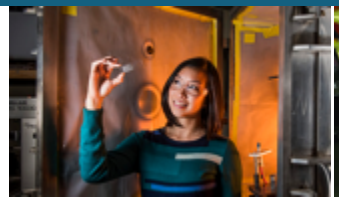
SAND2021-7612PE

Sandia National Laboratories

MELCOR Accident Consequence Code System



Dept 8855

Sandia National Laboratories

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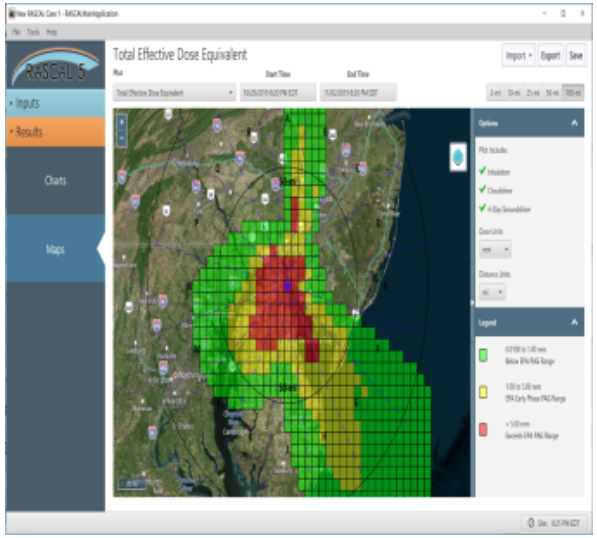
Contents

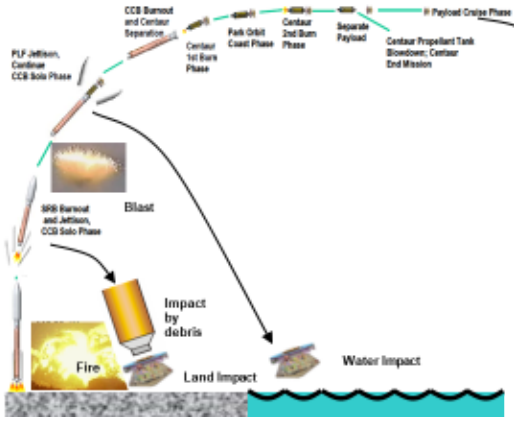
Accident Consequence Modeling and Analysis Department at SNL

Recognized worldwide as leaders in consequence and probabilistic risk analysis of nuclear energy systems and facilities, we leverage our ability to form multi-disciplinary teams and our unique knowledge of specialized codes to drive mission success.

MACCS



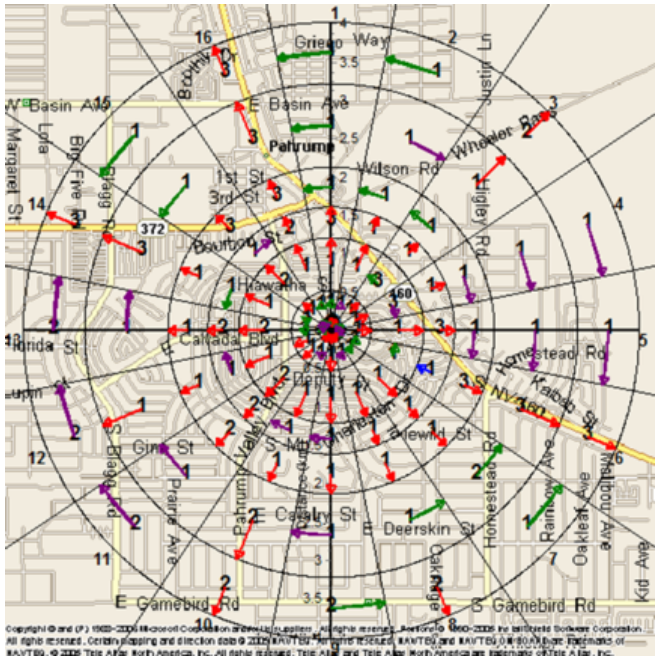
RASCAL



Launch Safety

What is MACCS Used For?

- Simulates the release of radioactive material on the surrounding environment
- Nuclear facility licensing
  - Environmental assessment
- Emergency planning and response
- Probabilistic Risk Assessments (PRA)
  - Informing design decisions
  - Informing upgrade decisions

