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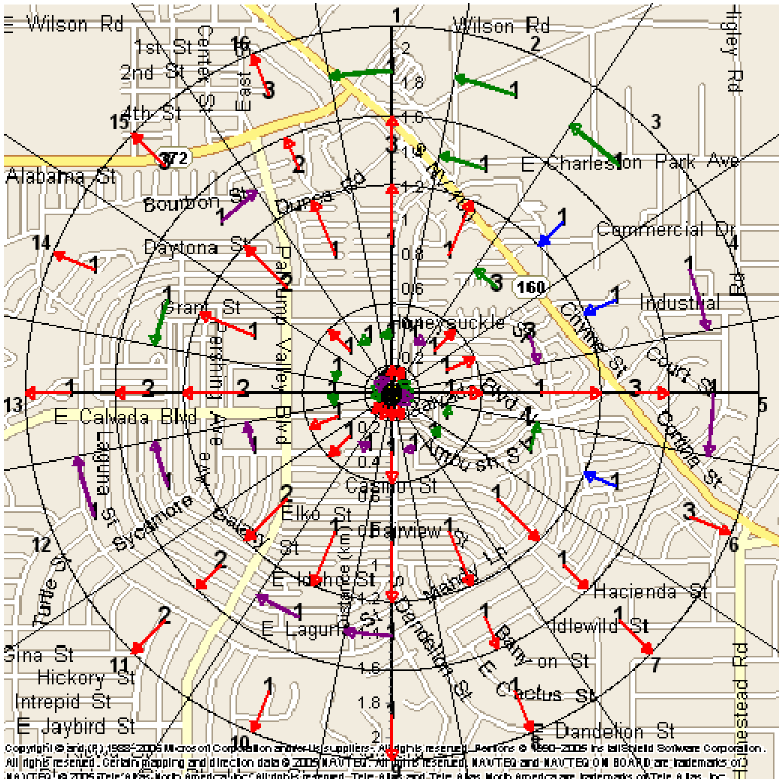

EARLY-Phase Health Effects

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Objectives

- Learn about dose pathways and how they are modeled
- Learn how health effects are modeled
  - Early (also called acute or prompt) health effects
  - Latent cancer health effects
- Learn that most of the health effect models should only be modified
  - When new ICRP, FGR, BEIR, or equivalent data become available
  - Preferably with the involvement of a trained health physicist

Exposure Pathways

- Internal pathways
  - Inhalation (direct and resuspension)
  - Ingestion (food and water)
- External pathways
  - Cloudshine
  - Groundshine
  - Deposition onto skin

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Calculating Exposures

- Begins with estimating two basic quantities
  - Time integrated air concentration, χ_i (Bq·s/m^3)
  - Ground concentration, D_i (Bq/m^2)
- Time integration period for exposure depends on usage
- Exposures should account for transient effects
  - Radioactive decay of activity of isotope i and ingrowth of daughter product j

$$\frac{dA_i}{dt} = -\frac{\ln(2)}{t_{h_i}} A_i$$

$$\frac{dA_j}{dt} = +\frac{\ln(2)}{t_{h_i}} A_i - \frac{\ln(2)}{t_{h_j}} A_j$$

  - Population movement (moving receptor)
  - Weathering effects on ground concentrations (discussed later)
- Typically accounts for 69 isotopes for reactor accidents
  - Subsequent discussion is for single isotope and stationary receptor

Types of Doses

- Absorbed dose – energy per mass deposited in a specific organ (Gy)
- Equivalent dose – biological effect of dose to a specific organ (Sv)
  - Calculated by summing products of absorbed dose for each type of radiation and radiation weighting factor (quality factor)
- Committed dose – time integral (usually over 50-yr period) of internal dose
- Effective dose – weighted average of committed, equivalent doses to a set of organs (represents entire body)
  - Calculated by summing products of equivalent dose for each tissue type and tissue weighting factor

