A Review of the NRC Emergency Response Code RASCAL Version 2.1

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1. INTRODUCTION

The Radiological Assessment System for Consequence AnaLysis (RASCAL) code is a set of personal computer-based programs developed for use by U.S. Nuclear Regulatory Commission (NRC) responding to radiological emergencies mostly during the early phase of an accident, including those who report to the site of a nuclear power plant accident to conduct an independent assessment of dose projections. RASCAL Version 2.1, developed by Oak Ridge National Laboratory, Batelle - Pacific Northwest Laboratory and Athey Consulting, was issued in March 1995. RASCAL contains the following three subprograms:

- ST-DOSE: generates estimates of source term, atmospheric dispersion, and dose from a radiological accident,
- FM-DOSE: generates estimates of dose from field measurements of radionuclide concentrations, and
- DECAY: generates estimates of radionuclide concentrations present after decay and ingrowth.

This paper is intended to be a review of the ST-DOSE computer code, with an emphasis on the meteorological aspects of the code. Included in this paper is a synopsis of ST-DOSE's modeling assumptions, a review of the code's input requirements, and a description of the program's output. A discussion of the uncertainties involved in dose projection modeling is also provided, along with a list of the code's strengths and suggested areas for improvement.

This author feels it is important for the nuclear meteorological community to remain cognizant of the Commission's latest efforts in emergency response atmospheric dispersion modeling and dose projection methodologies. Minimal regulatory guidance has been provided on this subject and a review of the NRC's latest emergency dose projection model reveals those modeling aspects which the Commission currently feels are crucial. In the event of an actual accident, it is also important that emergency responders understand the dose projection models which the Commission will utilize during the event.

Documentation concerning RASCAL Version 2.1 is provided in the User's Guide[1] and an accompanying Workbook[2] which contains exercises designed to familiarize the user with RASCAL. Much of the description of the ST-DOSE model presented in this paper was obtained from these two documents. The RASCAL software and documentation is available from the Energy Science and Technology Software Center, P.O. Box 1020, Oak Ridge, TN, 37831-1020 (423-576-2606). Additional information on the ST-DOSE atmospheric dispersion calculations can be found in the documentation for the MESOI and MESORAD computer codes[3,4].

2. MODELING ASSUMPTIONS

The source term, atmospheric dispersion, and dosimetry assumptions used by ST-DOSE to estimate doses and consequences resulting from the accidental release of radionuclides to the atmosphere are described below.

2.1 Source Term

The sections that follow contain brief descriptions of the various calculational options available for determining the total amount of activity released for purposes of performing dose projections within ST-DOSE.

a. Isotopic Release Rates

This option computes the source term through the input of a release rate for each radionuclide (e.g., Ci/sec). The total amount of activity released is determined by multiplying the release rates by the release duration. Radiological decay is not computed for this source term. This option is intended for use in monitored releases and can be used for reactor accidents as well as non-reactor accidents.

b. Isotopic Release Concentrations

This option computes the source term through the input of a release concentration (e.g., Ci/cc) for each radionuclide and a release flow rate (e.g., cc/sec). The total amount of activity released is determined by multiplying the concentrations by the release rate and release duration. Radiological decay is computed from the Start of Decay time to the Start of Release to Environment time. This option is intended for use in monitored releases and can be used for reactor accidents as well as non-reactor accidents.

c. Mix Specified by Analyst

This option computes the source term through the input of a gross release rate (e.g., Ci/sec) and an estimate of the percentages of the release that are in each of seven radionuclide categories. The total amount of activity released is computed by multiplying the release rate times the release duration. The isotopic concentrations assumed in the release are based on a standard core inventory at shutdown (Ci/Mw(t)) which is decayed from the Start of Decay time to the Start of Release to Environment time. This calculation assumes the entire release is from a monitored pathway.

d. Plant Conditions

This option calculates the source term based on assumptions of core and containment conditions as well as release pathways. Any one of the six following release pathways can be selected for consideration:

- Large Dry or Sub-atmospheric Containment Leakage/failure: This option assumes the core is uncovered and the release fractions are typical of a gap, in-vessel melt, or vessel melt-through release. The release is assumed to occur by way of a dry pathway through the primary system into the containment atmosphere.

- Ice Condenser Containment Leakage/failure: This option assumes the core is uncovered and the release fractions are typical of a gap, in-vessel melt, or vessel melt-through release. The release is assumed to occur by way of a dry pathway through the primary system into the containment atmosphere through the ice condenser. Options to reduce the source term by considering the combined effects of fans and the ice bed are available.

- BWR Containment Dry Well Leakage/failure: This option assumes the core is uncovered and the release fractions are typical of a gap, in-vessel melt, or vessel melt-through release. The release is assumed to occur by way of a dry pathway through the primary system into the containment dry-well atmosphere without passing through the suppression pool.

- BWR Containment Wet Well Leakage/failure: This option assumes the core is uncovered and the release fractions are typical of a gap, in-vessel melt, or vessel melt-through release. The release is assumed to occur by way of a wet pathway through the suppression pool into the containment wet-well atmosphere.

- Containment By-pass: This option assumes the core is uncovered and the release fractions are typical of a gap, in-vessel melt, or vessel melt-through release. The release is assumed to occur by way of a line that by-passes the containment.

- Steam Generator Tube Rupture: This option calculates coolant concentrations which approximate either typical coolant concentrations, coolant concentrations with 100x the normal non-noble fission product spike, gap release from the core, or in-vessel melt release from the core. The coolant is assumed to be released through a steam generator tube rupture to the secondary side (due to failure of one or two steam generator tubes or due to the operation of one to three charging pumps) and then to the atmosphere through either safety relief valves or through the condenser and then the steam-jet air ejector. The affected steam generator can be assumed to be either partitioned or not partitioned (partitioning refers to particulates being retained in the steam generator water and not entering the release).

