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RASCAL Version 2.1 User's Guide

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1 Introduction

The Radiological Assessment System for Consequence AnaLysis (RASCAL) (Athey et al. 1989, 1992) is a set of personal computer-based tools. RASCAL Version 2.1 contains tools to estimate source term, atmospheric transport, and dose from a radiological accident (ST-DOSE), to estimate dose from field measurements of radionuclide concentrations (FM-DOSE), and to compute decay of radionuclides (DECAY). RASCAL was developed for use by U.S. Nuclear Regulatory Commission (NRC) personnel who report to the site of a nuclear accident to conduct an independent assessment of dose projections. RASCAL Version 2.1 has been written to update and enhance RASCAL Version 2.0. It includes the following major changes:

(1) A new isotopic source term has been added, which allows entry of a single release rate and isotopic concentrations and which can include the effects of radioisotope decay.

(2) A new source term calculation method has been added which allows computation of a reactor source term based on a containment monitor reading.

(3) A new source term calculation for a spent fuel pool accident has been added.

(4) The WASH-1400 source term calculation has been removed.

(5) The dose tables have been modified to include an indication of whether or not the doses computed exceed Environmental Protection Agency (EPA) Protective Action Guides (PAGs).

(6) The external dose factors have been replaced with those from Federal Guidance Report No. 12 (EPA 1993). A major difference in these dose factors is that bremstrahlung is now included.

(7) Graphical output can now be saved in PCX graphics format and in a format compatible with the NRC geographic information system (GIS).

(8) Field Measurements to Dose (FM-DOSE) has been modified to include consideration of the effect of delay for re-entry on first-year and second-year dose, a variable resuspension rate, and to compute a factor used to estimate first-year dose from R/hr measurements on the ground.

(9) The user interface has been modified to allow the use of a mouse.

(10) ST-DOSE and FM-DOSE input and output can be saved for later modification and display.

This document describes how to run RASCAL, ST-DOSE, FM-DOSE, and DECAY. The appendices contain discussions of the calculations performed by the models and the data files used. Sample problems for ST-DOSE, FM-DOSE, and DECAY are included in Appendices G, I, and J, respectively. They include the complete input to these models and selected output from that input.

This document may be used in conjunction with a companion workbook, RASCAL Version 2.1 Workbook (NRC, in press), which is being published.

The details of the technical aspects of the codes contained in Version 2.1 of RASCAL are covered in the following documents: NUREG-1228 (McKenna and Giitter 1988) describes estimation of source terms. Atmospheric transport, diffusion, and deposition calculations in ST-DOSE follow the general procedures used in the MESOI code (Ramsdell, Athey, and Glantz 1983) and the MESORAD code (Scherpelz et al. 1986, Ramsdell et al. 1988). Additional information on

atmospheric dispersion and deposition can be found in *Handbook on Atmospheric Diffusion* (Hanna, Briggs, and Hosker 1982) and *Atmospheric Science and Power Production* (Randerson 1984). *Atmospheric Science and Power Production* also includes a general discussion of calculation of doses. Calculation of cloud-shine doses near the plant makes use of the finite-puff model from MESORAD. Additional information on calculation of doses is found in ICRP Publications 26 and 30 (ICRP 1977; 1981) and in EPA protective action guidance (EPA 1992). References in this document will assist in locating the detailed information.

The RASCAL documentation and software is available from:

Energy Science and Technology Software Center
P.O. Box 1020
Oak Ridge, TN 37831-1020

615-576-2606 phone
615-576-2865 fax

1.1 Role of Dose and Consequence Models

Before using RASCAL, or any other dose projection model, to assess accidents, you must understand that, under certain conditions, protective actions must NOT await dose projections. In the event of a core damage accident that may result in a major release, protective actions must be initiated before the release begins to be most effective. You should become completely familiar with the discussion of these concepts contained in NUREG-1210 Vol. 2 and 4 (McKenna et al. 1987).

The significance of estimated doses differs depending on the use to which the dose estimates will be put. Two protective action objectives must be considered during the response to a radiological emergency (NRC 1987):

(1) prevent doses sufficient to cause early health effects (injuries or deaths) and

(2) reduce the chances of doses above limits established by the EPA and the U.S. Department of Health and Human Services (HHS) PAGs.