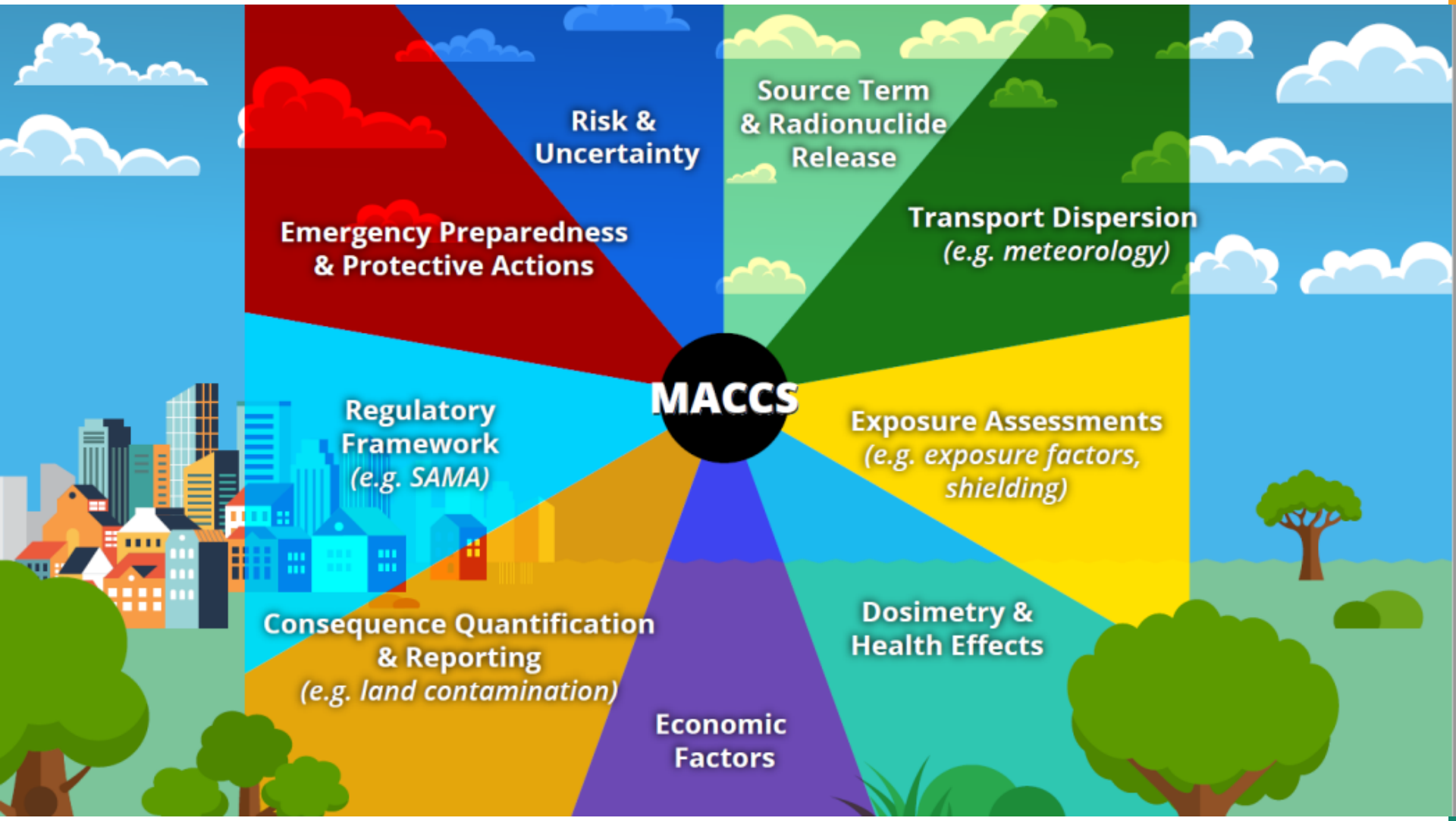


MACCS Network Evacuation Map

MACCS - History

- Calculation of Reactor Accident Consequences (CRAC) Code (1975)
  - Developed for the Reactor Safety Study (WASH-1400)
- CRAC2 (1982)
  - Primarily used in 1982 siting study (NUREG/CR-2239)
- MACCS (MELCOR Accident Consequence Code System) (1990)
  - Primarily used in NUREG-1150
- MACCS2 (1998)
  - Developed to support DOE documented safety analyses of nuclear facilities
- WinMACCS/MACCS (2008-2021)
  - Enhance user friendliness
  - Reduce likelihood of user errors
  - Enable routine examination of uncertainty

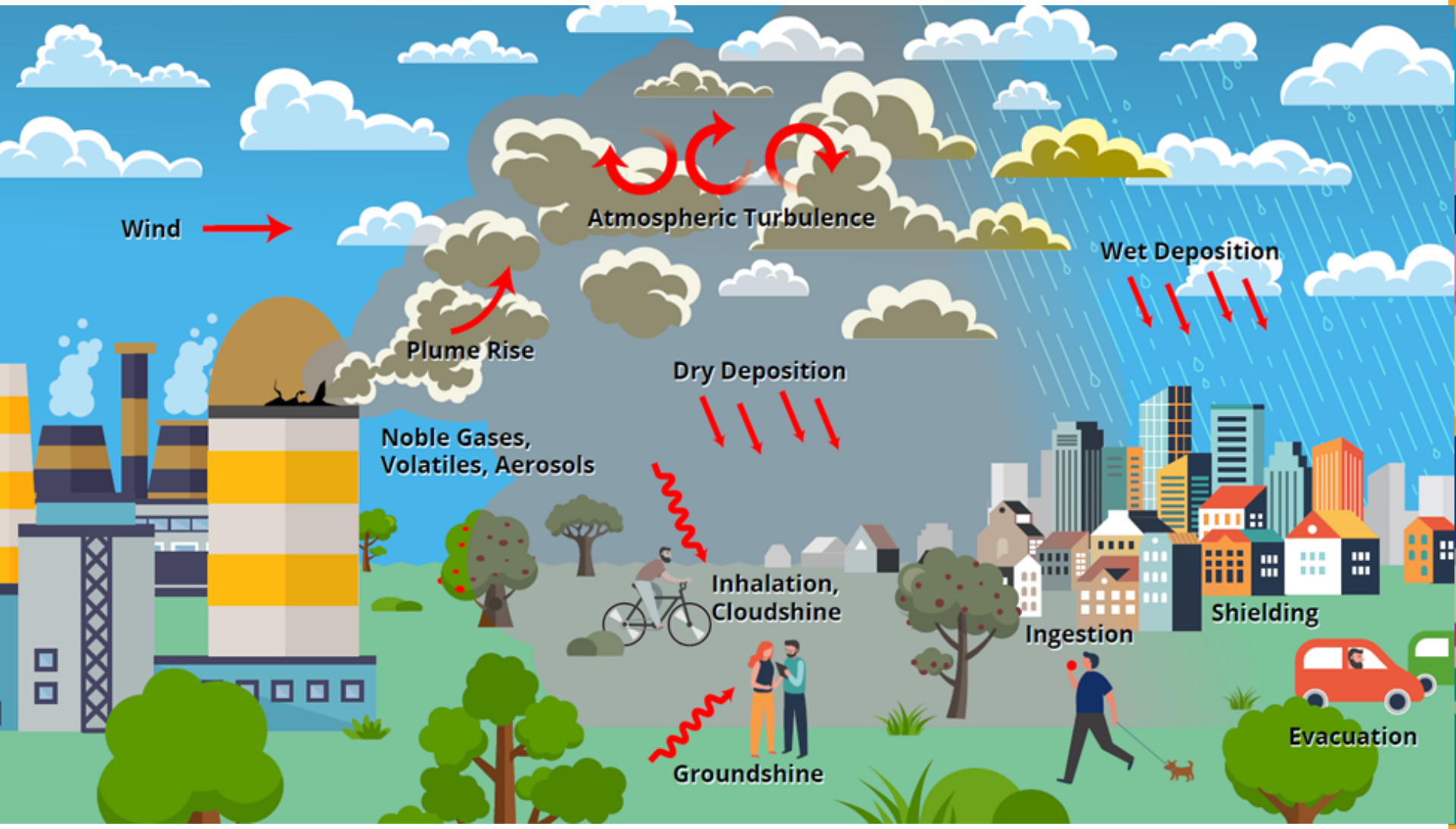
MACCS – How does it work?



