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# THE RADIOLOGICAL ASSESSMENT SYSTEM FOR CONSEQUENCE ANALYSIS - RASCAL


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## ABSTRACT

The Radiological Assessment System for Consequence AnaLysis, Version 2.1 (RASCAL 2.1) has been developed for use during a response to radiological emergencies.[1,2] The model estimates doses for comparison with U.S. Environmental Protection Agency (EPA) Protective Action Guides (PAGs) and thresholds for acute health effects. RASCAL was designed to be used by U.S. Nuclear Regulatory Commission (NRC) personnel who report to the site of a nuclear accident to conduct an independent evaluation of dose and consequence projections and personnel who conduct training and drills on emergency responses. It allows consideration of the dominant aspects of the source term, transport, dose, and consequences. RASCAL consists of three computational tools: ST-DOSE, FM-DOSE, and DECAY. ST-DOSE computes source term, atmospheric transport, and dose to man from accidental airborne releases of radionuclides. The source-term calculations are appropriate for accidents at U.S. power reactors. FM-DOSE computes doses from environmental concentrations of radionuclides in the air and on the ground. DECAY computes radiological decay and daughter in-growth. RASCAL 2.1 is a DOS application that can be run under Windows 3.1 and 95. RASCAL has been the starting point for other accident consequence models, notably INTERRAS, an international version of RASCAL, and HASCAL, an expansion of RASCAL that will model radiological, biological, and chemical accidents.

## I. INTRODUCTION

RASCAL 2.1 has been developed to compute doses and health effects during a response to a radiological emergency. RASCAL is designed to be simple to use. It computes 'best-guess' doses, rather than conservative doses. The first version of RASCAL(1.3)[3] was released in 1989. It superseded the IDAS methodology used by NRC at that time. The current version is RASCAL 2.1. RASCAL 2.1 has been widely distributed throughout the United States and other countries. RASCAL 3.0 (for Windows 95) is under development. Other versions of RASCAL have been created for related

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uses. The international version, INTERRAS, was created for the International Atomic Energy Agency (IAEA) primarily for radiological emergency response by eastern European countries. Another version, HASCAL, is being developed for the Defense Nuclear Agency as part of its worldwide Hazard Prediction and Assessment Capability. Biological and chemical accident analysis capabilities will be added to HASCAL.

## II. RASCAL 2.1

RASCAL 2.1,[1,2] which is a major modification of RASCAL 2.0,[4] was released in March 1995. The entire user interface was redesigned, based on the comments of users. RASCAL now allows the saving of cases for later modification of data or display of results and supports the use of a mouse for user input. The tabular output of ST-DOSE and FM-DOSE has been changed to include an indication of whether or not EPA PAGs have been exceeded. RASCAL 2.1 uses Federal Guidance Reports 11 and 12 dose factors.[5,6]

Three new source-term calculations have been added to ST-DOSE: (1) a source term based on the reactor containment monitor reading,[7] (2) a source term for a spent fuel pool accident, and (3) an isotopic concentration source term. The containment monitor reading option computes a fractional core damage state from the monitor reading, based on curves that have been predetermined for each reactor type. The spent fuel pool source term assumes a Zircaloy fire or fuel cladding failure and allows the entry of the number of fuel batches involved and the age of the youngest batch. A building wake calculation has been added to the atmospheric transport calculations..

The intermediate-phase dose calculations in FM-DOSE now allow the inclusion of reentry delay in the calculation of first- and second-year doses and the use of a variable resuspension rate. FM-DOSE now also calculates a factor that can be used to estimate a first-year dose from R/h measurements of activity on the ground.

## III. RASCAL 3.0

The development of a Windows 95 version of RASCAL (version 3.0) has begun. ST-DOSE will include new source-term options for (1) fire, (2) coolant releases, (3) spent fuel dry storage/cask transportation, and (4) calculation of a source term based on a containment air sample. A variety of new ways to estimate the core condition and leakage rate have been added. It will be possible to vary the amount released through time, but it will not be possible to vary the mix through time. All 825 radionuclides in Federal Guidance Reports 11 and 12 will be available in the isotopic source-term options.

A version of the atmospheric transport model RACHET[8] will replace TADMOD (based on MESORAD),[9] the current atmospheric transport model in ST-DOSE. RACHET will allow the use of meteorological field input (wind fields, spatially varying precipitation, terrain, etc.). Creation of these fields will be part of a separate preprocessor. The maximum assessment grid radius will be 50 miles.