As discussed in NUREG-1210 (McKenna et al. 1987), the first of these objectives should be met as a result of actions taken based on plant conditions before any release occurs. However, there may be considerations that require an assessment of the possible consequences of an accident as part of the process of making other response decisions. Acute effects can result from exposure to high dose rates over short durations.

To use the results of RASCAL appropriately, you should have an understanding of the role and limitations of this and other models. Considerable attention has been given to the use of dose projections as the only basis for initiating offsite protective actions. However, it should be recognized that, for some very severe accidents, real-time dose projections would be available too late for an early protective response offsite. Studies have shown that, for a very severe accident with a major release shortly after core damage, protective actions for the population close to the plant (e.g., within 2-3 miles) must start before or soon after the release to be most effective in preventing severe early health effects. (Burke and Heising 1982; NRC and EPA 1978; NRC 1979). [The effectiveness of protective actions is discussed in Vol. 4 of NUREG-1210 (McKenna et al. 1987)].

In the early emergency response phase, assessment of plant conditions and general weather should be used in protective action decision-making. Use of dose projections should be secondary. After a release, environmental monitoring information should form a major part of the basis for additional protective actions.

1.2 Uncertainties in Dose and Consequence Models

Predicting doses or consequences, as illustrated in Figure 1.1, requires several steps: (1) predicting the quantity and timing of the release from the plant (source term), (2) predicting the movement of the plume (transport), and (3) predicting the dose

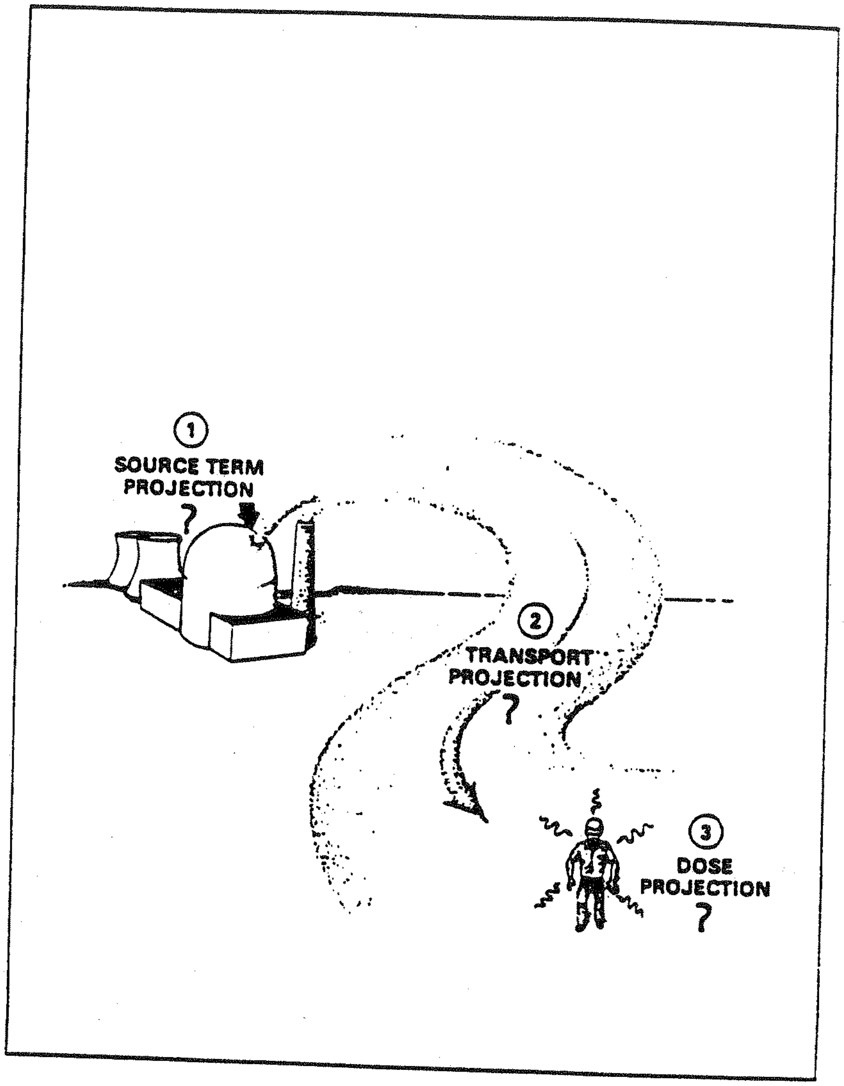

Figure 1.1 Steps in predicting consequences

from the plume and predicting the health effects from the dose. Each of these steps requires collection of appropriate data, and data collection and the subsequent computations are subject to uncertainties.

