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RASCAL - A SCREENING MODEL FOR ESTIMATING DOSES FROM RADIOLOGICAL ACCIDENTS

Andrea L. Sjoreen
Oak Ridge National Laboratory
Mail Stop 243
P.O. Box X
Oak Ridge, TN 37831

George F. Athey
Phoenix Associates
Suite 600
4720 Montgomery Lane
Bethesda, MD 20814

Cheryl A. Sakenas
Thomas J. McKenna
U.S. Nuclear Regulatory Commission
MS MNBB 3302
Washington, DC 20555

ABSTRACT. The Radiological Assessment System for Consequence AnaLysis (RASCAL) is a new MS-DOS-based dose assessment model which has been written for the U.S. Nuclear Regulatory Commission (NRC) for use during response to radiological emergencies. RASCAL is designed to provide crude estimates of the effects of an accident while the accident is in progress and only limited information is available. It has been designed to be very simple to use and to run quickly. RASCAL is unique in that it estimates the source term based on fundamental plant conditions and does not rely solely on release rate estimation (e.g., Ci/sec of I-131). Therefore, it can estimate consequences of accidents involving unmonitored pathways or projected failures. RASCAL will replace the older model, IRDAM.

I. INTRODUCTION

The NRC has developed three levels of models to assist in responding to radiological emergencies: (1) research models to be run on mainframe computers to analyze potential accident consequences, (2) intermediate models to be run on minicomputers during the accident, and (3) screening models to be run on microcomputers either when an accident is anticipated or by NRC personnel to whom only microcomputers are available at an accident site.

The Radiologic Assessment System for Consequence AnaLysis (RASCAL)[1] has been written to replace NRC's old screening model, the Interactive Rapid Dose Assessment Model, IRDAM.[2] IRDAM has been in use in the NRC's response program for several years. IRDAM is written in BASIC for an Osborne microcomputer. It has been used by the NRC personnel who report to the site of a nuclear accident to conduct an independent assessment of dose projections. IRDAM uses a straight-line Gaussian-plume model for atmospheric transport and estimates whole body dose equivalent from cloud exposure and thyroid dose equivalent from inhalation. These doses can be calculated for radionuclides of iodine and the noble gases. Since IRDAM's development, considerable progress has been made in assessing of severe accident source terms and consequences. It does not reflect the current NRC understanding of those aspects of a severe accident important to early dose assessment. RASCAL has been written to correct the technical and operational problems in IRDAM, to run on the microcomputers presently in use by the NRC, and to reflect current understanding of severe accidents.

RASCAL estimates doses resulting from accidental atmospheric releases of radionuclides. As with all models used to project severe accident dose, the resulting doses are considered to be only crude estimates of probable dose. The model requires only information that might be available during an emergency and has been written to be as self-explanatory as possible. It runs on a MS DOS microcomputer. RASCAL provides default values for all user input and help screens for most entries. It is composed of six FORTRAN programs and six C programs that are run by a DOS batch file.

RASCAL has been written in four parts: source term, atmospheric transport, dose, and graphical output. The data required are accident location, either an assessment of plant conditions or an estimated source term, and basic meteorologic information. The quantity released can be entered by the user or computed using the method of source term estimation based on plant conditions.[3] If the source term has been estimated independently, the transport and dose models can be used to calculate the effects of any atmospheric radiological release. Atmospheric transport is modeled using both Lagrangian puff and Gaussian plume models taken from MESORAD.[4] Cumulative effective doses are computed for the pathways of inhalation, cloud immersion, and ground surface exposure. Overhead cloud shine dose is computed based on the model in MESORAD. Inhalation dose equivalents for lung, bone, and thyroid are also computed. The distributions of any of the doses and the cumulative air or ground concentrations can be plotted on the computer screen.

II. SOURCE TERM CALCULATIONS

The model allows three methods for estimating the source term based on: (1) user-specified isotope release rates, (2) a gross release rate, and (3) plant conditions. The first method allows entry of a release duration and a specific release rate for up to 50 radionuclides. These radionuclides were selected for inclusion in the model because they are the most important for early health effects of any radiological accident. Note that any radiologic accident, not only reactor releases, may be modeled using this method. The second method allows the user to specify a gross release rate (Ci/sec or Bq/sec). The composition of the release can be estimated either based on the percentages of noble gases, iodines, and particulates contained in the release or based on plant conditions using the method described next. The third method allows the source term to be estimated based on precalculated assumptions of dominant accident conditions.[3]

The basic assumptions of the third method are that: (1) there is a small set of accident conditions that dominate any severe accident release, (2) there are scaling factors that can characterize the effects of these dominant conditions on the release, and (3) the dominant conditions can be recognized and characterized during an accident.

The basic steps for source term estimation are:

1. Estimate the amount of fission products released from the core. Four levels of core damage/release are allowed: normal coolant, gap release, grain boundary release, and melt.

