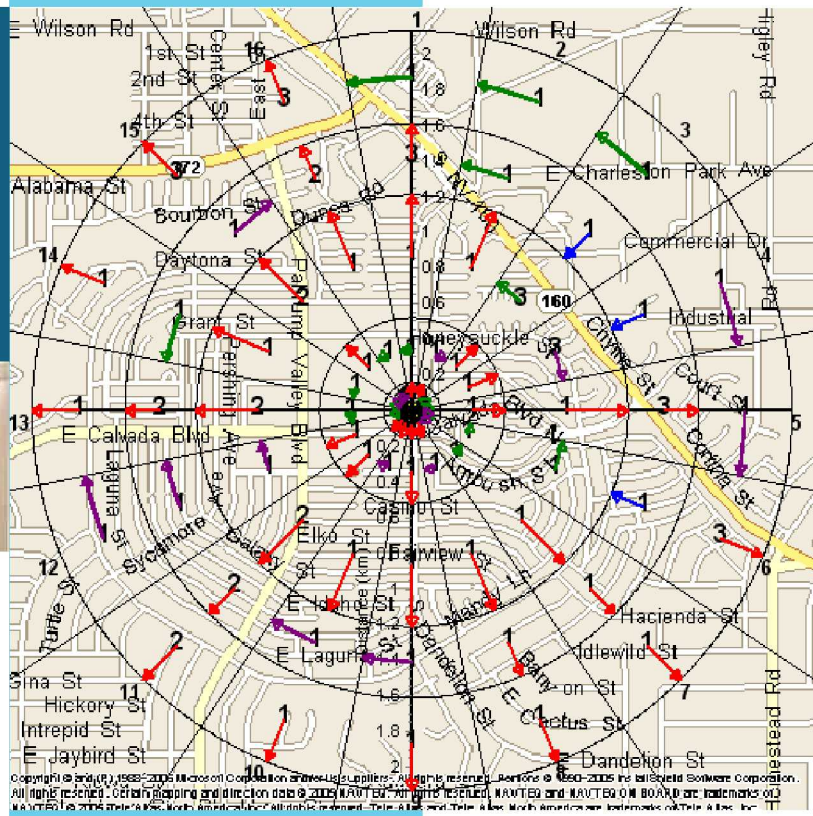
SAND2019-13355PE

Advanced Cohort Modeling





Author

Nate Bixler

Sandia National Laboratories

Presented at AMUG 2019, Nov. 4 – 6, 2019
Daejeon, Republic of Korea

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND2019-XXXX C

Objectives

- Learn how emergency response is modeled
- Learn how to define emergency-phase cohorts
- Learn how to use the more advanced features for defining the locations of cohorts
- Observe a demonstration of how to define cohort locations using advanced option
- Perform an exercise to define cohort locations using advanced option

Definition of a Cohort

- A cohort is a group of the population that behaves similarly
- Examples are
  - Non-evacuating cohort – a group of the public that does not evacuate even if they are instructed to
  - Shadow evacuation cohort – a group of the public that evacuates even though they are not instructed to do so
  - Special facilities – a group of the public that resides in hospitals, nursing homes, prisons, or other facilities and that are unable to evacuate on their own
  - Divisions of the public that evacuate early, intermediate, or late after instructed to do so

Introduction to Protective Measures

- Mitigative actions are protective measures designed to reduce exposures and health effects
- Mitigative measures in MACCS are divided into three phases (as defined by the US EPA) with different protective actions possible in each phase
  - Emergency phase – from 1 to 40 days from the beginning of an accident
  - Emergency-phase protective actions are called emergency-response (ER) actions
    - Evacuation
    - Sheltering
    - Relocation
    - KI ingestion

Introduction to Protective Measures (cont.)

- Intermediate phase - begins immediately after the emergency phase and extends up to 1 year
  - Temporary relocation when dose projection is too high
  - Dose projection period (e.g., 1 yr) and allowable dose (e.g., 2 rem) are often different than in emergency phase
- Long-term phase - follows the intermediate phase
  - Based on habitability and farmability
  - Mitigative actions attempt to reduce long-term health effects
    - Decontamination*
    - Temporary interdiction*
    - Condemnation*
    - Crop disposal in the year of the accident
    - Restricted crop production

*Long-term exposure is based on groundshine and resuspension inhalation

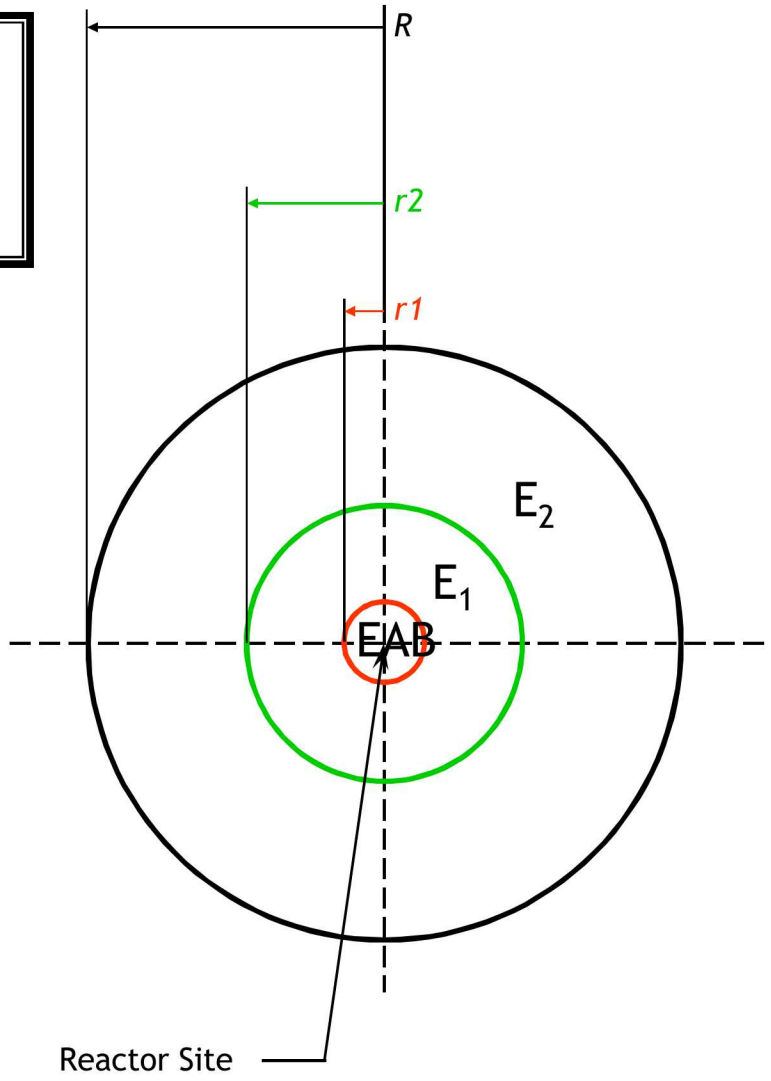
MACCS Modeling of Phases

- The emergency phase is modeled by EARLY
  - Duration is specified by user
  - Extends up to 40 days after the arrival of the first plume at a spatial location
- EARLY can model up to twenty emergency-phase cohorts
- CHRONC models intermediate and long-term phases using a single cohort

Emergency Response Zones

Exclusion Area Boundary	(< r1)
↗ E_1: Emergency Planning Zone (EPZ)	(r1 - r2)
↗ E_2: Shadow Evacuation Zone	(r2 - R)
↗ R: Relocation Zone	(> R)

- The exclusion area boundary is bounded by *r1*.
- Evacuation and sheltering generally occur within the EPZ (UPZ in Korea), designated by *r2*.
- Sheltering followed by relocation occur within R (PAZ in Korea).
- Relocation applies to all of the population that does not evacuate.