MACCS - Capabilities

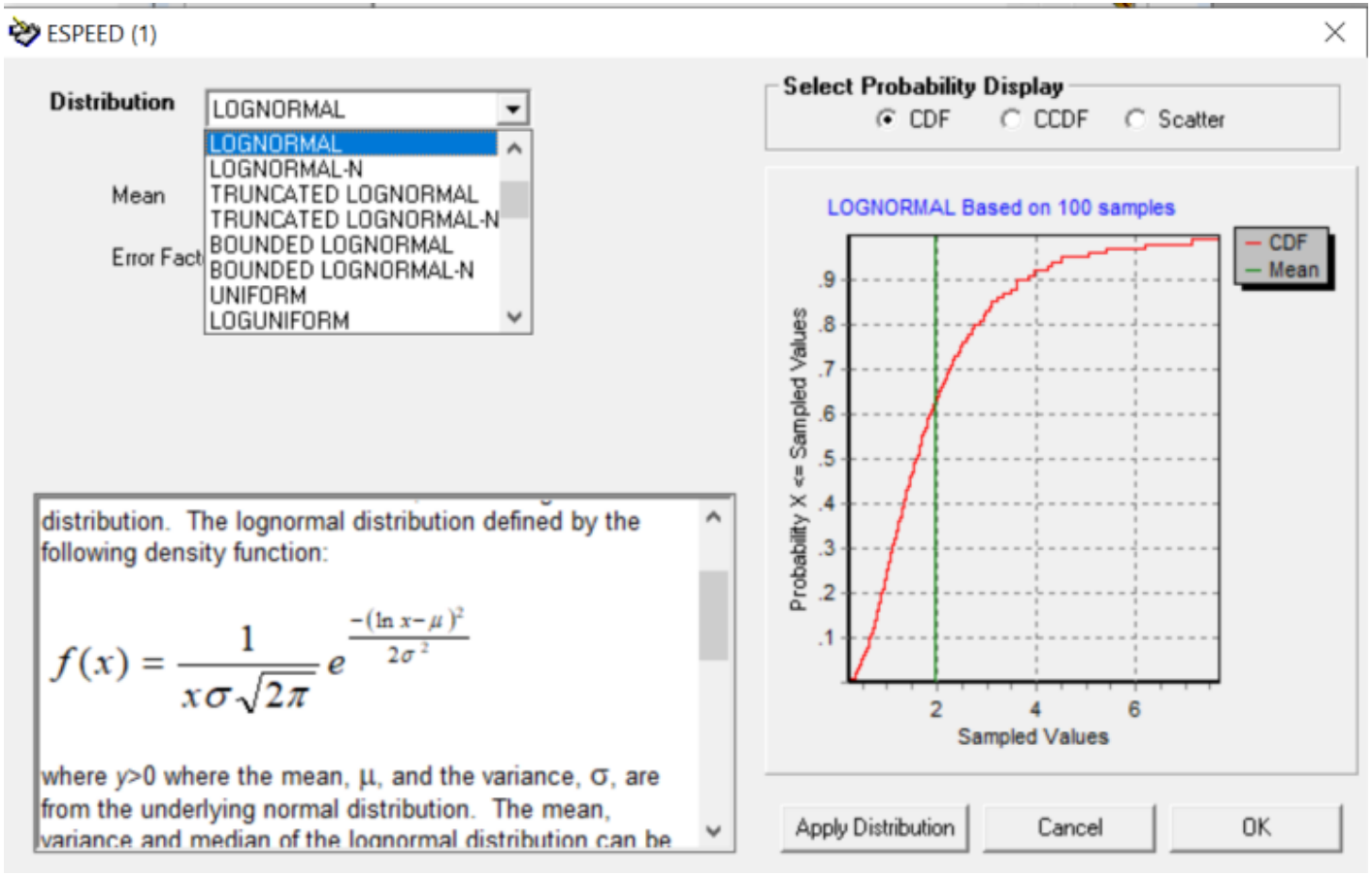
- Representation of source term
  - Magnitude, characteristics, and timing of release
  - Very flexible
- Atmospheric transport and dispersion
  - Gaussian Plume segment model
  - Lagrangian Particle tracking model
- Wet and dry deposition
- Exposure pathways to humans
  - Inhalation
  - Cloudshine
  - Groundshine
  - Resuspension
  - Ingestion
- Uncertainty Characterization
- Emergency actions
  - Sheltering
  - Evacuation
  - KI ingestion
  - Relocation
- Long-term remedial actions
  - Decontamination
  - Temporary or permanent interdiction of property
  - Crop disposal
- Economic losses
  - Evacuation and relocation per diem costs
  - Long-term relocation cost
  - Decontamination costs
  - Loss of property use
  - Depreciation during interdiction
  - Condemnation
  - GDP Losses

Atmospheric Transport Capabilities



Capabilities – Parametric Uncertainty

- Most parameters may be specified as “uncertain”
- 30 uncertainty distribution options
- Latin hypercube sampling



Capabilities – Weather Sampling

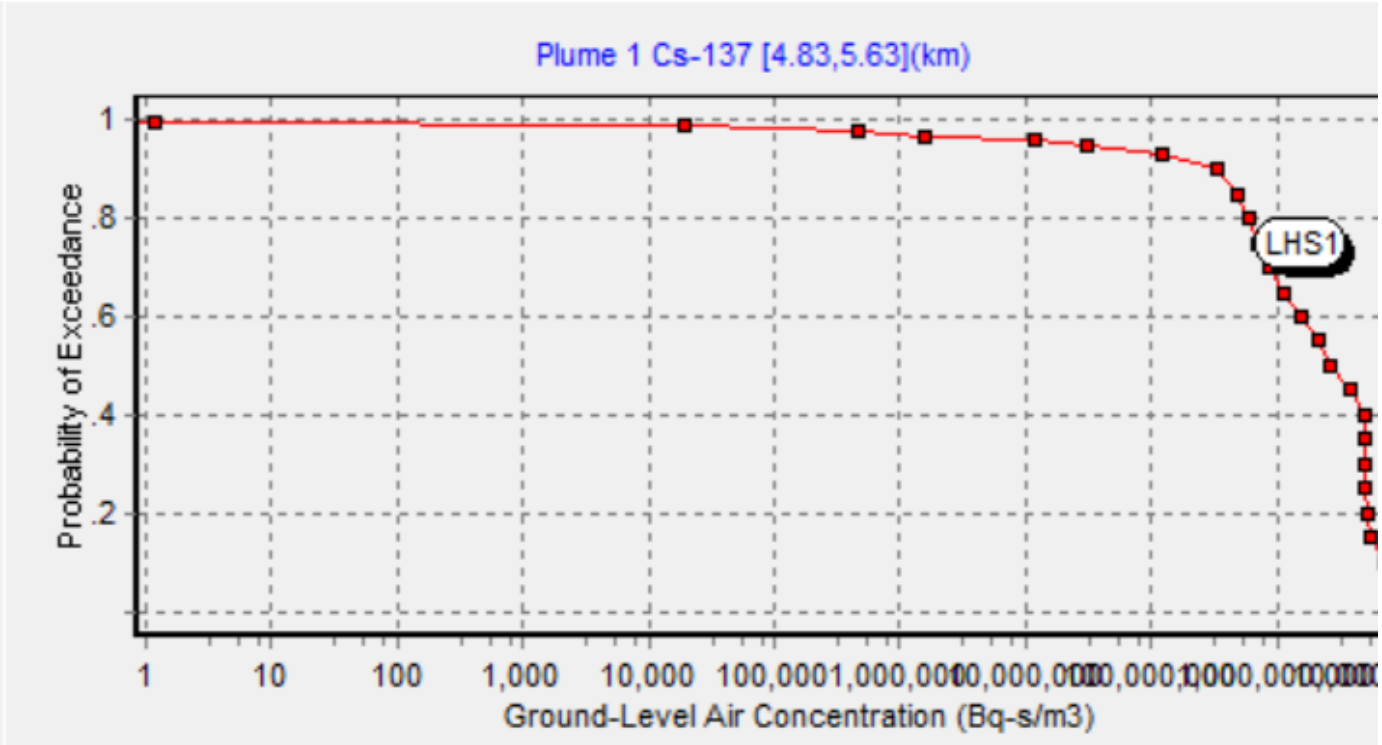
- Five options to specify weather
  - Constant weather
  - User supplied 120 weather points
  - Fixed start time
  - Uniform bin sampling
  - Nonuniform bin sampling
  - Stratified random sampling
- Sampling for multi-year data for specific locations
  - File contains information on day, hour, wind direction, wind speed, atmospheric stability class, precipitation rate and mixing height
  - Fifteen-minute, thirty-minute, or hourly averages

```
244 20 13 185  0
244 21 13 195  0
244 22 13 195  1
244 23 14 145  0
244 24 13 125  0
245  1 13 145  0
245  2 13 135  1
245  3 12 115  2
245  4 10 125  2
245  5 10 135  0
245  6  9 145  0
245  7  9 134  1
245  8 11 214  0
245  9 11 214  0
245 10 11 252  1
245 11 12 311  0
245 12 12 351  0
245 13 12 301  0
```