The first five release pathways listed above assume the release pathway includes containment leakage to the environment. The release from the containment is a function of one of eight leak rate categories ranging from half the containment design leak rate (at half the design pressure) up to a catastrophic failure of the containment (100% leak in one hour). Note that the calculated release can be reduced by indicating the presence of either sprays or filters or both.

e. <u>Containment Monitor Readings</u>

This option computes the source term through the input of a containment monitor reading and other accident data. The release is computed as a function of core damage state, reactor power level, and containment leak rate. The core source term is first determined by multiplying the reactor power (Mw(t)) by a standard core inventory (Ci/Mw(t)). The fraction of the core source term released into containment is then determined as a function of the core damage state (gap release, in-vessel severe core damage, or vessel melt through) which is estimated from the containment monitor reading. The release from the containment is then a function of one of eight containment leak rate categories ranging from half the containment design leak rate (at half the design pressure) up to a catastrophic failure of the containment (100% leak in one hour). Note that the calculated release rate can be reduced by indicating that containment sprays are on and that the release is through a filtered pathway.

f. <u>Spent Fuel/Spent Fuel Pool Accident</u>

This option computes the source term based on a spent fuel or spent fuel pool accident. The release is computed assuming either a zircalloy fire or a fuel cladding failure in the spent fuel located in a spent fuel pool. The release is computed as a function of the inventory available for release and the containment leak rate. The inventory available for release is a function of the number of fuel batches in the pool, the age of the youngest batch of fuel in the pool, and the fuel damage state (fuel cladding failure or zircalloy fire). The release from the containment is a function of one of seven containment leak rate categories ranging from half the containment design leak rate (at half the design pressure) up to a catastrophic failure of the containment (100% leak in one hour). Note that the calculated release can be reduced by indicating the presence of either sprays or filters or both.

Ingrowth of radioactive decay products is calculated for all source terms except those based on isotopic release rates or containment monitor readings. Decay and ingrowth begin at the reactor shutdown time and end when the release to the environment begins.

Holdup in containment allows reduction of source term determined on the basis of plant conditions. The holdup period begins when the radionuclides are released from the primary system into the containment atmosphere and ends when they are released to the environment. Note that the maximum allowable release duration for any release pathway is 24 hours.

2.2 Dispersion

The methods used in ST-DOSE to compute atmospheric plume transport and diffusion are described in this section.

The meteorological conditions used to disperse the plume (wind speed, wind direction, stability class, mixing layer depth, and precipitation) are allowed to vary as a function of time by entering two or more sets of meteorological conditions. Meteorological conditions are not allowed to vary as a function of horizontal location. The minimum interval between meteorological data sets is 15 minutes and the maximum number of meteorological data sets which can be entered during any one run is four.

a. Plume Transport:

ST-DOSE divides the atmosphere into two layers: a lower layer (between the earth's surface and the top of the mixing layer) and an upper layer (above the top of the mixing layer). In the lower layer, wind speed is assumed to increase with height as a function of stability; in the upper layer, the wind speed is held constant. The wind direction is the same in both layers.

The basic time step for atmospheric transport and diffusion is five minutes and an estimate of the wind speed at the effective release height is used to transport and diffuse the plume. The 10-m wind speed and effective release height are entered by the user and the wind speed at the effective release height is estimated from the 10-m wind speed and stability class.

b. Diffusion Model

Any given ST-DOSE run will utilize either a plume diffusion model, a puff diffusion model, or a combination of both models. The plume diffusion model employs the familiar straight-line steady-state Gaussian model as follows:

$$\chi = \frac{Q'}{\pi u \sigma_y \sigma_z} \cdot \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right] \cdot \sum_{n=-1}^{n=1} \exp\left[-\frac{(2nH-h_e)^2}{2\sigma_z^2}\right] \qquad (1)$$

where χ = the concentration at ground level (Ci/m^3)
Q' = the release rate (Ci/sec)
u = the average wind speed at release height (m/s)
σ_y,σ_z = the horizontal and vertical diffusion coefficients (m)
H = the mixing layer thickness (m)
h_e = the effective release height (m)

The basic assumptions of the plume model are a constant release rate, constant meteorological conditions, and an finite wind speed greater than zero.

The puff diffusion model is a Lagrangian-trajectory Gaussian puff model which simulates the plume by a sequence of puffs. Concentrations are computed as a function of distance from the center of puffs as the puffs are moved by the wind:

$$\chi = \frac{Q}{\pi^{3/2}\sigma_y^2\sigma_z} \cdot \exp\left[-0.5\left(\frac{r}{\sigma_y}\right)^2\right] \cdot \sum_{n=-1}^{n=1} \exp\left[-\frac{(2nH-h_e)^2}{2\sigma_z^2}\right] \qquad (2)$$

where Q is the total activity in the puff (Ci) and r is the horizontal distance from the center of the puff. Plumes are approximated by releasing a sequence of puffs. The concentration at any point is estimated as the total of the concentrations estimated at the point from all puffs. Puffs are released at five-minute intervals with only one puff being released if a release duration is shorter than five minutes.

The user can select either the plume model option or the puff model option when executing the code. If the plume model option is selected, the plume model is used to calculate dispersion as long as the wind speed is one mph or greater. If the wind speed is below one mph, the puff model is used instead of the plume model (plume model results become unrealistic as the average wind speed approaches zero since the wind speed is in the denominator of the plume model dispersion equation). Also, since the plume model is a steady-state model, only the first set of user-supplied meteorological conditions are used and any additional sets of supplied meteorological data are ignored.

If the puff model option is selected, the plume model is used to calculate dispersion within two miles and the puff model is used to calculate dispersion beyond two miles. However, if the wind speed is less than one mph, then the puff model is used to calculate dispersion for all distances.

Table 1 summarizes the conditions under which each of the two dispersion models are used within ST-DOSE. Note that in spite of the user's selection of either the plume model option or the puff model option, Table 1 demonstrates that the user does not have direct control over which diffusion model algorithm is implemented, except for distances beyond two miles when the wind speed exceeds one mph. Since the plume diffusion model cannot handle more than one set of meteorological conditions, the puff diffusion model option should be chosen under variable meteorological conditions.