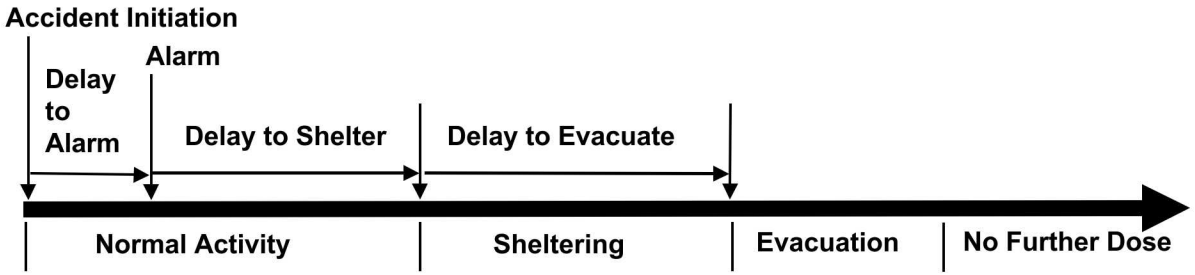
Shielding Factors

- Specified for each of three groups
  - Evacuees
  - People taking shelter
  - People continuing normal activity
- Shielding factors are multipliers in dosimetry calculations for each pathway and activity
  - Cloudshine
  - Groundshine
  - Inhalation
  - Skin deposition
- Typical relationship

  1.0 ≥ SFs for evacuees ≥ SFs for normal activity ≥ SFs for sheltering ≥ 0.0

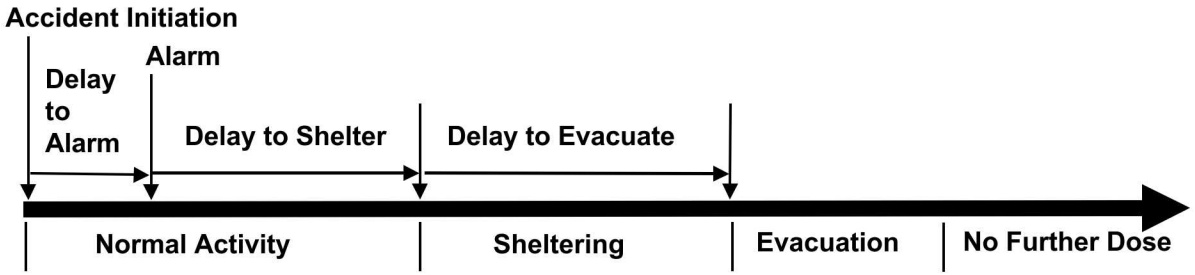
Sheltering and Evacuation

- First period: Delay time prior to sheltering (user-specified for each zone)
  - Normal activity (and normal activity shielding factors) are used
  - Delay time is from off-site alarm time or plume arrival time (cohort specific)
- Second period: Delay time prior to evacuation (user-specified for each zone)
  - Shielding factors for sheltering are used
  - Delay time is from beginning of sheltering



Sheltering and Evacuation (cont.)

- Third period: Evacuation
  - Speeds are user specified and can vary with
    - Three phases
    - Weather
    - Grid element
  - Evacuation is to user-specified distance from reactor site
  - Evacuating shielding factors apply
  - Exposure to plume depends on location relative to front and back of plume
- Fourth period: After evacuation
  - Following evacuation, evacuees avoid further exposure in EARLY



Sheltering and Evacuation (cont.)

- Fifth period: After end of Emergency Phase
  - Evacuees move back to original spatial element if intermediate-phase dose criterion is satisfied.
  - Any additional exposures are from intermediate and long-term exposure pathways in CHRONC.

Intermediate Phase

- The Intermediate Phase begins at the end of the Emergency Phase.
- Extends for a user-specified interval of time up to 30 years.
  - Duration can be zero.
  - Sum of durations of emergency and intermediate phases and time to decontaminate cannot exceed 32 years.
- Relocation is the only mitigative action during intermediate phase.
- Relocation criterion parameters are
  - Dose limit
  - Critical organ
  - Dose-projection period

Long-Term Phase

- Starts at end of intermediate phase
- Mitigative actions depend on
  - Projected doses
  - Cost-effectiveness of the action
- Decontamination worker doses are calculated for
  - Farmland
  - Non-farm properties

Decontamination and Temporary Interdiction Based on Habitability Criterion

- Based on dose projection over a user-specified time period
- Land is habitable when projection is less than dose limit
- Population is present for rest of long-term phase when habitability criterion is met
- Mitigative actions are considered in order when the habitability criterion is not met
  - Decontamination (up to three levels of increasing effectiveness)
  - Period of interdiction following maximum decontamination
    - Atomic decay
    - Weathering
  - Condemnation of land

