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From: Ghosh, Tina
Sent: Monday, January 31, 2011 10:48 AM
To: Stuyvenberg, Andrew
Subject: FW: Modeling Review - Indian Point
Attachments: Modeling Review Document 6 14 10.doc

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From: Jones, Joe A [mailto:jojones@sandia.gov]
Sent: Tuesday, June 15, 2010 3:53 PM
To: Palla, Robert; Ghosh, Tina
Cc: Bixler, Nathan E
Subject: Modeling Review - Indian Point

Bob and Tina,

We have completed our review of the AERMOD and CalPuff models comparing characteristics to the MACCS2 model. Joe Schelling, one of our MACCS2 modelers, did the research on this and he and Nate iterated the document a couple of times.

Please let us know if you have any questions regarding this review.

Thanks
Joe

Hearing Identifier: IndianPointUnits2and3NonPublic_EX
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Mail Envelope Properties (6F9E3C9DCAB9E448AAA49B8772A448C55EE2C75CCD)

Subject: FW: Modeling Review - Indian Point
Sent Date: 1/31/2011 10:48:04 AM
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From: Ghosh, Tina

Created By: Tina.Ghosh@nrc.gov

Recipients:
"Stuyvenberg, Andrew" <Andrew.Stuyvenberg@nrc.gov>
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Severe Accident Mitigation Analysis Modeling Plan

6/14/2010

Objective

The objective of this plan is to determine the feasibility, and if appropriate, the level of effort required to use the AERMOD and CALPUFF models in the same capacity MACCS2 is used to perform consequence modeling in terms of dose, contamination, and economic cost for severe accident mitigation alternatives (SAMA) analyses. AERMOD and CALPUFF are preferred and recommended by the U.S. Environmental Protection Agency for modeling air dispersion and air quality [1,2]. As air dispersion and air quality models, AERMOD and CALPUFF include models of contaminant dispersion and deposition that produce contaminant concentrations at various receptor locations as a function of time. MACCS2 models dispersion and deposition of a radioactive plume released from a nuclear power plant, and includes models of radioactive decay and ingrowth, ground contamination, dose consequences to the public for defined emergency response, and economic impacts of the release.

MACCS2 Overview

The purpose of the MACCS2 code is to simulate the impact of severe accidents at nuclear power plants on the surrounding environment. The principal phenomena considered in MACCS2 are atmospheric transport, mitigative actions based on dose projection, dose accumulation by a number of pathways, including food and water ingestion, early and latent health effects, and economic costs [3].

MACCS2 models atmospheric dispersion and transport, and includes models for deposition, weathering, resuspension, and radioactive decay. A Gaussian plume model is used to model plume dispersion during downwind transport. Scaling factors are used in MACCS2 to model effects of surface roughness on plume dispersion. Statistical distributions of consequence measures that depict the range and probability of consequences are generated by MACCS2 in terms of complementary cumulative distribution functions (CCDFs).[4] These distributions are generated using stratified Monte Carlo sampling of combinations of representative sets of source terms, weather sequences, and exposed populations. Radioactive decay and ingrowth, and dry and wet aerosol deposition processes are modeled. Economic effects models in MACCS2 are intended to estimate the direct offsite costs resulting from a reactor accident and include costs resulting from both short-term and long-term protective actions [3].

The principal phenomena considered in MACCS2 are atmospheric transport using a Gaussian plume model, short-term and long-term dose accumulation through several pathways (including cloudshine, groundshine, inhalation, deposition onto the skin, and food and water ingestion), mitigative actions based on dose projection, early and latent health effects, and economic costs. The following phenomena can be incorporated within a single calculation:

- Release characteristics;

- Meteorological sampling;
- Atmospheric dispersion and deposition;
- Exposure pathways and duration;
- Protective actions and dose mitigation;
- Movement of populations as cohorts;
- Individual and population doses; and
- Health and economic consequences.