Calculating Doses for Internal Pathways

- Direct inhalation

  $$\text{Dose} = \chi \times (\text{Breathing Rate}) \times SF_{Inh} \times DCF_{Inh}$$

- Resuspension inhalation

  $$\text{Dose} = D \times (\text{Resuspension Factor}) \times (\text{Breathing Rate}) \times SF_{Inh} \times DCF_{Inh}$$

- Ingestion

  $$\text{Dose} = D \times (\text{Area Occupied by Crop}) \times (\text{Transfer Factor}) \times (\text{Fraction Consumed}) \times DCF_{Ing}$$

Calculating Doses for External Pathways

- Cloudshine (Immersion)

  Dose = χ x (Finite Cloud Correction Factor) x SF_{CS} x DCF_{CS}

- Groundshine

  Dose = D x SF_{GS} x DCF_{GS}

Ingestion

- Crops
  - Direct deposition onto plants
  - Deposition from resuspension
  - Deposition of contaminated irrigation water onto plants
  - Root uptake
  - Removal from surfaces by rain or irrigation
  - Up splash from rain or irrigation
  - Etc.
- Animal products (milk and meat)
  - Feed consumption
  - Water consumption
  - Dirt consumption
  - Accumulation factor

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Resuspension Processes

- Contaminated soil resuspends in atmosphere from wind depending on
  - Particle size
  - Surface roughness
  - Vegetative cover
  - Wind speed
- Mechanical (vehicles, walking)
- Resuspension diminishes over time from
  - Weathering (removal by overland runoff, leaching, covering)
  - Radioactive decay
- Air concentration is usually calculated from an empirical equation

$$C = kD \qquad k = C_1 \cdot 2^{-t/H_1} + C_2 \cdot 2^{-t/H_2} + C_3 \cdot 2^{-t/H_3}$$

Emergency Phase

i	C_i (m^{-1})	H_i (yr)
1	10^{-4}	0.05

Long-Term Phase

i	C_i (m^{-1})	H_i (yr)
1	10^{-5}	0.5
2	10^{-7}	5
3	10^{-9}	50

Groundshine Weathering

- Causes are the same as for resuspension weathering
- Effect of weathering is more gradual – partially results from shielding
- Modeling treatment is the same

Cloudshine

- Cloudshine dose conversion factors are for immersion
- Immersion assumes
  - Cloud of uniform concentration above an infinite, flat plane
  - Receptor (representing a human) is slightly above the flat plane
- Real cloudshine is for a nonuniform concentration distribution
- Receptor may be some distance from the center of the cloud
- MACCS corrects the immersion dose using a finite cloud correction factor

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Finite Cloud Correction Factor