Snippet of MACCS weather file

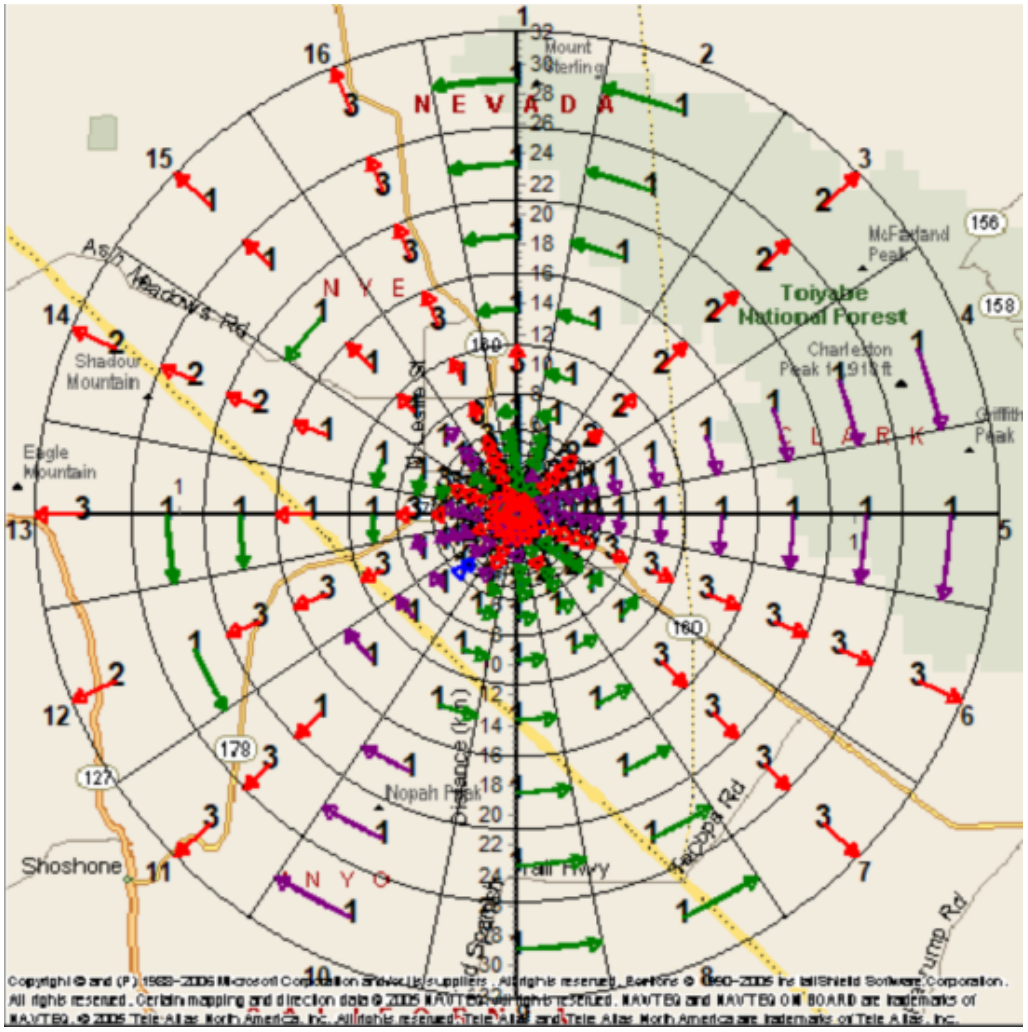
Capabilities – Statistical Results

- Complementary cumulative distribution functions (CCDFs)
- User may specify probabilities for tabular results
- Results include air and ground concentrations, individual dose, population dose, projected dose, acute fatalities, injuries and cancer by organ, cancer fatalities, and detailed economic losses



Capabilities – Evacuation Modeling

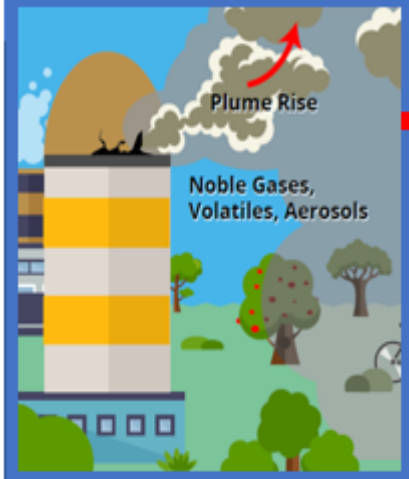
- Radial, keyhole, and network evacuation patterns
- Up to 20 cohorts
- Notification delays
- Response delays
- Protection factors
- Breathing rates
- Evacuation speeds
- Speed multipliers
- Dose thresholds



Capabilities - Health Impacts

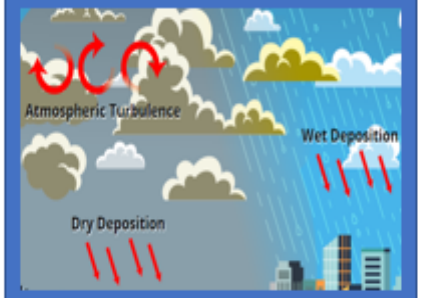
1. Characterize Source Term

- Describes the magnitude and timing of the release
- MELCOR or manual specification



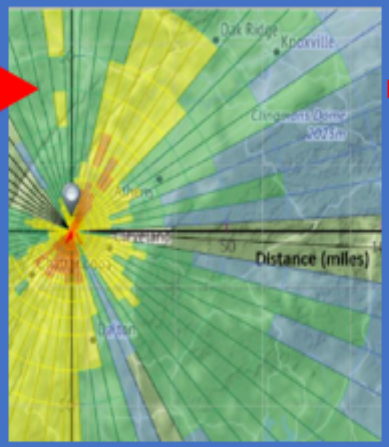
2. Model Atmospheric Transport

- Describes atmospheric transport and dispersion of release
- Gaussian Plume Segment, Gaussian Puff, and Particle Tracking Models



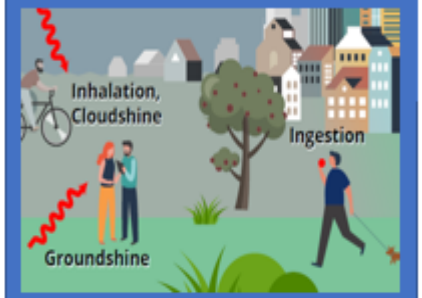
3. Calculate Concentrations

- Describes amount and activity for each radionuclide on a spatial grid over time
- Factors in decay and daughter products