MACCS2 has three major components, ATMOS, EARLY, and CHRONC. Of these components, only ATMOS, which treats dispersion and deposition using a Gaussian plume model, has similarities to AERMOD and CALPUFF. The EARLY and CHRONC modules are used to model emergency phase events and radiological consequences and economic costs of response actions, which are not considered in the functionality of AERMOD and CALPUFF.

ATMOS calculates the dispersion and deposition of material released to the atmosphere as a function of downwind distance, and uses a Gaussian plume model with Pasquill-Gifford dispersion parameters. ATMOS treats the following phenomena: building wake effects, buoyant plume rise, plume dispersion during transport, wet and dry deposition, and radioactive decay and ingrowth [4].

EARLY models the time period immediately following a radioactive release, referred to as the emergency phase, which may extend up to one week after the first plume reaches any downwind location. User-specified scenarios may include evacuation, sheltering, and dose-dependent relocation. Dose calculations from early exposure consider five pathways: cloudshine, cloud inhalation, groundshine, resuspension inhalation, and skin dose from deposition onto skin. Acute doses and lifetime dose commitments are calculated [4].

CHRONC simulates events following the emergency-phase time period. CHRONC calculates the number of health effects resulting from direct exposure to contaminated materials as well as health effects caused by subsequent consumption of contaminants. It calculates mitigative actions taken to reduce doses to the public, including decontamination, interdiction, and condemnation of property. CHRONC calculates the economic costs of these long-term protective actions as well as the costs from the emergency response actions modeled during the emergency phase [4].

EPA Regulatory Atmospheric Modeling Codes

Two code systems recommended by the U.S. Environmental Protection Agency (EPA) for use in regulatory atmospheric modeling, and required for use for several programs are the AERMOD and CALPUFF modeling systems [1,2]. The EPA Support Center for Regulatory Atmospheric Modeling website provides the following basic descriptions of these modeling systems [1]:

- AERMOD Modeling System - A steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

- CALPUFF Modeling System - A non-steady-state puff dispersion model that simulates the effects of time- and space-varying meteorological conditions on pollution transport, transformation, and removal. CALPUFF can be applied for long-range transport and for complex terrain.

AERMOD Overview

AERMOD was designed for short range (up to 50 km) dispersion from stationary sources, and includes modeling of surface terrain on the behavior of air pollution plumes and of building downwash effects. A Gaussian plume model is used [5]. AERMOD can model exponential decay. (The default regulatory option forces use of a 4 hr half life for SO_2 in an urban source, and does not allow for exponential decay for other applications [6].) Multiple sources from a single point can be modeled, and there are several options for specifying an array of receptor locations. Only a single value of halflife can be used in a given run [7]. The original version of the AERMOD model did not include algorithms to handle the gravitational settling and removal by dry deposition of particulates, or scavenging and removal by wet deposition of gases and particulates [8]. However, the AERMOD User Guide Addendum 09292 describes the later inclusion of dry and wet deposition algorithms for both particulate and gaseous emissions [10]. No dose pathway, dose mitigation (KI ingestion, sheltering, or evacuation), or economic models appear to be included in AERMOD.

CALPUFF Overview

CALPUFF is proposed by the EPA for applications involving long-range transport, which is typically defined as transport over distances beyond 50 km, and requires approval by the relevant reviewing authorities for EPA regulatory applications involving transport distances less than 50 km [11]. A puff model may be used for most applications where a plume model is appropriate, but the technical decision on using a puff model should be based on whether the straight-line, steady-state assumptions on which a plume model is based are valid [11]. The EPA approved version of the CALPUFF System includes Version 5.8 – Level 070623 of CALPUFF and includes changes through MCB-D. Wet and dry deposition, and chemical transformation are modeled. No radioactive decay and ingrowth, dose pathway, dose mitigation (e.g., evacuation), or economic models are included in CALPUFF.

A summary comparison of the dispersion and deposition models of the ATMOS component of MACCS2, AERMOD, and CALPUFF are shown in Table 1. More detailed summary information on the latter two codes from Appendix A to Appendix W of 40 CFR Part 51 is shown in Appendix A.