Table 1. ST-DOSE Internal Selection Criteria for Utilizing the Plume Versus the Puff Diffusion Model Algorithms

User-Supplied Inputs		Diffusion Model Used	
Diffusion Model	Wind Speed	Distance ≤ 2 Miles	Distance > 2 Miles
Plume	< 1 mph	PUFF	PUFF
	≥ 1 mph	PLUME	PLUME
Puff	< 1 mph	PUFF	PUFF
	≥ 1 mph	PLUME	PUFF

c. Effective Release Height

The ST-DOSE model can handle both ground level and elevated releases. The release mode implemented by the model is a function of the effective release height, the building wake model option, and the wind speed at the effective release height. Ground mode releases (which assume a plume height of 0 meters) are assumed to occur whenever the user-supplied effective release height is less than 31 ft (10 m) or when the building wake model option is selected and the wind speed is equal to or greater than one mph. Elevated mode releases (which assume a plume height equal to the user-supplied effective release height) are assumed to occur for all other release scenarios. A summary of the conditions under which ground mode versus elevated mode releases are assumed to occur is provided in Table 2. Note that the RASCAL User's Manual suggests that the building wake option should be used unless the release is from a tall isolated stack.

Table 2. ST-DOSE Internal Selection Criteria for Determining Ground Versus Elevated Mode Releases

User-Supplied Inputs			Resulting Release Mode
Effective Release Ht	Building Wake Model Option	Wind Speed	
< 31 ft	ON or OFF	all	GROUND
≥ 31 ft	OFF	all	ELEVATED
	ON	< 1 mph	ELEVATED
		≥ 1 mph	GROUND

d. Diffusion Coefficients

Whenever the effective release height is at or below the mixing layer height, both the horizontal and vertical plume diffusion coefficients are calculated based on the stability class provided by the user. If the effective release height is above the mixing layer height, the horizontal plume diffusion coefficient is determined utilizing the user-supplied stability class and the vertical plume diffusion coefficient is calculated assuming very stable "G" stability conditions.

Diffusion coefficients are estimated as a function of stability class and distance travelled using the algorithms from the NRC XOQDOQ and PAVAN computer codes[5,6]. However, if the wind speed is less than one mph, diffusion coefficients are calculated as a function of transit time; the horizontal diffusion coefficient grows at a rate of 700 m per hour and the vertical diffusion coefficient is assumed to grow as if the wind speed were 0.9 mph in G stability.

Note that when the building wake option is selected and a ground mode release occurs, the diffusion coefficients are increased to account for plume meander at low wind speed and building wake effects. Since the amount of increase is inversely proportional to the wind speed, the building wake correction is not applied when the wind speed is less than one mph.

e. Dry Deposition

Dry deposition is computed from the ground-level air concentration using a deposition velocity of 0.3 cm/sec for particles and gases. This deposition velocity is considered appropriate for iodine and conservative for other elements. Noble gases are not deposited.

Material deposited by dry deposition is removed in the puff diffusion model as it is deposited, thereby conserving mass; material is not removed from the plume in the plume diffusion model. As a result, there may be small differences between concentrations and doses computed by the two models if the release contains anything other than noble gases.

f. Wet Deposition

Wet deposition is computed using a washout coefficient that is a function of precipitation type and rate. The washout coefficient increases with increasing precipitation rate and is higher for liquid precipitation than it is for frozen precipitation. Noble gases are not affected by wet deposition.

Material deposited by wet deposition is effectively removed from subsequent downwind calculations with both the puff and plume diffusion models. However, since the methods of treating depletion differ slightly between the two models, there may be slight differences in computed doses between the two models under certain conditions.

g. Topographic and Terrain Effects

The effects of land forms (e.g., valleys) on plume transport and the effects of terrain elevation on ground-level plume concentrations are not considered by the current version of ST-DOSE.

2.3 Dosimetry

ST-DOSE does not compute dose rates; rather, it provides a snapshot of integrated dose to a person standing outside. Two sets of integrated doses are generated: acute health effect doses (for insight into early health effects) and chronic health effect doses (for comparison with EPA Early Phase Protective Action Guidelines). A brief description of the methods used to compute the various dose types is provided in this section.

a. Acute Doses

Acute doses are calculated for insight into locations where early health effects (e.g., injury and deaths) are possible[7]. Acute health effects are typically estimated based on absorbed dose to specific organs and ST-DOSE calculates acute doses to red bone marrow and thyroid since these are considered the most critical organs for typical reactor accidents. An acute lung dose is also calculated in the event of a plutonium release. Table 3 summarizes the dose consequences for the various types of dose calculated by ST-DOSE.

Table 3. Acute Health Effect Thresholds[7]

Dose Type	Threshold	Consequences
Total Acute Bone Dose	> 50 rem	Vomiting and diarrhea possible
	> 150 rem	Death possible
Acute Lung Dose	> 700 rem	Death possible
Thyroid Effective Dose Equivalent	> 3000 rem	Hypothyroidism

The calculated total acute bone dose is a sum of doses calculated from cloud shine, initial ground shine, and inhalation; the calculated thyroid dose is solely the result of inhalation.

Cloud shine dose calculations are calculated for the duration of exposure to the plume using a finite-puff model if the magnitude of the horizontal diffusion coefficient is less than 400 m and a semi-infinite cloud model if the diffusion coefficient is greater than 400 m.

The initial cumulative ground-shine dose at each location is computed by multiplying the cumulative ground surface concentration by dose factors and a correction factor of 0.7 that accounts for scattering from surface roughness (the surface roughness correction factor is used because the dose factors were computed for exposure above a smooth infinite plane). The dose factors used have been computed for dose at one meter above the ground. The initial ground shine dose is calculated from the arrival of the plume to the end of the selected exposure period.

The acute cumulative bone and thyroid inhalation dose equivalents are a 30-day commitment to the bone and thyroid of an adult. The inhalation dose is calculated for the duration of exposure to the plume using an adult's breathing rate and appropriate dose factors.

b. Chronic Doses

Chronic doses are calculated for comparison with EPA protective action guidelines (PAGs)[8]. The latest EPA PAGs are based on the 50-year total effective dose equivalent (TEDE) and thyroid committed dose equivalent. The TEDE is the sum of cloud shine, 4-day ground shine, and 50-year inhalation effective dose equivalents; the thyroid committed dose equivalent is based on the inhalation dose. The 4-day ground shine is the sum of the initial ground shine dose and the dose from the time-integrated activity for the remainder of the 4 days.

Table 4 summarizes the recommended protective actions for the various types of dose calculated by ST-DOSE.