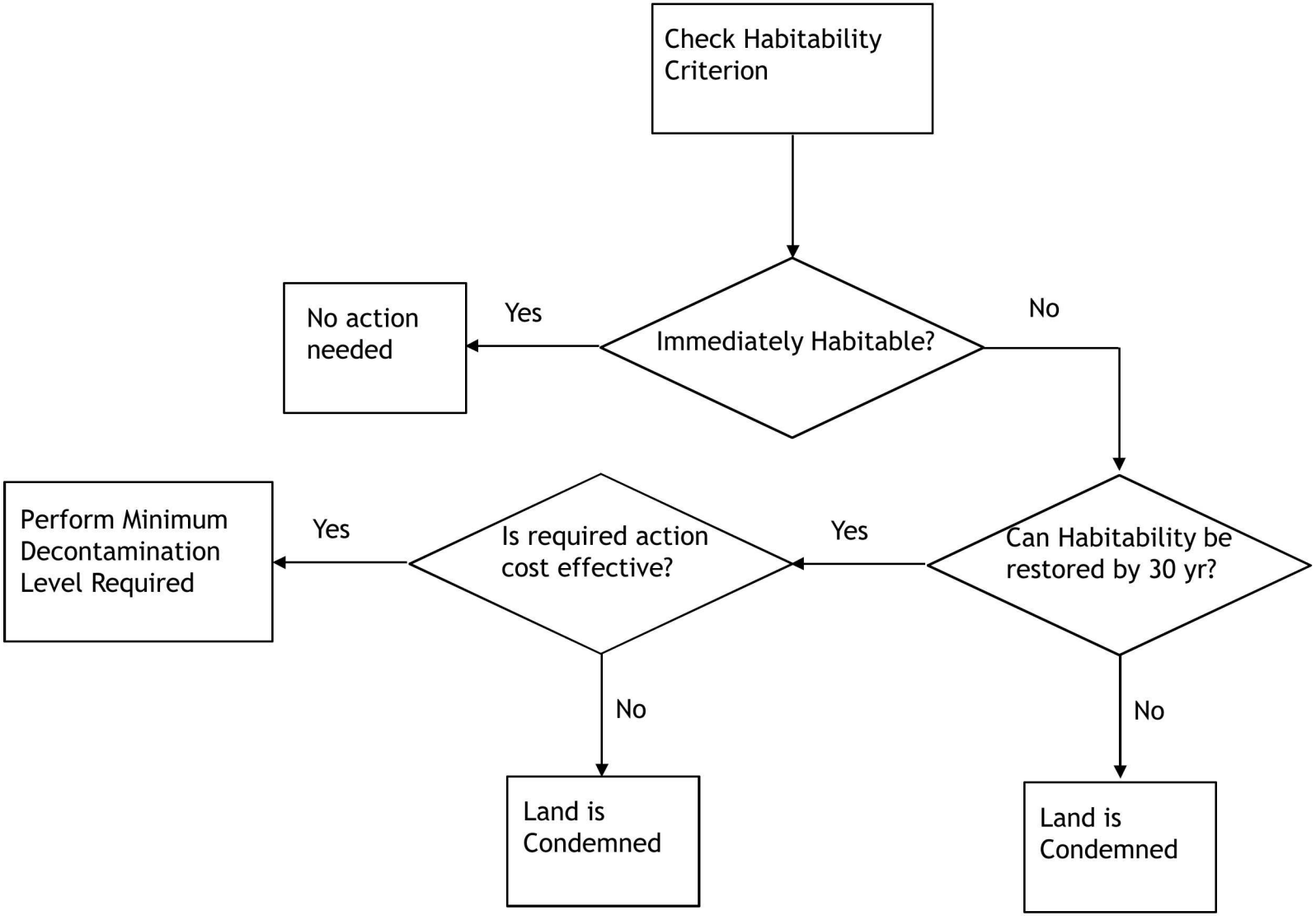
Long-Term Ingestion Doses

- Three mitigative actions are modeled for farmland.
  - Disposal of milk and/or crops during year of accident
  - Removal of farmland from production when uninhabitable
  - Removal of farmland from production when too contaminated to grow crops (not farmable)
- User specifies maximum allowable food doses.
  - Short-term (year of accident) milk dose
  - Short-term (year of accident) food dose (other than dairy)
  - Long-term dose from all food

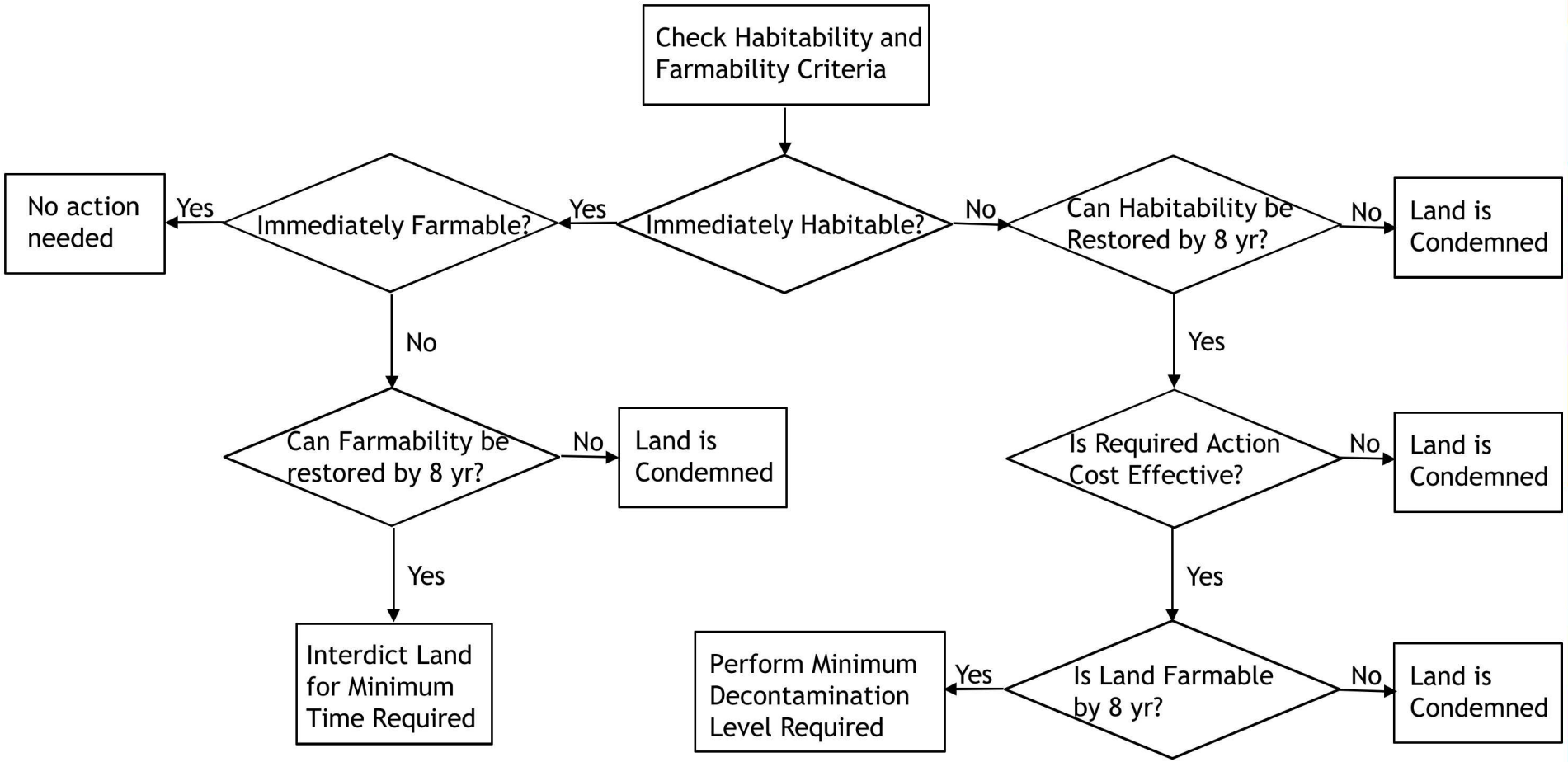
Long-Term Ingestion Doses (cont.)

- Farmland is condemned when
  - Land cannot be restored to habitability and farmability
  - Costs of decontamination and interdiction exceed farm value
- User-specified limits affect
  - Milk and crop disposal during year of accident
  - Ability to farm in subsequent years