Table 1. Summary Comparison of Atmospheric Dispersion and Deposition Models

Parameter	MACCS2/ATMOS	AERMOD	CALPUFF
Plume Model	Non-steady-state Gaussian plume with multiple plume segments; Plume expansion factor for meander; Briggs model for buoyant plume rise	Steady-state Gaussian plume model	Non-steady-state Lagrangian Gaussian puff model; Wind shear puff split; Briggs model; Partial penetration; Buoyant and momentum rise; Stack tip effects; Vertical wind shear
Dispersion	Two models: Pasquill-Gifford stability class sigma-y and sigma-z; Time-based dispersion function	No user input	Five models, including P-G
Building Wake and Terrain Effects	Building wake entrainment; Surface terrain effects modeled with scaling factor	Stack-tip downwash; Surface terrain effects (via surface roughness length)	Building downwash by two methods; Applicable to rough or complex terrain; Simulates changes in the flow and dispersion rate induced by terrain features
Wet Deposition	Exponential function of rain duration and intensity	Wet particulate and gaseous deposition	Empirical scavenging model as function of pollutant and precipitation type
Dry Deposition	Source depletion by particle size dependent deposition velocity	Dry particulate and gaseous deposition	Resistance model
Meteorological Sampling	Weather bin or random sampling of annual data; Specification of mixing layer height; 15-min, 30-min, or hourly time periods	Surface boundary layer and profile variables; Hourly time periods	Hourly wind/temp on 3D grid, w/2D parameters
Material Sources	Point or area source w/multiple plume segments, aerosol sizes, and isotopic components	Multiple sources; point, volume, area, and line; Variable emission rates	Time varying point, line, volume, and area sources; Variable emission rates

Parameter	MACCS2/ATMOS	AERMOD	CALPUFF
Receptor Locations	Polar grid centered on facility; Up to 35 radial intervals; Up to 64 compass directions; Up to 7 receptors per grid	Multiple receptors; Discrete, polar or Cartesian grid networks; Variable receptor height	Essentially unlimited gridded or discrete receptors
Range	0.05 to 9999 km;	Up to 50 km	10's of m to 100's of km
Decay and Ingrowth	Radioactive decay and daughter ingrowth over six generations	Single exponential decay	Linear removal and chemical conversion

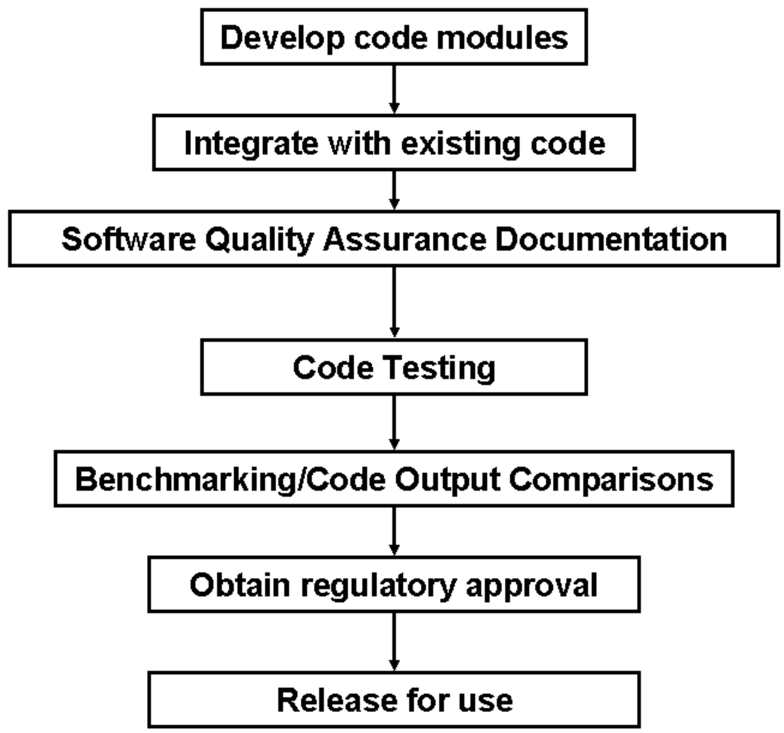
All three codes use a type of Gaussian dispersion model. AERMOD uses the simplest Gaussian representation, which is a steady-state plume; MACCS2 also uses a plume model, but the wind speed, stability class, and precipitation rate can change as the plume moves through the grid. CALPUFF uses a Gaussian puff model, which allows wind direction to change along the course of the plume.