4. Evaluate Exposure Pathways

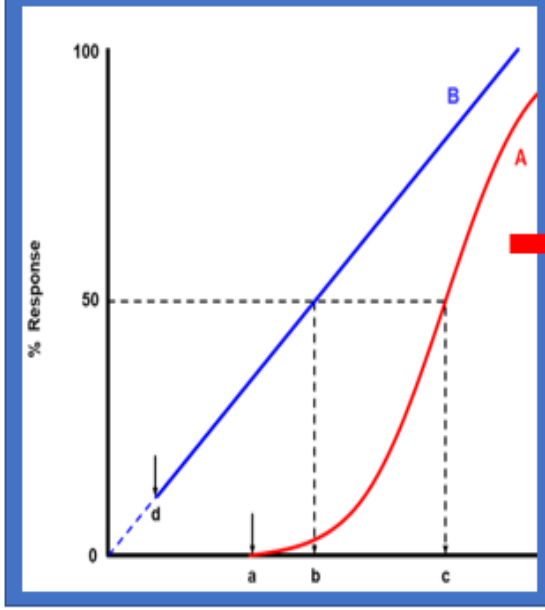
- Describes effective dose to specific organs and whole body from:
  - Inhalation
  - Ingestion
  - Cloudshine
  - Groundshine
  - Resuspension



Capabilities - Health Impacts

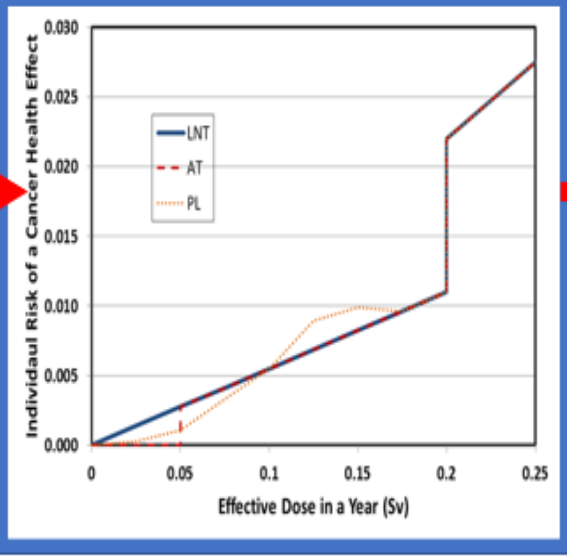
5. Apply Dose Response Models

- Apply dose response models to translate individual doses to dose responses



6. Calculate Risks to Individuals and Population

- Acute: apply hazard functions
- Latent: apply LNT, AT, or PL models for increased cancer risk



7. Apply Protective Actions and/or Emergency Response Planning

- Reduce risk to the public by:
  - Evacuation
  - Relocation
  - Sheltering
  - KI ingestion
  - Food Embargo
  - Interdiction
  - Decontamination
  - Condemnation

Economic Consequence Modeling

Capabilities - Economic Impacts

- Original Cost-Based Economic Model
- New state-of-practice input-output (I-O) economic model called RDEIM introduced in 2020
- Losses reported nationally, regionally, and by industry
- Direct, indirect, and induced losses
- Economic modeling considers:

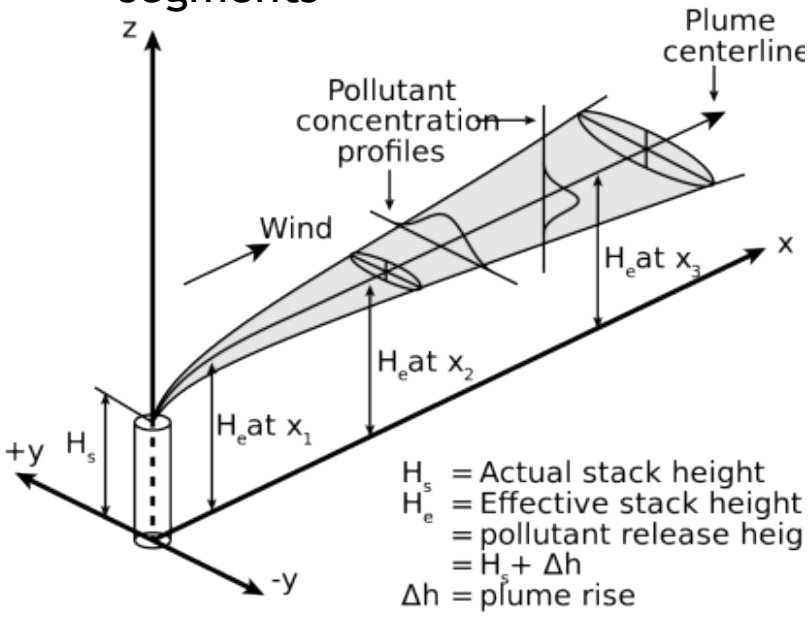
Components of Cost-Based Model	Components when using RDEIM
Evacuation/relocation costs	Evacuation/relocation costs
Long-term relocation	Long-term relocation
Decontamination costs	Decontamination costs
Expected return on investment	GDP losses, including direct, indirect, and induced
Depreciation on property improvements	Depreciation on property improvements
Value of condemned property	Value of condemned property
Disposal of contaminated crop and dairy products	Disposal of contaminated crop and dairy products (Added back in with WinMACCS 4.1.0)

Atmospheric Transport Modeling

- MACCS has two options for atmospheric transport and dispersion modeling:

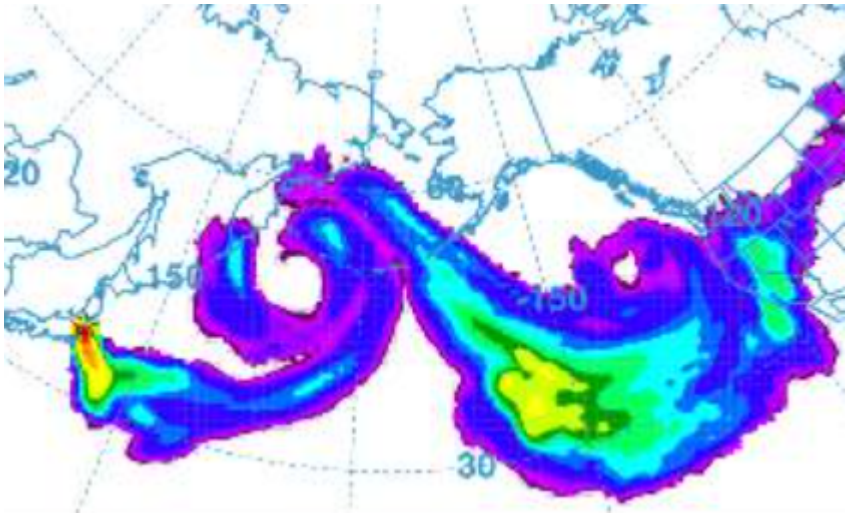
Gaussian

- Models dispersion as normal distribution
- Plume divided into plume segments



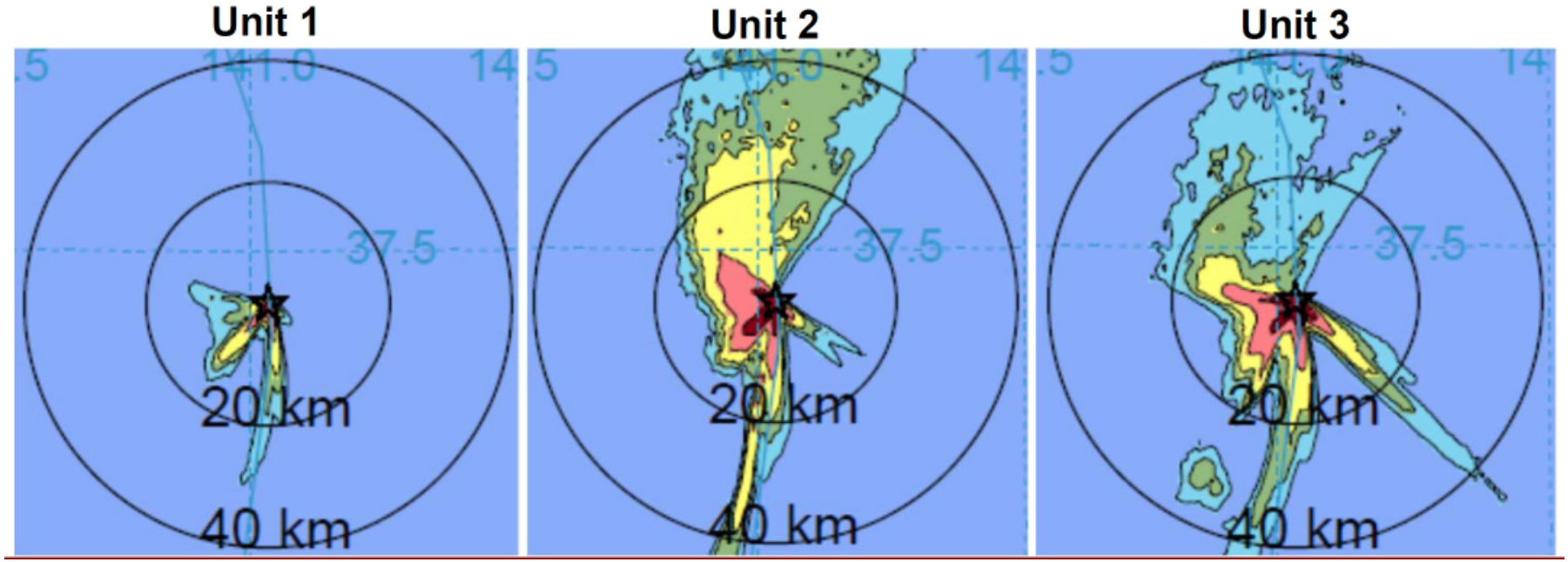
HYSPLIT

- Calculates dispersion by computing the statistics of the trajectories of a large number of the particles
- More appropriate for complex terrain and weather patterns

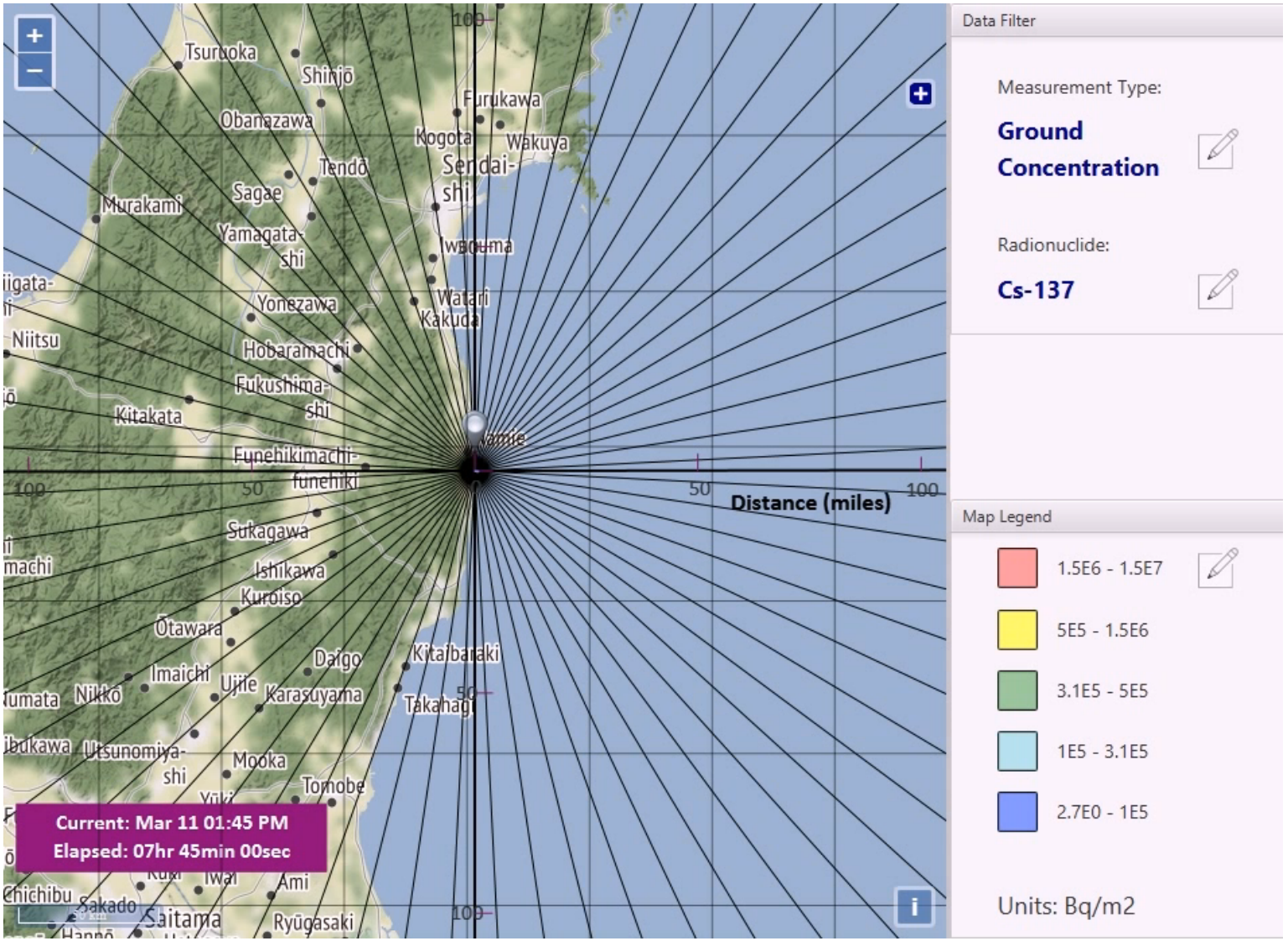


Example Application: Fukushima

- First multi-unit accident at a nuclear power plant
- Performed benchmarking study using MACCS HYSPLIT atmospheric transport modeling
- Focus on Cs-137 ground deposition data

