Overview of the MACCS Code Suite, April 2024

AJ Nosek, PhD

US Nuclear Regulatory Commission

2024 European MELCOR / MACCS Users Group Meeting

Outline

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- MACCS Calculational Models
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  - Radiogenic Health Effects
- Software Components of the MACCS Code Suite
- Architecture of WinMACCS Components
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- Recent MACCS Developments

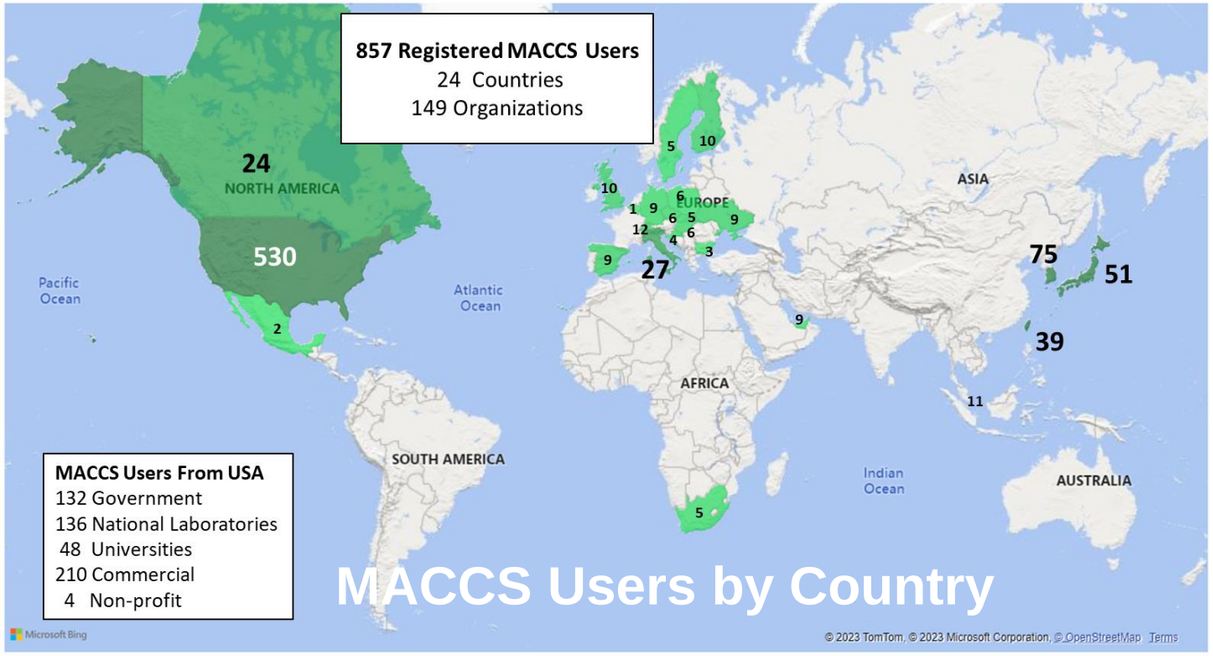
Purpose of MACCS Code

- The purpose of MACCS is to simulate and understand the public consequences of severe nuclear accidents.
- Created by Sandia to support NRC research and regulatory applications
  - Origins go back to the mid-1970s
- MACCS is typically used for prospective analyses, e.g.,
  - Probabilistic risk assessments (NUREG-1150 and NRC's Level 3 PRA)
  - Probabilistic consequence assessments (SOARCA)
  - Consequence assessments for license and license renewal of nuclear facilities (support for NEPA analyses)
  - Cost-benefit analyses (support for regulatory / backfit analyses)
  - Research projects to inform emergency preparedness
- MACCS is very versatile with a large set of user inputs
- MACCS can quickly run thousands of Monte Carlo simulations for PRA applications
  - Large set of weather trials (hundreds or thousands)
  - Significant set of source term categories (ten or twenty) plus additional sensitivity studies

MACCS Code Distribution

- MACCS belongs to the Cooperative Severe Accident Research Program (CSARP)
- MACCS support codes include:
  - WinMACCS
  - MelMACCS
  - SecPop (U.S. only)
  - MACCS-HYSPLIT Tools
  - AniMACCS
- Instructions for requesting the MACCS code and MACCS-related documents can be found at: https://maccs.sandia.gov/

NRC Cooperative Programs	Research Areas
Code Applications and Maintenance Program (CAMP)	Thermal Hydraulics
Cooperative Severe Accident Research Program (CSARP)	**Severe Accidents**
Radiation Protection Computer Code Analysis and Maintenance Program (RAMP)	Radiation Protection

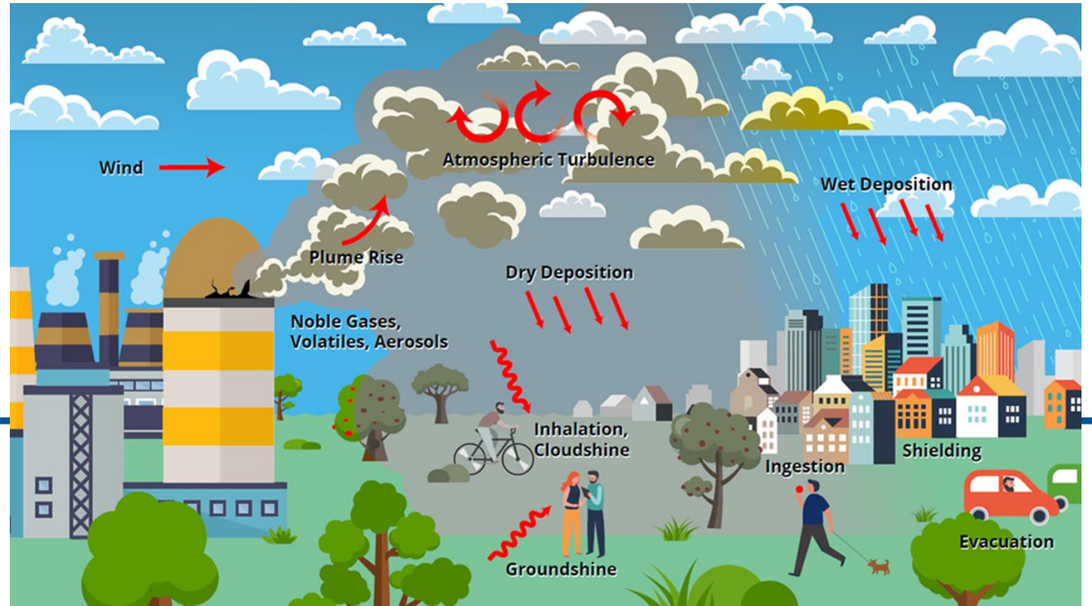


International MACCS User Group (IMUG)

- Save the Date!
  - October 21 – 25, 2025
  - U.S. NRC Headquarters
    - Rockville, Maryland, USA
- This year, IMUG will be a joint meeting with RAMP
  - The RAMP program manages a set of 21 nuclear codes with models for atmospheric, emergency response, environmental, nuclear power plant licensing, and other dose calculations.
- IMUG / RAMP 2025 to include the following:
  - Symposium topic: Code applications in the regulatory framework (tentative)
  - An in-person MACCS Workshop
  - An in-person tour of the NRC Incident Response Center (tentative)
- If you would like to join:
  - Send me your email (MACCSCodes@nrc.gov), or
  - Check our MACCS events webpage as we get closer to the date (https://maccs.sandia.gov/events.aspx)