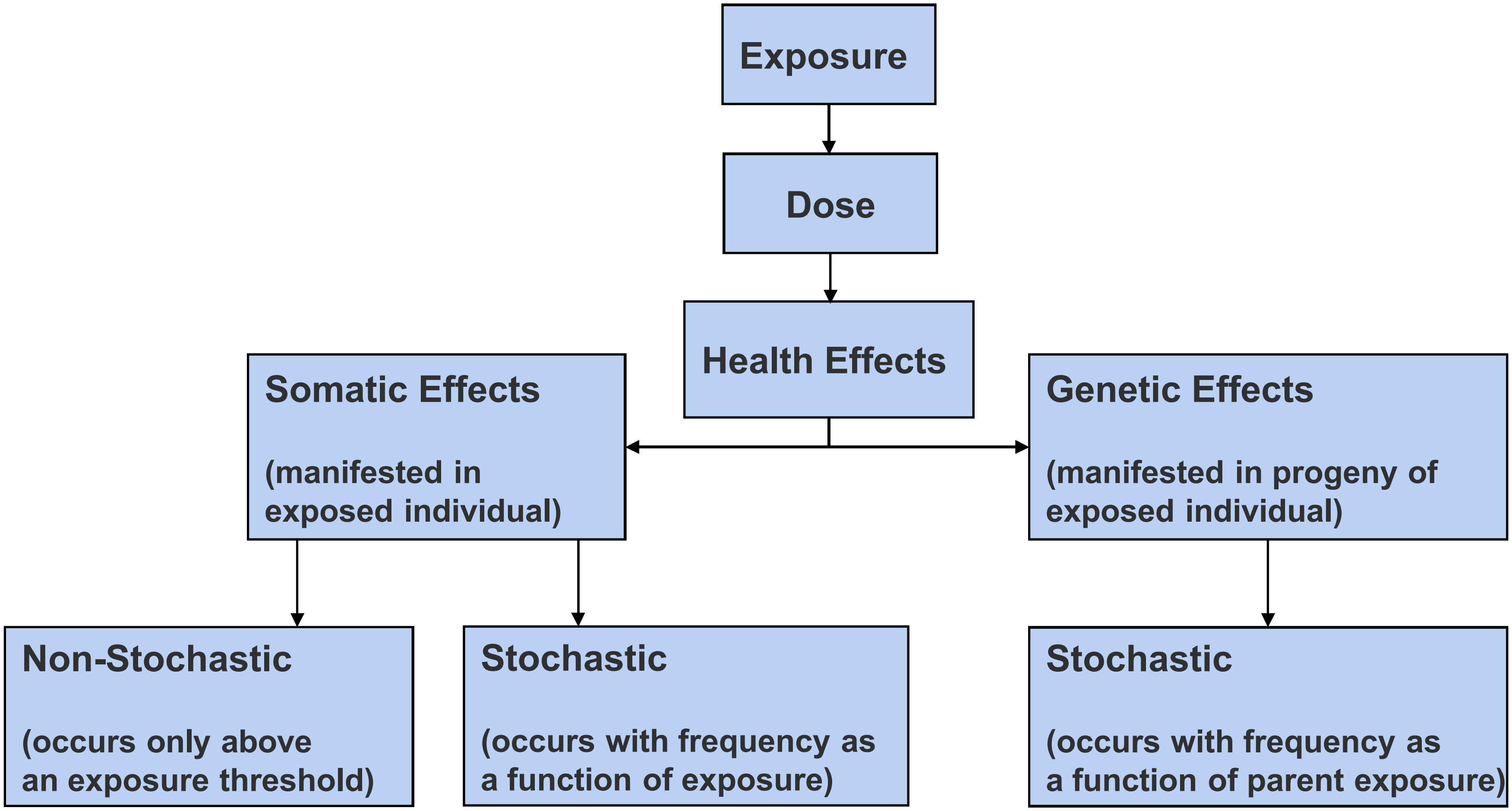
Diffusion Parameter $\sqrt{\sigma_y \sigma_z}$ **(m)**	**Dimensionless Distance to Cloud Centerline** $\sqrt{y^2+z^2}\Big/\sqrt{\sigma_y \sigma_z}$ **(Unit of Effective Plume Size)**					
	0	1	2	3	4	5
3	0.020	0.018	0.011	0.007	0.005	0.004
10	0.074	0.060	0.036	0.020	0.015	0.011
20	0.150	0.120	0.065	0.035	0.024	0.016
30	0.220	0.170	0.088	0.046	0.029	0.017
50	0.350	0.250	0.130	0.054	0.028	0.013
100	0.560	0.380	0.150	0.045	0.016	0.004
200	0.760	0.511	0.150	0.024	0.004	0.001
400	0.899	0.600	0.140	0.014	0.001	0.001
1000	0.951	0.600	0.130	0.011	0.001	0.001

Note: Data from Reactor Safety Study Table VI 8-1 with correction of a typographic error of data. For 0.7 MeV gamma photons.

