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Consequence Analysis with WinMACCS 3.4

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Abstract: MACCS2 calculates the consequences of a release of radioactive material from a commercial power reactor or other facility and has been one of the most widely used consequence codes since its release in 1997. WinMACCS is a Windows user interface to MACCS2, allowing Latin Hypercube sampling of MACCS2 variables and visualization of results.

A number of improvements to MACCS2 have been incorporated into the initial public release version of the WinMACCS code. Improved models include the following:

- Several improvements to the Gaussian plume modeling capabilities, including buoyancy and dispersion modeling
- Improved weather modeling, including a variable mixing height model and greater angular and temporal resolution of the meteorological data
- Expanded limits on inputs, including up to 20 emergency response cohorts, i.e., a population group that responds similarly in terms of emergency response
- A potassium iodide (KI) ingestion model for sites where potassium iodine is distributed
- A dose and lifetime threshold model to allow exploration of a threshold in the relationship between dose and health effects
- Evaluation of land areas contaminated above specified isotopic concentrations and/or dose levels
- Updated dose conversion factors based on FGR-13 for internal dosimetry and FGR-12 for external dosimetry

In addition, WinMACCS has a user-friendly interface with significant advantages over the old input-file interface.

- Displays input parameters in a logical and organized fashion
- Depending on user-specified model selection, displays which inputs are needed. Interface visually conveys which inputs are already defined, and which need to be defined or updated before performing a calculation
- Checks input validation data for self consistency
- Minimizes quality assurance issues by organizing all input data into projects
- Facilitates exploring the effect of uncertain inputs using Latin Hypercube sampling, including source term and most other real-valued input parameters
- Assembles statistical values from multiple realizations into text files and graphs
- Overlays network evacuation directions onto road maps
- Includes on-line and context sensitive user interface help

WinMACCS is an ideal tool for level-3 PRA applications and other consequence analyses.

Keywords: MACCS2, Consequence Modeling, Dose, Level-3 PRA

1. INTRODUCTION

MACCS2 version 1.12 [1] was developed at Sandia National Laboratories and first released in 1997. MACCS2 allows the user to estimate the consequences from a release of radioactive vapors and aerosols into the atmosphere. It models a comprehensive set of exposure pathways, including cloudshine, groundshine, deposition onto skin, direct inhalation and inhalation of resuspended aerosols, and ingestion of contaminated food and water. MACCS2 allows short- and long-term treatment of mitigative responses. It also facilitates sampling of weather conditions from an annual meteorological file and estimation of uncertainties associated with weather.

A subsequent version, 1.13.1, was released in 2004. This version did not include any new modeling capabilities; it was intended to allow users to run on Windows 2000 and more recent operating systems and contained fixes for two known defects that had been reported to the user community.

Further refinements of the MACCS2 code have been made since 2004, resulting in the latest version, 2.4, which is now being released to the user community. The improvements to MACCS2 are discussed in Section 2.

MACCS2 is now distributed with a user-friendly interface, WinMACCS. The interface greatly facilitates the development of input files, allows the user to explore uncertainties in most of the real-valued input variables, and produces post-processed results, both in text and graphical form. The user interface is described further in Section 3.

2. MACCS2 MODELING IMPROVEMENTS

The current version of MACCS2, version 2.4, is beginning to be released to the user community. This version contains a large number of modeling refinements and improved capabilities. These are laid out in this section.

2.1. Plume Buoyancy

The original plume buoyancy model in MACCS2 is due to Briggs [2]. The implementation of this model is described in the MACCS models manual [3]. However, recent assessments of this model have shown that another plume rise model, also due to Briggs, is superior under unstable to neutrally stable atmospheric conditions [4]. The new model predicts significantly less plume rise for Pasquill stability classes A through D than the original MACCS2 model, and thus predicts higher doses from a buoyant release at small downwind distances.

2.2. Dispersion

Traditionally, MACCS2 has allowed user to define tabulated or power-law functions to express horizontal (cross-wind) and vertical dispersions as functions of downwind distance. Data to support the dispersion functions has typically been measured out to distances of about 30 km. In the past, the functions have been extrapolated to distances much greater than 30 km. For example, in NUREG-1150 [5] these dispersion functions were used to distances of 1600 km (1000 mi).

More typically, a time-based representation is used for long-range dispersion. A dispersion model, in which horizontal dispersion is a linear function of time, is now available in MACCS2. The user can choose a downwind distance for converting from a distance-based to a time-based dispersion function. By default, the distance is 30 km. The user can also choose the linear coefficient in the time function. The default value is 0.5 m/s.

2.3. Plume Meander

The original MACCS2 plume meander model uses a power-law representation that depends on release duration. In this model, the horizontal dispersion is multiplied by a meander factor that is independent of downwind distance, of stability class, or of wind speed.