Table 4. EPA Early Phase Protective Action Guidelines[8]

Dose Type	Threshold (rem)	EPA Early Phase Protective Action Guidelines			
		Normal Environmental Conditions		Hazardous Environmental Conditions(a)	
		General Population	High Risk Groups(b)	General Population	High Risk Groups(b)
Total Effective Dose Equivalent (TEDE)	1	Evacuate	Shelter	Shelter	Shelter
	5	Evacuate	Evacuate	Evacuate	Shelter
	10	Evacuate	Evacuate	Evacuate	Evacuate
Thyroid Effective Dose Equivalent	5	Evacuate	Shelter	Shelter	Shelter
	25	Evacuate	Evacuate	Evacuate	Shelter
	50	Evacuate	Evacuate	Evacuate	Evacuate

(a) Environmental conditions that impose a substantially higher risk than an individual would normally be expected to take.

(b) Groups which present a higher than average risk from evacuation (e.g., persons not readily moved).

3. RUNNING THE MODEL

3.1 Hardware Requirements

The RASCAL Version 2.1 dose assessment system requires an IBM PC or PS/2 compatible computer with the following specifications:

8086 or 80286 CPU (80386 or 80486 recommended)
DOS Version 3.1 or later (DOS Version 6.+ recommended)
640 kB RAM (with 520 Kb free at run time)
Hard disk with 2.6 MB free for installation and 200 Kb free at run time
Math Coprocessor
VGA+ graphics adapter and monitor (for graphics output)
Recommended: pointing device (mouse or trackball)

Since the software is provided on one 3½ 1.44 MB floppy disk drive, having a 3½ floppy disk drive is helpful when installing the code.

3.2 Input Requirements

ST-DOSE is designed to run using information that would be available during an emergency and has been written to be as self-explanatory as possible. Interaction with the program is via the keyboard or mouse. The user is guided through data entry by text on each screen. User input is requested through the use of a variety of menus, data forms, and help windows.

Data required by ST-DOSE are accident location (i.e., plant name), either an estimated source term or an assessment of plant conditions, and basic meteorological information. A listing of the general input requirements for executing ST-DOSE is provided in Exhibit 1.

3.3 Output Description

ST-DOSE computes integrated doses for insight into potential early health effects and for comparison to EPA PAG's. Output results are provided using a variety of text windows and graphics screens. All text and graphic output can be either viewed or printed. The types of doses generated and their use are presented in Table 5.

Three text summaries are available: a summary of user inputs, a listing of the computed source term (including the amount of each radionuclide released and the fraction of core inventory released), and a maximum dose report. An example of a maximum dose report is provided in Exhibit 2. This report lists doses calculated at distances of ½, 1, 2, 5, 10, and (if selected) 25 miles for the nine types of doses listed in Table 5. The report also "stars" any TEDE and thyroid committed dose equivalents which exceed the early phase EPA PAGs.

Ten sets of graphics are also available: nine sets showing dose patterns (one set for each of the nine types of doses listed in Table 5) plus a tenth set showing deposition patterns. Each set of graphics includes two plots: one for distances between one-half and two miles and a second for distances beyond two miles. The first plot is based on a polar grid and the second plot is based on a 5-25 mile polar grid for the plume diffusion model and on either or 2-10 mile or 2-25 mile cartesian grid for the puff diffusion model. Examples of the graphic outputs are provided in Exhibit 3.

Table 5. Types of Doses Calculated and Their Uses

Dose Type	Uses
Total Acute Bone Dose	Insight into early health effects
Acute Lung Dose	Insight into early health effects (for Pu releases)
Total Effective Dose Eq. (TEDE)	Comparison with EPA early phase PAGs
Thyroid Effective Dose Eq.	Insight into early health effects; Comparison with EPA early phase PAGs
Cloud Shine Dose	Comparison with old EPA early phase PAGs and component of Total Acute Bone Dose and TEDE
Initial Ground Shine Dose	Component of Total Acute Bone Dose
Four-Day Ground Shine Dose	Component of TEDE
Acute Bone Inhalation	Component of Total Acute Bone Dose
Inhalation CEDE	Component of TEDE

4. MODELING UNCERTAINTIES

The RASCAL User's Guide devotes several pages discussing the uncertainties involved in emergency response dose projection modeling. The authors of the RASCAL User's Guide apparently believe that the users of this and other emergency response dose projection models should have an understanding of the limitations of these models. As a meteorologist, this author is also interested in comparing the uncertainties involved in plume transport and diffusion modeling with the uncertainties inherent with the other components of dose projection modeling. Consequently, much of the RASCAL User's Guide discussion on dose projection modeling uncertainty is outlined below.

Predicting doses from an airborne radioactive release requires several steps:

- Predicting the quantity and timing of the release (source term)
- Predicting the plume transport and diffusion (plume dispersion)
- Predicting the resulting dose from the plume (dosimetry)

Each of these steps requires collection of appropriate data, and data collection and the subsequent computations are subject to uncertainties. Table 6 provides estimates of overall uncertainties associated with dose assessments for severe accidents (core melt) based on the difficulties of estimating source term, plume dispersion, and dosimetry. The RASCAL User's Guide concludes that the best that should be expected early in an accident release sequence is that projected doses may be within a factor of 10 of the average doses measured from field monitoring; it is likely that they will be less accurate.

The RASCAL User's Guide also warns that there can be a 10- to 100-fold spread among the various dose estimates calculated by the various organizations responding to an accident (e.g., licensee, NRC, state and local officials, the U.S. Department of Energy). Each responding organization may bring their own dose projection model and each of these models: (1) may be based on different modeling assumptions; (2) may be executed with different input conditions; and (3) may produce dissimilar types of doses and dose rates.

Table 6. Components of Dose Assessment Uncertainty for a Severe (Core Melt) Accident

Element	Uncertainty Factor(a)		
	At Best	Most Likely	Near Worst
Source Term (event and sequence)	5(b)	100-1,000(c)	1,000,000(d)
Dispersion			
Transport (rate)	1	2	10(e)
Transport (direction)	22°	45°	180°
Diffusion (concentration)	2	5	10
Dosimetry (external)	3	4	10
Overall			
Dose	10	100-10,000	1,000,000
Direction	22°	45°	180°

(a) These estimates are for an averaged (e.g., 15-30 min) dose at a location, not for a specific or single monitor reading.
(b) Source term for a monitored release based on effluent monitor readings.
(c) Source term based on actual or projected plant conditions.
(d) Source term for an unmonitored release on monitor readings.
(e) Plume transport during low wind speed conditions.