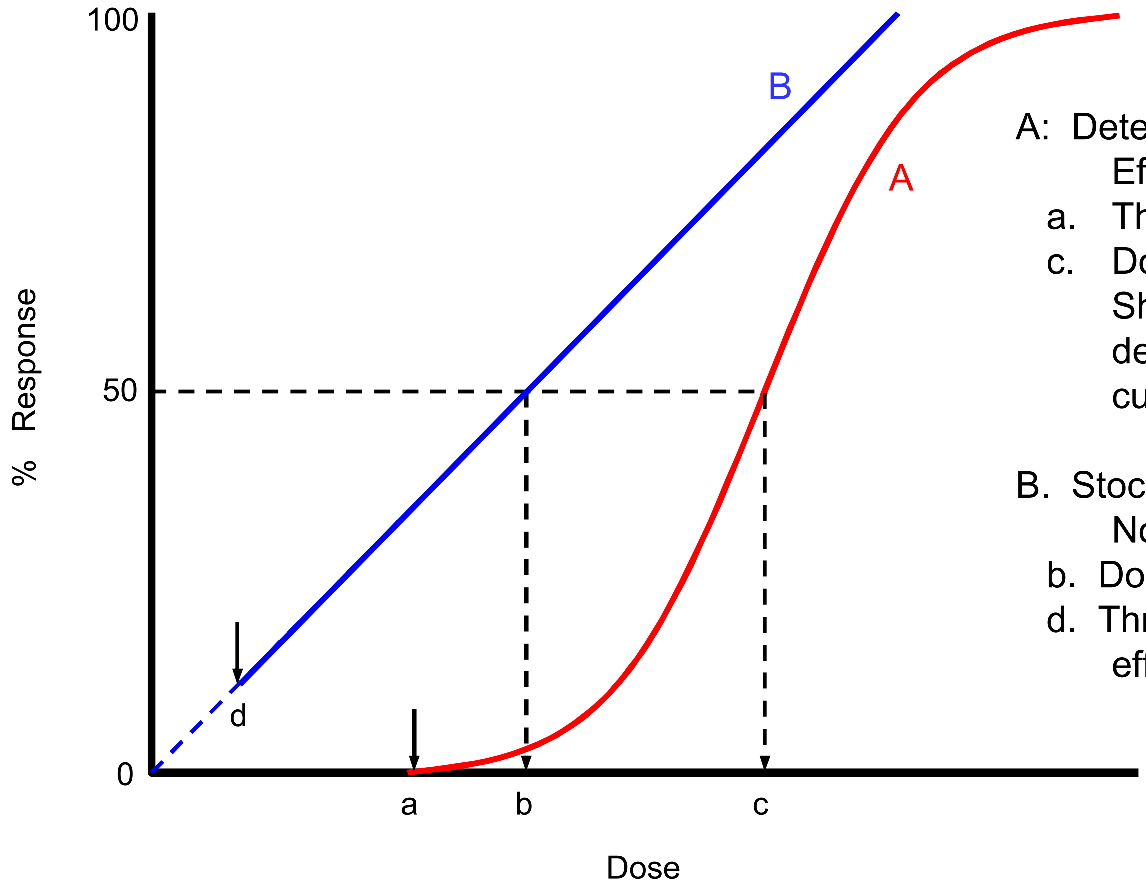
Effects of Radiation on Cells

- Cells undamaged by dose (no health effects)
- Damaged cells operate normally following repair (no health effects)
- Damaged cells operate abnormally following repair (potential latent cancer health effect)
- Cells die as a result of dose (potential early health effect)