In the regulatory arena, the standard model is described in Regulatory Guide 1.145 [6]. The model described is limited in that it assumes that release duration is 2 hours and therefore does not account for the effect of release duration on the magnitude of plume meander. However, it does account for the effects of stability class and wind speed on the magnitude of the meander factor. It also assumes that the meander factor diminishes beyond 800 m downwind in a manner similar to that of an area source.

The Regulatory Guide 1.145 plume meander model is now implemented as an option in MACCS2. In addition, MACCS2 also allows plume meander to be switched off.

2.4. Mixing Height

The original MACCS2 model assumed a fixed value of mixing height. When sampling from a meteorological data file, the file contains daytime and nighttime values for the mixing height for each season. However, the original model only used the daytime values.

The new model allows for night to day transitions in mixing height. To use the new model, the user must specify a latitude and longitude of the release location. The model estimates sunrise and sunset times based on these values. The mixing height is modeled to increase linearly from its nighttime value and its daytime value during the time between sunrise and sunset. The mixing height stays at the daytime value once that value is attained, which occurs at the first sunset.

2.5. Angular and Temporal Resolution of Meteorological Data

MACCS2 version 1.12 required hourly meteorological data and used a fixed angular resolution of 16 compass sectors (22.5° each). The new version allows for 15-min, 30-min, or 1-hr time averaging of weather data. Furthermore, it allows the user to specify 16, 32, 48, or 64 compass sector resolution. Meteorological and site data files must be at a resolution consistent with the grid resolution. WinMACCS allows standard 16-compass-sector site files to be interpolated onto higher-resolutions grids.

2.6. Expanded Limits

MACCS2 version 1.12 was created when computer memory was at a premium. Current-generation computers allow for significantly greater memory usage without a speed penalty. Furthermore, newer FORTRAN compilers allow for dynamic memory allocation. These improvements have enabled larger and more flexible limits on MACCS2 input parameters.

The parameter limits that have been increased are as follows: (1) the number of compass sectors has been increased from 16 to 64; (2) the number of chemical groups for defining radionuclide release fractions has been increased from 10 to 20; (3) the number of aerosol size bins has been increased from 10 to 20 to allow better compatibility with MELCOR capabilities; (4) the maximum number of plume segments has been increased dramatically from 4 to 200, allowing for time resolution on the same scale as the meteorological data; and (5) the number of emergency-phase cohorts has been increased significantly from 3 to 20.

2.7. KI Model

A new model has been added to allow prophylactic ingestion of potassium iodide (KI) to be modeled. A number of sites in the US have distributed KI to members of the public in the vicinity of their commercial nuclear power plants. Ingestion of KI, if taken shortly before exposure to radioiodine, can saturate the thyroid with iodine and limit further uptake. A KI model has been implemented in MACCS2 to model the effect of KI ingestion. The model allows the user to choose the fraction of the public that would take KI and also to choose the efficacy of the KI, which depends strongly on the timing of KI ingestion compared with exposure to radioiodine.

2.8. Threshold Models

MACCS2 was originally built around a linear no-threshold (LNT) assumption for dose response. The original capability has been extended to include several threshold-type models. The simplest of these is an annual threshold model, in which dose responses are only accounted when the dose within a year exceeds the specified threshold. The second option incorporates the concept of a lifetime threshold. The most general option allows the user to create a dose-response function between annual dose and health effects with a set of piecewise continuous linear functions. With this option, the user can create a super-linear or sub-linear health effects model.

2.9. Land-Contamination Areas

A capability has been added to edit land areas that exceed either user-specified dose levels or activity levels. In addition, statistics on land contamination levels can be generated for each grid cell.

2.10. Dose Conversion Factors

A new dataset of dose conversion factors based on FGR-12 [7] for external dosimetry and FGR-13 [8] for internal dosimetry has been created and is distributed with the new code version. The new dataset includes 825 radionuclides and the dose conversion factors for all pathways, including those for acute health effects.

3. WinMACCS

MACCS2 was originally created to be run in command-line mode. The input files are ASCII text that must be edited by hand. The original MACCS2 interface has been supplanted by WinMACCS.

WinMACCS improves the usability of MACCS2 in the following ways: (1) it offers a logical organization of input values; (2) it guides the user to understand which input values are required, which are defined properly, and which still need to be defined; (3) it improves QA by retaining information in projects that contain all information needed to rerun a calculation; (4) optionally, WinMACCS can launch multiple realizations to explore source term and other input uncertainties; (5) it can create requested statistical values for single- or multiple-realization runs.

Some of the key features of WinMACCS are highlighted in the subsequent sections.