2. Identify the dominant release pathway. The pathways allowed are:
   BWR dry well containment leakage/failure,
   BWR wet well containment leakage/failure,
   steam generator tube rupture,
   large, dry, or sub-atmospheric containment leakage/failure,
   ice condenser containment leakage/failure, and
   containment bypass (event V).

3. Characterize the dominant mechanisms that will act to reduce the release. These would include filters, pools of water, sprays,and natural processes.

4. Estimate the release rate. Three leak rates are allowed for containment leakage or bypass accidents: design, failure to isolate (100%/day), or catastrophic failure (100%/hr). Seven leak rates are allowed for steam generator tube rupture accidents: 1 to 4 tubes at full pressure or 1 to 3 pumps at low pressure.

The four steps above provide enough information to roughly determine the mix of radionuclides that is being released and to select the reduction factors that are appropriate for the release processes in effect. This method is described in detail in McKenna and Giitter.[3]

III. ATMOSPHERIC DISPERSION MODEL

Two atmospheric dispersion models are used to estimate material concentrations. The first model is a straight-line Gaussian and is used only for the concentration estimates on a polar grid for distances up to

2.6 km. A Lagrangian puff model is used as the primary dispersion model. Both models are derived from the MESORAD computer code.[4] The puff model estimates concentrations at the nodes on a Cartesian grid and may also contribute to the concentration estimates on the polar grid. The polar grid has receptors at 10 degree intervals around three concentric circles, with radii of 800, 1600, and 3200 meters. The spacing between receptors on the Cartesian grid may be 0.5, 1.6, or 2.6 kilometers. The diffusion coefficients used in both models are a function of atmospheric stability (A – G) and travel distance.

The atmospheric dispersion model reads the release height and duration from the file written by the source term model. To make the atmospheric dispersion model run faster, only a unit release each of a depositing and a non-depositing material are transported. The estimated source term is combined with the air and ground surface concentrations computed by this model in the dose model. Radioactive decay and daughter buildup are not included in the transport model. The source term is decayed over the transport time in the dose model. The model also incorporates source depletion via dry deposition and washout (wet deposition), which are used to estimate surface contamination for all receptors on both grids.

IV. DOSE CALCULATIONS

Because the transport model only computes air concentration and ground surface concentration for a unit release, these quantities must be scaled to each radionuclide released by the dose model. Each radionuclide in the source term is depleted by radiologic decay over the assessment time. The result is multiplied by the cumulative air concentration computed for a unit release of a depositing or non-depositing material, as appropriate for that radionuclide. Cumulative ground surface concentrations are computed analogously for radionuclides which are not noble gases.

Cumulative effective dose equivalents are computed from inhalation, cloud exposure, and ground surface exposure. The ICRP definition of effective dose has been used.[5] A total adult dose is computed as the sum of these. Thyroid, lung, and bone doses are computed for inhalation only. Ground surface dose is the ground surface concentration times the appropriate dose factor. Inhalation dose is the air concentration times the breathing rate times the appropriate dose factor. The cloud dose is the larger of the air immersion dose and the overhead cloud shine dose at each location. The air immersion dose is the air concentration times the appropriate dose factor. The overhead cloud shine dose is computed by scaling and translating single puff doses that were computed for RASCAL by MESORAD. MESORAD was run for representative values of release height, atmospheric stability, wind speed, grid spacing, and photon energy. The overhead cloud shine dose distributions from representative puffs were saved. These data are translated and added across the grid according to the release height, atmospheric stability, horizontal diffusion coefficient, and locations of the puffs generated by RASCAL. The doses thus computed are scaled to the actual photon energies and intensities of each radionuclide in the release and, finally, by the release rate of each radionuclide.

V. OUTPUT

The results of the RASCAL may be printed or plotted on the computer screen using high resolution graphics. Lower resolution graphics may be written to an ASCII file to be either printed on a line printer or transferred over a phone line to another site. A text description of the model assumptions may be added to the ASCII file thus produced. Cumulative air concentration, ground surface concentration, or any of the doses may be plotted. For any type of data, either the large or small grid may be displayed.

VI. DISCUSSION

The results from RASCAL have been compared to those from MESORAD. The two produce the same air and ground surface concentrations. The doses computed are different because RASCAL has more recently calculated dose factors and a slightly different cloud shine model. The resulting doses are comparable when these differences are taken into account. The source term computed by RASCAL matches those published in McKenna and Giitter.[3] RASCAL is being tested by NRC emergency response personnel and modifications of it will continue as comments are received. When testing is completed the NRC plans to publish the model as part of a training manual on the role, shortcomings, and methods of dose/consequence projections during severe nuclear accidents.

Two additional source term computation options are being added: source term estimation for spent fuel and spent fuel pool accidents[3] and WASH-1400 source terms.[6]

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