The largest single component of uncertainty is expected in the estimate of the source term. Unanticipated catastrophic containment failure is a case in which the source term could be underestimated by a factor of 1,000,000 if monitor readings are used to estimate the source term. For lesser (non-core damage) accidents in which the total release is through a monitored pathway and consists mostly of noble gases, the source term uncertainty can be reduced. However, the transport and dose uncertainties would remain unchanged.

The differences between actual plume behavior and the behavior simulated by models is another major source of uncertainty. Dose models project doses based on average environmental concentrations. Because of this, a monitoring team within the actual plume (Figure 1.2, point B) may observe greater doses than projected, and if a team is out of the plume (point A), doses may be lower than projected. One would not expect preliminary field monitoring results to agree with model projections, even under the best circumstances.

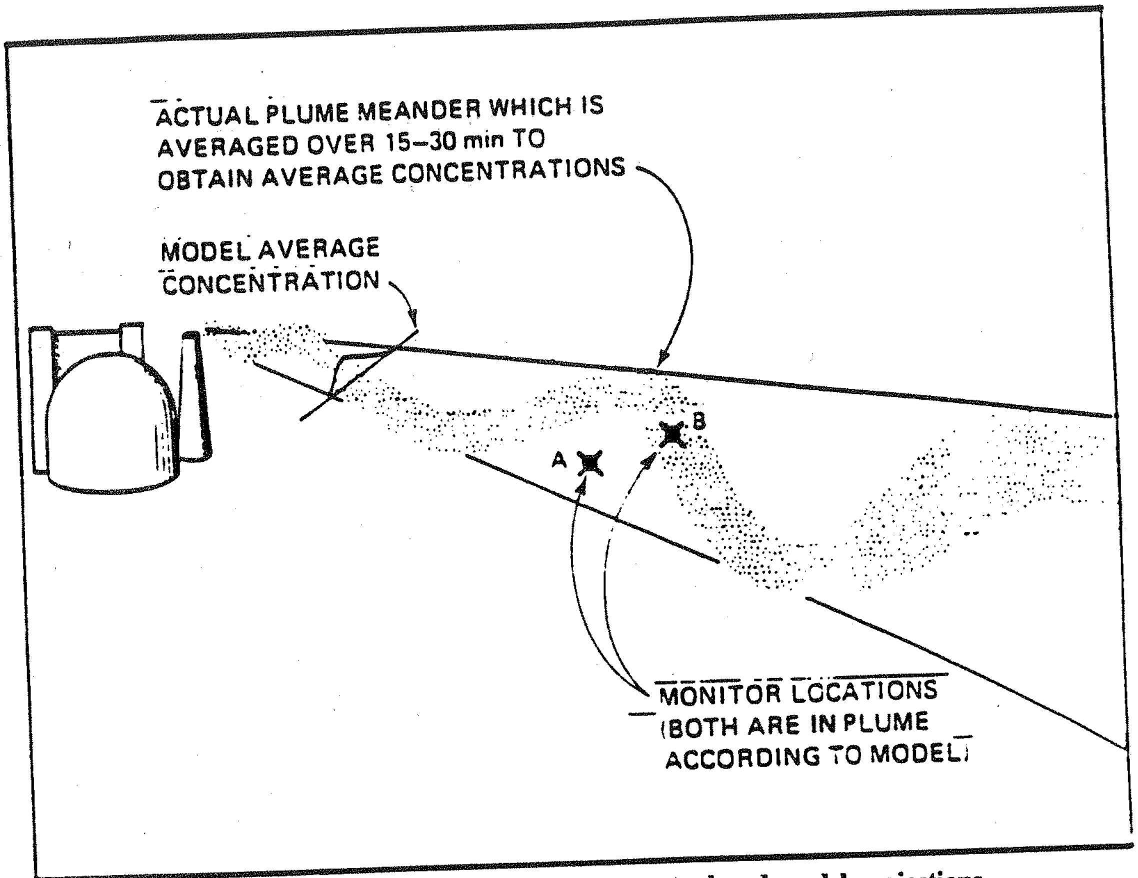

Figure 1.2 Relationship between actual and model projections

Differences should be expected in the consequences estimated by various dose and consequence models even if the same input conditions (e.g., source terms, meteorology, and dose factors) are used. Various response organizations may perform analyses based on different assumptions. For example, the NRC may concentrate on projections based on possible additional plant failures, while the state may make dose projections based on estimates of actual releases. The state might estimate effective dose equivalent while the NRC may be interested in acute health effects and therefore acute dose to bone marrow. A 10- to 100-fold (or greater) spread in calculated doses can be anticipated among the various response organizations [licensee, NRC, state and local officials, and U.S. Department of Energy (DOE)]. It is clear that one should not expect close agreement among various dose projections and early field monitoring data. Dose projections should be viewed as only rough estimates. All organizations concerned need to understand the accident processes, the technical aids, and the resulting consequence assessments. Indiscriminate use of technical aids such as dose or consequence projection models without understanding their shortcomings and the unpredictability of accident conditions can provide misleading input to protective action decision-making.