3.1. Input Data

WinMACCS displays categories of input parameters, as shown in Figure 1. Icons to the left of the category name indicate whether the parameters in the category are required (red or green), not required (grey), or optional (orange). Red icons with an X through them indicate that required data are not properly defined.

The first thing the user should do when running WinMACCS is to open the Project Properties screen shown in Figure 2. This screen displays the basic modeling choices that the user must make to run a calculation. Once these choices are made, the screen shown in Figure 1 amends the status icons next to each category of variables so that the user can logically revise or define input values.

Figure 3 displays an example for inputting parameters. In this case, a set of logical flags must be selected, one for each chemical group, to determine whether wet and/or dry deposition should be modeled. Normally, these flags are set to false for the noble gases (designated by Xe) and true for all other chemical groups. The flags can be selected from a drop-down menu or by typing in all or part of the key words “true” or “false.”

Notice that the parameter window displays several pieces of information about the variable being filled in. In Figure 3, for example, the window shows that the selected variable is a logical, the number of values for each variable that are required (9), and a definition of the variable and how it is used.

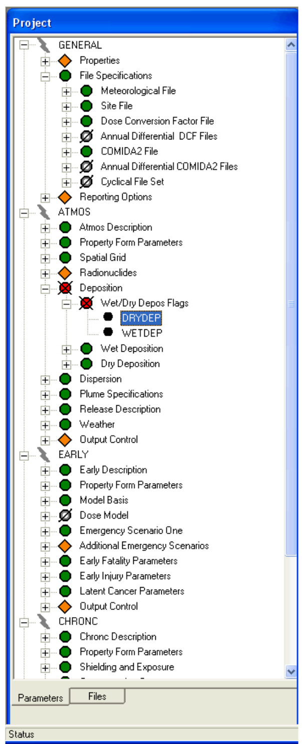


Figure 1. Input Categories and Parameters

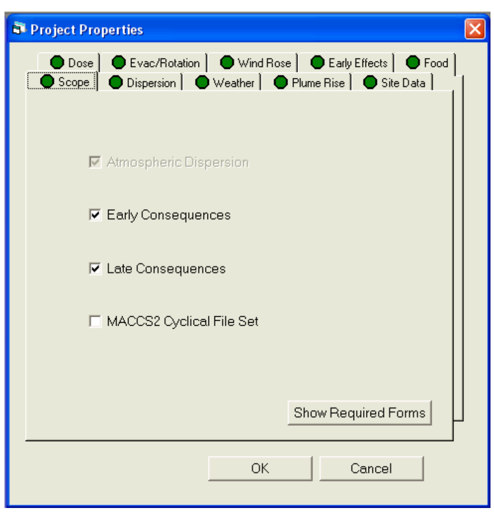


Figure 2. Project Properties

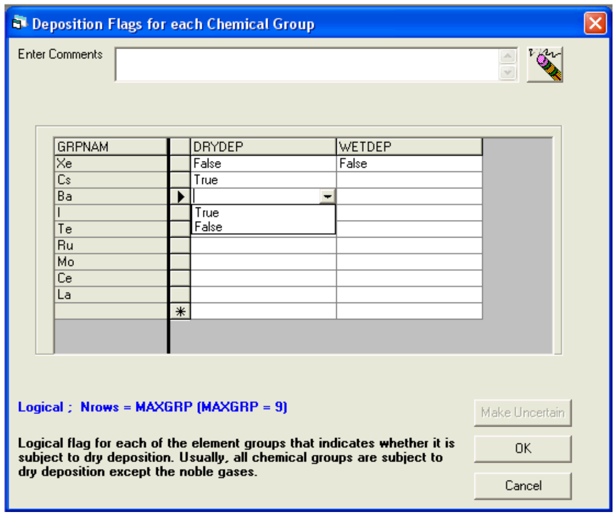


Figure 3. Parameter Windows

3.2. Uncertain Inputs

Most real valued input variables can be made uncertain by either double clicking on the entry or by selecting the "Make Uncertain" button on the parameter form. (The Make Uncertain button is shown in Figure 3, but is inactive because logical flags cannot be made uncertain.)

The form shown in Figure 4 allows the user to select a distribution type and input parameters to define an uncertain distribution. In the figure, the distribution type is a normal distribution. A total of 30 distribution types are supported. A mathematical description of the selected distribution type is displayed in the lower left corner of the window. The window also allows the selected distribution to be plotted in several formats, CDF, CCDF, and scatter. Uncertain inputs are calculated using the software tool called LHS (Latin Hypercube Sampling) [9].