Details of the uncertainty involved in the various steps required to perform dose projections follows.

4.1 Source Term

During an accident, predicting or characterizing the timing and composition of the release is the first step in projecting dose consequences.

Following the Three Mile Island Unit 2 accident in 1979, on-line radiation monitors capable of measuring noble gases released through plant vents were installed as upgrades at US power reactors. For lesser (non-core damage) accidents in which the total release is through a monitored pathway and consists mostly of noble gases, it may be possible to obtain a good characterization of the release, assuming the monitors stay on scale and are properly calibrated. However, the mixture of radionuclides in the release may not match the mixture assumed in the calibration of the monitor.

For the more severe (core damage) accidents, radioactive iodine and other particulate releases are considered a greater public health threat than noble gas releases. However, on-line monitors for radioactive iodine and other particulate releases are considered impractical. Therefore, the presence of iodine and particulates in a release are typically determined through an analysis of samples taken during the release, an analysis which may require several hours. This means that rapid estimates of non-noble fission product source terms are not available for the more severe types of accidents.

The type of release having the greatest public health threat would be a fast and unfiltered severe accident release via an unmonitored pathway to the atmosphere (for example, a core melt in conjunction with an unanticipated catastrophic containment failure). The RASCAL dose assessment component ST-DOSE attempts to address such unlikely scenarios by estimating source terms based on plant conditions. This allows unmonitored pathways to be considered and projections to be made before the start of a release. However, detailed plant conditions may not be known during an accident and, even if all plant conditions were known, current computer models can predict the source term only to within a factor of 100. The result is that it would be difficult to predict the source term with a reasonable degree of accuracy in the early response to a severe accident.

4.2 Plume Dispersion

The differences between actual plume behavior and the behavior simulated by atmospheric dispersion models is another major source of uncertainty in dose modeling. Meteorological data for modeling plume transport are typically available from meteorological towers in the vicinity of the site. However, the meteorological conditions for the site do not necessarily provide definitive information on conditions away from the plant. Nuclear power plants are also typically located in complex terrain areas (such as in river valleys or on the coast) where wind directions and flows can, at times, vary considerably within a short distance from the plant. ST-DOSE is a "generic" dispersion model which does not account for the effects of local terrain on the transport and diffusion of material.

Another difference between actual plume behavior and modeled plume behavior is that atmospheric dispersion models are designed to predict "average" plume concentrations for a given set of meteorological conditions. Instantaneous plume concentrations at a specific location can, at times, be lower and higher than the predicted average plume concentration due to the "meandering" of the plume around the axis of the primary downwind direction. Because of this, a monitoring team situated directly downwind of a release may alternately observe doses lower and higher than the "average" predicted dose as the plume meanders overhead.

4.3 Dosimetry

The final step in dose projection is determining whether the estimated doses indicate possible early health effects or exceed EPA PAGs. Various correction factors are used to account for the radioactive cloud size and position and dose factors are used to convert the resulting plume exposures to doses. The correction factors are based on simple approximations of complex conditions; the dose factors are based on a combination of limited data assumptions, some of which are controversial. The choice of correction and dose factors can have a major influence on dose projections.

5. CONCLUSIONS

The RASCAL Version 2.1 emergency response code has proven to be a useful tool for the NRC as active participants in nuclear power plant radiological emergency exercises. The model provides the Commission a fast and user-friendly method for performing dose projections using information which should be readily available during an accident. The model is flexible in that a variety of input and output units can be used and cases can be saved for later display or modification. Model results can be based on either a measured source term or an estimated source term based on plant conditions. A workbook is provided to help familiarize the user with the code and there are numerous help screens available to provide additional information for each input item and data field.

The RASCAL code continues to be an evolving code as it is reviewed on an ongoing basis and future revisions are being considered which will reflect advances in the understanding of reactor accidents and the needs of the NRC staff. Based on personal experience with the code, this author presents the following suggestions for enhancements for future versions of the code.

5.1 Variable Source Term

ST-DOSE currently uses only one steady-state source term value for the duration of the release. In actuality, the source term could vary as an accident progresses. For example, the core condition could deteriorate or the radionuclide mix could change with time. Consideration should be given to allow the ST-DOSE source term to vary with time as is currently done with the meteorological conditions.

5.2 Wind Speed Input

ST-DOSE accepts wind speed inputs only as integer values. Both the NRC Regulatory Guidance documents and the American National Standard for meteorological data collection at nuclear power plant sites specify wind speed measurement accuracies of ±0.5 mph[10-12]. Utilizing wind speed data rounded to the nearest whole number reduces the precision of the available data. This could be significant during low wind speeds. For example, entering wind speed values of one mph versus two mph could effect the calculated dose by up to a factor of two. Consideration should be given to allow the ST-DOSE wind speed inputs as other than integer values.

5.3 Effective Release Height

ST-DOSE requires the user to supply the effective release height (which is generally assumed to be equivalent to the height of the release point without plume rise effects). This effective release height is reset to zero by the model whenever the building wake option is selected and the wind speed at the effective release height is equal to or exceeds one mph. This is a relatively simplistic approach for estimating effective release height. For example, the effective release height for a typical primary vent stack release could be more than twice the physical stack height during calm, neutral and unstable conditions due to the effect of momentum plume rise. Likewise, building downwash could lower the effective stack height during higher wind speeds but such conditions will not always result in a ground level release. The EPA has recently revised its Industrial Source Complex (ISC3) models to reflect their latest experience concerning the effects of building aerodynamic downwash[9]. Consideration should be given to revising the ST-DOSE effective release height assumptions to reflect this current research.