Based on conclusions drawn from the sections that follow discussing the difficulties of estimating source term, plume movement, dose, and resulting consequences, overall estimates of the uncertainties associated with dose assessment for severe accidents have been made. These estimates are given in Table 1.1. In general, the uncertainty factors are ratios between model projections for an accident sequence and average dose rates that might be observed. Uncertainty factors for plume location are expressed in degrees. It is apparent that, overall, 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 doses based on field monitoring; it is likely that they will be less accurate.

Table 1.1 Components of source-term uncertainty

Element	Uncertainty Factor[a]		
	At Best	Most Likely	Near Worst[b]
Source term (event and sequence)	5	100-1,000	1,000,000
Dispersion			
Diffusion (concentration)	2	5	10
Transport (direction)	22°	45°	180°
Transport (rate)	1	2	10 (low wind speed)
Dosimetry[c]	3	4	10
Overall (dose and direction)	10 22°	100-10,000 45°	1,000,000 180°

[a]These estimates are for an averaged dose at a location (e.g., 15-30 min), not for a specific or single monitor reading.

[b]Unmonitored case.

[c]For external dose only. For CEDE, uncertainties would be much greater.

1.2.1 Source-Term Modeling

During an accident, predicting or characterizing the composition and timing of the release (the source term) is the first step in projecting consequences. Errors associated with predicting the source term have a direct impact on the accuracy of dose and consequence projections.

As illustrated in Figure 1.3, the most important example is a release from a major containment failure. In the event of such a failure, effluent monitoring systems located in routinely monitored release pathways (e.g., stacks) may not be adequate to permit assessment of the extent and characteristics of a severe release. On-line radiation monitors capable of measuring the noble gases released through plant vents were installed as part of the upgrades to power reactors following the Three Mile Island--Unit 2 accident (NRC 1980). (Note that noble gases are not considered as great a threat to the public as radioactive iodine and other particulates.) On-line monitors for iodine and other particulates were not considered practical.

Therefore, the presence of iodine and particulates in a release at many plants is determined through analysis of samples taken during the release. This analysis may require several hours. In addition, the mixture of radionuclides in the release may not match the mixture assumed in the calibration of the monitor. Therefore, while current systems can characterize most releases, they cannot provide fast estimates of those very unlikely releases that pose the greatest threat to the public. Even more important, plant monitoring systems are designed for routine releases of radioactivity. Because an accident resulting in