Dose calculations will be updated, as needed, to allow a comparison with the calculations of other agencies. Some of the FRMAC Assessment Manual[10] calculations will be included in FM-DOSE. Emergency-worker limits will be computed. Ingestion and skin doses will not be computed.

The DECAY program will be modified to permit the tabular and graphic display of radionuclide decay chains. These displays will be available throughout RASCAL in the help system.

A back-calculation tool will be added to RASCAL that will use a straight-line Gaussian plume model and Monte Carlo methods to estimate the released source term from available field measurements. The uncertainty in this source term will be calculated based on the uncertainty in the meteorology.

IV. INTERRAS

INTERRAS, the International version of RASCAL 2.1, was created for the analysis of radiological accidents at international power reactors as well as other nonreactor accidents. Modifications to the calculations include the addition of some radionuclides, the modification of the plant-conditions source-term options, and the replacement of the EPA Protective Action Guides (PAGs) calculations with calculations of IAEA Intervention Levels (ILs).

Modifications have been made to ST-DOSE to make it more appropriate for International assessments. All plant-specific data have been removed from INTERRAS. The default units are metric, but English units are also available. Twelve radionuclides have been added to the isotopic source terms.

Source-term options for two plant conditions were added: the Dry Containment Leakage/Failure and the Suppression Pool (Wet Well), or Bubble Tower Failure options. The first replaces both the "Large Dry or Subatmospheric" and "Dry Well" options in RASCAL 2.1. The second replaces the Wet Well option. The effect of water depth in the suppression pool or bubble tower is considered.

The containment monitor source-term option has been modified to allow calculations at VVER reactors. VVER 1000's are treated the same as U.S. PWRs. VVER 213s and VVER 230s are treated the same as U.S. BWRs, with the release through the dry well. VVER 213s monitor readings are modified by a factor of 0.83.

The doses calculated in ST-DOSE were modified only slightly. The maximum acute exposure period has been increased from 4 days to 1 week, and the 4-day ground-shine calculation has been eliminated. Radiological decay and ingrowth are now included in the calculation of the ground-shine dose. The acute (30-day) lung and bone marrow inhalation dose factors have been replaced with 2-day dose factors. The EPA protective action guides used to flag doses in RASCAL 2.1 have been replaced by IAEA ILs.

The dose calculations in FM-DOSE were modified slightly. The maximum acute exposure period has been increased from 4 days to 1 week, and the 4-day ground-shine calculation has been eliminated. The acute (30-day) lung and bone marrow inhalation dose factors have been replaced with 2-day dose factors. Also, the intermediate-phase first- and second-year doses have been changed to first- and second-month doses. The EPA PAGs used to flag doses in RASCAL 2.1 have been replaced by IAEA ILs. Thirteen radionuclides were added.

V. HASCAL

The Hazard Assessment System for Consequence Analysis (HASCAL) is being developed to support the analysis of radiological, biological, and chemical incidents anywhere in the world for the Defense Nuclear Agency (DNA). HASCAL is a component of the Hazard Prediction and Assessment Capability (HPAC), which is a comprehensive nuclear, biological, and chemical hazard effects planning and forecasting modeling system that is being developed by DNA. HASCAL version 0.7 computes best-guess estimates of the consequences of radiological incidents, as well as estimates of the probability of exceeding specified doses. HASCAL 0.7 estimates the amount of radioactivity released, its atmospheric transport and deposition, and the resulting radiological doses to man.

At present, the enhancements of HASCAL over RASCAL, for source-term modeling are (1) site-specific data for all power reactors in the world and two generic reprocessing facilities, (2) new source-term computation options for all power reactors, worldwide, (3) the inclusion of 1040 radionuclides, rather than the 82 in RASCAL, and (4) the ability to enter source terms in mass units, as well as activity units. The atmospheric transport model, SCIPUFF, has been added to HASCAL as an alternative to the TADMOD model. SCIPUFF allows (1) the calculation of the probability of exceeding a dose, (2) the use of historical climatological data, (3) the detailed maps of all accident sites, (4) the animation of plume movement through time, and (5) the estimation of radiological decay and daughter ingrowth during atmospheric transport.

HASCAL contains a database of all nuclear power reactors in the world. This database contains the reactor name, location, type, rated power, construction date, and keys to the inventory file and files of meteorological data, if available. More detailed data are present for U.S. reactors and are being added for non-U.S. reactors.