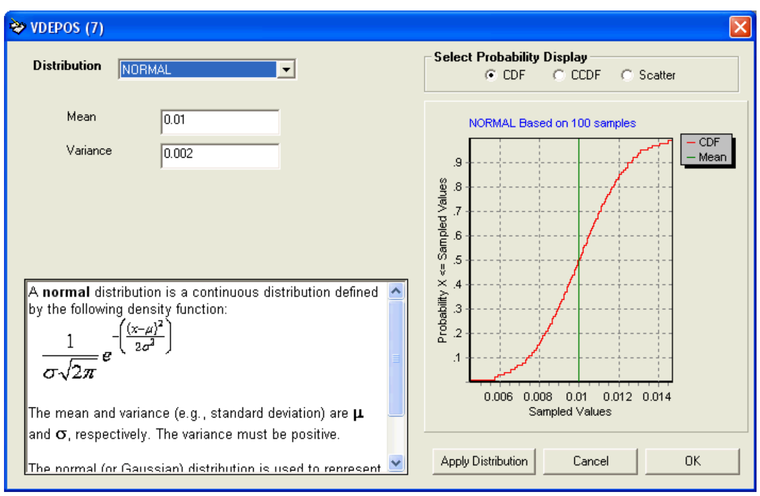


Figure 4. Creating a Distribution to Represent Parameter Uncertainty

3.3. Post Processing

Two types of post processing are available, summary text data and graphical displays. Figure 5 displays the window in which specific quantiles (fractional probabilities) can be requested for a summary report. In addition to the requested quantile levels, the summary report always contains mean values for each requested result type. The summary report can be produced for single- or multiple-realization calculations.

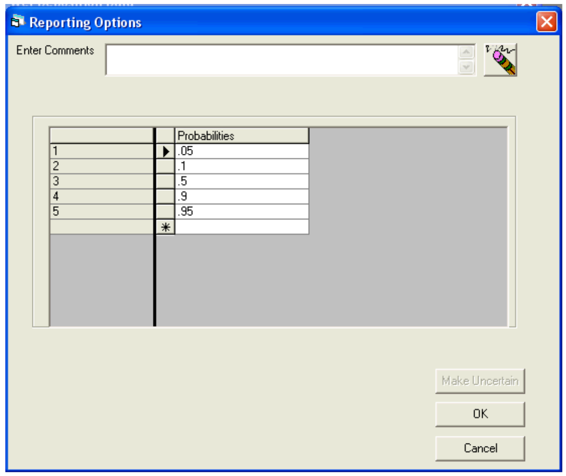
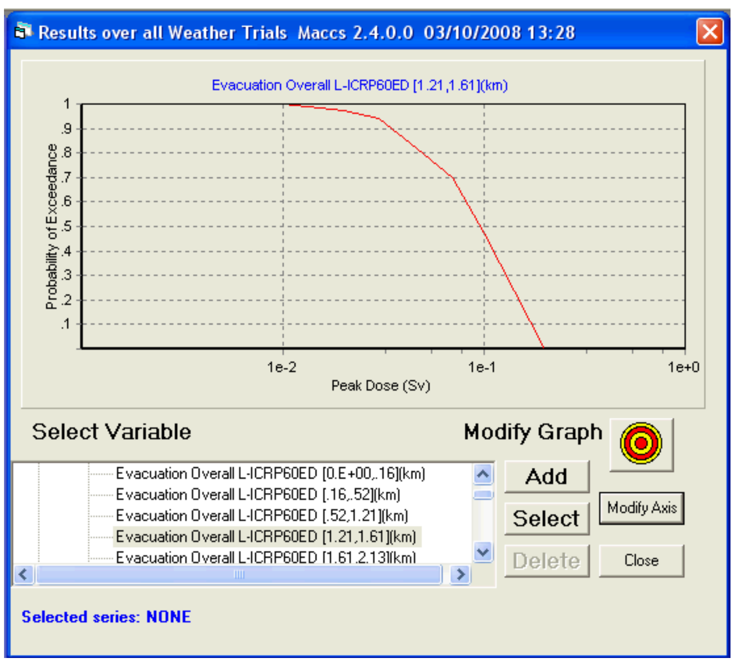


Figure 5. Creating a Summary Report

Figure 6 displays one of the types of graphical results that can be created. The ordinate represents the probability of exceedance associated with the weather data, i.e., from the weather sampling process. The abscissa shows the peak dose (Sv) in the range of 1.2 to 1.6 km downwind. Percentile values can be read from this plot, e.g., the 50-percentile result is slightly less than 0.1 Sv (10 rem).



5. Graphical Results

4. CONCLUSIONS

A number of modeling improvements have been made to MACCS2 over the past 5 years, leading to the current version 2.4 that is described in this paper. Furthermore, a user interface, WinMACCS, has been created to improve the usability of the MACCS2 code, also described in this paper. The current version, WinMACCS 3.4, is now being release to the MACCS2 user community. Those interested in receiving a copy of WinMACCS 3.4, including MACCS2 version 2.4, should send an email request to the first author at nbixler@sandia.gov.

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