Logic Diagram for Non-Farmland



Logic Diagram for Farmland

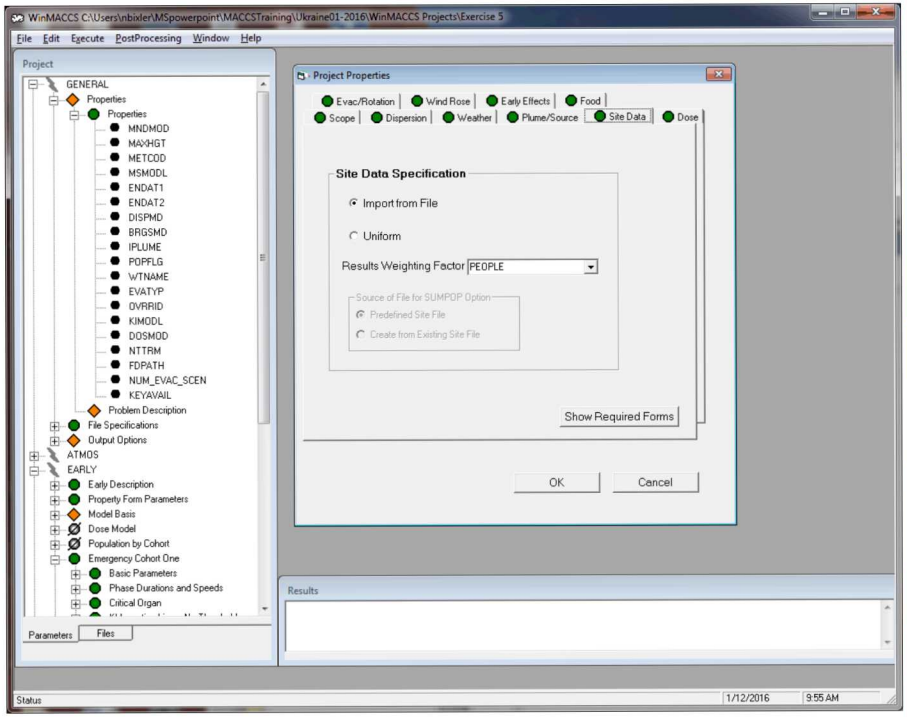


Cohort Models and Parameters

- Population distribution
- Type of evacuation
- Basic parameters
- Phase durations and speeds during evacuation
- KI ingestion
- Boundaries
- Shielding and exposure
- Notification delays
- Response delays
- Network evacuation parameters (advanced feature)
- Keyhole parameters (advanced feature)

Defining Population Distributions

- Uniform population density and site data can be used when evaluating a generic site or when metrics are limited to
  - Individual doses
  - Average health-effect risks
- Site file containing population and other site data should be used when metrics include
  - Population doses
  - Number of health effects
  - Population-weighted health-effect risks
  - Land contamination areas
  - Economic losses

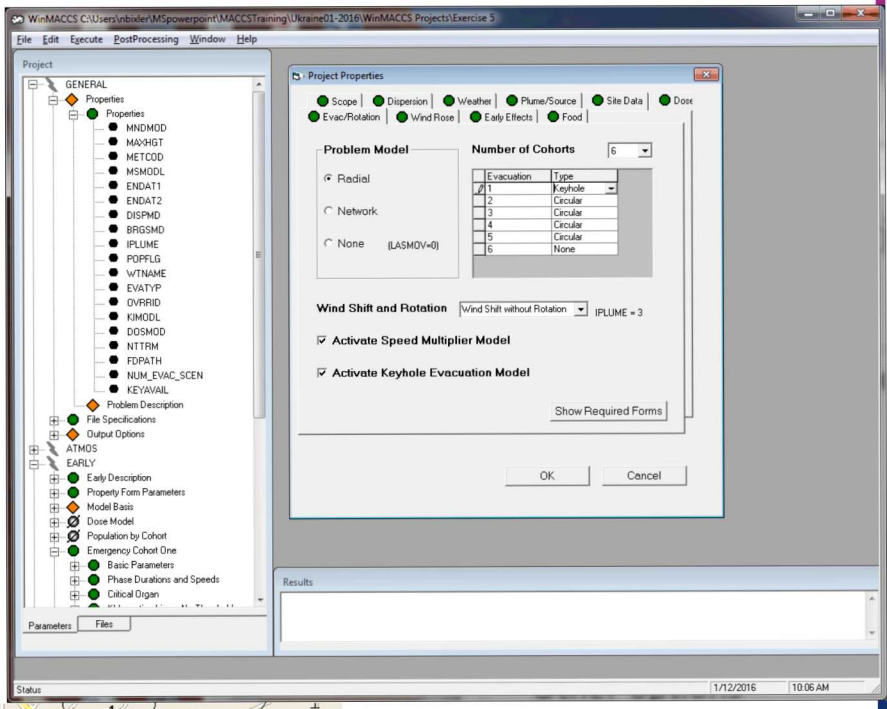


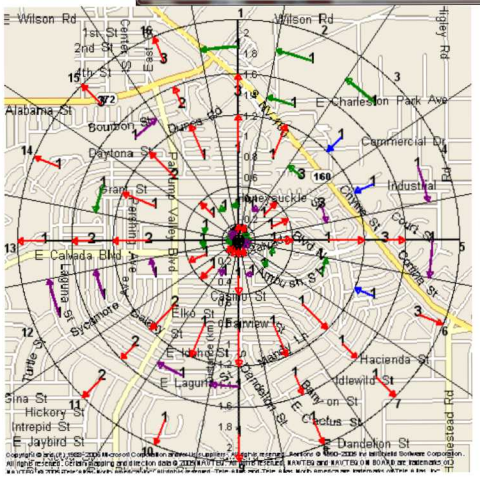
Site File Contents

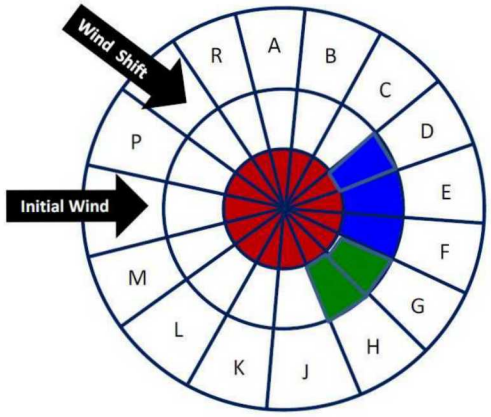
- Format is defined in NUREG/CR-6613 Vol. 1
- Contents include
  - Grid definition
  - Population by grid element (PEOPLE or TIME option)
  - Land fractions by grid element
  - Economic region index by grid element
  - Watershed index by grid element
  - Crop season and share data
  - Watershed definitions
  - Regional economic data
- Contents optionally include
  - Population by grid element for each cohort (SUMPOP option)

Types of Evacuation

- Two types of evacuation model choices
  - Radial or network
  - Evacuation shape
    - None
    - Circular
    - Keyhole
- Other options
  - Activate speed multiplier model (advanced option)
  - Wind shift and rotation

