry and because the photon energy frequency distribution changes with time as short-lived radionuclides decay. The effort required to properly implement a finite plume correction is equivalent to the effort expended in developing the finite volume element method in MESORAD.

In the case of elevated releases, IRDAM incorporates a unique algorithm which is sufficiently simple and rapid to permit elevated plume calculations on a microcomputer. This algorithm approximates a Gaussian plume with two concentric cylinders. The radii are equal to σ_y and $2\sigma_y$, respectively. The concentrations of the center cylinder and the outer annulus are approximately Gaussian. The photon energy distributions of the released radionuclides are collapsed to three energy groups that are weighted according to the attention of 50m of air. The results are generally within a factor of two of codes such as WRAITH, which contain rigorous point kernel integration routines.

Dispersion estimates are limited to an accuracy of a factor of two or three by the stochastic nature of atmospheric turbulence. Hence, the limitations of IRDAM's simple dosimetry approximations do not constrain the ability of the code to estimate dose projections under accident conditions.

MESORAD accommodates rapid changes in composition of released plumes by estimating physical decay, daughter radionuclide ingrowth, deposition, washout, and plume depletion. The code calculates the concentration profile and resulting radiation doses are for each radionuclide in each puff.

IRDAM monitors the isotopic composition of the plume for elevated releases or when the exact mixture is specific as an input. Otherwise, the release is modeled to consist exclusively of a mixture of Xe-133 and I-131 when the age of the released material is greater than 24 hours. For more rapid releases, a time-dependent correction factor modifies the dose conversion factors of Xe-133 and I-131 to values that represent the appropriate mixtures of noble gases and iodines.

Both models convert calculated concentrations of radionuclides to environmental dose equivalent or dose commitment uptake rates. The U.S. Environmental Protection Agency, however, has issued radiological protective action guidance (PAG) in the form of projected dose integrals. MESORAD calculates projected doses by carrying the simulation forward in time.

IRDAM calculates the product of the dose rate and the release duration at each distance. The default duration is 8 hours, which is a reasonable approximation of the 99th percentile of the wind direction persistence distribution.

The amount of time required to achieve an integrated dose equivalent equal to a PAG at a given location is an important factor which influences protective action decision making. Using MESORAD, the emergency response analyst may project doses using forecast meteorology and releases, observing the time at which PAGs or other administrative limits are attained at locations of interest. IRDAM produces a table of transport times which, in conjunction with the dose rate data, allows the analyst to calculate the amout of time corresponding to the accumulation of the PAG or administrative limit.