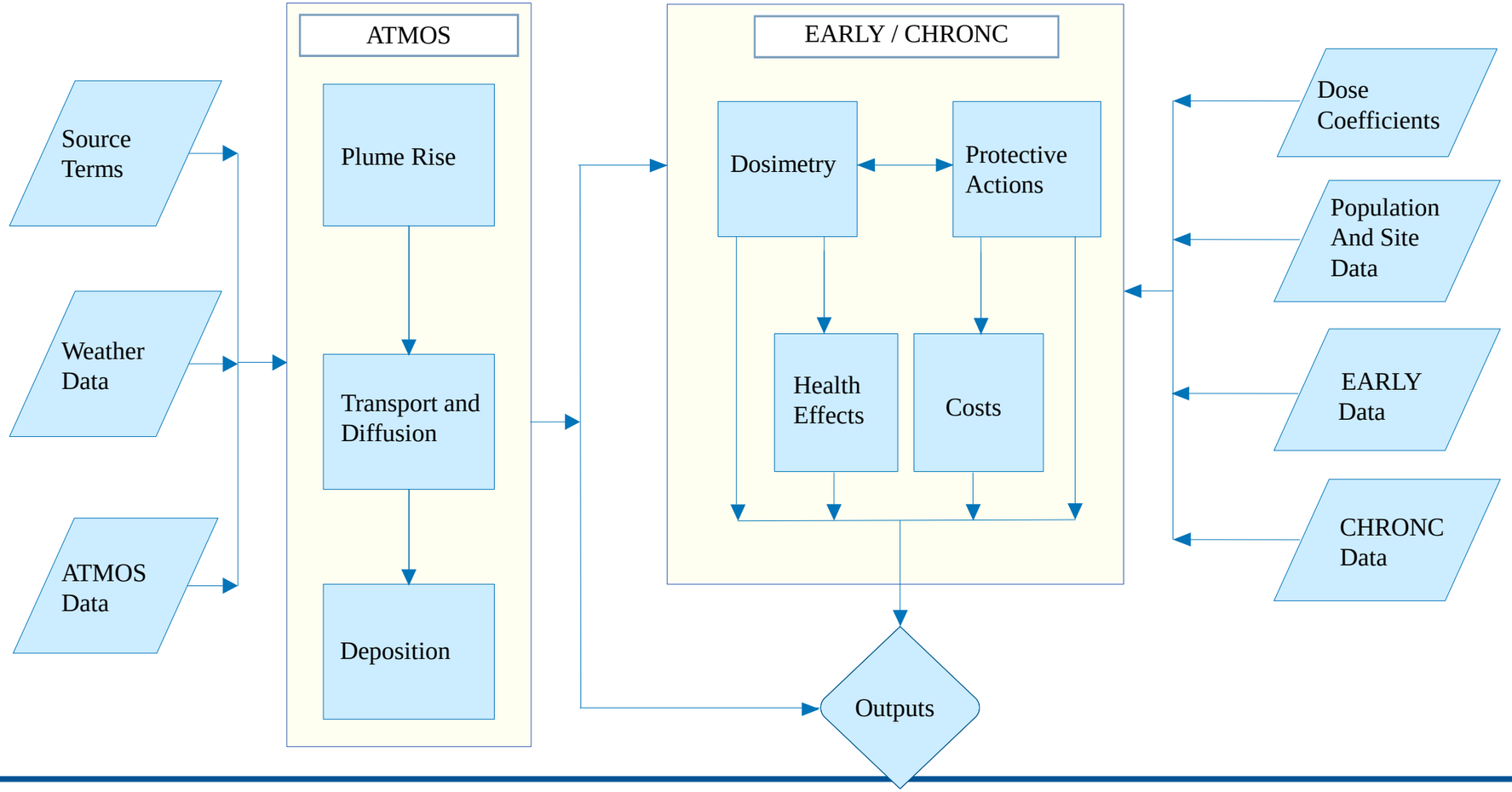
Phenomena Treated by MACCS

- Representation of source term
- Atmospheric dispersion
  - Statistical sampling of archived weather data
  - Wet and dry deposition
- Dose exposure pathways
  - Inhalation
  - Cloudshine
  - Groundshine
  - Resuspension
  - Ingestion
  - Skin deposition



- Emergency response
  - Sheltering
  - Evacuation
  - Potassium iodide (KI) ingestion
  - Relocation
- Long-term protective 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
  - Property value for permanent interdiction
- Radiogenic health effects
  - Early health effects
  - Cancer incidence / fatalities

Progression of a MACCS Calculation



MACCS Code Modules

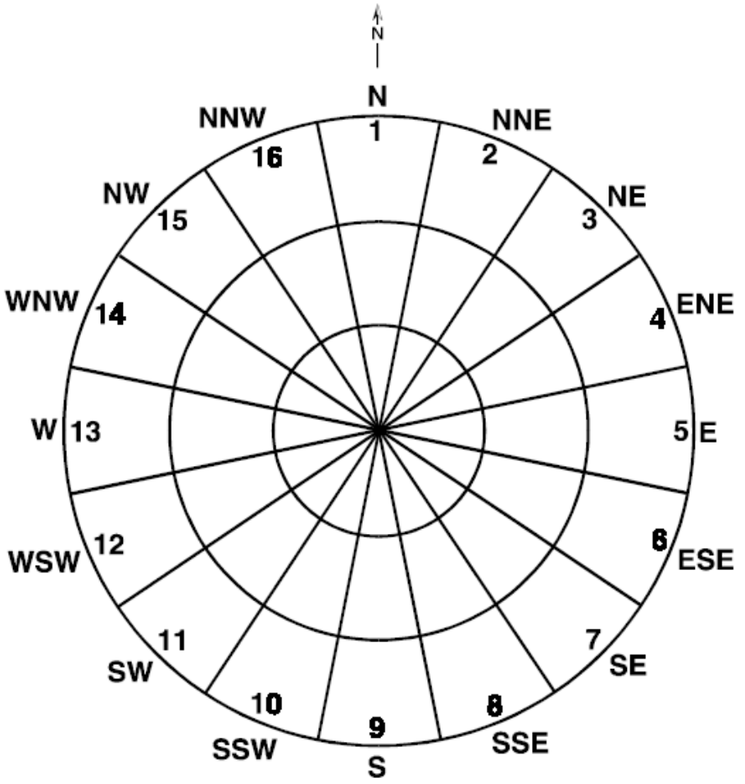
- ATMOS
  - Estimates transient air and ground concentrations
  - Option for Gaussian Plume Segment or Lagrangian Particle models
- EARLY
  - Treats emergency phase (up to 40 days, usually one week)
  - Estimates projected doses from plume passage and ground contamination
  - Models cohort-specific emergency response actions
  - Estimates accumulated doses and health effects to cohorts
- CHRONC
  - Treats intermediate phase (up to 30 years, usually zero or one year)
  - Treats long-term phase (up to 300 years, usually 50 years)
  - Estimates projected doses from ground contamination
  - Models long-term protective actions (i.e., relocation / property interdiction, food interdiction, decontamination, and condemnation)
  - Estimates accumulated doses and health effects
  - Estimates economic losses, land contamination, displaced individuals, and other societal impacts.

MACCS Outputs

Output Name	ATMOS	EARLY	CHRONC
Type 0: Atmospheric Results for Specified Downwind Distances	X		
Type 1: Health Effect Cases		X	X
Type 2: Early Fatality Distance		X	
Type 3: Population Exceeding Early Dose Threshold		X	
Type 4: Average Individual Risk		X	X
Type 5: Population Dose		X	X
Type 6: Centerline Dose		X	X
Type 7: Centerline Risk		X	X
Type 8: Population-Weighted Individual Risk		X	X
Type A: Peak Dose for Specified Distances		X	X
Type B: Peak Dose for Specified Spatial Elements		X	X
Type C: Land Area Exceeding Dose		X	
Type D: Land Area Exceeding Concentration		X	
Type E: Population Movement Across Radius		X	
Type 9: Breakdown of Long-term Population Dose			X
Type 10: Economic Cost Measures			X
Type 11: Maximum Distance for Protective Actions			X
Type 12: Impacted Area / Population			X
Type 13: Maximum Annual Food Ingestion Dose			X
Type 14: Evacuated and Relocated Population			X

MACCS Spatial Grid

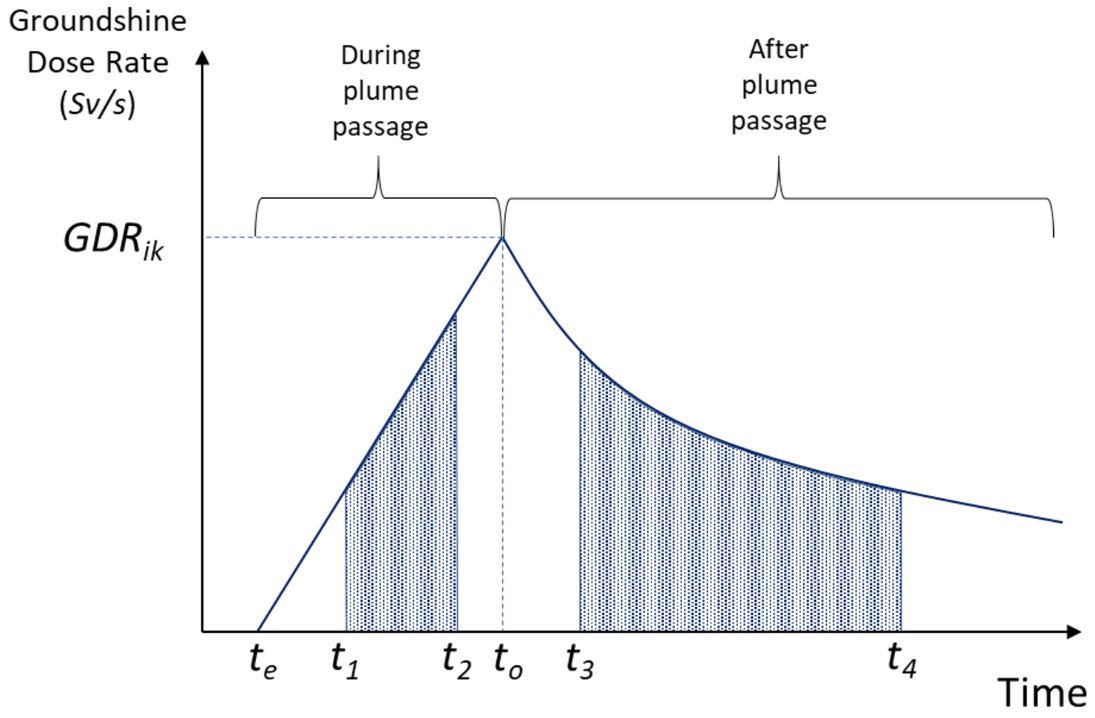
- Calculations are performed on a radial polar grid
- The user specifies the number of compass sectors and radial intervals, and the outer distance of each radial interval
- MACCS calculates results for each spatial element