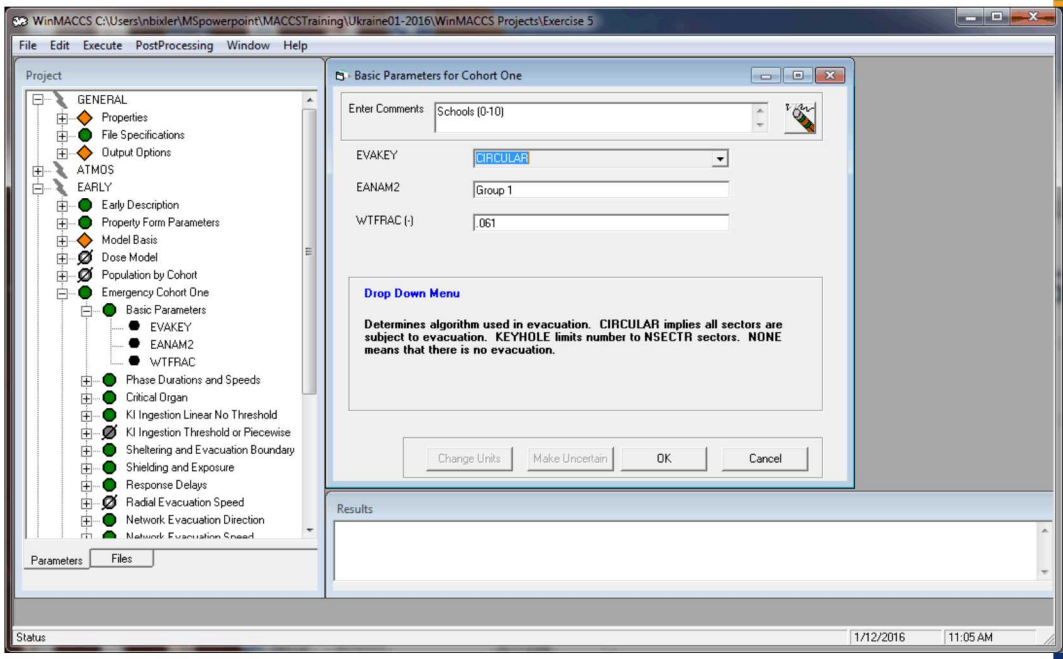






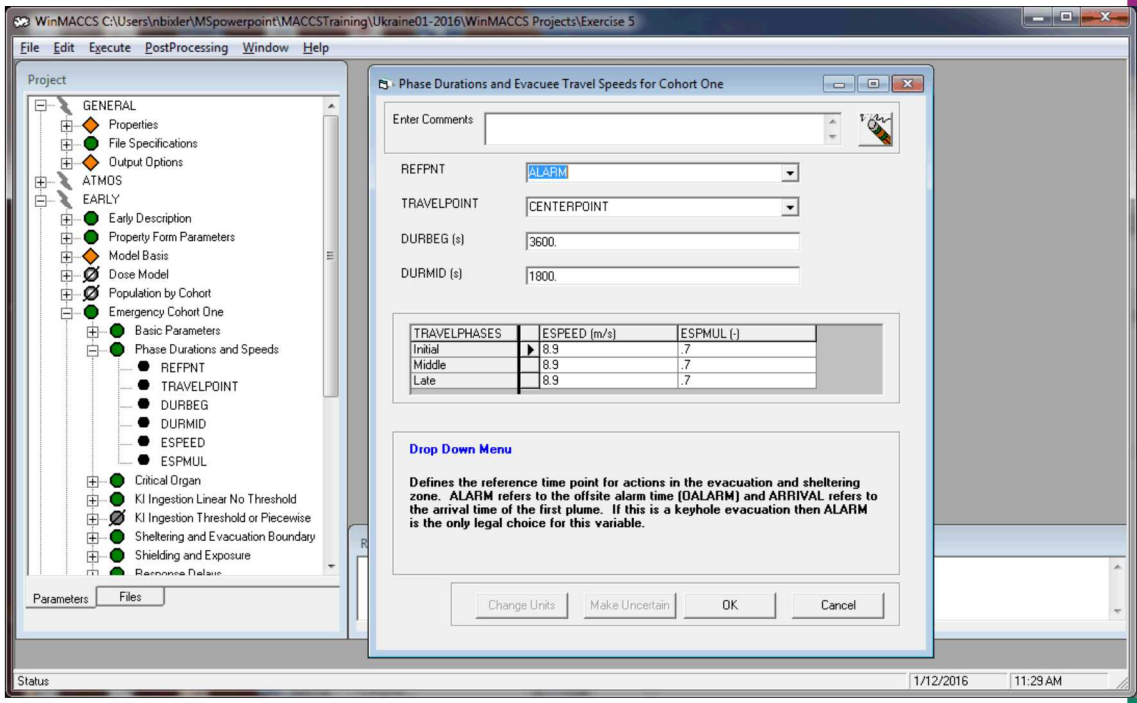
Basic Cohort Parameters

- Evacuation shape for cohort (read only)
- Cohort name
- Population fraction
  - Fraction of population in cohort
  - Fraction of population in cohort is uniform over entire grid
  - A more advanced feature allows a nonuniform distribution over the grid (SUMPOP)



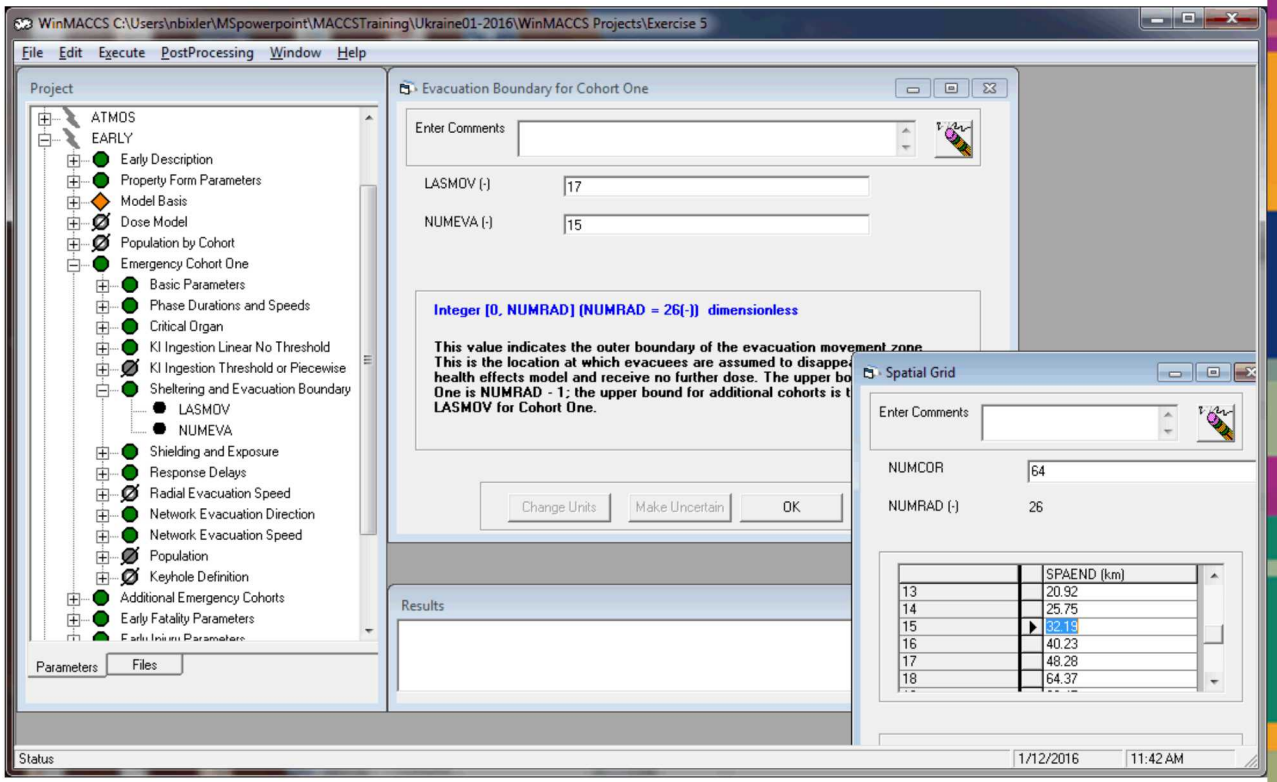
Phase Durations and Speeds

- Reference point for emergency actions: alarm or plume arrival
- Location where evacuee moves to next grid element
- Duration of beginning and middle phases of evacuation
- Evacuation speeds
- Multiplier during precipitation events