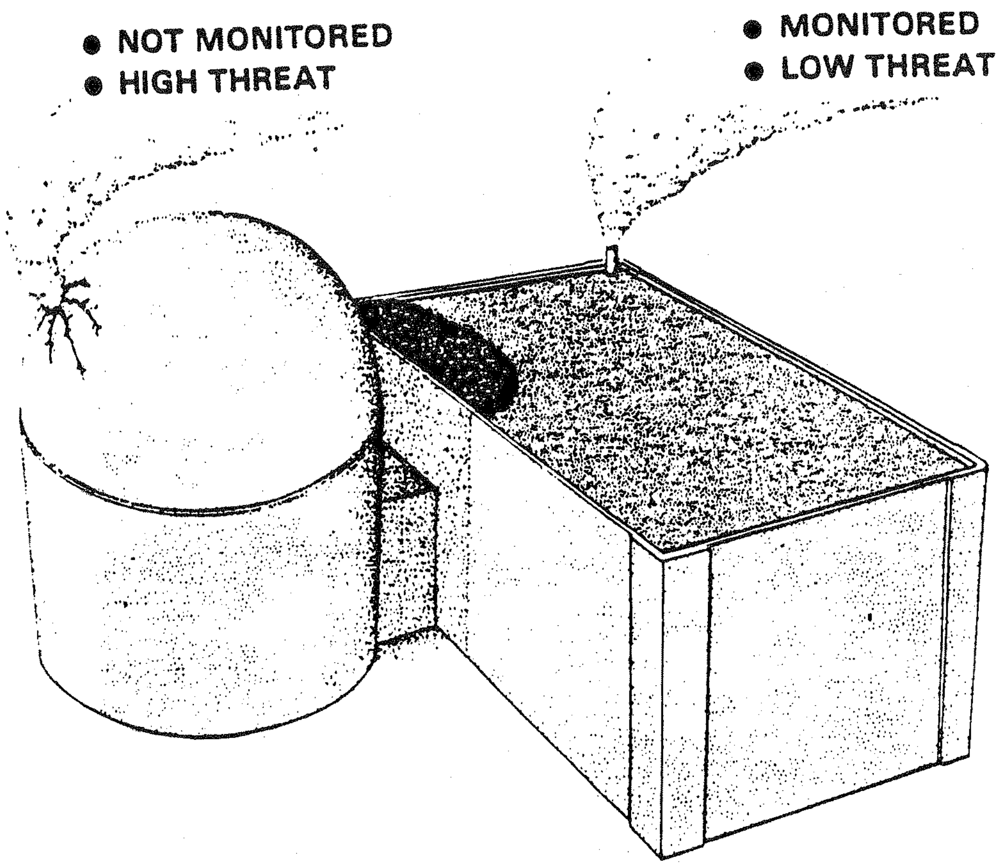

Figure 1.3 Types of releases

early health effects (death and injuries) offsite would be one that is both fast and unfiltered, the release would most likely b via an unmonitored pathway to the atmosphere.

For accidents in which the release is through a monitored pathway (e.g., the stack), it may be possible to obtain a good characterization of the release. At a minimum, the magnitude can be estimated in relative terms (e.g., "this release has the possibility to exceed EPA PAGs") if the monitors stay on scale and are properly calibrated. By their very nature, however releases resulting in early health effects most likely cannot be characterized by effluent monitors.

Methods of estimating source terms have been developed that are based on consideration of actual or projected plant conditions (McKenna and Giitter 1988). The RASCAL dose assessment component, ST-DOSE, incorporates the methods developed by McKenna and Giitter (1988) to estimate source terms based on plant conditions. The advantages of these methods are that unmonitored pathways can be considered and projections can be made before the start of the release.

However, studies described in draft NUREG-1150 (NRC 1987) showed that, even if all plant conditions were known, curr computer models could predict the source term only to within a factor of 100. These studies highlight the difficulty of source-term estimation because detailed plant conditions would not be known during an actual accident. Therefore, source term estimates produced by ST-DOSE or any other model based on plant conditions must be considered very crude. The result is that, early in the response to a severe accident resulting in a major release, it will be very difficult to predict the source term with a reasonable degree of accuracy. For a more complete discussion of source-term estimation during sevei accidents, see NUREG-1228 (McKenna and Giitter 1988).

1.2.2 Transport Modeling

After estimating the amount of radioactive material being released or that might be released from the plant, the next step in the dose projection process is characterization of the movement of the material through the atmosphere. However, even if you could accurately estimate the source term, substantial uncertainties would still be associated with dose projections to offsite areas. Transport is modeled using a very simple picture of a very complex system--the atmosphere. To predict doses and consequences, the model must estimate the integrated concentrations of radionuclides in air and on the ground at points in space.

In 1981 a nonradioactive tracer (SF_6) study was conducted at the Idaho National Engineering Laboratory. Lewellen et al. (1985), compare the resulting air concentrations with predictions made by various models to evaluate the models' potential use in emergency-response situations. Clearly, even the most complicated model could not reproduce what actually occurred in the atmosphere. This example illustrates that it is very difficult to model transport on a local scale and that small effects can have major impacts on the projection of consequence.