An important distinction between these codes is that AERMOD and CALPUFF were specifically designed to treat chemical air pollutants. Because of this, they treat removal of the pollutants by chemical reaction but do not handle radioactive decay with daughter ingrowth. On the other hand, MACCS2 was specifically designed to treat radioactive air pollutants. It treats radioactive decay and daughter ingrowth for decay chains up to a length of six.

An approach to addressing the objective of this plan is to evaluate whether or not output generated by AERMOD and CALPUFF could be used as input to a post-processing routine to model radioactive decay and dose pathway processes, emergency phase relocation actions, and economic costs. That is, AERMOD and CALPUFF account for plume dispersion and deposition, and provide material concentrations at receptor locations. Approximation would be needed to model radioactive decay with daughter ingrowth during atmospheric transport for a large set of parents and daughters, and the corresponding adjustment made to deposited concentrations. An approach to modeling cloudshine effects would also be needed to ensure that predictions are not underestimated. From the deposited material concentrations, it may be possible to develop a set of dose conversion factors to account for various uptake pathways. The most difficult implementation would be to account for the interaction between time-dependent plume concentrations and evacuating public. Deposited material concentrations could be used to estimate economic costs for mitigative actions. However, the mitigative actions, such as decontamination of property, are coupled with public doses. As a result, a coupled model is required to properly treat these effects.

Unlike MACCS2, neither AERMOD nor CALPUFF appear to have options for generating statistical distributions of consequences for variations in source terms, meteorology, or populations. Alternatively, it may be possible to incorporate these modeling functions in the codes directly.

Developing, testing, producing quality assurance (QA) documentation, and obtaining EPA approval for either AERMOD or CALPUFF in the context of nuclear reactor accidents would likely require considerable effort over a period of several years. Some of the steps involved are shown in the following graphic.



AERMOD Output

For each averaging period (1, 3, 8, or 24 hours or 1 month), concurrent averages for all receptors for each day of data processed are generated. Receptor networks are printed first, followed by concurrent averages for each source group. Optional output files include POSTFILE, a file of concurrent (raw) results at each receptor. Appendix D of the AERMOD User Guide shows for the POSTFILE option a file including X and Y coordinates of the receptor location, receptor height, averaging period, source group ID, and either the date variable for the end of the averaging period or the number of hours in the period for period averages [9].

CALPUFF Output

CALPUFF output files include one-hour averaged concentrations at gridded and discrete receptor locations for selected species and of wet and dry deposition fluxes; hourly reports of mass fluxes into and out of regions, and of mass changes for all species, are also produced. The CALPOST postprocessor program averages and reports concentrations or wet/dry fluxes based on hourly data in the CALPUFF output file [12].

Summary

The objective of this plan is to determine the feasibility, and if appropriate, the level of effort required to use the AERMOD and CALPUFF models in the same capacity as MACCS2 for performing consequence modeling in terms of dose, health effects, land contamination, and economic cost for SAMA analyses. Because AERMOD and CALPUFF do not include models for emergency response, radioactive decay and ingrowth, radiological health effects, mitigative actions, or economic costs, code revision or development of post-processing utilities would be needed to utilize either of these codes to model nuclear reactor accident consequences in a manner similar to MACCS2. Statistical sampling of parameter distributions is also a feature of MACCS2 that is not available in AERMOD or CALPUFF. Developing, testing, and acquiring acceptance of the results produced by these approaches would involve significant effort. Model assumptions and constraints needed for these utilities may limit the accuracy/fidelity of the results obtained.