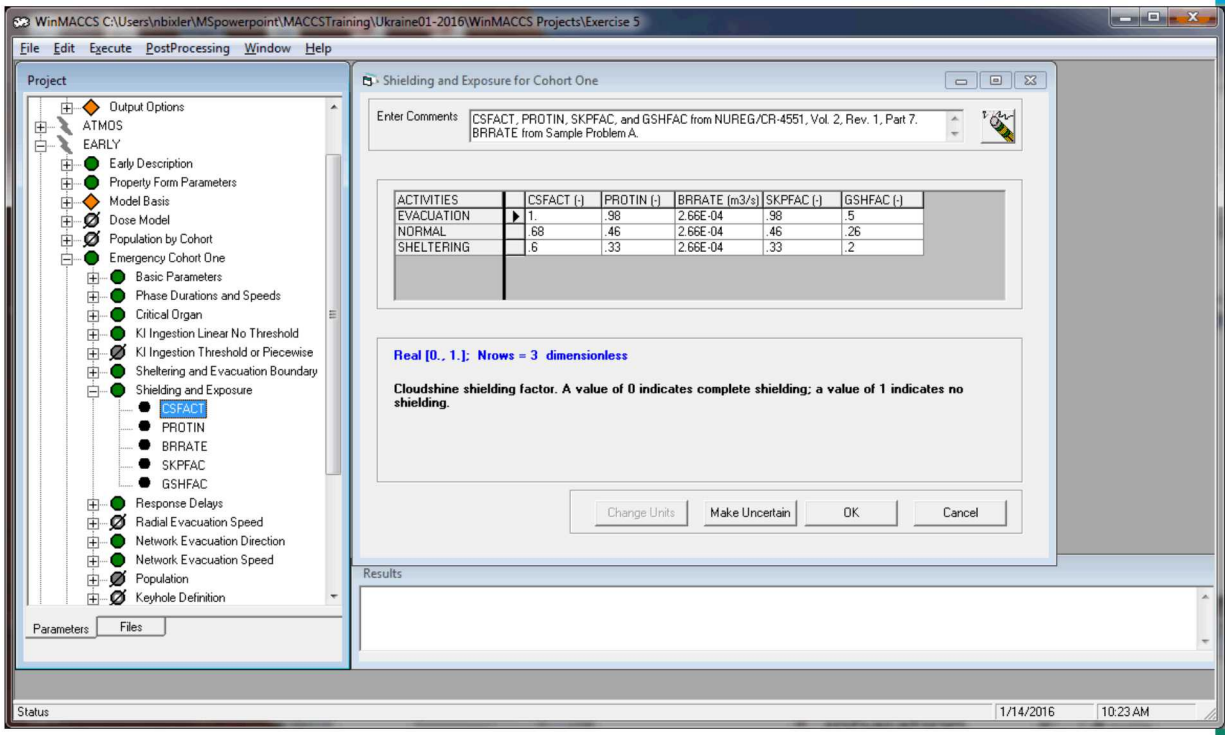
Evacuation Boundaries

- Inner boundary (NUMEVA) is the index (referenced to spatial grid definition) of the outer boundary for evacuation
- Outer boundary (LASMOV) is the index of the distance at which evacuees no longer receive a dose during the emergency phase



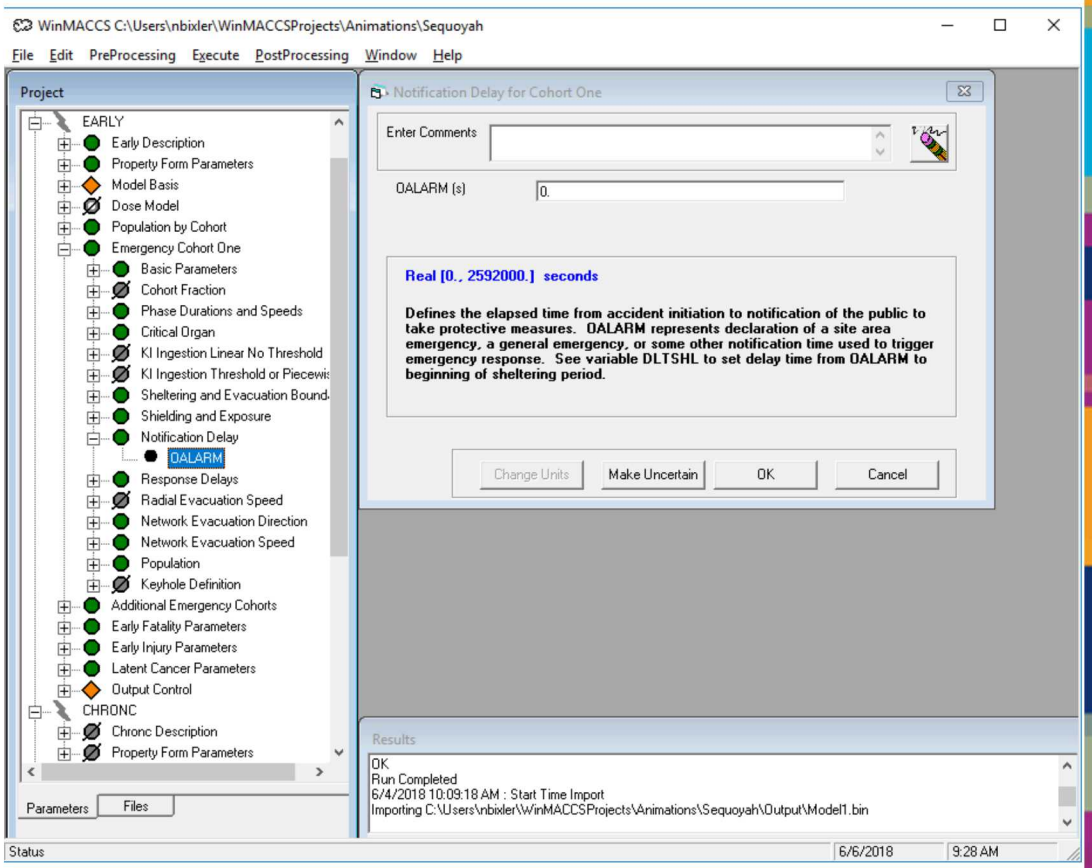
Shielding and Exposure

- Shielding and protection factors define the dose fraction received by
  - Dose pathway
    - Cloudshine
    - Inhalation
    - Skin
    - Groundshine
  - Activity
    - Evacuation
    - Normal
    - Sheltering
- Breathing rate