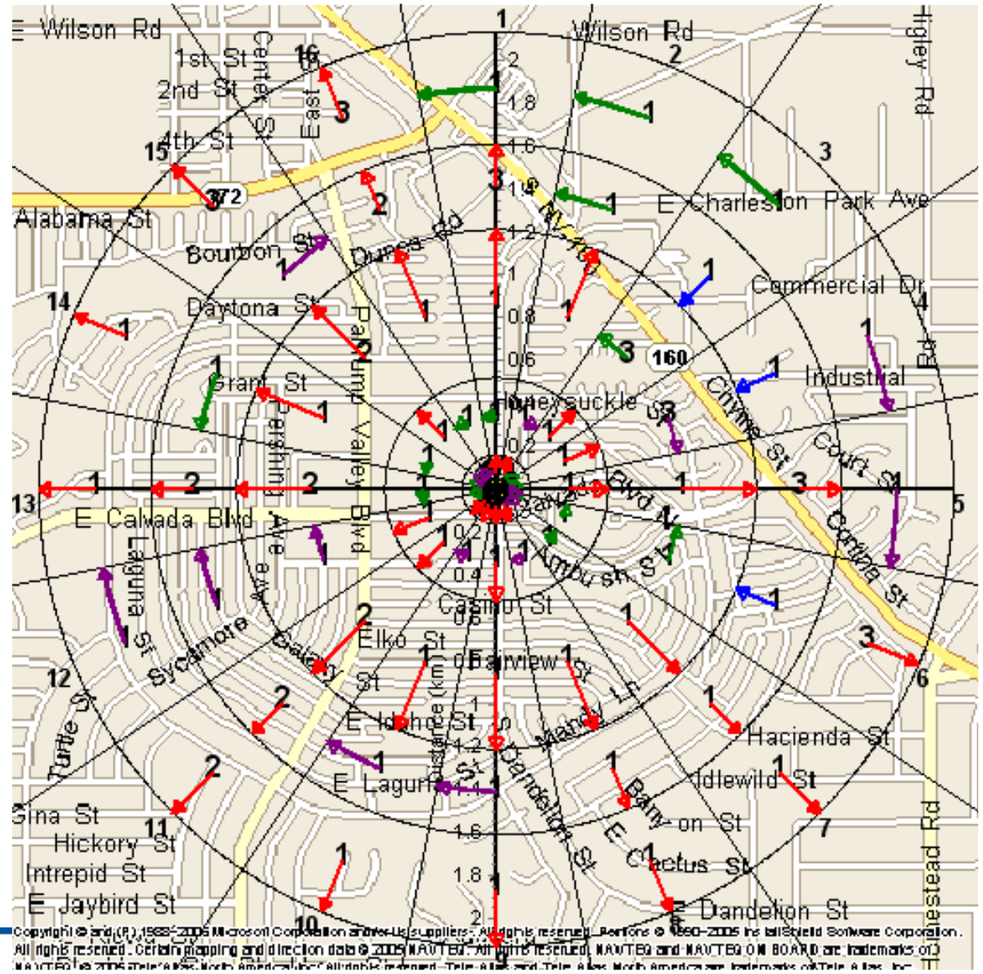


Example of MACCS polar coordinate grid with 16 sectors and 3 radial divisions.
(reproduced from Fig. 2-1 of NUREG/CR-6613 Vol. 1

MACCS Time-Dependent Calculations

- The timing of protective actions affects consequences
- Example: Figure below shows groundshine dose accumulation during the emergency phase

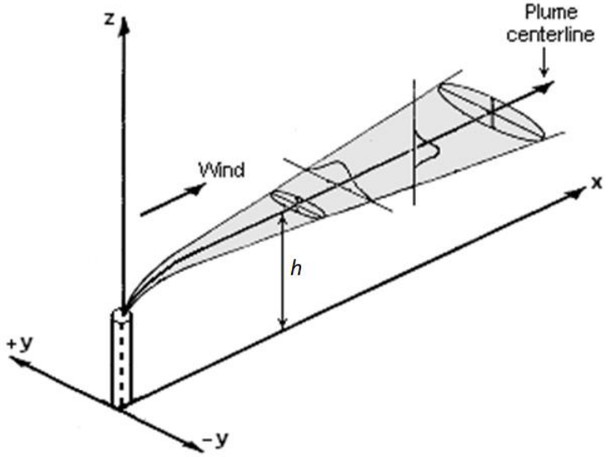




Network evacuation scheme

Atmospheric Dispersion

- Gaussian approach:
  - Gaussian plume equations with dispersion parameters
  - Plume nearfield effects (building wake and meander)
  - Boundary layer constraint
  - Wet and dry deposition
  - Off-centerline correction factors
- MACCS / HYSPLIT approach:
  - HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) is a code for computing complex dispersion and deposition simulations
  - HYSPLIT is executed independently of MACCS
  - HyGridConvert is used to convert air and ground concentrations from HYSPLIT to MACCS spatial grid
- Factors common to both:
  - Weather sampling routine
  - Plume rise height calculation
  - Radioactive decay and ingrowth



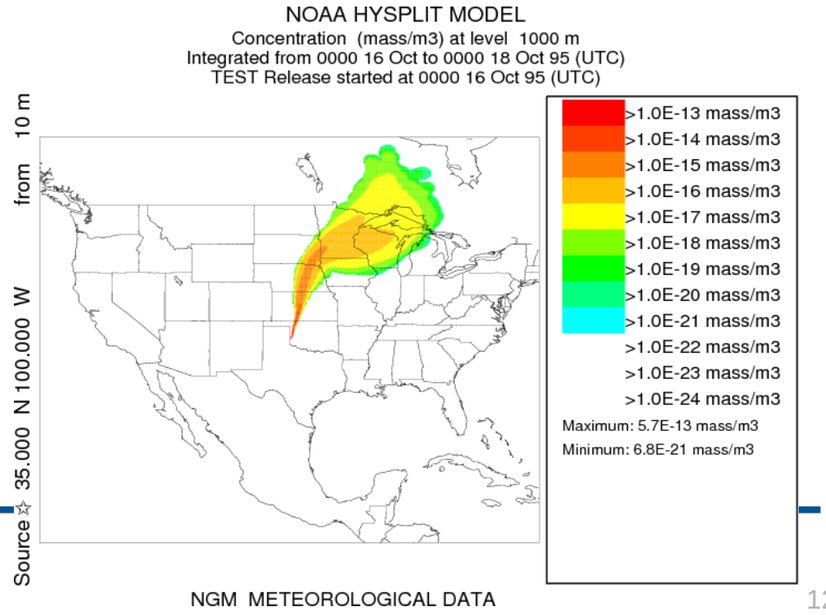
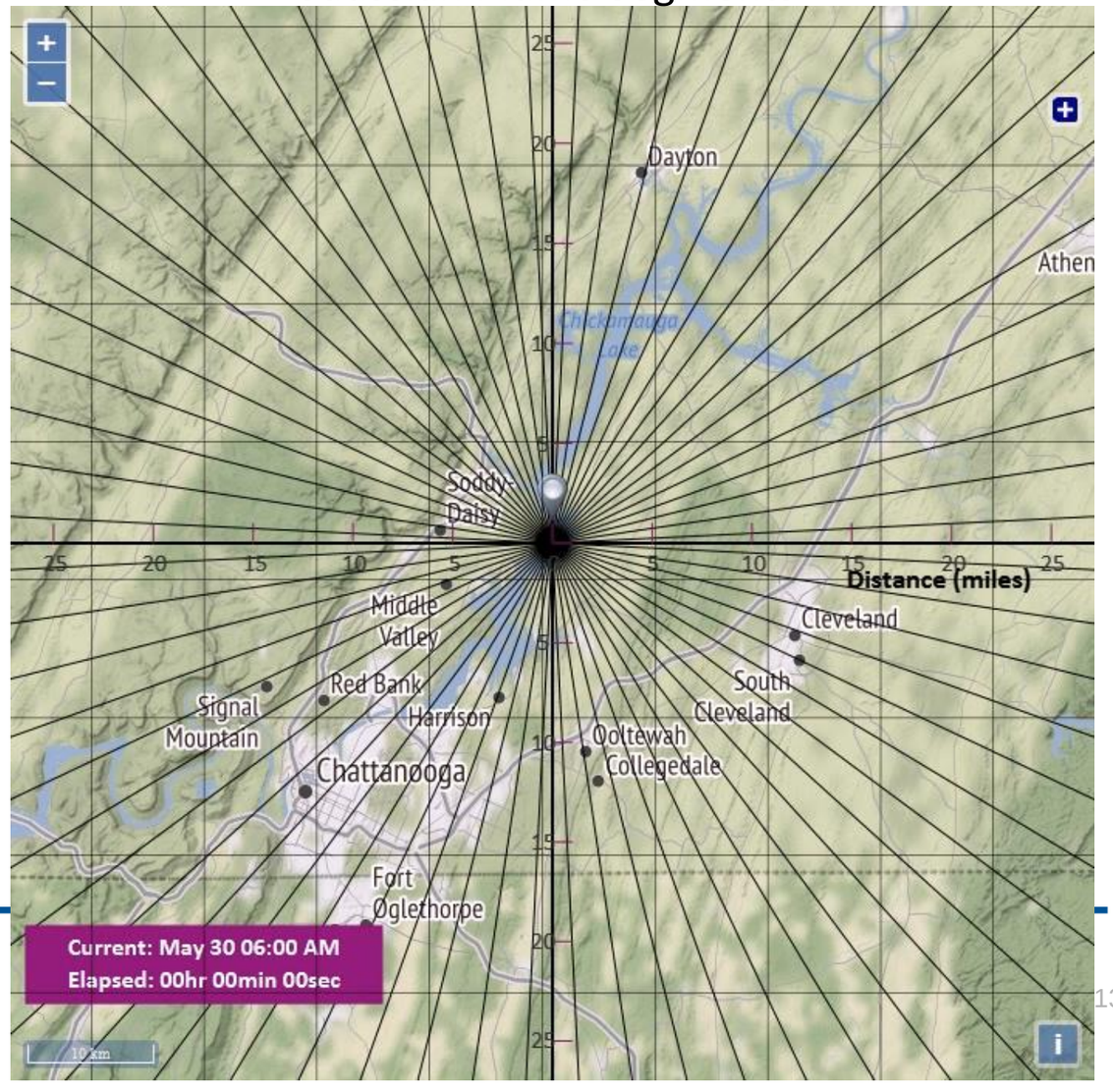