5.4 Terrain Effects

ST-DOSE is currently a straight-line flat terrain model; that is, the effects of land forms (such as river valleys) and terrain height on plume transport and diffusion are not considered. The MESOI atmospheric dispersion model which serves as the basis of the ST-DOSE atmospheric dispersion model utilizes a three-dimensional wind field which allows the horizontal components of the wind to vary as a function of time and location[3]. Wind data from one up to as many as 30 measurement locations can be entered into the model. These wind data can be assumed to reflect the effects of terrain or, if the wind data are limited or the terrain is complex, the wind field can be modified to represent terrain effects. MESOI also alters plume height as a function of terrain height as the plume is carried downwind. Although customizing ST-DOSE with terrain data from a variety of nuclear power plant sites could be a significant effort, consideration should be given to implementing the MESOI terrain effect features discussed above into the ST-DOSE model.

5.5 Dose Rates

ST-DOSE currently produces doses integrated over a user-specified exposure period as output; it does not generate dose rates. However, field monitoring teams attempting to verify the plume location and release rate during an actual release would measure dose rates, not integrated doses. Consideration should be given to generating dose rates as a ST-DOSE output to allow the comparison of field monitoring team data with the results from the ST-DOSE dose projections.

5.6 Graphics Printing

The current version of ST-DOSE requires several minutes (on a 486 66Mhz PC) to generate a graphic print file. During this period of time, the user is unable to use the computer for any other purposes (such as executing "what if" scenarios). Consideration should be given to improving the speed of the graphics print driver so that the generation of dose plots does not tie up the computer for extended periods of time.

6. ACKNOWLEDGEMENTS

I would like to thank Aby Mohseni from the NRC's Incident Response Division for his assistance in providing information concerning the NRC's experience with the code as well as his review of the draft manuscript of this paper.

7. REFERENCES

1. A.L. Sjoreen, G.F. Athey, J.V. Ramsdell, and T. McKenna, RASCAL Version 2.1 User's Guide, NUREG/CR-5247, Vol. 1, Rev. 2, December 1994.

2. G.F. Athey, A.L. Sjoreen, and T.J. McKenna, RASCAL Version 2.1 Workbook, NUREG/CR-5247, Vol. 2, Rev. 2, December 1994.

3. J.V. Ramsdell, G.F. Athey, and C.S. Glantz, MESOI Version 2.0: An Interactive Mesoscale Lagrangian Puff Dispersion Model with Deposition and Decay, NUREG/CR-3344, November 1983.

4. R.I. Scherpelz, T.J. Bander, G.F. Athey, and J.V. Ramsdell, The Mesorad Dose Assessment Model, Vol. 1, Technical Basis, NUREG/CR-4000, Vol. 1, March 1986.

5. J.F. Sagendorf, J.T. Goll, and W.F. Sandusky, XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations, NUREG/CR-2919, September 1982.

6. T.J. Bander, PAVAN: An Atmospheric Dispersion Program for Evaluating Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Stations, NUREG/CR-2858, November 1982.

7. S.M. Abrahamson et al, Health Effects Models for Nuclear Power Plant Accident Consequence Analysis, Low LET Radiation, Part II: Scientific Bases for Health Effects Models, NUREG/CR-4214, Rev. 1, 1989.

8. U.S. Environmental Protection Agency, Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA 400-R-92-001, May 1992.

9. U.S. Environmental Protection Agency, User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume II - Description of Model Algorithms, EPA-454/B-95-003b, September 1995.

10. U.S. Nuclear Regulatory Commission, Onsite Meteorological Programs, Safety Guide 23 (Regulatory Guide 1.23), February 1972.

11. U.S. Nuclear Regulatory Commission, Instrumentation for Light-water-cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident, Regulatory Guide 1.97, Revision 3, May 1983.

12. American Nuclear Society, American National Standard for Determining Meteorological Information at Nuclear Power Sites, ANSI/ANS-2.5-1984, September 1984.

Exhibit 1. ST-DOSE Data Input Requirements

A. General Data

- Case Title and Site Name
- Data Source Label (Projected Data or Actual Data)
- Default Radiation Units(Ci, R/hr, and Rem or Bq, Gy/hr, and Sievert/grey)
- Event Dates and Times
  - Reactor Shutdown
  - Release to Containment (within 1 yr after reactor shutdown)
  - Start of Release to the Environment (within 24 hrs after release to containment)
  - End of Release to Environment (1 min to 24 hrs after release to containment)
  - End of Exposure (within 48 hrs after end of release)

B. Source Term Data (one of the following bullets)

- Isotopic Release Rates
  - Release Rates (e.g., Ci/sec)
- Isotopic Concentrations
  - Release Rate (e.g., cc/sec)
  - Concentrations (e.g., Ci/cc)
- Mix Specified by Analyst
  - Gross Release Rate (e.g., Ci/sec)
  - Percentage of Release (% Kr/Xe, I, Cs, Te/Sb, Ba/Sr, Ru/Mo, and La/Y/Ce/Np)
- Containment Monitor Readings
  - Reactor Type (PWR, BWR Mark I, BWR Mark II, or BWR Mark III; Wet Well or Dry Well)
  - Reactor Power (e.g., Mw(t))
  - Monitor Reading (e.g., R/hr)
  - Containment Sprays (On or Off)
  - Release Path (Filtered or Unfiltered)
  - Containment Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
- Spent Fuel/Spent Fuel Pool
  - Fuel Condition (Zircalloy Fire or Fuel Cladding Failure)
  - Reactor Power (Mw(t))
  - Last Batch In Pool (e.g., date and time)
  - Number of Batches (1 through 15)
  - Sprays (On or Off)
  - Release Path (Filtered or Unfiltered)
  - Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)

Exhibit 1. ST-DOSE Data Input Requirements (continued)