Figure 1.4 shows the plume patterns predicted by three models and the actual pattern. Frame A shows the pattern for a simple, straight-line Gaussian plume model of the type used by many emergency-response organizations (e.g., IRDAM). Frame B shows the pattern predicted by a Gaussian-puff trajectory model (e.g., ST-DOSE), and frame C shows the pattern predicted by a more sophisticated model that considers wind fields and terrain effects (e.g., ARAC). Compare the patterns in frames A, B, and C with the measured concentration pattern shown in frame D.

Typically, data are available from meteorological towers in the site vicinity. The initial transport of radioactive material from a site will be dominated by local conditions (e.g., topography and meteorology). The weather and wind information for the site does not provide definite information on conditions away from the plant, particularly during periods of low wind speed. In addition, most models, including ST-DOSE, do not account for the effects of local terrain on the transport and diffusion of material. Nuclear power plants are typically located in complex areas (e.g., in river valleys or on the coast) where wind direction and flows can vary considerably within a short distance of the plant. As an example, a 180° difference in wind direction could result from sea breeze effects at a coastal site, as shown in Figure 1.5. This variability is the reason protective actions should not be based solely on the wind direction observed at the plant. For severe accidents, actions should be taken in all directions near the plant (within 2 or 3 miles).

The effects of meteorological conditions early in the Three Mile Island incident illustrate the problems inherent in taking protective actions in the downwind direction only. Figure 1.6 presents the hourly wind vector as measured by the site meteorological system during the first day of the accident. It is evident that wind direction at the site varied dramatically throughout the 12-hour period.

Between 7:30 and 8:00 a.m., the State of Pennsylvania issued warnings of imminent evacuation to the west of the site. (A Site Area Emergency was declared at 7:20 a.m., followed by a General Emergency at 7:23 a.m.) About an hour later, the emergency classification was reduced to a standby notice because dose rate measurements to the west showed no significant releases. Had an evacuation of the area to the west of the site been initiated at 8:00 a.m., the evacuation area would have been inadequate for any release that might have taken place after 8:00 a.m., because local wind conditions changed. At 9:00 a.m., the area to the north of the site was downwind, and at 11:00 a.m. the area to the east was downwind.

The NRC Special Inquiry Group (Rogovin 1979) noted later that, based on in-plant observations, evacuation of the complete low-population zone (2.5-mile radius surrounding the site) would have been warranted no later than 7:30 a.m.