Figure from HYSPLIT User's Guide (2022, p. 110)

Atmospheric Dispersion: Gaussian Transport Model

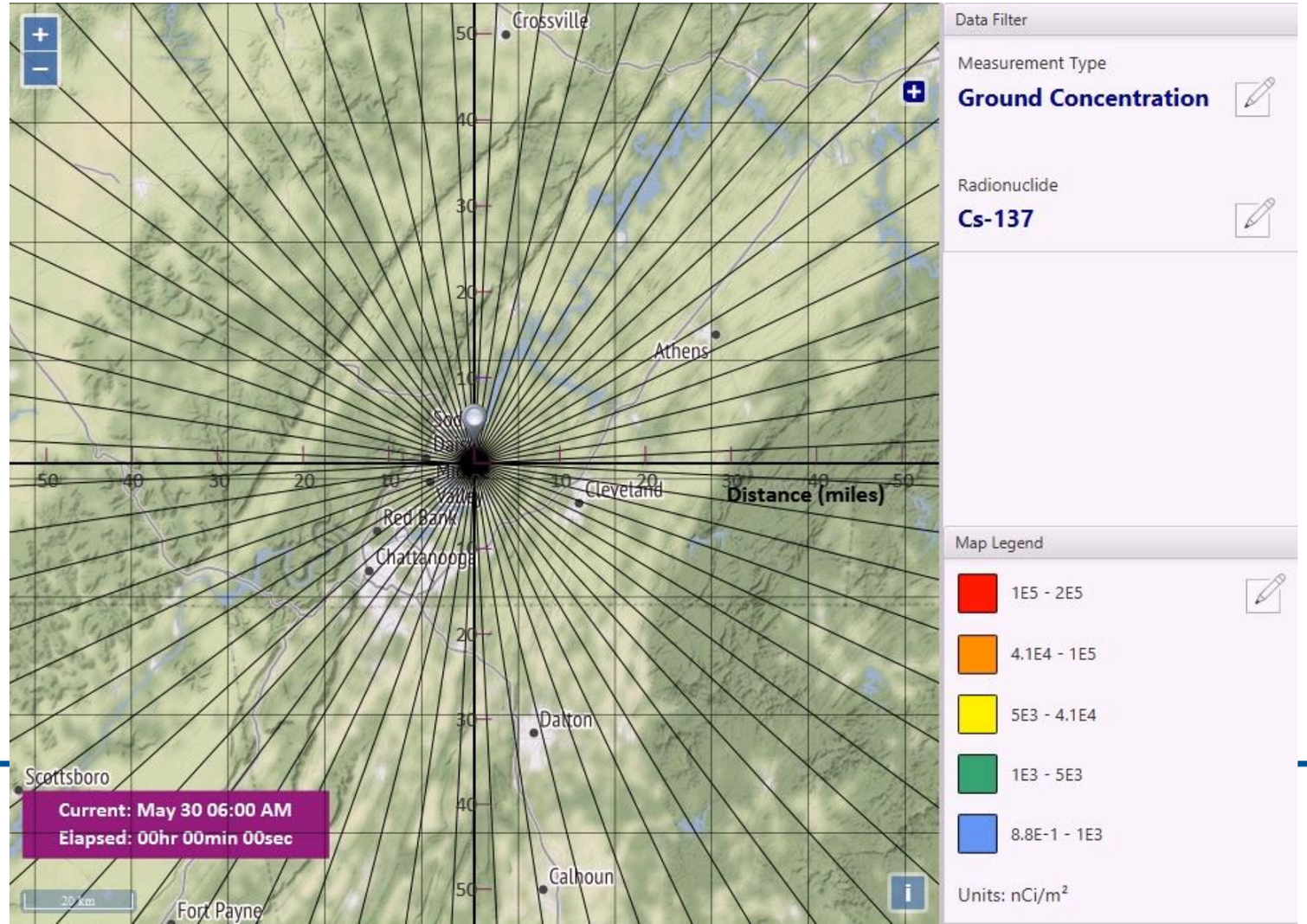
- The plume segment direction is based on observed wind direction at time of release.
- After release, plume segments do not change direction.
- After release, plume segment dispersion changes with observed changes in weather
  - Plume speed changes with windspeed
  - Plume diffusion rate changes with stability class
  - Wet deposition rate changes with rain rate

Gaussian Plume Segments



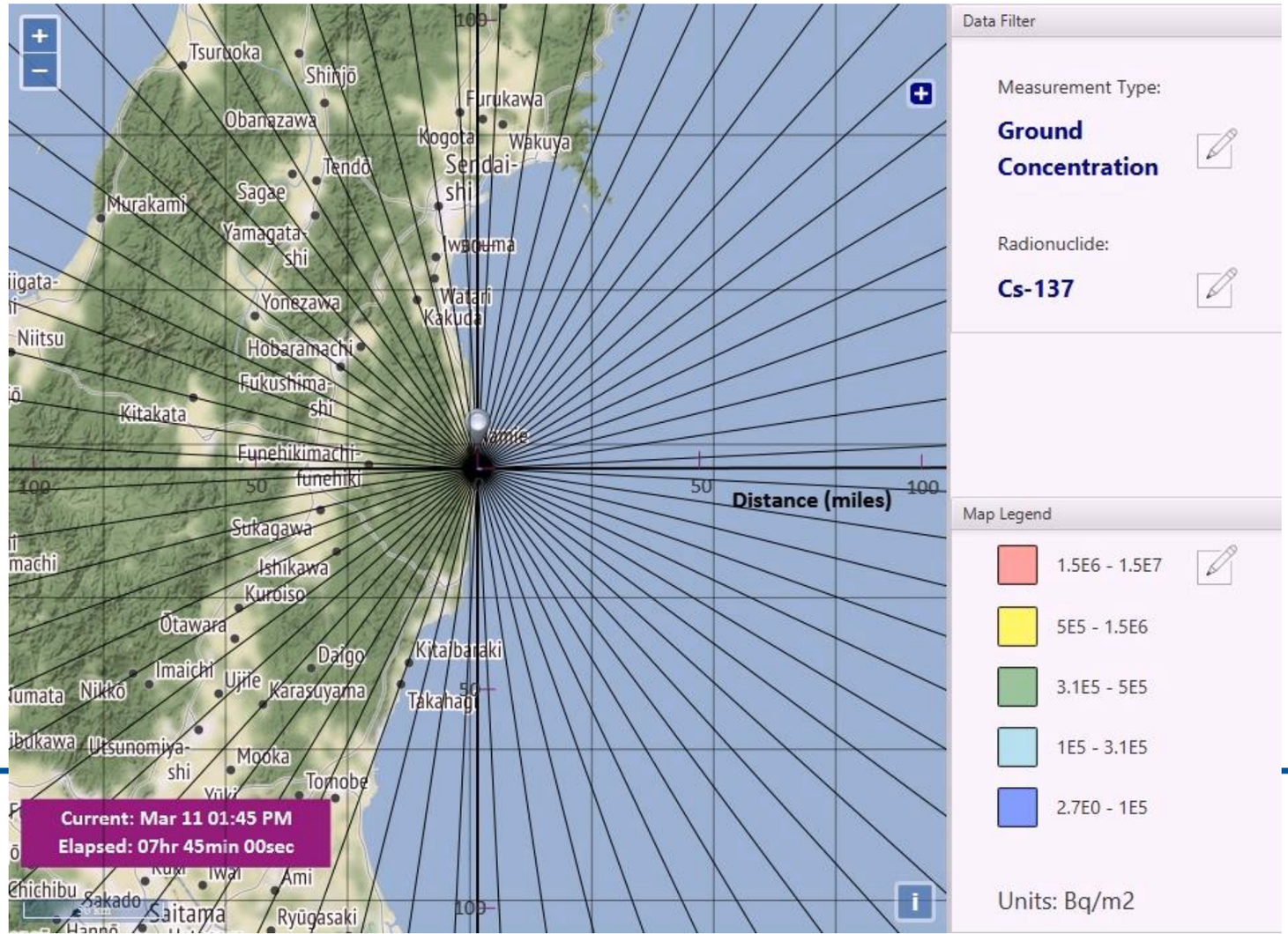
Atmospheric Dispersion: Gaussian Transport Model