Radioactive Exposure can Induce Somatic and Genetic Health Effects



Dose-Response Curves



A: Deterministic (Acute) Effect:
- a. Threshold dose
- c. Dose → 50% incidence

Shape factor that determines width of curve

B. Stochastic Effect (Linear No-Threshold) :
- b. Dose → 50% incidence
- d. Threshold of observable effects

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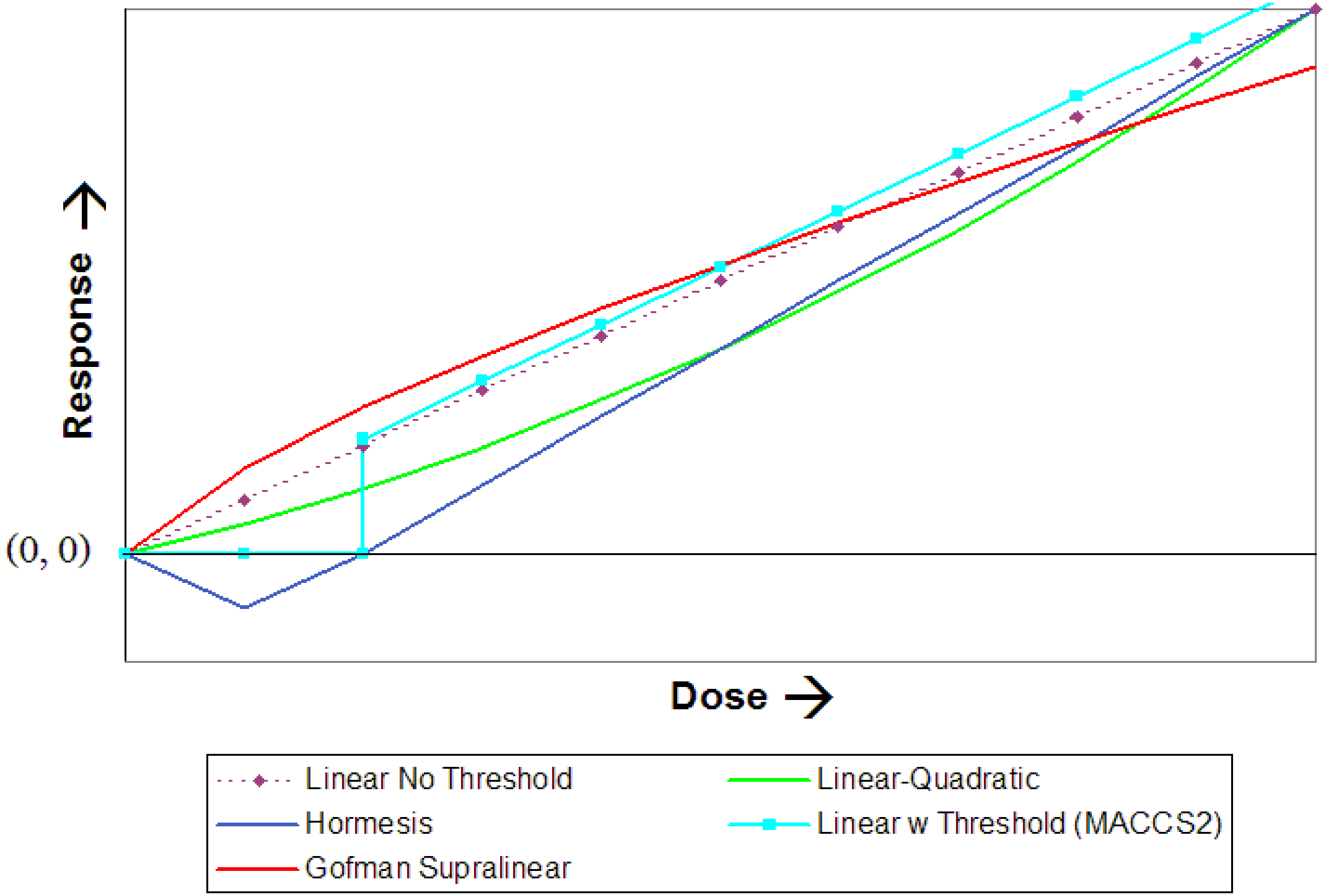
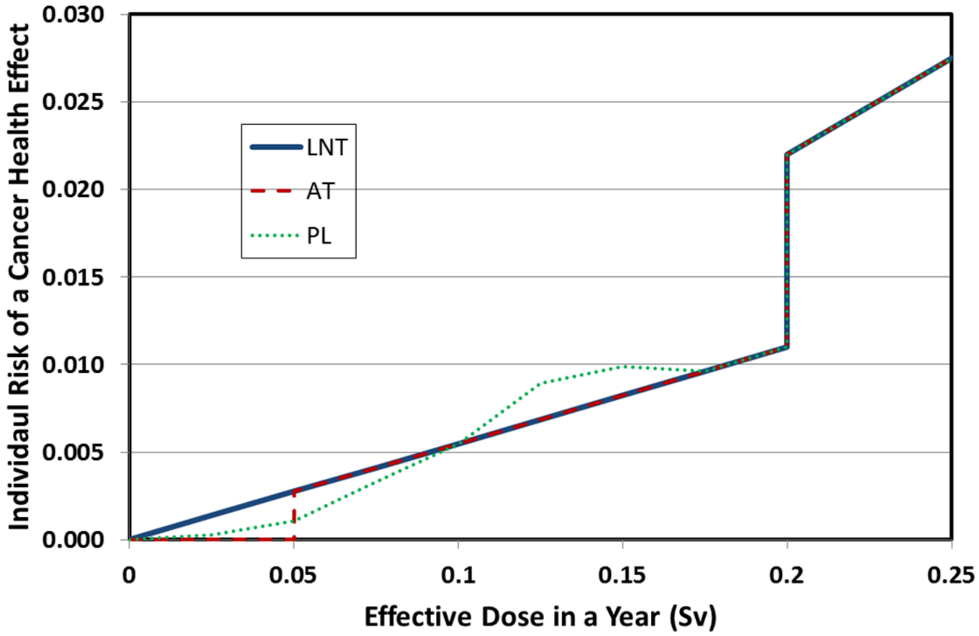
Other Possible Dose-Response Curves for Stochastic Health Effects