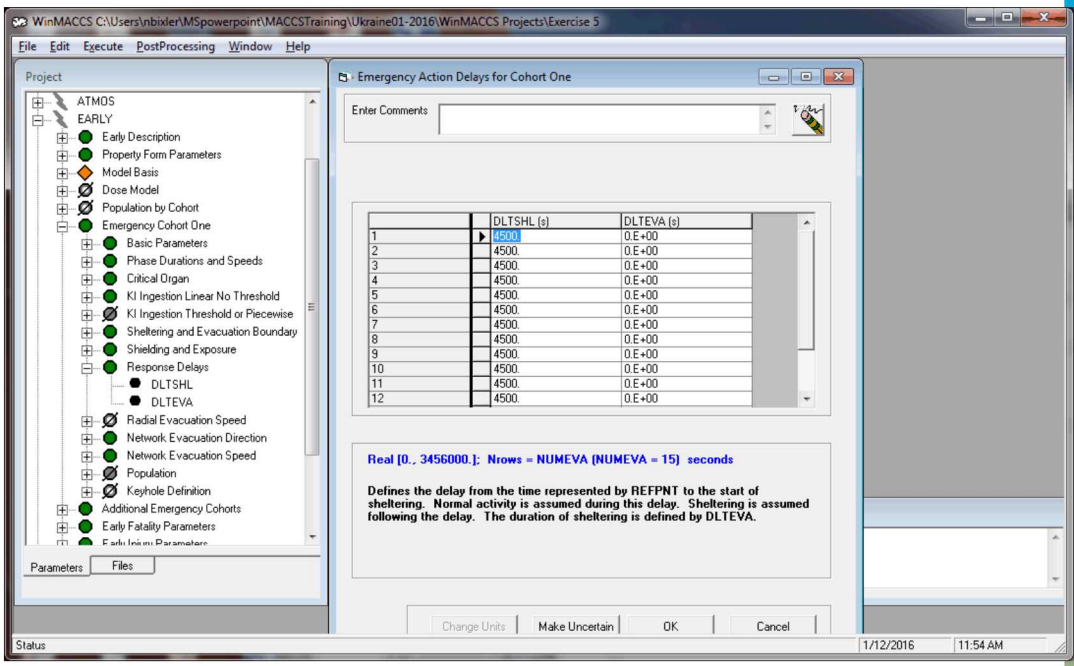
Notification Delay

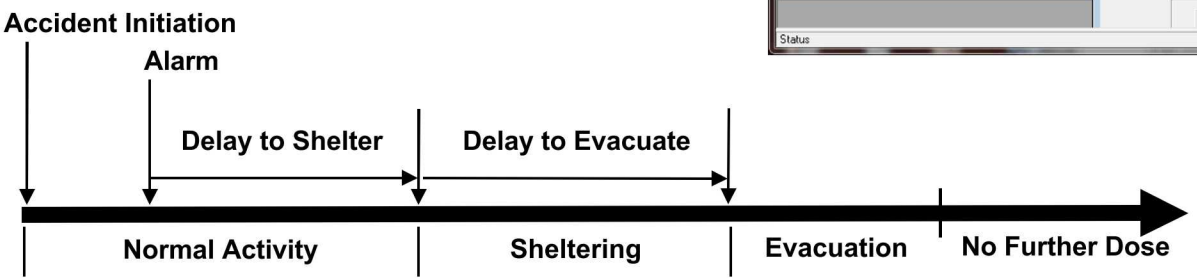
- Notification delay (OALARM) is specified for each cohort
  - Usually related to declaration of general emergency (GE)
  - Some sites notify some facilities at site area emergency (SAE)



Response Delays

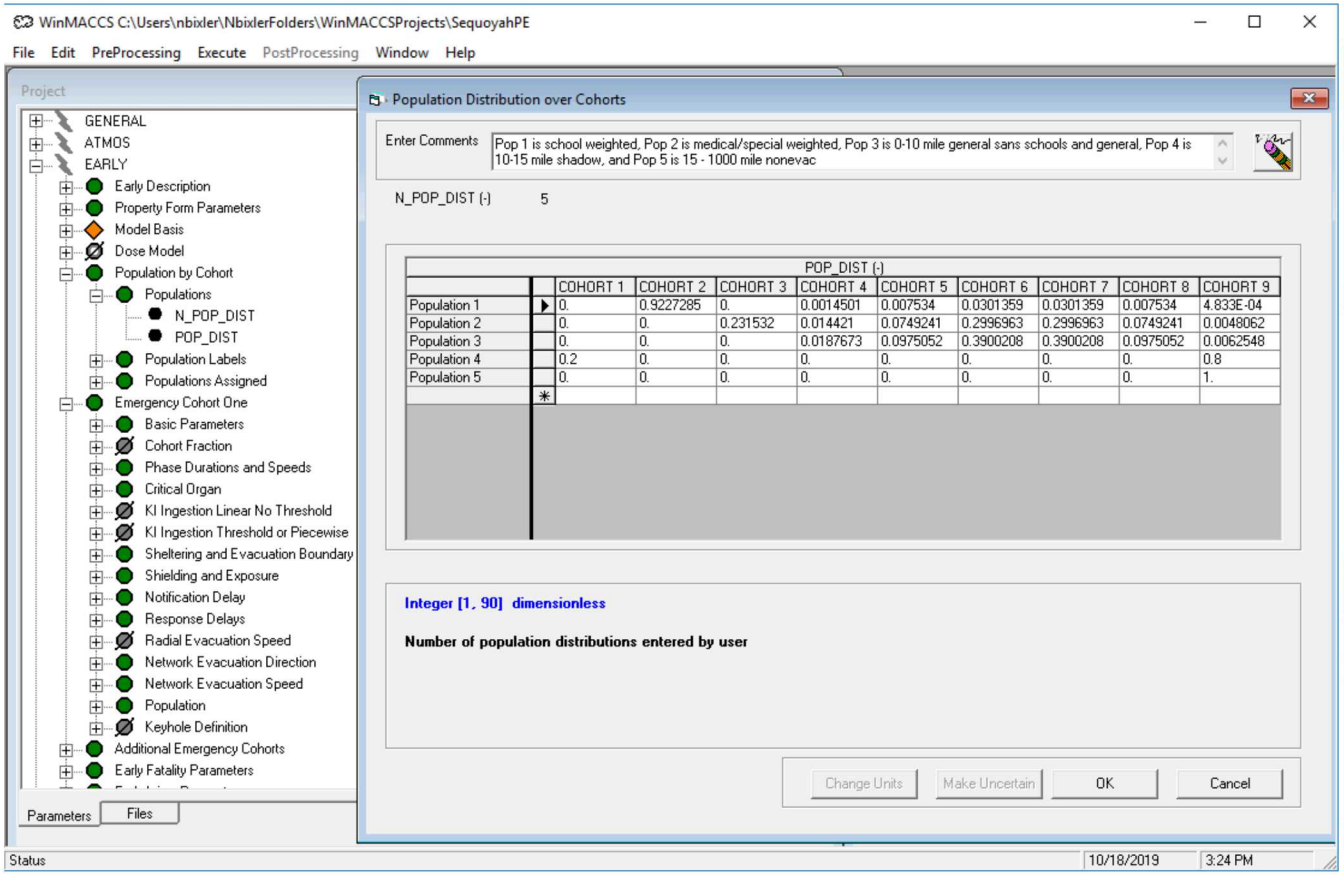
- Delays are specified for each ring within the evacuation zone
  - Delay to shelter
  - Delay to evacuation
- Delays are generally different for each cohort