Ground Deposition



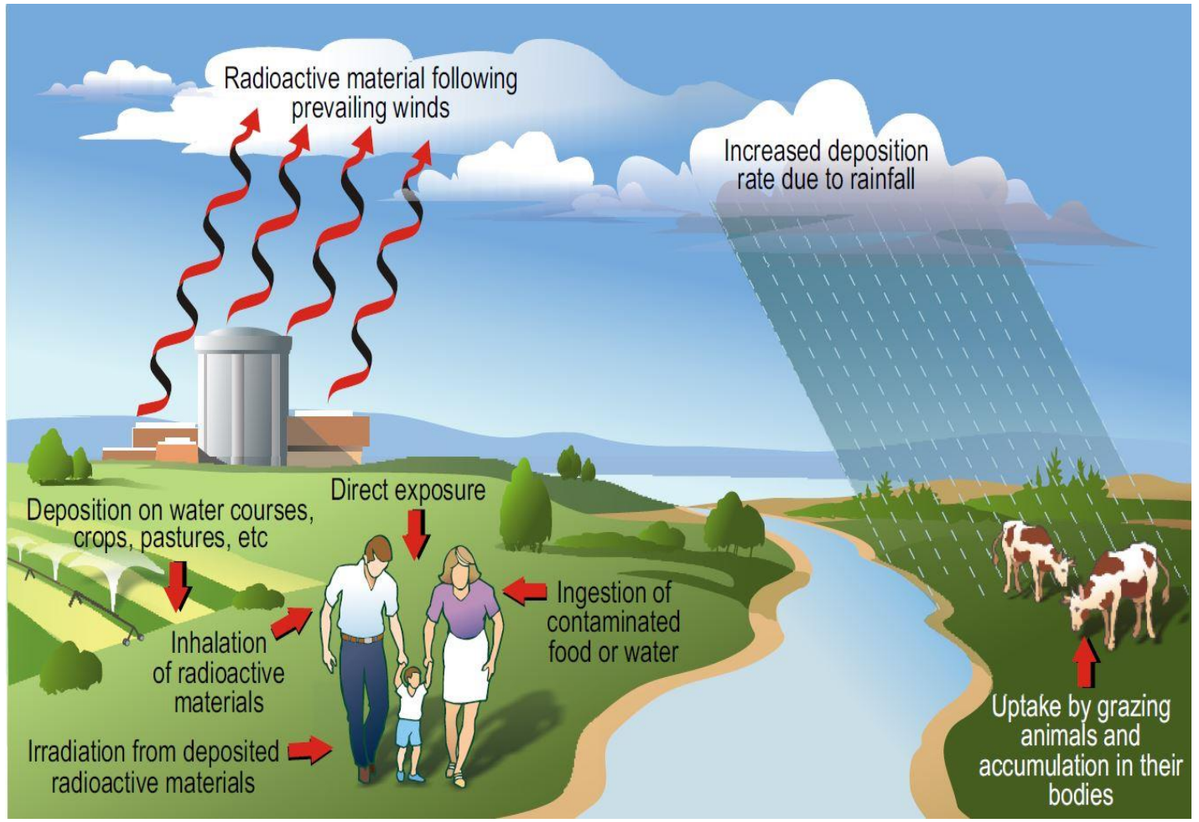
Atmospheric Dispersion: MACCS / HYSPLIT Model

Ground Deposition



Dosimetry: Exposure Pathways

- Early Doses
  - Cloudshine
  - Groundshine
  - Direct inhalation
  - Resuspension inhalation
  - Skin deposition
- Late Doses
  - Groundshine
  - Resuspension inhalation
  - Food ingestion
  - Water ingestion



Dosimetry: Dose Coefficients

- The dose models use dose coefficients to convert from time-integrated air concentrations or ground concentrations to dose.
- External pathways use a dose rate coefficient (e.g., *Sv/s per Bq/m^2*)
- Internal pathways (inhalation and ingestion) use an intake-to-dose coefficient (*Sv/Bq*)
- Separate internal dose coefficients are provided for acute, lifetime, and annual doses

Dosimetry:
Types of Calculated Doses

- Acute dose
  - The portion of the dose that contributes to early health effects (i.e., accounts for the sparing effect)
  - Includes only early-phase contributions to dose
  - Uses a weighting factor (<1.0) to account for reduced risk associated with protracted internal doses from inhalation
- Lifetime dose
  - The dose that contributes to stochastic health effects (e.g., cancer)
  - Includes both early-phase and late-phase contributions to dose
- Annual dose
  - The same as the lifetime dose, except annual doses are discretized into annual periods
  - Includes both early-phase and late-phase contributions to dose

Protective Actions

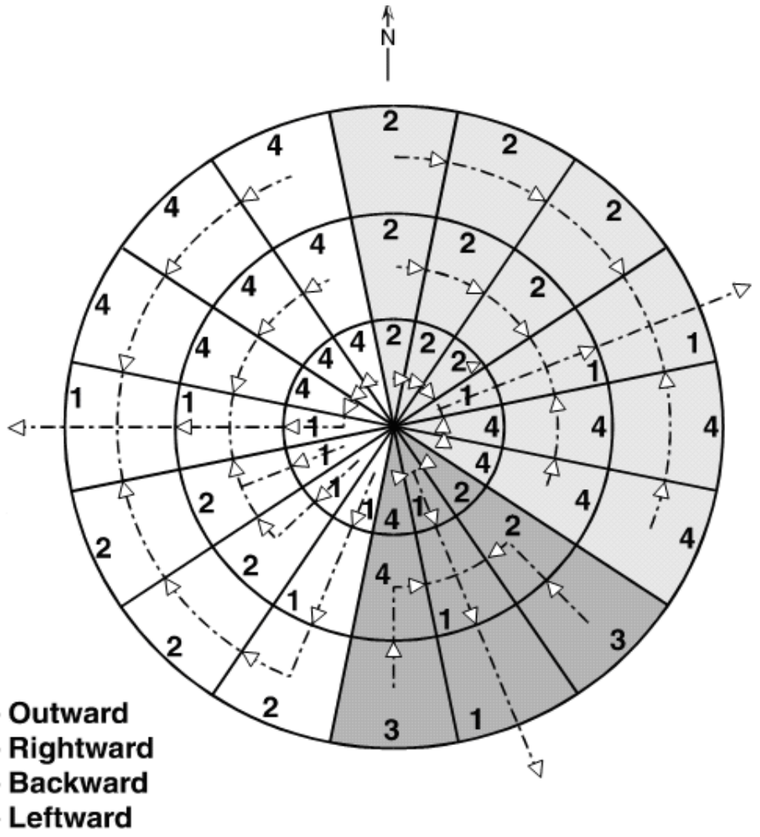
- Protective actions reduce radiation exposures.
- Protective actions are a tradeoff: They reduce radiogenic health effects but at a cost of other types of societal and economic impacts.
- Many protective actions are dose-dependent
  - If a projected dose exceeds a dose criterion during a specified exposure period, it triggers a protective action.

Protective Actions

- Early phase
  - Evacuation and sheltering model
  - Early relocation
  - Potassium iodide ingestion
- Intermediate phase
  - Intermediate-phase relocation
- Long-term phase
  - Decontamination
  - Non-farm areas: temporary and permanent relocation
  - Farm areas: farming restrictions

Protective Actions: Evacuation Transit and Routing

- Two evacuation routing options
  - Radial evacuation: Evacuees travel radially outward
  - Network evacuation: Evacuees travel along user-specified grid
- During transit, MACCS models evacuees as moving from spatial grid midpoint to midpoint in a stepwise fashion until they reach the travel boundary



Network evacuation direction with corresponding IDIREC values on a spatial grid.

Protective Actions: Population Cohorts

- User can divide the regional population into population cohorts that have similar characteristics during an emergency response
  - Cohorts can have different protection factors, breathing rates, evacuation timelines, evacuation regions, and other factors.
  - In the intermediate and long-term phases, MACCS treats all survivors as a single population cohort.
- For each cohort, MACCS runs a separate simulation
- Many outputs report both summary results from all cohorts and cohort-specific results