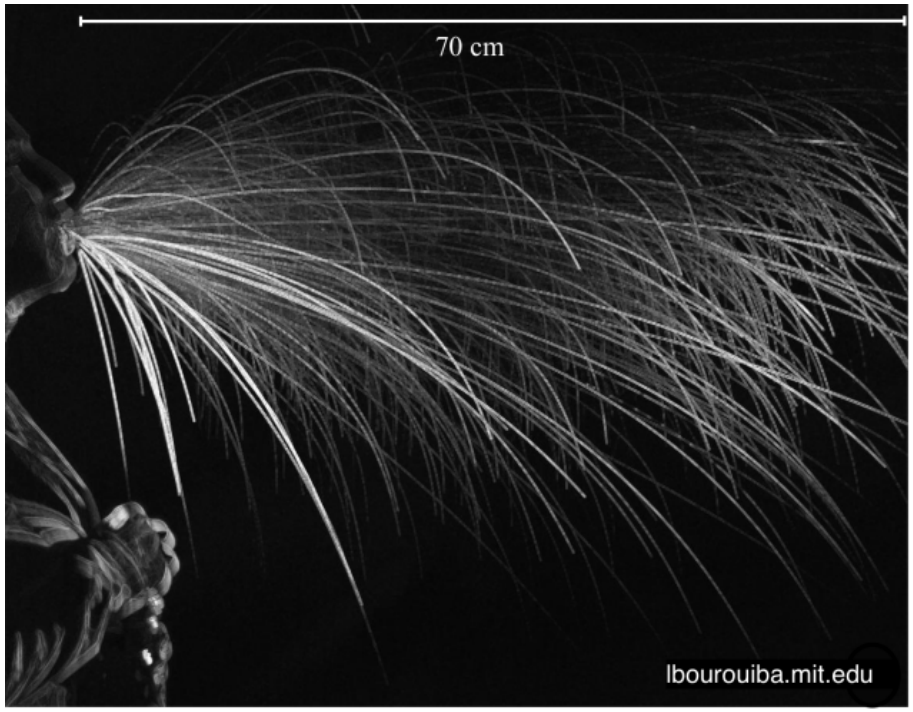


Fukushima Animation



Broad Applicability of MACCS

- Concepts in MACCS are applicable to a broader range of atmospheric transport problems, beyond nuclear applications
- Analog input parameters and modeling changes to apply MACCS to chemical/biological transmission applications:
  - Half-life
  - Particle size distribution
  - Deposition velocity
  - Humidity effects
  - Source height



(Bourouriba et al., 2014)

Contents

- Accident Consequence Modeling and Analysis
- Purpose and History of MACCS Code
- MACCS Capabilities
- Atmospheric Transport Modeling
- Uncertainty Characterization
- Evacuation Modeling
- Health Impacts Modeling
- Economic Impacts Modeling
- Example MACCS Applications
- Broader Applicability

Dept 8855 is always looking for new opportunities to apply strengths and build valuable partnerships!

BACKUPS

MACCS 4.0 Evolutionary Improvements

- Limits extended on a large set of input parameters
  - Number of output requests for all output types (999)
  - Number of plume segments using multi-source model (9999)
  - Duration of food ingestion with COMIDA2 (50 yr)
- Common, large auxiliary files stored in a data repository
- Convenience enhancements added for cyclical file management
- Simplified method to eliminate quadratic parameters for the linear-quadratic dose-response model
- Qualifiers can be tab-separated in reports to facilitate importing into a spreadsheet
- Input parameters can be exported, including distribution definitions
- Results for each weather trial are used to define quantile results
- Unused correlations are supported
- Processing multi-source releases in cyclical fashion is supported
- New features implemented to facilitate uncertainty/cyclical-file preprocessing

MACCS 4.0 Revolutionary Improvements

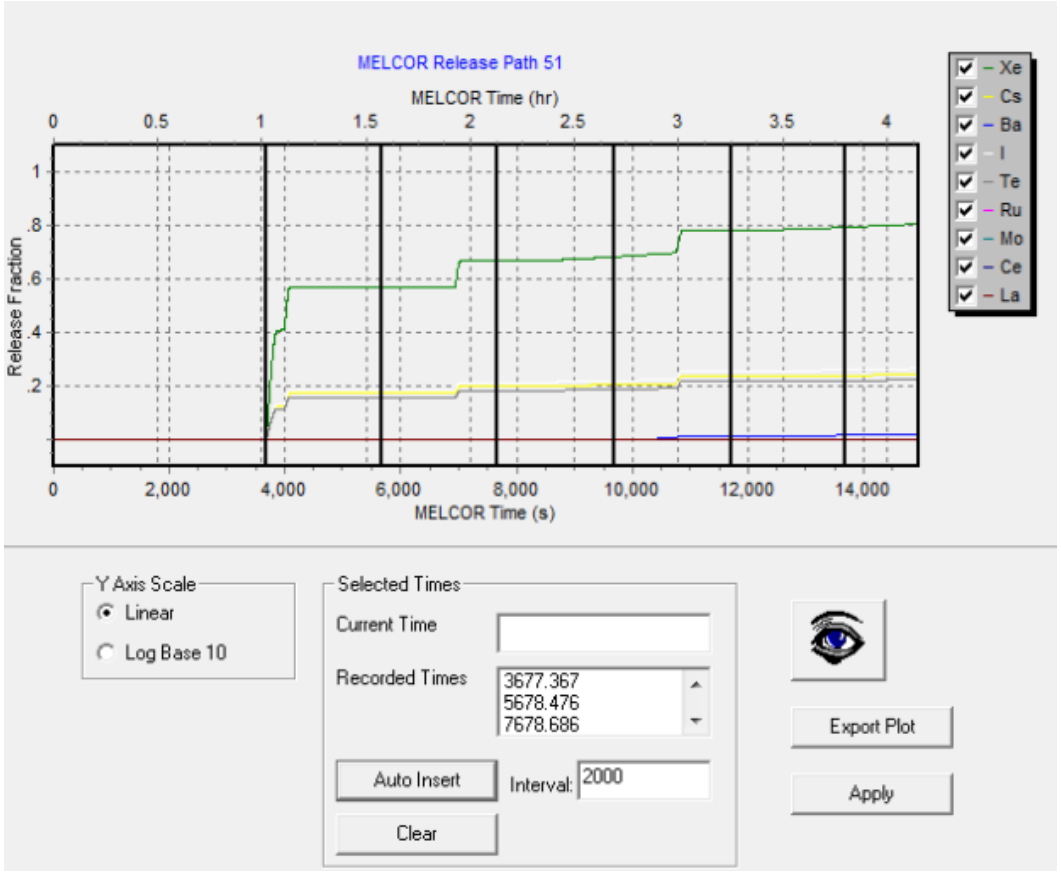
- Optional capability to perform high-fidelity atmospheric transport modeling with HYSPLIT
  - User is responsible for downloading HYSPLIT (from NOAA) and supporting tools (special request to Sandia)
  - Preprocessor steps needed prior to running WinMACCS and MACCS
  - Significantly more computing requirements than the Gaussian model
- Optional state-of-practice, GDP-based model (RDEIM) to account for economic losses (database currently supports contiguous USA)
  - Initially developed prior to 2015
  - Peer review conducted in 2015 led to significant improvements
  - Model was improved and benchmarked between 2015 and 2020
  - Benchmark report published in May 2020
  - Latest version of SecPop supports site data requirements
- Parallel processing capability for running simultaneous instances of MACCS
- Support for special files needed by animation tool, AniMACCS