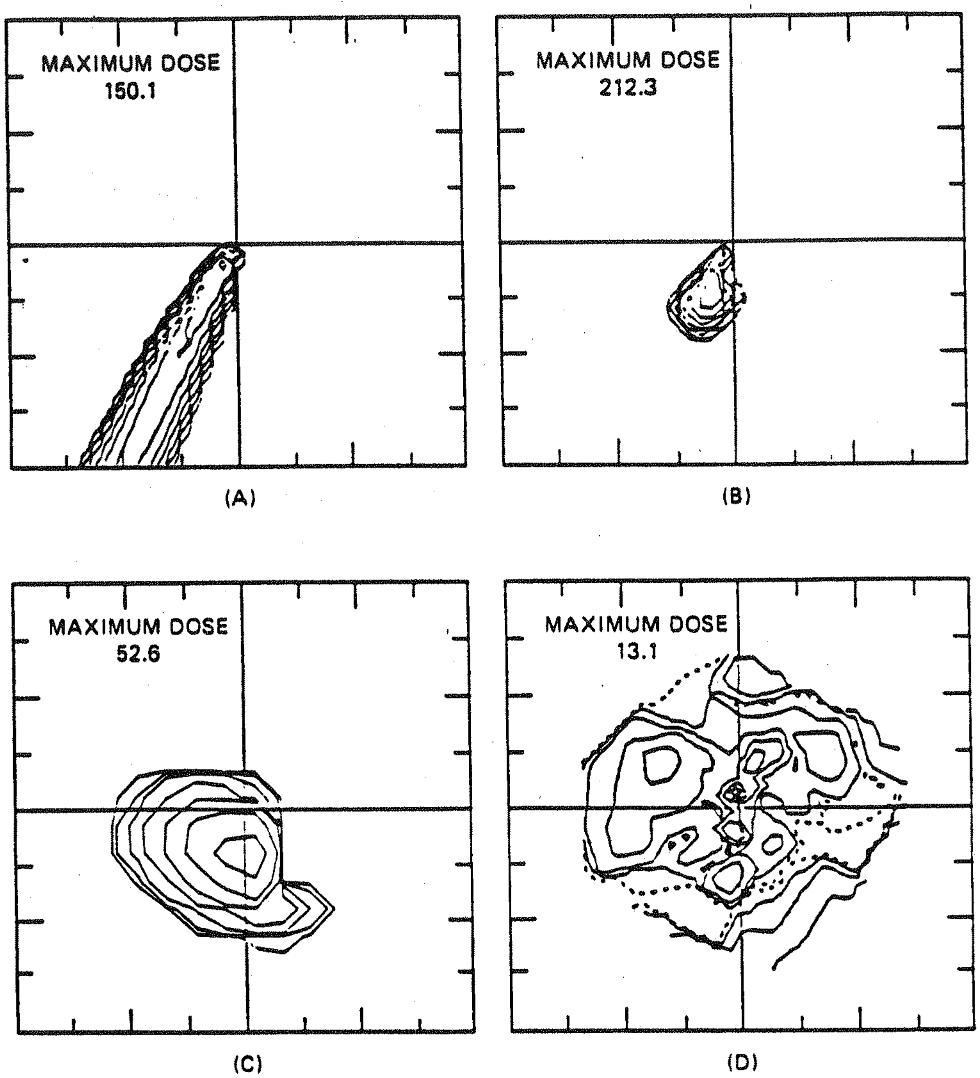

Figure 1.4 Comparison of model predictions and observed doses: (A) Gaussian Plume Model,(B) Puff-Trajectory Model, (C) Complex Numerical Model, and (D) Doses Actually Observed

1.2.3 Dose and Health Effects

The final step in dose projection is to determine whether the estimated doses indicate possible early health effects or the possibility of exceeding EPA PAGs. Dose factors are used to convert exposures to doses and various correction factors to account for the radioactive cloud size and position. These correction factors are based on simple approximations of complex conditions. The dose factors are based on a combination of limited data and assumptions, some of which are controversial. Dose factors available for various ages and organs cover a wide range. Thus, the choice of dose and correction factors can have a major influence on the projections.