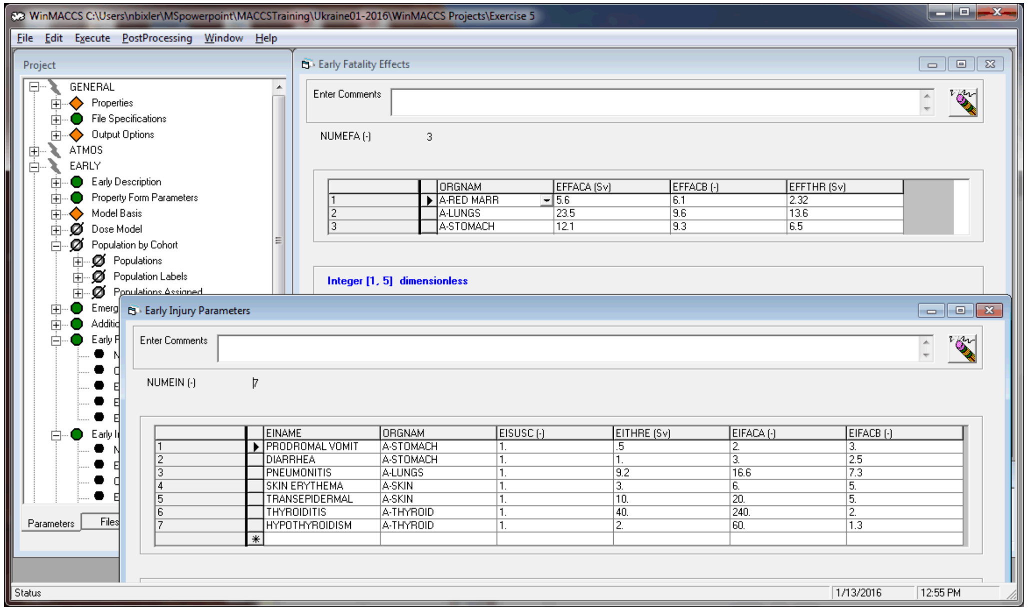
Dose-Response Models in MACCS

- Linear no-threshold model (including dose and dose-rate effectiveness factor)
- Annual threshold model
- Piecewise linear model
- Linear quadratic model (not pictured)
  - Quadratic at low doses
  - Linear at high doses