Files of meteorological data for the meteorological station nearest each reactor site have been added to HASCAL. These files contain 15-day mean hourly meteorology, including standard deviations for wind speeds. They can be read by HASCAL to provide default meteorologic conditions over the assessment period for the day and time of the incident for either the SCIPUFF or TADMOD models. This meteorological data file is required to run SCIPUFF in its probabilistic mode.

The reactor inventory files that are being added to HASCAL contain more detailed reactor inventories than are used in RASCAL—data for 1040 radionuclides vs the ~80 radionuclides available in RASCAL. Currently, files are available for the following types of reactors: PWRs, BWRs, PHWRs (Candus), VVERs, RBMKs, AGRs, and GCRs. These inventories were computed using ORIGEN[11] and can be used to perform source-term calculations for reactors for which no accident scenarios have been defined, using the percentage of total inventory source-term option. A generic reprocessing plant inventory has been added.

Different source-term calculations are available, depending on the type of facility selected. Up to seven source-term options are available in HASCAL: isotopic release rates or concentrations, a release defined as a gross mix of available isotopes, releases based on plant conditions, releases based on the containment monitor reading, spent fuel pool accidents, and a percentage of total inventory by MELCOR[12] element category. The computed source-term table is now subdivided by MELCOR element category. Isotopic source terms may be entered in units of either activity or mass.

Plant conditions source terms are available for all types of power reactors that have inventory data. For example, for RBMKs there is a calculation for a prompt critical accident involved one-third, two-thirds, or all of the core at operating power. The release fractions used are based on assessments of the Chernobyl accident.[13,14]

Comparisons of the number of Curies released using RASCAL PWR inventory vs the new inventory in a severe core damage accident result in about a 10% increase using the new data. For comparison of the two inventories in an accident that releases the total inventory of a PWR (which is nearly impossible, physically), the new inventory results in a factor of 3.5 more Curies released.

The inclusion of SCIPUFF in HASCAL provides the capability of probabilistic prediction of atmospheric transport. The multidimensional wind field capability allows SCIPUFF to treat longer range assessments than can TADMOD. The dispersion algorithm in SCIPUFF is based on second-order closure theory and is therefore very different from that in TADMOD. Differences in resulting concentration predictions from the two models can be more than an order of magnitude under extreme conditions when the atmosphere is very stable or for very light wind conditions.

SCIPUFF provides a probabilistic prediction of the atmospheric dispersion and surface deposition processes, with the capability to model multidimensional, time-dependent wind fields. Uncertainty in the wind field, including both boundary-layer-scale turbulent eddies and larger scale unknown variations, leads to a random component in the concentration field which requires at least the mean value and the standard deviation for a quantitative description. SCIPUFF uses turbulence closure theory to predict the concentration fluctuation variance as a function of the wind field uncertainty[15,16] and provides a probabilistic description of the resulting impact using a parameterized probability distribution function.[17] HASCAL can then use the SCIPUFF prediction to compute probabilistic radiological doses and to provide an assessment of likelihood for various levels of health effects. SCIPUFF also includes the estimation of radiological decay and daughter ingrowth during atmospheric transport. A new interactive graphics interface is used to display the SCIPUFF results from HASCAL.

The dose calculations in HASCAL are designed for comparison with U.S. EPA protective action guides.[18] They are unchanged from RASCAL, except that SCIPUFF does not compute cloud-shine dose. The data used for those calculations have been expanded to take into account as many radionuclides as possible from the newly calculated reactor inventories. External dose factors have been calculated for all 1040 radionuclides in the inventory files. Inhalation dose factors for these radionuclides are being calculated. The inclusion of short-lived radionuclides in these inventories will allow estimation of doses from very short exposures for those radionuclides for which dose factors are available.

Planned enhancements to HASCAL include adding other types of radiological facilities, including research and production reactors, enrichment and storage facilities, waste processing and storage facilities, and mining and milling operations. Work on incident scenarios for the various types of power reactors continues. Additional scenarios appropriate for each type of facility will be developed, along with models of damage response and the resulting doses from various kinds of weapons attacks on worldwide nuclear facilities. Cloud-shine dose calculations and the ability to print results in a tabular form will be added to SCIPUFF. Inhalation dose factors will be computed for the full list of 1040 radionuclides.

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