B. Source Term Data (continued)

- Plant Conditions
  - Large Dry or Sub-atmospheric Containment leakage/Failure
    - Core Condition (Gap Release, In-vessel Core Damage, or Vessel Melt Thru)
    - Reactor Power (e.g., Mw(t))
    - Containment Sprays (On or Off)
    - Release Path (Filtered or Unfiltered)
    - Containment Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
  - Ice Condenser Containment Leakage/Failure
    - Core Condition (Gap Release, In-vessel Core Damage, or Vessel Melt Thru)
    - Reactor Power (e.g., Mw(t))
    - Containment Sprays (On or Off)
    - Release Path (Filtered or Unfiltered)
    - Recirculation Fans (On or Off)
    - Ice Bed Condition Before Core Damage (Exhausted or Not Exhausted)
    - Containment Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
  - BWR Containment Dry Well Leakage/Failure
    - Core Condition (Gap Release, In-vessel Core Damage, or Vessel Melt Thru)
    - Reactor Power (e.g., Mw(t))
    - Containment Sprays (On or Off)
    - Release Path (Filtered or Unfiltered)
    - Dry Well Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
  - BWR Containment Wet Well Leakage/Failure
    - Core Condition (Gap Release, In-vessel Core Damage, or Vessel Melt Thru)
    - Reactor Power (e.g., Mw(t))
    - Wet Well (Saturated or Sub-cooled)
    - Release Path (Filtered or Unfiltered)
    - Wet Well Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
  - Containment Bypass
    - Core Condition (Gap Release, In-vessel Core Damage, or Vessel Melt Thru)
    - Reactor Power (e.g., Mw(t))
    - Release Path (Filtered or Unfiltered)
    - Containment Leak Rate (1 of 8 categories from 0.002%/hr up to 100%/hr)
  - Steam Generator Tube Rupture
    - Coolant Concentration (Gap Release, In-vessel Core Damage, Typical Coolant, or Coolant with 100x Normal Non-Nobles)
    - Steam Generator Conditions (Partitioned or Not Partitioned)
    - Release Rate (1 Tube, 2 Tubes, 1 Pump, 2 Pumps, or 3 Pumps)
    - Release Is From (Steam Jet Air Ejector or Safety Valves)

Exhibit 1. ST-DOSE Data Input Requirements (continued)

C. **Dispersion Data**

- Effective Release Height (e.g., ft)
- Meteorological Data (from 1 to 4 sets)
  - Date and Time (should correspond to the start of release for the first set)
  - Wind Speed (e.g., mph)
  - Wind Direction (deg from)
  - Stability Class (A through G)
  - Mixing Layer Height (e.g., m)
  - Precipitation Type (None or Light/Moderate/Heavy Rain/Snow)
- Dispersion Model Option (Puff or Plume)
- Building Wake Option (On or Off)
- Calculation Radius (10-Mile or 25-Mile)

Exhibit 2. Example ST-DOSE Maximum Dose Report

```
user's guide g.1                                                        03/24/94 10:52
NO PLANT SELECTED      UNIT 1                                           Projected Data
Distance                              Maximum doses (rem)               Puff Model
from Site, mi(km)    .5( .8)   1.0(1.6)   2.0(3.2)   5.0(8.0)   10.(16.)
                     --------  --------   --------   --------   --------
Total EDE (EPA)      *2.4E+02  *1.5E+02   *9.7E+01   *2.3E+01   *1.1E+01
Thyroid (EPA)        *7.5E+03  *4.5E+03   *3.0E+03   *7.0E+02   *3.5E+02
Acute Lung            1.7E+01   1.0E+01    6.7E+00    1.6E+00    7.7E-01
Acute Bone Total      2.4E+00   1.5E+00    1.0E+00    2.6E-01    1.2E-01

Acute Bone Inhalatn   1.4E+00   8.4E-01    5.6E-01    1.3E-01    6.4E-02
Cloud Shine           5.5E-01   4.2E-01    2.9E-01    9.0E-02    4.6E-02
Inital Ground Shine   4.9E-01   2.9E-01    1.8E-01    3.6E-02    7.6E-03
4-Day Ground Shine    1.2E+01   7.1E+00    4.7E+00    1.1E+00    5.3E-01
CEDE Inhalation       2.3E+02   1.4E+02    9.2E+01    2.1E+01    1.1E+01

NOTES:
1. All values below 1.0E-03 have been set to zero
2. * marks values exceeding PAGs
3. Total EDE = Cloud Shine + 4-Day Ground Shine + CEDE Inhalation
4. Acute Bone Total = Acute Bone Inh. + Cloud Shine + Init. Ground Shine
5. TEDE PAG = 1.0E+00 rem, normally evacuate
6. Thyroid PAG = 5.0E+00 rem, evacuate
```