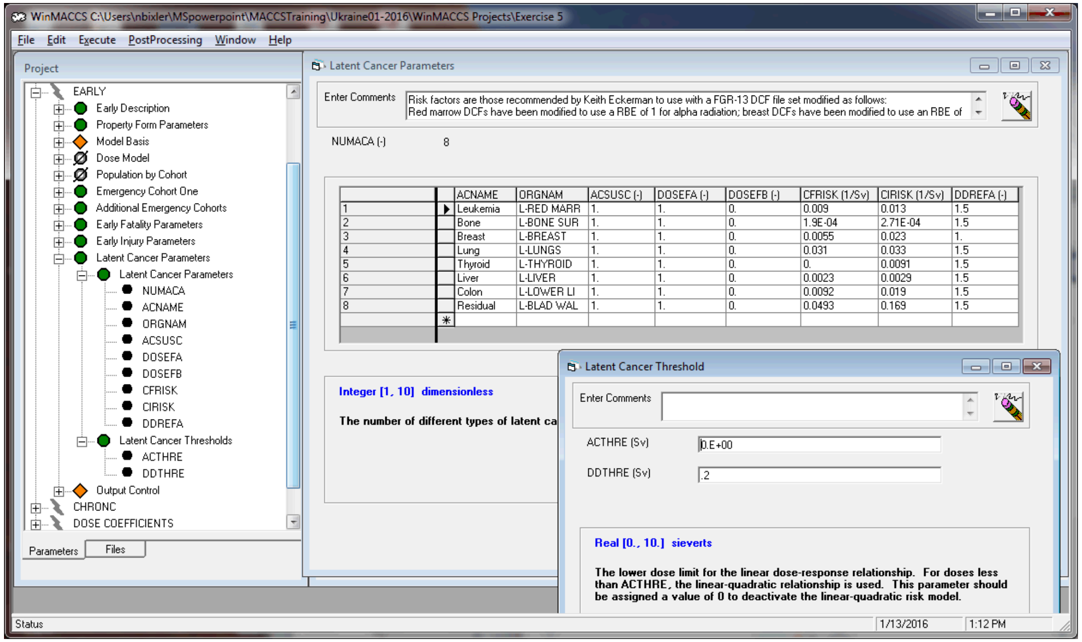


Early Health Effects

- Early injury and fatality parameters are slightly different
  - Early injury input requires a name and a population fraction susceptible to the injury
- Both require Weibull coefficients
  - Threshold
  - D50 or LD50
  - Shape factor
- Parameters should not normally need to be modified



Latent-Cancer Health Effects



- Parameters include
  - Cancer name
  - Associated organ
  - Fraction of the population susceptible to the effect
  - Linear factor in the dose-response model
  - Quadratic factor in the dose-response model
  - Cancer fatality risk factor at high dose rate
  - Cancer occurrence risk factor at high dose rate
  - Dose and dose-rate effectiveness factor (DDREFA)
  - Threshold for transition from quadratic to linear
  - Threshold for using the dose and dose-rate effectiveness factor

EARLY Outputs

- Health-Effect Cases
- Early-Fatality Radius
- Population Exceeding Threshold
- Average Individual Risk
- Population Dose
- Centerline Dose
- Centerline Risk
- Population-Weighted Risk
- Peak Dose
- Peak Dose Polar
- Land Area Exceeding Dose
- Land Area Exceeding Concentration
- Population Movement

Summary

- MACCS models all of the relevant exposure pathways for atmospheric releases
- Dose responses are modeled for both early and latent health effects
- MACCS supports a range of models and parameters for dose response
- Dose-response parameters should seldom be reexamined, only when
  - New data become available (e.g., BEIR VII)
  - However, exploring thresholds in dose response for latent health effects provides context on uncertainties