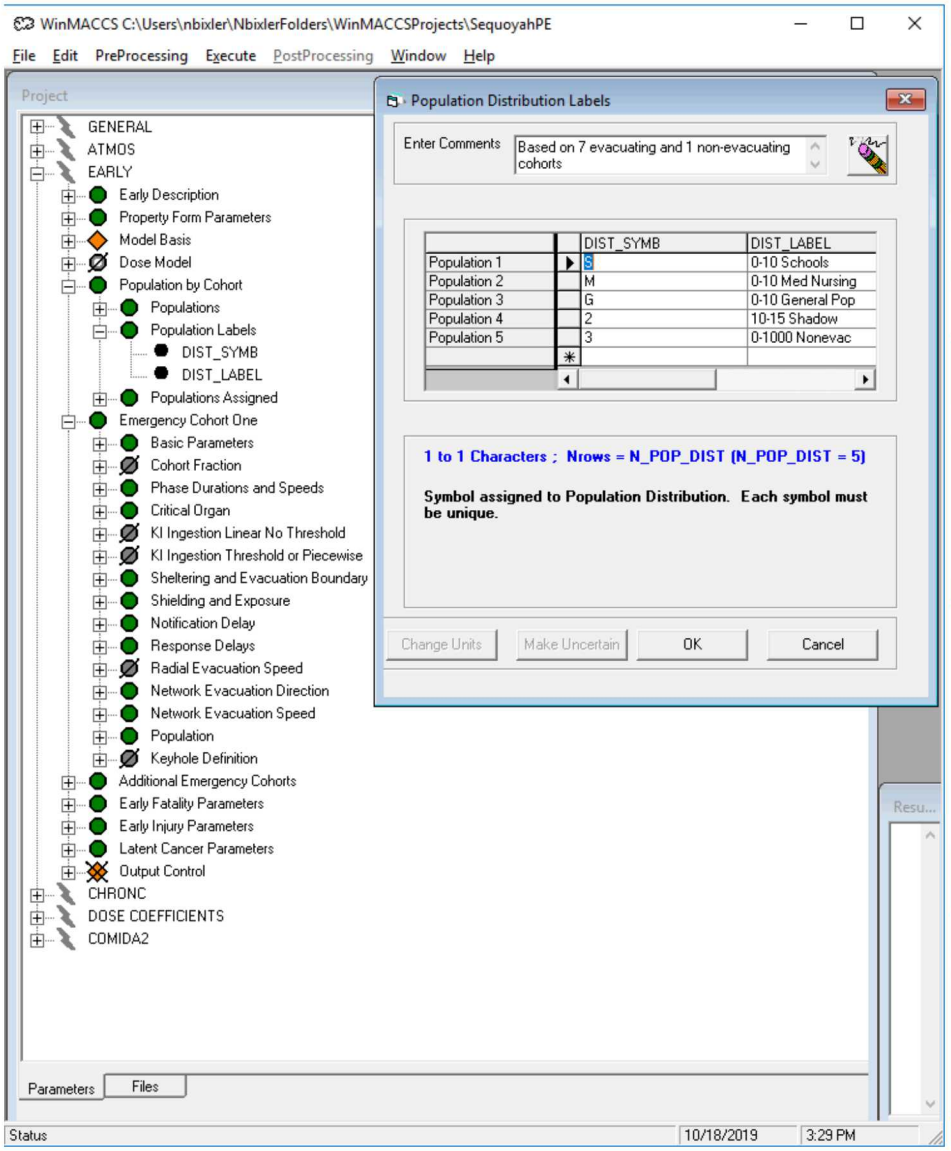
Nonuniform Cohort Definition - Populations

- Populations are defined that contain fractions of each cohort
- Fractions on each row should sum to unity
- Each grid element contains one of the populations



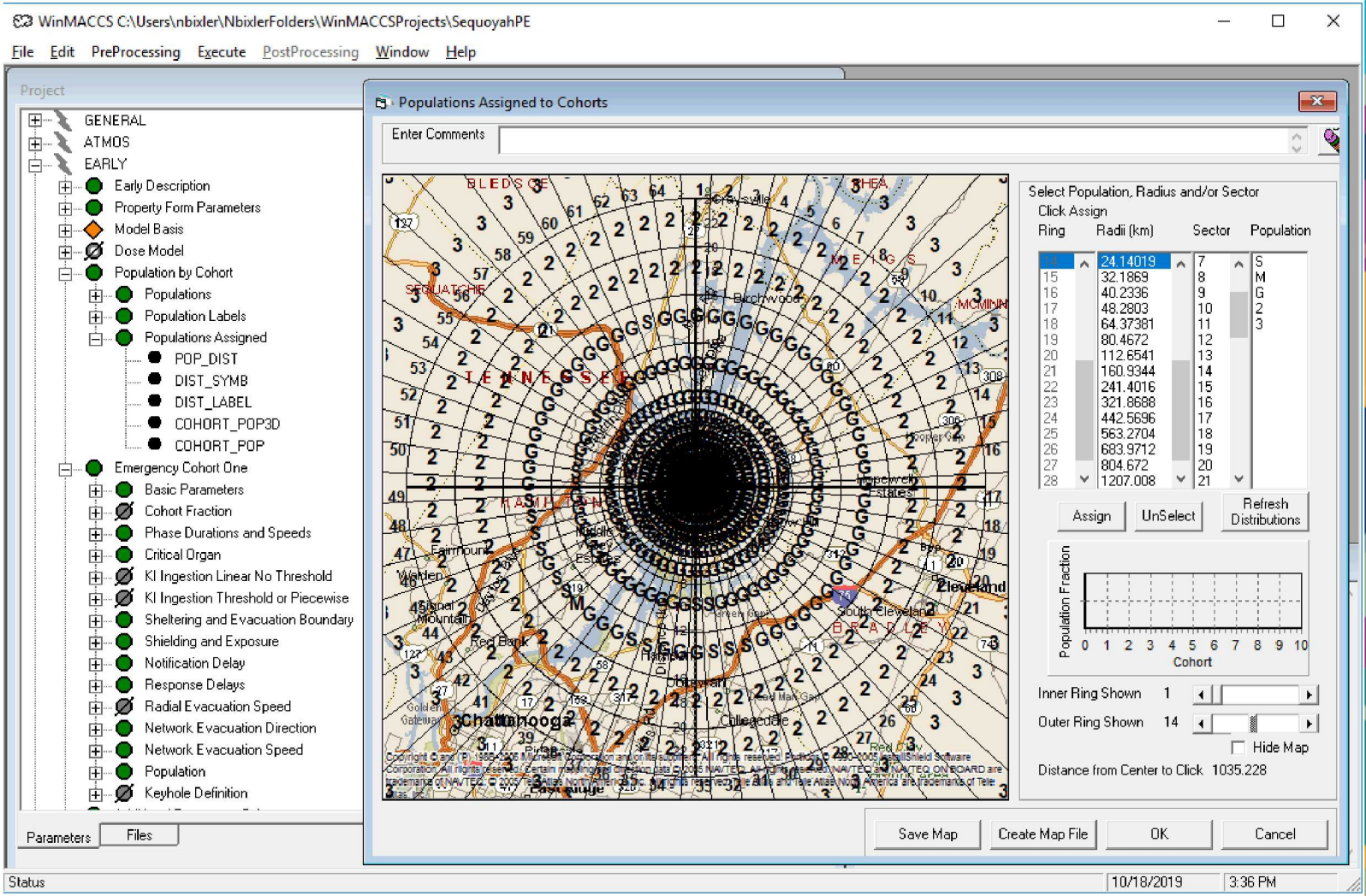
Nonuniform Cohort Definition – Population Labels

- Each population is given a label
- Labels are subsequently mapped onto the grid



Nonuniform Cohort Definition – Populations Assigned

- Final step is to map populations onto grid



Summary

- Emergency response reduces public exposure in case of an accident
- Cohorts are groups that behave similarly
- For the emergency phase, MACCS models
  - Relevant dose pathways
  - Sheltering, evacuation, relocation, and KI ingestion
- Essentially all of the cohort parameters depend on the site and accident sequence and need to be considered for each consequence analysis