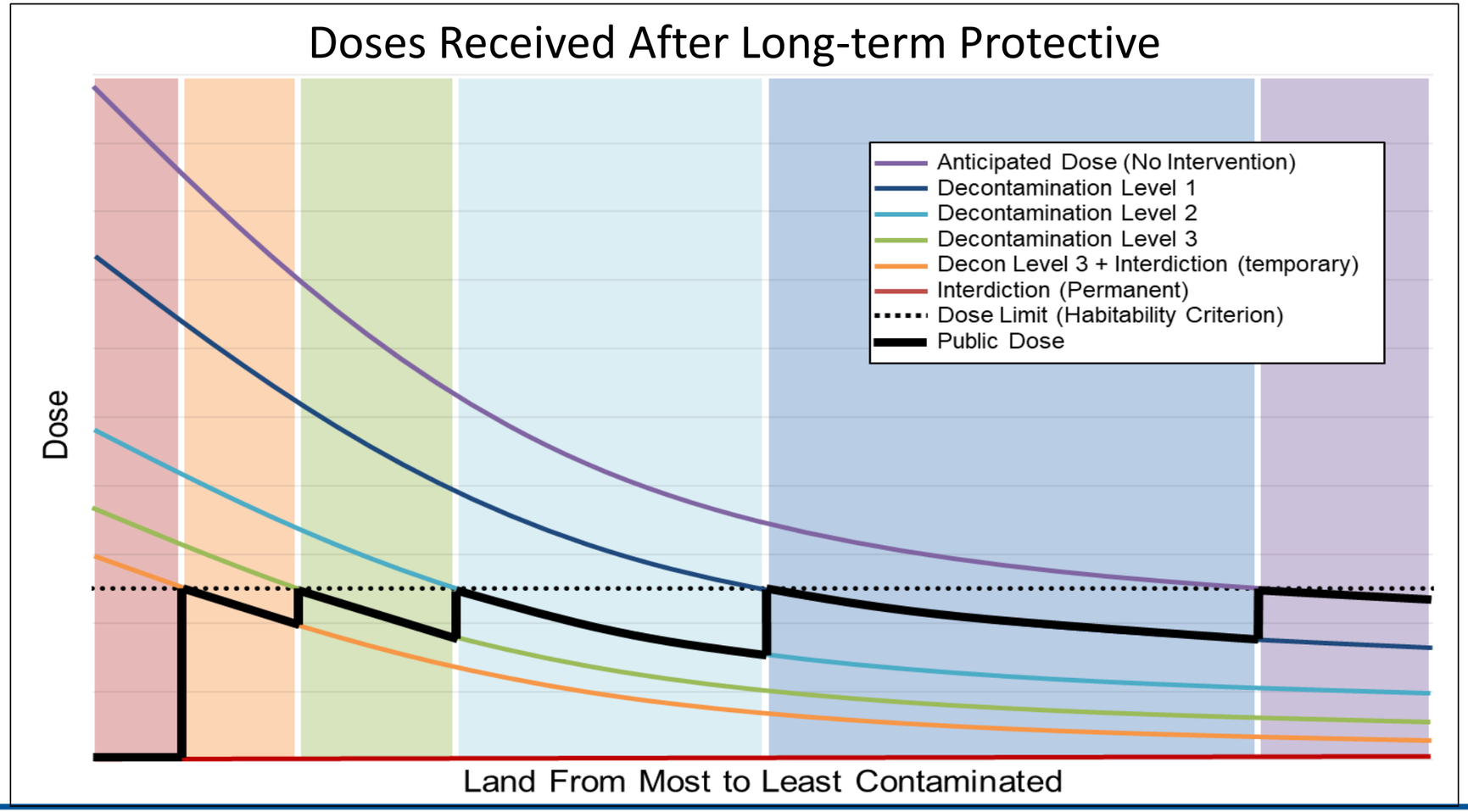
Protective Actions: Early Relocation

- Early relocation is a dose-dependent response that occurs outside the evacuation and sheltering boundary.
- The projected relocation dose can be based on either the “TOTAL” or “AVOID” option. (New in MACCS v4.2)
  - "TOTAL" evaluates the total dose from all air and ground concentrations and
  - "AVOID" evaluates the avoidable dose from ground pathways.
  - These new options are intended to mirror how decision-makers would evaluate doses during a radiological emergency using Turbo-FRMAC.
- Early relocation has two areas, hotspot and normal relocation, and can have separate relocation times and dose criteria.
- Once relocation occurs, displaced individuals receive no dose for the remainder of the early phase.

Protective Actions: Long-term Phase

- Land divided into farm and non-farm areas
- Non-farm areas:
  - Relocation occurs when projected dose exceeds any relocation criteria. (New in MACCS v4.2)
  - Return / reoccupation occurs when decontamination is complete (if applicable).
  - Condemnation occurs when decontamination is not feasible or cost effective.
- Farm areas:
  - Farming restrictions occur in farm areas when food ingestion doses exceed farmability criteria. (The farmability criteria depend on which food chain model the user selects.)
  - Farming restrictions also occur when farmland exceeds relocation criteria, as MACCS assumes farmland is otherwise not farmable.
- Decontamination:
  - Decontamination occurs when projected dose exceeds relocation criteria (both farm and non-farm areas), but only when it can restore the area and is cost effective.
  - A dose-dependent cleanup criterion allows users to model the acceptable cleanup level of contaminated areas. This allows users to model decontamination in lightly contaminated, habitable areas (non-farm area only). (New in MACCS v4.2)

Protective Actions: Long-term Non-farm Areas



Social And Economic Impacts

- Nuclear accident impacts can broadly be divided into two categories: market and non-market
- Market impacts (sometimes called “financial impacts” or “special damages”) include:
  - Onsite and offsite property damage
  - Economic disruptions
  - Accident-related expenditures
- Non-market impacts (sometimes called “noneconomic impacts” or “general damages”) include:
  - Health effects
  - Societal disruptions
  - Environmental damage

Social And Economic Impacts

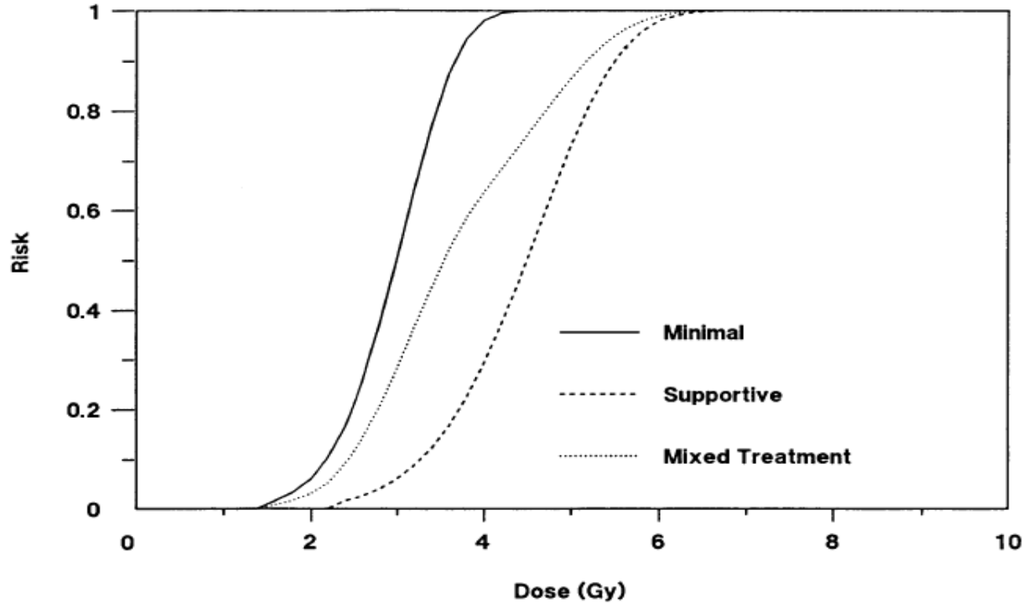
- Evacuation and early phase relocation costs
- Intermediate phase relocation costs
- Long-term costs in non-farm areas (*$/capita*) and farm areas (*$/farm hectare*)
  - Milk and crop disposal (farm areas only)
  - One-time relocation (non-farm areas only)
  - Decontamination
  - Property depreciation
  - Lost income
- Two methods to calculate lost income
  - “Loss of use” approach treats property as an investment based on a rate of return.
  - “GDP-based” approach using the Regional Disruption Economic Impact Model (RDEIM) input-output model to calculate direct, indirect, and induced losses; and recovery gains.
- Cost models do not consider
  - Onsite damages or disruptions
  - Property losses due to housing market impacts
  - Certain expenditures (e.g., removal of condemned structures, cost of litigation and a compensation system, medical expenses)
  - Economic disruptions due to stigma effects (e.g., tourism, trade)
  - Non-market impacts

Radiogenic Health Effects

- Health effects from ionizing radiation are broadly categorized into two main categories:
  - Stochastic effects, which include:
    - Cancer incidence / fatality
    - Heritable effects
  - Tissue reactions (i.e., deterministic effects), which include:
    - Early injury / fatality
    - Degenerative conditions (i.e., cataracts, cardiovascular disease, and cerebrovascular disease).
- MACCS analyses typically model cancer and early health effects.

Radiogenic Health Effects: Early Health Effects

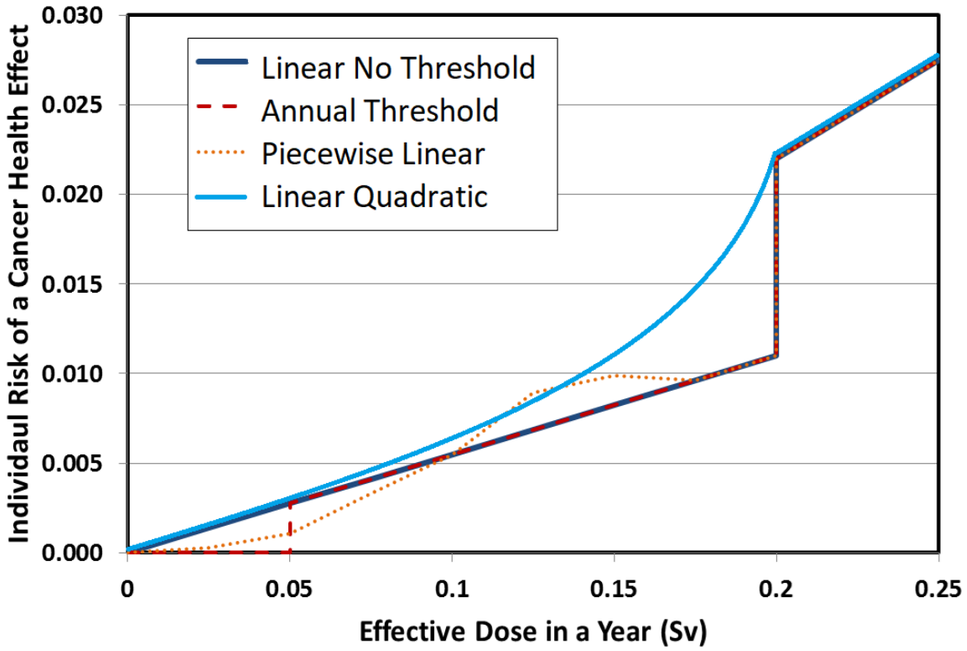
- MACCS estimates risk of early health effects (injury or fatality) using a dose response model based on a Weibull distribution.
- The early health effect estimates use acute doses, which account for the sparing effect.
- Early fatalities are estimated using a “pooled” risk model (i.e., the early fatality hazards are summed together)



Hematopoietic Syndrome Mortality Risks for Minimal Treatment, Supportive Treatment, and Mixed Treatment - Central Estimates for Exposure at High Dose Rate.
(reproduced from Figure 3.1 of Evans 1989)

Radiogenic Health Effects: Cancer Incidence / Fatality

- Four dose-response models are available in MACCS to calculate cancer incidence and fatalities:
  - Linear, no threshold (LNT) with a dose and dose rate effectiveness factor (DDREF)
  - Linear quadratic
  - Annual threshold
  - Piecewise linear
- The linear no-threshold and the linear-quadratic models use lifetime doses.
- The annual-threshold and piecewise-linear models use annual doses that exceed specified thresholds.