References

1. Preferred/Recommended Models, Technology Transfer Network, Support Center for Regulatory Atmospheric Modeling, U.S. Environmental Protection Agency, http://www.epa.gov/scram001/dispersion_prefrec.htm, accessed May 6, 2010.
2. Appendix A to Appendix W of Part 51 – Summaries of Preferred Air Quality Models, Federal Register, Vol. 70, No. 216, Nov. 9, 2005.
3. Jow, H-N, J.L. Sprung, J.A. Rollstin, L.T. Ritchie, D.I. Chanin, MELCOR Accident Consequence Code System (MACCS) Model Description, NUREG/CR-4691, SAND86-1562, Vol. 2, February, 1990.
4. Chanin, D, M.L. Young, J. Randall, and K. Jamali, Code Manual for MACCS2: Volume 1, User's Guide, NUREG/CR-6613, SAND97-0594, Vol. 1, May, 1998.
5. Table 1, AERMOD: Latest Features and Evaluation Results, EPA-454/R-03-003, June 2003. (aermod_mep.pdf)
6. User's Guide for the AMS/EPA Regulatory Model – AERMOD (Under Revision), EPA-454/B-03-001, U.S. Environmental Protection Agency, September 2004, p. 3-3.
7. User's Guide for the AMS/EPA Regulatory Model – AERMOD (Under Revision), EPA-454/B-03-001, U.S. Environmental Protection Agency, September 2004, p. 3-8.
8. User's Guide for the AMS/EPA Regulatory Model – AERMOD (Under Revision), EPA-454/B-03-001, U.S. Environmental Protection Agency, September 2004, p. 3-37.
9. User's Guide for the AMS/EPA Regulatory Model – AERMOD (Under Revision), EPA-454/B-03-001, U.S. Environmental Protection Agency, September 2004, Appendix D.
10. Addendum, User's Guide for the AMS/EPA Regulatory Model – AERMOD, (EPA-454/B-03-001, September 2004), U.S. Environmental Protection Agency, October 2009, p. 20.
11. Question 1.1.1., CALPUFF FAQs Answers, CALPUFF Modeling, The Atmospheric Studies Group at TRC, http://www.src.com/calpuff/FAQ-answers.htm#1.1.1 , accessed 4/29/2010.
12. Scire, J.S. D.G. Strimaitis, and R.J. Yamartino, A User's Guide for the CALPUFF Dispersion Model (Version 5), Earth Tech, Inc., January 2000.

Appendix A. Key Features of Refined Air Quality Models

Parameter	AERMOD[1]	CALPUFF[1]
Type of Model	AERMOD is a steady-state plume model, using Gaussian distributions in the vertical and horizontal for stable conditions, and in the horizontal for convective conditions. The vertical concentration distribution for convective conditions results from an assumed bi-Gaussian probability density function of the vertical velocity.	(1) CALPUFF is a non-steady-state time- and space-dependent Gaussian puff model. CALPUFF treats primary pollutants and simulates secondary pollutant formation using a parameterized, quasi-linear chemical conversion mechanism. Pollutants treated include SO_2, SO_4^{2-}, NO_X (i.e., NO + NO_2), HNO_3, NO_3^-, NH_3, PM–10, PM–2.5, toxic pollutants and others pollutant species that are either inert or subject to quasi-linear chemical reactions. The model includes a resistance-based dry deposition model for both gaseous pollutants and particulate matter. Wet deposition is treated using a scavenging coefficient approach. The model has detailed parameterizations of complex terrain effects, including terrain impingement, side-wall scraping, and steep-walled terrain influences on lateral plume growth. A subgrid-scale complex terrain module based on a dividing streamline concept divides the flow into a lift component traveling over the obstacle and a wrap component deflected around the obstacle. (2) The meteorological fields used by CALPUFF are produced by the CALMET meteorological model. CALMET includes a diagnostic wind field model containing parameterized treatments of slope flows, valley flows, terrain blocking effects, and kinematic terrain effects, lake and sea breeze circulations, a divergence minimization procedure, and objective analysis of observational data. An energy-balance scheme is used to compute sensible and latent heat fluxes and turbulence parameters over land surfaces. A profile method is used over water. CALMET contains interfaces to prognostic meteorological models such as the Penn State/NCAR Mesoscale Model (e.g., MM5; Section 12.0, ref. 86), as well as the RAMS, Ruc and Eta models.