Key Advanced Reactors Atmospheric Transport Issues to be Addressed

- Modeling near-field dispersion
  - May be required to estimate doses and other consequences at or just beyond the Exclusion Area Boundary (EAB), which may be very close to the reactor location
  - Examined MACCS against several near-field dispersion codes (SAND 2020-2609)
- Change in the formation of activation products
  - Isotopic inventory, if very different than that of a LWR, may need to be reevaluated to ensure that all important isotopes are included in the analysis
- Change in the chemical form of radionuclides
  - Differences in chemical form are most likely when the oxygen potential within the RCS is substantially different than that of a LWR, where steam is usually the dominant gas-phase component
  - May impact atmospheric transport and require modifications to dose coefficients for internal pathways
- Evolution of deposition behavior
  - May occur either because aerosols are hygroscopic or because some of the radionuclides are chemically reactive and change chemical form
- Cost of decontamination
  - Could be different for advanced reactors if the released isotopes and their unique chemical compositions influence decontamination methods and their effectiveness

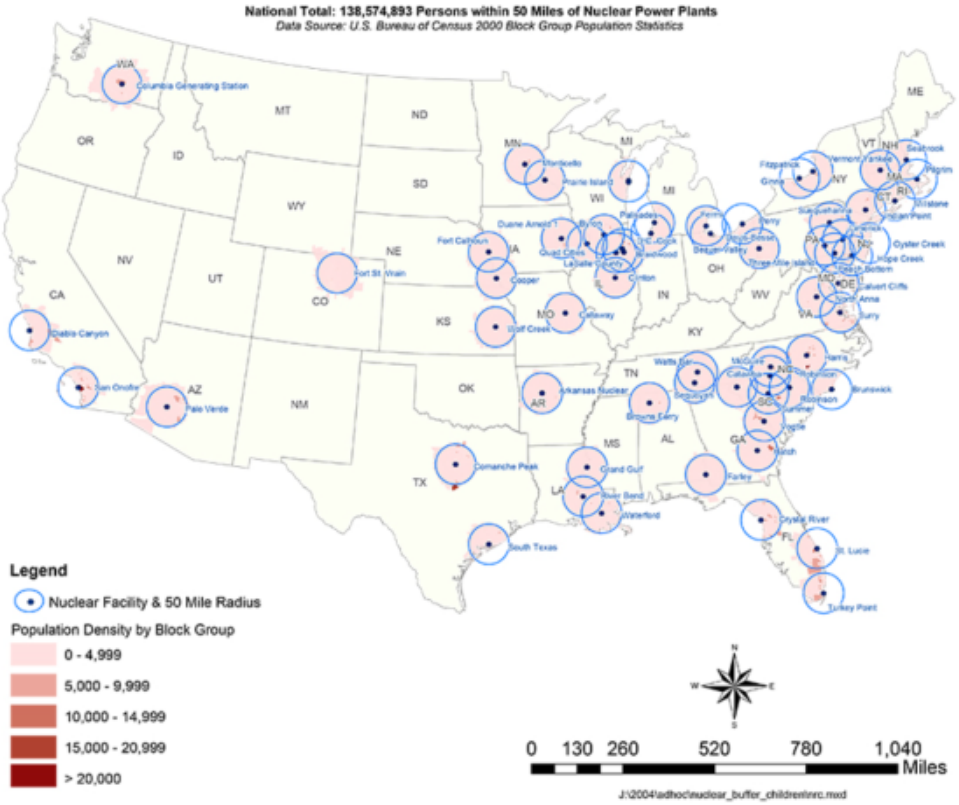
MACCS Code Suite - MelMACCS

- Provides user interface to translate data from MELCOR plot files into source term input files used by MACCS
- Facilitates partnership between MELCOR and MACCS



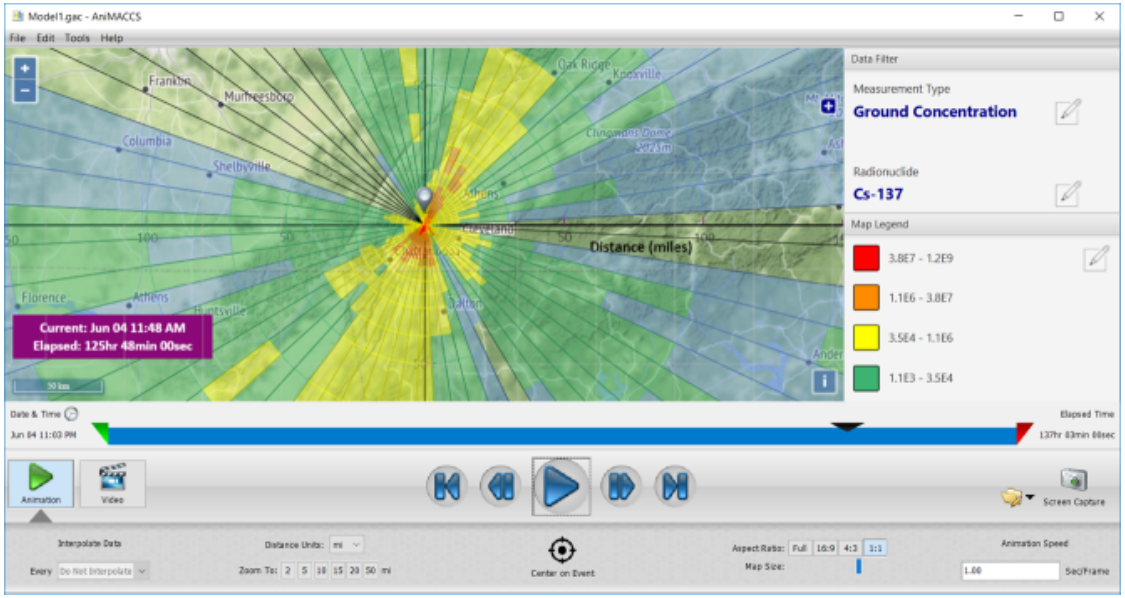
MACCS Code Suite - SecPop

- Uses census data to generate site files used by MACCS
- Calculates estimated population, land use, and economic data around any point specified by latitude and longitude within the continental United States



MACCS Code Suite - AniMACCS

- Allows MACCS single weather sequence runs to be animated
  - Movement of plume segments for Gaussian model
  - Instantaneous air concentrations (C, Bq/m^3)
  - Time-integrated air concentrations (χ, Bq-s/m^3)
  - Ground deposition (D, Bq/m^2)
- Creates both animations and snapshots



Industry	By Area	By Population
Agriculture, forestry, fishing, and hunting	X	
Mining	X	
Utilities	X	
Construction		X
Wholesale trade		X
Retail trade		X
Transportation & Warehousing	X	
Information		X
Finance & Insurance		X
Manufacturing		X
Real estate & rental leasing		X
Professional, scientific, and technical services		X
Management of companies & Enterprises	X	
Administrative & Waste management services	X	
Educational services		X
Health care & Social assistance		X
Arts, entertainment & recreation		X
Accommodations & food services		X
Other services, except government		X
Federal government		X
State & local government		X