Software Components of the MACCS Code Suite

- MACCS:
  - The main code of the MACCS code suite. MACCS assesses the public consequences associated with a hypothetical release of radioactive materials to the atmosphere, such as from a nuclear power plant accident.
  - MACCS simulates the atmospheric dispersion, dosimetry, protective actions, health effects, and costs of a release.
  - Current version is v4.2 (March 2023)
- WinMACCS:
  - The current graphical user interface for MACCS.
  - Current version is v4.2 (March 2023)
- MACCS-UI:
  - A new graphical user interface that will replace WinMACCS.
  - Planned release in 2024.

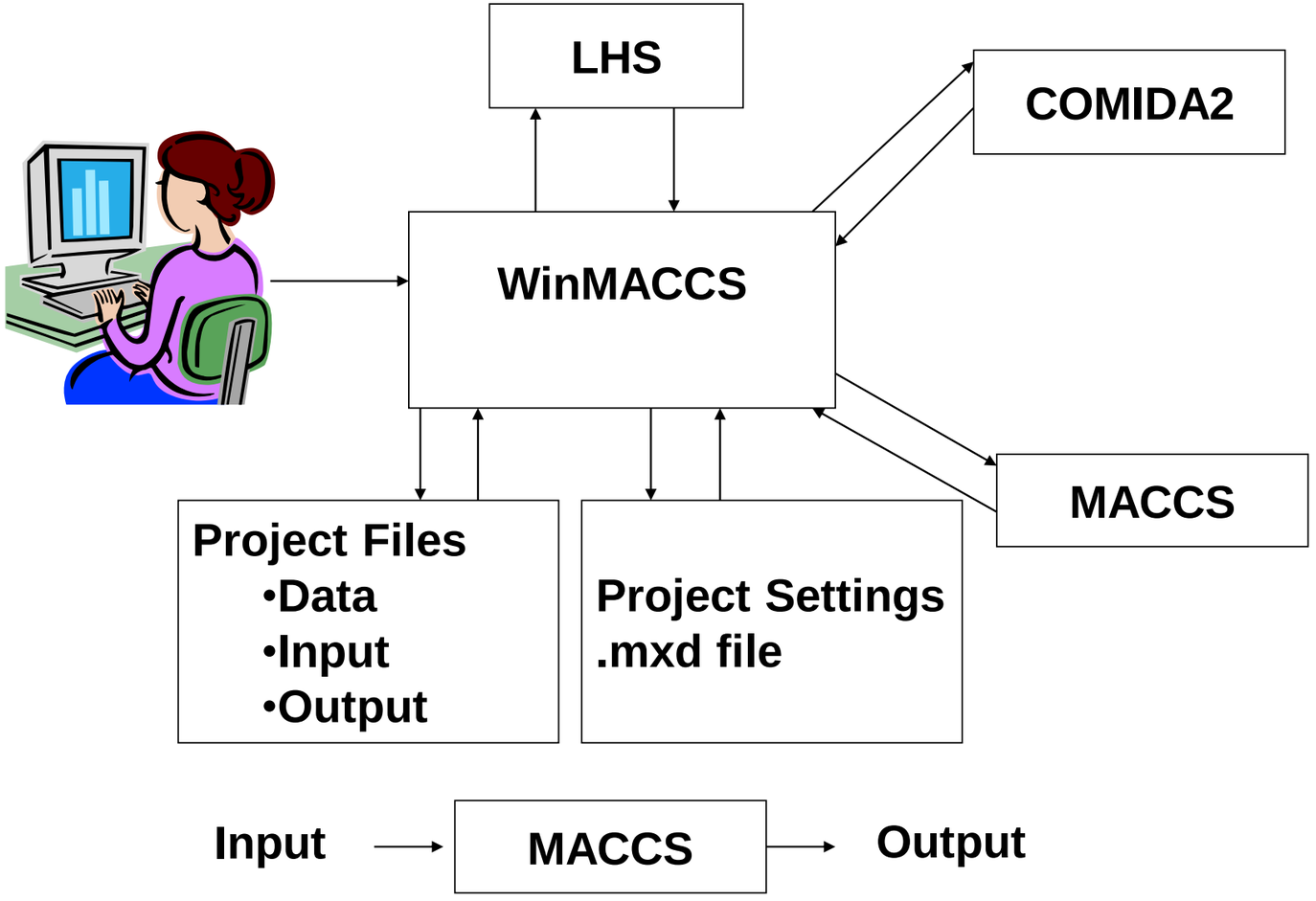
Software Components of the MACCS Code Suite (continued)

- MelMACCS:
  - An optional pre-processing code that reads a MELCOR output file and creates a MACCS input file that defines the atmospheric release (e.g., core inventory, release fractions, aerosol sizes, plume segment definitions).
  - Current version is v4.0 (September 2022)
- AniMACCS:
  - An optional post-processing code that allows for certain MACCS output information to be visually displayed and animated onto a geospatial map background
  - Current version is v1.3.1 (January 2022)
- MACCS-HYSPLIT Tools:
  - An optional set of tools to generate a meteorological input file and / or to use the HYSPLIT atmospheric dispersion code (available from the US National Oceanic and Atmospheric Administration [NOAA]) in place of the original MACCS straight-line gaussian plume model.
  - MacMetGen reads NOAA meteorological datasets to generate MACCS meteorological files.
  - GenHysplit calls on HYSPLIT to generate a set of output files of air and ground concentrations.
  - HyGridConvert converts the HYSPLIT air and ground concentrations into MACCS input files.
  - Current version of MACCS-HYSPLIT Tools is v1.2 (March 2023).

Software Components of the MACCS Code Suite (continued)

- COMIDA2:
  - An optional pre-preprocessing code that helps calculate anticipated food ingestion doses from farmland contamination via the food chain.
- LHS:
  - An optional pre-processing code to help model uncertain input parameters by running Monte Carlo simulations of MACCS.
- SecPop (US only):
  - An optional pre-processing code that creates a site file using US Census information.
  - Current version is v4.3.1 (July 2020)
  - Planning to update with new US census data in 2024
- RDEIM (US only):
  - An alternative economic consequence model that estimates the impact of a business disruption on the US gross domestic product considering interdependencies of US regional industries.

Architecture of WinMACCS Components



Auxiliary and Supporting Files

- Dose coefficient (DCF) files for LNT and non-LNT applications
  - FGR-13 (based on FGR-13 using standard radiation weighting factors)
  - FGR-13 Gray Equivalent (Rev. A) (based on FGR-13 using relative biological effectiveness (RBE) factors consistent with FGR-13 cancer induction modeling and with all SOARCA analyses)
  - Updated versions accompany MACCS 4.2
- COMIDA2 files to go with each type of dose coefficient file
  - Exposure duration (LASTACUM) set to 50 years
- NRC and DOE sample problems
- Tutorials based on NRC sample problems
- Fogbugz used for problem reporting and corrective actions – https://ersdt.fogbugz.com/

Recent MACCS Developments

- MACCS 4.0 was released in June 2020
  - HYSPLIT capability added
  - RDEIM economic model added
  - AniMACCS capability added
  - License keys now required (node-locked and time-limited)
- MACCS 4.1 was released in July 2021
  - Nearfield model updates
    - New plume meander models added
    - New plume entrainment model added
    - New building wake model added
- MelMACCS 4.0 was released September 2022
- MACCS 4.2 was released March 2023
  - Removal of node locking from license keys (still time-limited)
  - RDIEM economic model updates
  - Updates to dose-dependent protective actions
    - Early phase calculations for avoidable and total dose added
    - Long-term phase cleanup criterion added (allows for decontamination in habitable areas)
    - Long-term phase dual dose criteria added
  - Increase in maximum number of radionuclides
  - Skin pathway standardization
- MACCS modernization underway!

Any Questions?