Exhibit 3. Example ST-DOSE Graphics Output

a. Example of Graphics for ⅓-2 miles

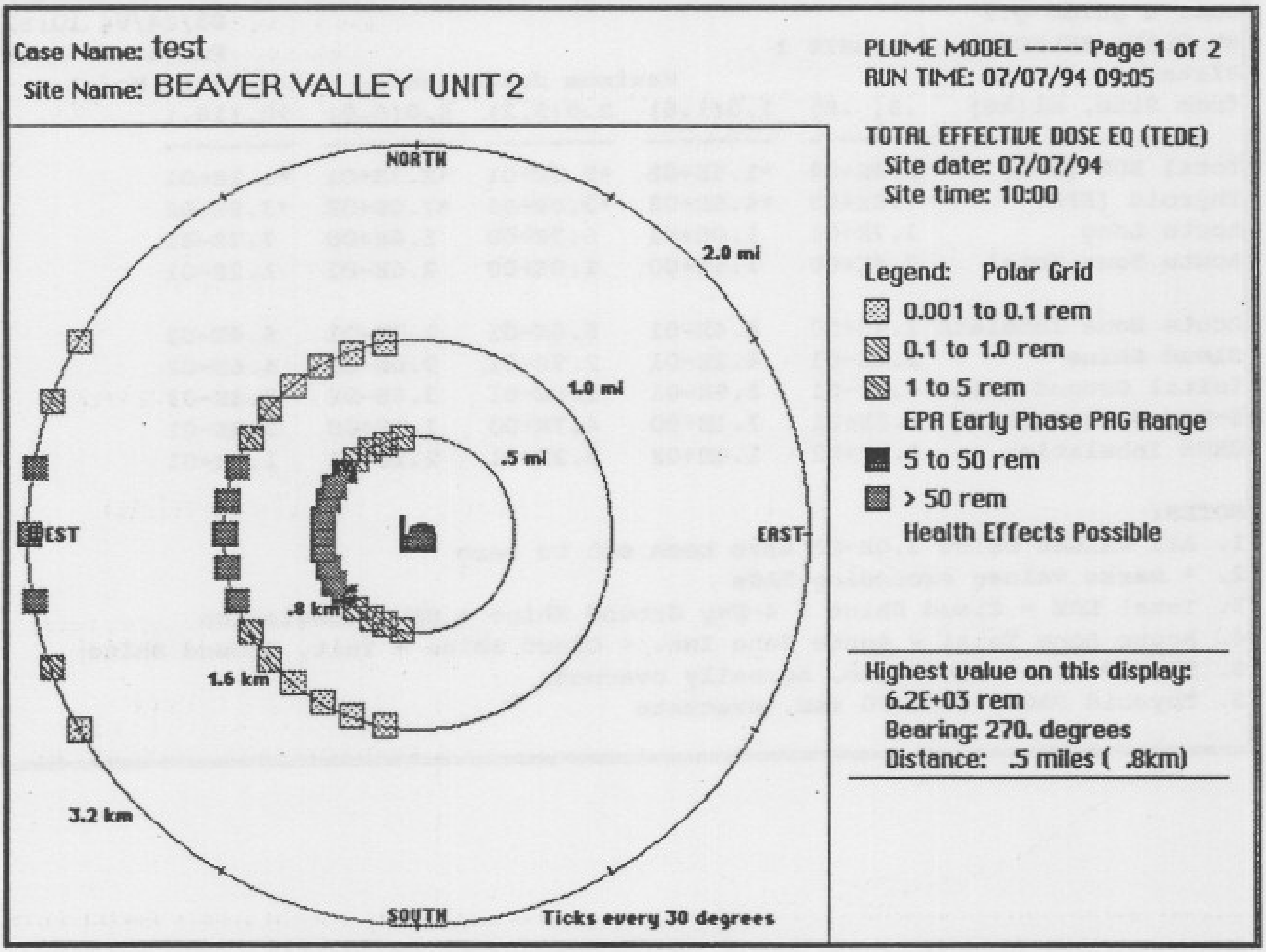

Exhibit 3. Example ST-DOSE Graphics Output (continued)

b. <u>Example of Graphics for 2-25 miles (plume model)</u>

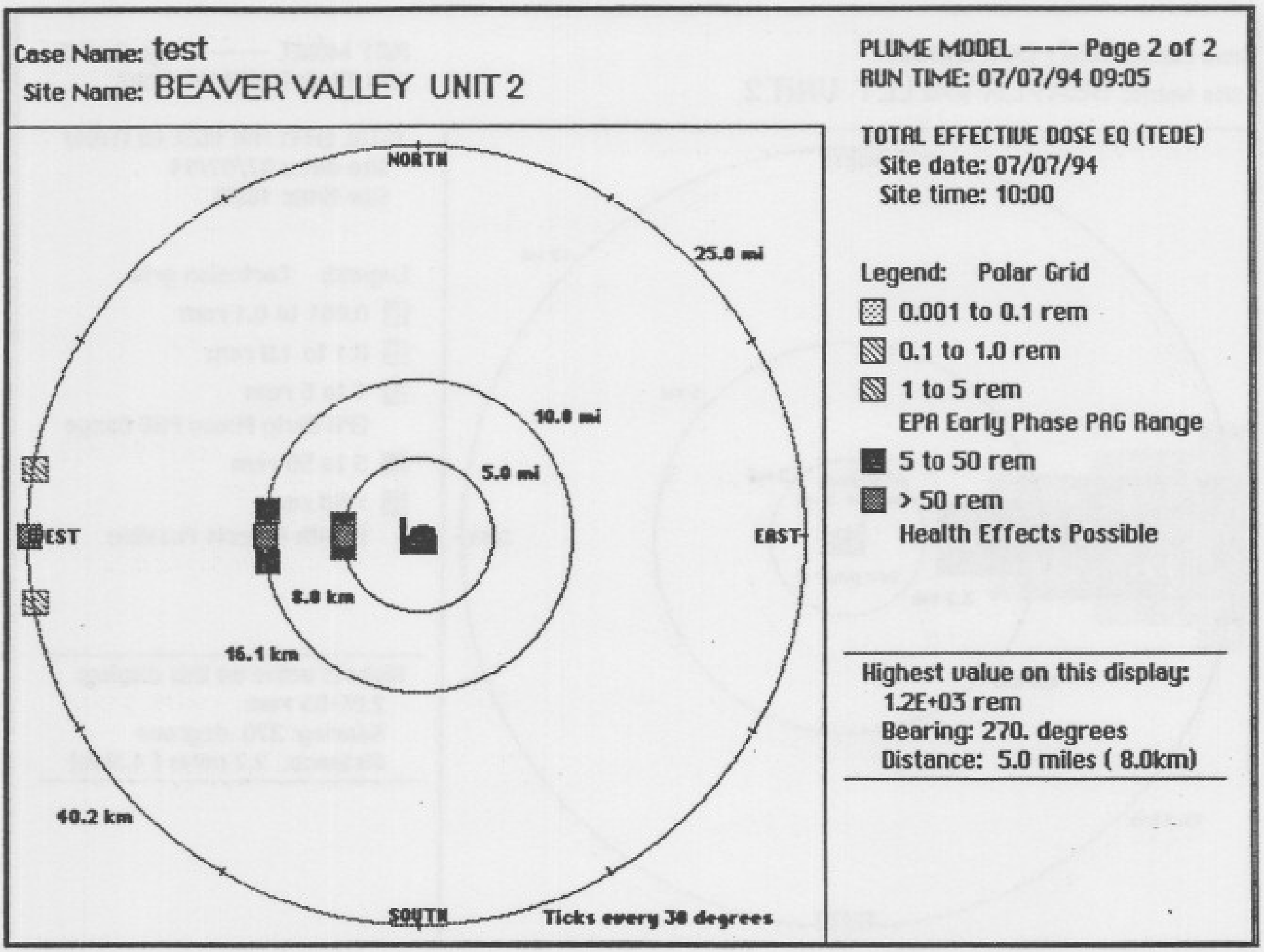

Exhibit 3. Example ST-DOSE Graphics Output (continued)

c. <u>Example of Graphics for 2-10 miles (puff model)</u>