Parameter	AERMOD[1]	CALPUFF[1]
Pollutant Types	AERMOD is applicable to primary pollutants and continuous releases of toxic and hazardous waste pollutants. Chemical transformation is treated by simple exponential decay.	CALPUFF may be used to model gaseous pollutants or particulate matter that are inert or which undergo quasi-linear chemical reactions, such as SO_2, SO_4^{2-}, NO_X (*i.e.*, NO + NO_2), HNO_3, NO_3^-, NH_3, PM–10, PM–2.5 and toxic pollutants. For regional haze analyses, sulfate and nitrate particulate components are explicitly treated.
Source-Receptor Relationships	AERMOD applies user-specified locations for sources and receptors. Actual separation between each source-receptor pair is used. Source and receptor elevations are user input or are determined by AERMAP using USGS DEM terrain data. Receptors may be located at user-specified heights above ground level.	CALPUFF contains no fundamental limitations on the number of sources or receptors. Parameter files are provided that allow the user to specify the maximum number of sources, receptors, puffs, species, grid cells, vertical layers, and other model parameters. Its algorithms are designed to be suitable for source-receptor distances from tens of meters to hundreds of kilometers.

Parameter	AERMOD[1]	CALPUFF[1]
Plume Behavior	(1) In the convective boundary layer (CBL), the transport and dispersion of a plume is characterized as the superposition of three modeled plumes: The direct plume (from the stack), the indirect plume, and the penetrated plume, where the indirect plume accounts for the lofting of a buoyant plume near the top of the boundary layer, and the penetrated plume accounts for the portion of a plume that, due to its buoyancy, penetrates above the mixed layer, but can disperse downward and re-enter the mixed layer. In the CBL, plume rise is superposed on the displacements by random convective velocities (Weil *et al.*, 1997). (2) In the stable boundary layer, plume rise is estimated using an iterative approach, similar to that in the CTDMPLUS model (see A.5 in this appendix). (3) Stack-tip downwash and buoyancy induced dispersion effects are modeled. Building wake effects are simulated for stacks less than good engineering practice height using the methods contained in the PRIME downwash algorithms (Schulman, *et al.*, 2000). For plume rise affected by the presence of a building, the PRIME downwash algorithm uses a numerical solution of the mass, energy and momentum conservation laws (Zhang and Ghoniem, 1993). Streamline deflection and the position of the stack relative to the building affect plume trajectory and dispersion. Enhanced dispersion is based on the approach of Weil (1996). Plume mass captured by the cavity is well-mixed within the cavity. The captured plume mass is re-emitted to the far wake as a volume source. (4) For elevated terrain, AERMOD incorporates the concept of the critical dividing streamline height, in which flow below this height remains horizontal, and flow above this height tends to rise up and over terrain (Snyder *et al.*, 1985). Plume concentration estimates are the weighted sum of these two limiting plume states.	Momentum and buoyant plume rise is treated according to the plume rise equations of Briggs (1975) for non-downwashing point sources, Schulman and Scire (1980) for line sources and point sources subject to building downwash effects using the Schulman-Scire downwash algorithm, and Zhang (1993) for buoyant area sources and point sources affected by building downwash when using the PRIME building downwash method. Stack tip downwash effects and partial plume penetration into elevated temperature inversions are included. An algorithm to treat horizontally-oriented vents and stacks with rain caps is included.