- Instructions for requesting the MACCS code and MACCS-related documents can be found at: https://maccs.sandia.gov/
- Supporting documents
  - WinMACCS & MACCS User Guides
    - MACCS User's Guide and Reference Manual Report (SAND2023-01315)
    - MACCS Theory Manual (SAND2021-11535)
  - Technical Bases for Consequence Analyses Using MACCS (NUREG/CR-7270)
  - MACCS-HYSPLIT Tools documentation
  - Benchmark, verification and validation reports
  - Complete set of published SOARCA reports

References

- CRAC / MACCS Research Projects:
  - WASH-1400, NUREG-75/014, “An Assessment of Accident Risks in U. S. Commercial Nuclear Power plants,” U.S. Nuclear Regulatory Commission, Washington, DC, 1975.
  - NUREG/CR-2239, “Technical Guidance for Siting Criteria Development,” U.S. Nuclear Regulatory Commission, Washington, DC, December 1981.
  - NUREG-1150, Vol. 1, “Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC, 1990.
  - NUREG/CR-7110, Vol. 1, Rev. 1, “State-of-the-Art Reactor Consequence Analyses Project Volume 1: Peach Bottom Integrated Analysis,” U.S. Nuclear Regulatory Commission, Washington DC, 2013.
  - NUREG/CR-7110, Vol. 2, Rev. 1, “State-of-the-Art Reactor Consequence Analyses Project Volume 2: Surry Integrated Analysis,” U.S. Nuclear Regulatory Commission, Washington DC, 2013.
  - NUREG/CR-7245, “State-of-the-Art Reactor Consequence Analyses (SOARCA) Project Sequoyah Integrated Deterministic and Uncertainty Analyses,” U.S. Nuclear Regulatory Commission, Washington, DC, 2019.
  - Draft NUREG, “U.S. NRC Level 3 Probabilistic Risk Assessment (PRA) Project, Volume 3d: Reactor, At-Power, Level 3 PRA for Internal Events and Floods, Draft for Comment,” U.S. Nuclear Regulatory Commission, Washington DC, 2022. ADAMS Accession No. ML22067A215.
- MACCS Code Manuals:
  - SAND2021-11535, “MACCS Theory Manual,” Sandia National Laboratories, Albuquerque, NM, 2021.
  - SAND2023-01315, “MACCS User Guide – Version 4.2,” Sandia National Laboratories, Albuquerque, NM, 2023.

Backup Slides

MACCS Lineage

- 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 (2011)
  - Enhance user friendliness
  - Reduce likelihood of user errors
  - Enable routine examination of uncertainty

MACCS 4.0 Improvements (06/2020)

- Optional capability to perform high-fidelity atmospheric transport modeling with HYSPLIT (Lagrangian)
- Optional state-of-practice, GDP-based model (RDEIM) to account for economic losses (database currently supports contiguous USA)
- Support for special files needed by animation tool, AniMACCS
- Limits extended on a large set of input parameters
- Input parameters can be exported, including distribution definitions
- Results for each weather trial are used to define quantile results

MACCS 4.1 Improvements (07/2021)

- Near-field modeling improvements:
  - Comparison of several near-field atmospheric transport and dispersion codes including QUIC, ARCON96, and AERMOD concluded MACCS provides a conservatively bounding assessment in the near-field
  - MACCS v4.1 enhancements added for plume meander and trapping and downwash to simulate or bound near-field assessments of other codes
- New projective peak dose output option
- Documentation added to help menu in WinMACCS
- Updates to the RDEIM economic model
- Mixing layer information for each time period
- Time synchronization between local time and UTC
- Pop-up window for converting previous version
- Linux version of MACCS 4.1

MACCS 4.0/4.1 Licensing Process

- MACCS 4.0/4.1 contains new licensing features
  - Software is locked to a specific computer
  - Licenses are for one-year duration
- Steps to activate license
  - Run WinMACCS 4.X.0 Setup.exe (no installation key required)
  - Open WinMACCS 4.X.0
    - A popup screen briefly describes the licensing process
    - Readme file provides more details on licensing process
  - Run CreateLicenseRequestFile.exe in folder C:\Users\Public\WinMACCS to create license.request
  - Send a copy of license.request to wg-maccs-entity@sandia.gov
  - Once approved, Sandia sends product.key to user
  - License key is linked to WinMACCS

MACCS 4.2 Improvements (03/2023)

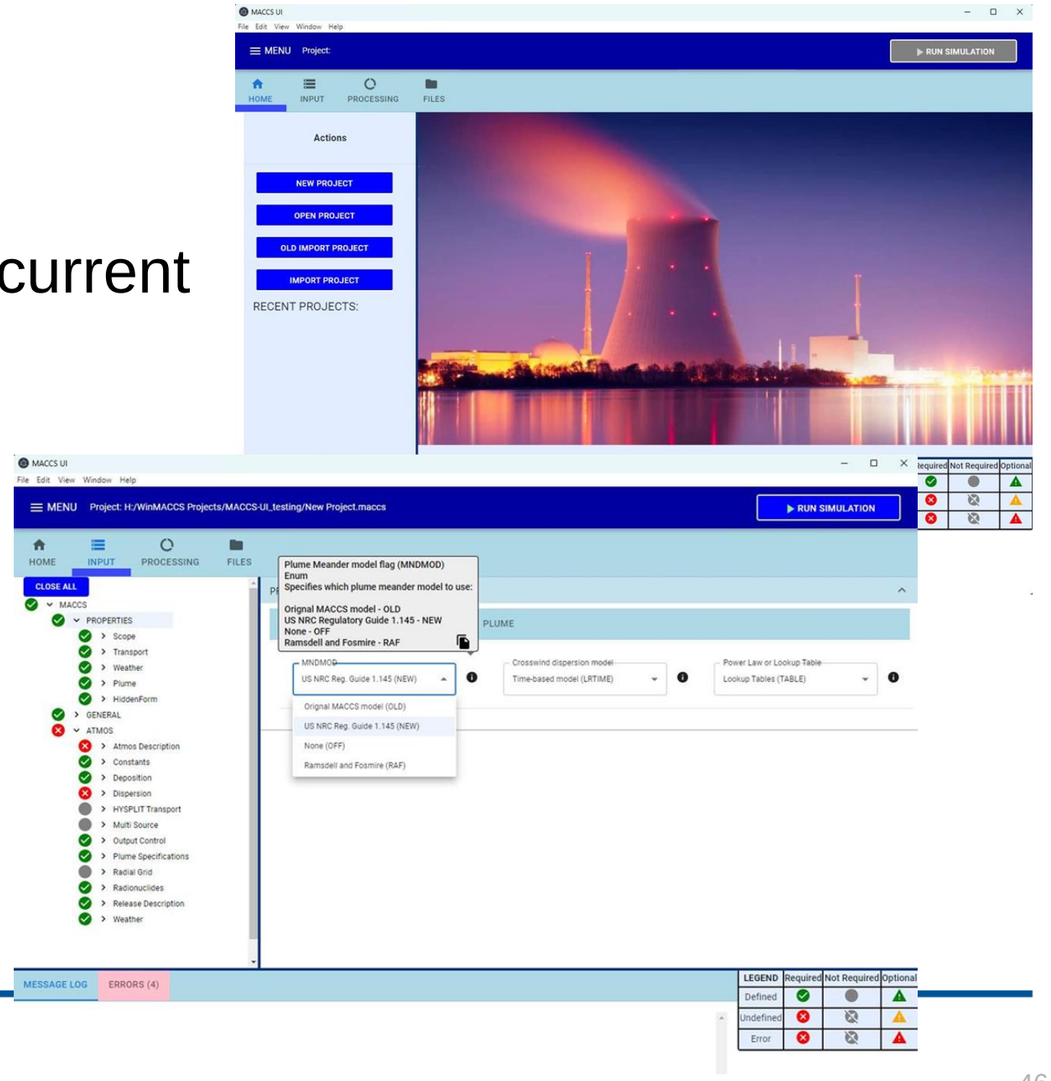
- Remove node locking from license
  - Only time limit for licenses
  - Removes three steps from process
  - License included in 4.2 installer expires March 2024, new one to be issued before then
- Up to 999 radionuclides
  - Still limited to six member decay chain length
  - Need dose coefficient data for radionuclides
- Split indirect costs in economic model
- Dual dose criteria
- Relocation dose projection and timing
- Decontamination in habitable areas
- Skin pathway standardization

MACCS Modernization

- Working collaboratively with the NRC to determine the future vision for MACCS
  - Effectively tackle the consequence analysis challenges of the future
  - Incorporate modern programming languages and techniques
  - Be compatible with modern computing platforms
  - Increased flexibly and modularity
  - Support advanced reactor consequence analysis and future model updates
- Divided into two main efforts
  - User Interface (MACCS-UI)
  - Analysis code (MACCS)

User Interface Modernization

- Visual Basic 6 no longer supported
  - Java, JavaScript and other modern tools
- MACCS-UI to have the same functionality as current WinMACCS
  - Ability to add more capabilities in the future
- Same interface with MACCS
  - Atmos.inp, Early.inp, Chronc.inp
  - Model1.out, Model1.bin
  - Import previous WinMACCS 4.x projects



Analysis Code Modernization

- Goals and benefits
  - Maintain backwards compatibility
  - Compatible with what users currently use
    - MACCS UI
    - Command line
  - Better readability and easier modification of code
  - Improve and modify input functionality
  - Increase output capabilities
  - Work to support potential improvements and model capabilities
- Modern programming practices will be used for enhanced readability and modification of MACCS code
  - Convert mix of Fortran 77 & 90+ portions of code to modern Fortran
  - Clean up memory use by using dynamic memory
  - Modularize to facilitate adding or replacing models
- Implement such that MACCS remains in a release-ready state

Overview: MACCS / RASCAL

	MACCS	RASCAL
Inputs	Hundreds	<20
Input time	Hours to Days	<10 min
Run time	Minutes to Days	<5 min
Source Term	External Input	Included (Simplistic)
ATD Models	Y	Y
Weather	Sampled Historic Obs	Live Weather
Dose Calculations	Y	Y
Protective Actions	Credited	Not Credited
Health Effects	Y	N
Economic Effects	Y	N