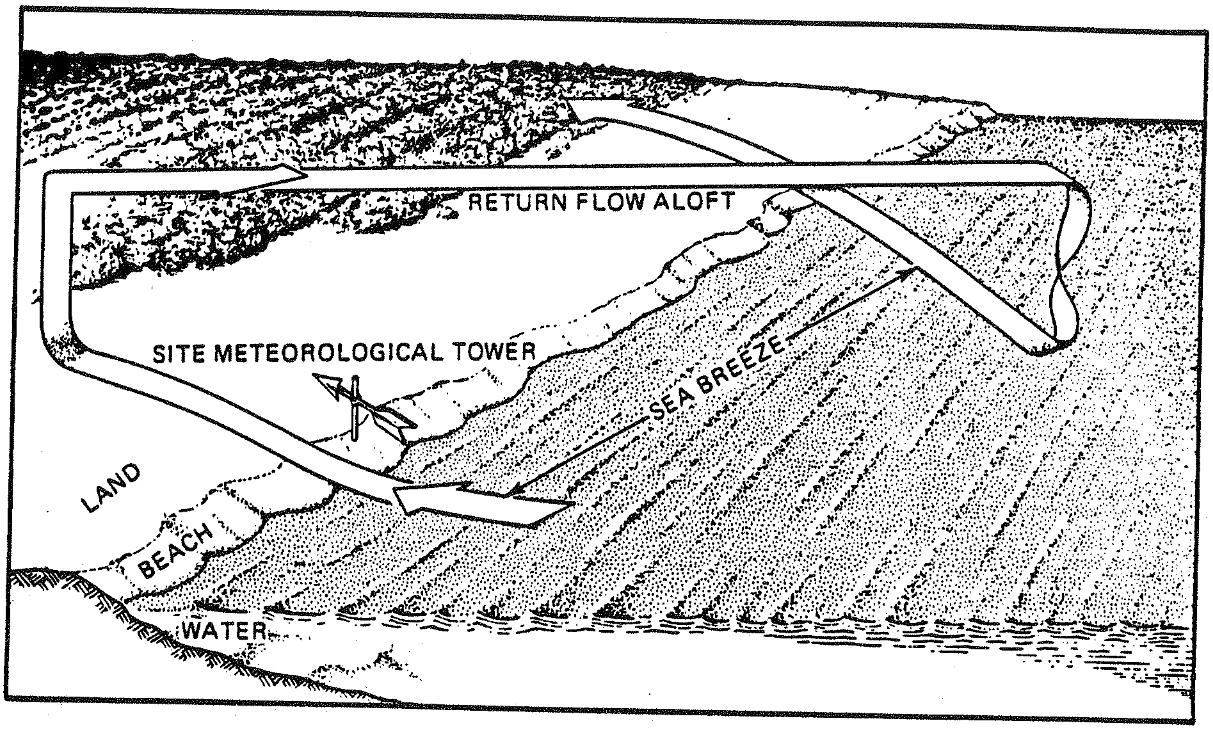

Figure 1.5 Trajectory resulting from sea breeze

Acute health consequences estimated from very high dose rates are more certain than health effects estimated from low dose rates. However, even though the projection of health effects from high dose rates may be the best understood process in accident consequence analysis, it is far from completely understood. Some of the uncertainty in dose projections can be bypassed by using the consequence rather than dose estimates to describe health effects from the accident. For example, the model can express results in terms of the type of health effects produced or in relation to the EPA PAGs, rather than as specific doses.

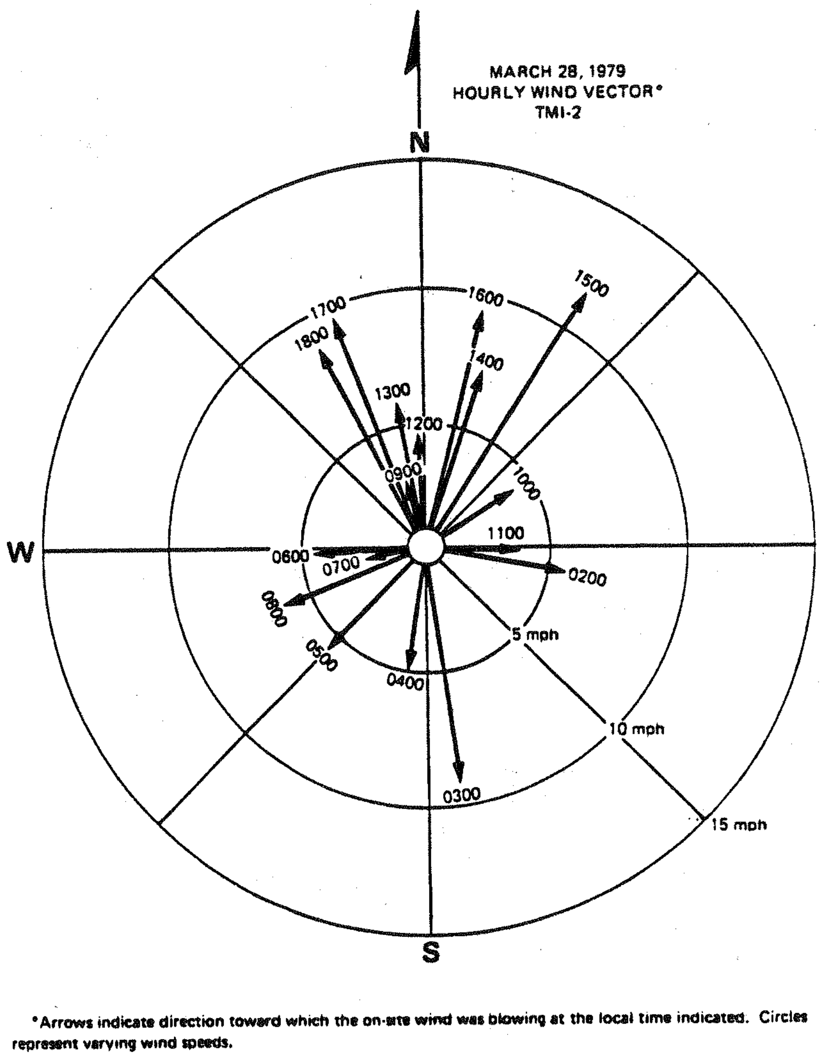

Figure 1.6 Hourly wind vector at Three Mile Island, Unit 2, on March 28, 1979