Parameter	AERMOD[1]	CALPUFF[1]
	However, consistent with the steady-state assumption of uniform horizontal wind direction over the modeling domain, straight-line plume trajectories are assumed, with adjustment in the plume/receptor geometry used to account for the terrain effects.	
Horizontal Winds	Vertical profiles of wind are calculated for each hour based on measurements and surface-layer similarity (scaling) relationships. At a given height above ground, for a given hour, winds are assumed constant over the modeling domain. The effect of the vertical variation in horizontal wind speed on dispersion is accounted for through simple averaging over the plume depth.	A three-dimensional wind field is computed by the CALMET meteorological model. CALMET combines an objective analysis procedure using wind observations with parameterized treatments of slope flows, valley flows, terrain kinematic effects, terrain blocking effects, and sea/lake breeze circulations. CALPUFF may optionally use single station (horizontally-constant) wind fields in the CTDMPLUS, AERMOD or ISCST3 data formats.
Vertical Wind Speed	In convective conditions, the effects of random vertical updraft and downdraft velocities are simulated with a bi-Gaussian probability density function. In both convective and stable conditions, the mean vertical wind speed is assumed equal to zero.	Vertical wind speeds are not used explicitly by CALPUFF. Vertical winds are used in the development of the horizontal wind components by CALMET.
Horizontal Dispersion	Gaussian horizontal dispersion coefficients are estimated as continuous functions of the parameterized (or measured) ambient lateral turbulence and also account for buoyancy-induced and building wake-induced turbulence. Vertical profiles of lateral turbulence are developed from measurements and similarity (scaling) relationships. Effective turbulence values are determined from the portion of the vertical profile of lateral turbulence between the plume height and the receptor height. The effective lateral turbulence is then used to estimate horizontal dispersion.	Turbulence-based dispersion coefficients provide estimates of horizontal plume dispersion based on measured or computed values of σ_v. The effects of building downwash and buoyancy-induced dispersion are included. The effects of vertical wind shear are included through the puff splitting algorithm. Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.

Parameter	AERMOD[1]	CALPUFF[1]
Vertical Dispersion	In the stable boundary layer, Gaussian vertical dispersion coefficients are estimated as continuous functions of parameterized vertical turbulence. In the convective boundary layer, vertical dispersion is characterized by a bi-Gaussian probability density function, and is also estimated as a continuous function of parameterized vertical turbulence. Vertical turbulence profiles are developed from measurements and similarity (scaling) relationships. These turbulence profiles account for both convective and mechanical turbulence. Effective turbulence values are determined from the portion of the vertical profile of vertical turbulence between the plume height and the receptor height. The effective vertical turbulence is then used to estimate vertical dispersion.	Turbulence-based dispersion coefficients provide estimates of vertical plume dispersion based on measured or computed values of σ_w. The effects of building downwash and buoyancy-induced dispersion are included. Vertical dispersion during convective conditions is simulated with a probability density function (PDF) model based on Weil *et al.* (1997). Options are provided to use Pasquill-Gifford (rural) and McElroy-Pooler (urban) dispersion coefficients. Initial plume size from area or volume sources is allowed.
Chemical Transformation	Chemical transformations are generally not treated by AERMOD. However, AERMOD does contain an option to treat chemical transformation using simple exponential decay, although this option is typically not used in regulatory applications, except for sources of sulfur dioxide in urban areas. Either a decay coefficient or a half life is input by the user. Note also that the Plume Volume Molar Ratio Method (subsection 5.1) and the Ozone Limiting Method (subsection 5.2.4) and for point-source NO_2 analyses are available as non-regulatory options.	Gas phase chemical transformations are treated using parameterized models of SO_2 conversion to SO_4^{2-} and NO conversion to NO_3^-, HNO_3. Organic aerosol formation is treated. The POSTUTIL program contains an option to re-partition HNO_3 and NO_3^- in order to treat the effects of ammonia limitation.
Physical Removal	AERMOD can be used to treat dry and wet deposition for both gases and particles.	Dry deposition of gaseous pollutants and particulate matter is parameterized in terms of a resistance-based deposition model. Gravitational settling, inertial impaction, and Brownian motion effects on deposition of particulate matter is included. CALPUFF contains an option to evaluate the effects of plume tilt resulting from gravitational settling. Wet deposition of gases and particulate matter is parameterized in terms of a scavenging coefficient approach.

[1] Appendix A to Appendix W of Part 51 – Summaries of Preferred Air Quality Models, Federal Register, Vol. 70, No. 216, November 9, 2005.