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Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model

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dispersion and deposition modules are more modern than those in RASCAL. A comparison of RASCAL and RATCHET to ADAPT/LODI has been included.

The objective of this study is to determine if the average ATD results from these codes are sufficiently close that more complex models are not required for the NRC purposes of planning, cost-benefit, and PRA or different enough that one or both of the NRC codes should be modified to provide more rigorous ATD. The decision will be made by the NRC using results of this study and other factors, most notably run time and input requirements.

It would be best if MACCS2 and RASCAL/RATCHET results could be compared with measurements over the long distances and types of terrain of interest to the NRC. However, such measurements do not exist, so the less desirable comparison with a state-of-the-art code was chosen to provide input into the decision on the adequacy of MACCS2 ATD. The comparison was also an opportunity to gain additional baseline information on the performance of the RASCAL/RATCHET code. Comparisons of LODI/ADAPT results with intentional and unintentional releases can be found in Foster, et al. (2000). These comparisons, although over shorter ranges than those of interest to the NRC, demonstrate that LODI/ADAPT is sufficiently accurate for the purposes of this study.

2. SELECTION OF THE STUDY SITE

Quite a few locations were considered as possible sites for this study. These included currently operating nuclear power plants, several DOE laboratory sites, and a few other locations. The following criteria were considered in making a final selection:

- a data set with sufficient observations to characterize the horizontal wind field as a three-dimensional function of height and position from the source out at least 160.9 km (100 miles),
- topography that would interact with the large-scale flow producing local modification of wind speed and direction, and
- a site with changes in surface properties that could affect the local flow, such as a coastal site with a land-sea breeze.

As we considered the possible sites, we could identify only one that satisfied the first criterion, the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site in Oklahoma and Kansas. No other site provided regular upper air data at more than one location within 160.9 km (100 miles) of the source. To use a different site would have required use of a regional model to determine the flow fields, and we wanted to base this study solely on observations. The topography of Oklahoma and Kansas is relatively smooth and has minimal effect on the wind field, and the surface is fairly uniform and therefore produces relatively little local thermal forcing. However, wind fields in Oklahoma and Kansas are frequently affected by low-level nocturnal jets and occasional severe storms. Therefore, the last two criteria were only partially satisfied, but there was sufficient variability for the purpose of this study. At the outset we realized that if the differences between MACCS2 and ADAPT/LODI were large at the ARM site, they would be large everywhere, and the transport and dispersion module in MACCS2 would likely require replacement. But if the differences were small, the adequacy of MACCS2's atmospheric transport and dispersion module might still be unresolved for some special locations.

3. MODELS

3.1 MACCS2

The MELCOR Accident Consequence Code System Version 2 (MACCS2) (Chanin et al. 1998) was developed at Sandia National Laboratories for the NRC. Its primary use is in performing consequence analyses in support of level-3 probabilistic risk assessments (PRAs). It is also used by the NRC for planning purposes and cost-benefit analyses.

MACCS2 is the latest in a series of NRC-sponsored codes for estimating off-site consequences following a release of radioactive material into the environment. The first code in the series was CRAC (Calculation of Reactor Accident Consequences), which was developed for the Reactor Safety Study (WASH-1400, 1975). The first version of MACCS was released to the public in 1987. A subsequent version was used in the benchmark PRA study reported in NUREG-1150.

MACCS2 is a versatile code, with most of its parameters being under user control to facilitate the performance of sensitivity and uncertainty analyses. The principal phenomena considered by MACCS2 are atmospheric transport and dispersion (ATD), short- and long-term mitigative actions, exposure pathways and doses, deterministic and stochastic health effects, and economic costs. Of these capabilities, only the ATD processes are considered in the present study.

The atmospheric models in MACCS2 are relatively simple. Released material is assumed to travel downwind in a straight line. The concentration profiles in the cross-wind and vertical dimensions are approximated as being Gaussian. The Gaussian plume model was chosen for MACCS2 because it requires minimal computational effort and allows large numbers of realizations to be calculated. These realizations represent uncertainty in weather data at the time of a hypothetical accident and uncertainty in other input parameters to represent degree of belief. Large numbers of realizations (hundreds) are generally needed to perform PRA and sensitivity studies.

3.1.1 Meteorological Representation

The normal calculation mode for MACCS2 is to sample from hourly weather data for one year and to calculate ATD using a Gaussian model in each of 16 directions. Each direction corresponds to a 22.5 degree-wide sector that is centered on a standard compass point. Each weather sequence is weighted by its probability of occurrence. The weather sequences are normally chosen, and have been chosen for this study, to emphasize sampling of sequences believed to be important to the prediction of early health effects in an exposed population. This emphasizes selection of weather sequences probability of the wind blowing in the specified direction. The probabilities associated with the possible wind directions are constructed for each weather bin and are proportional to the number of trials in the bin in which the wind blows in the specified direction. This probability is given by

$$P_{BR} = N_{BR} / N_B,$$

where P_{BR} is the probability of a sample in bin B having wind direction R and N_{BR} is the number of weather trials in bin B with wind direction R. The final probability for weather trial T with wind rotation R used in the MACCS2 code is simply the product of the two probabilities, as follows:

$$P_{TR} = P_{BR} \cdot P_T,$$

where P_{TR} is the probability of weather trial T with wind direction R.

MACCS2 uses single-point weather data. Thus, it approximates weather data as spatially uniform. The weather data file contains the following information: Julian day of the year, hour of the day, wind direction, stability class, and precipitation rate. It also contains seasonal mixing heights (discussed in subsection 5.2). While MACCS2 does not model spatial variation in wind conditions, it does model time dependence. Once a plume is formed, its direction is not allowed to change; however, the wind speed, stability class, and precipitation rate can change hour-by-hour.

3.1.2 Atmospheric Transport and Dispersion

The plume is assumed to move downwind at the prescribed wind speed adjusted for plume centerline elevation. The plume broadens by dispersion due to atmospheric turbulence as it is transported downwind. MACCS2 allows dispersion to be treated either by means of a lookup table or as a power-law function of distance. For this work, the standard Tadmor and Gur lookup tables (Tadmor and Gur 1969, Dobbins 1979) were used to determine cross-wind and vertical dispersion as a function of downwind distance and stability class.

Vertical dispersion is assumed to occur only within the mixing layer. MACCS2 uses four mixing heights to represent the four seasons of the year. These mixing heights represent seasonal averages of the daily maximum values of the mixing heights. Calculation of the mixing heights used in this study is discussed in section 5. The MACCS2 Gaussian plume model treats the ground surface and a surface at the mixing height as planes of reflective symmetry.