RESRAD-OFFSITE Code

(Expanded Source Term Models and DCGL Derivation Using Probabilistic Analysis)

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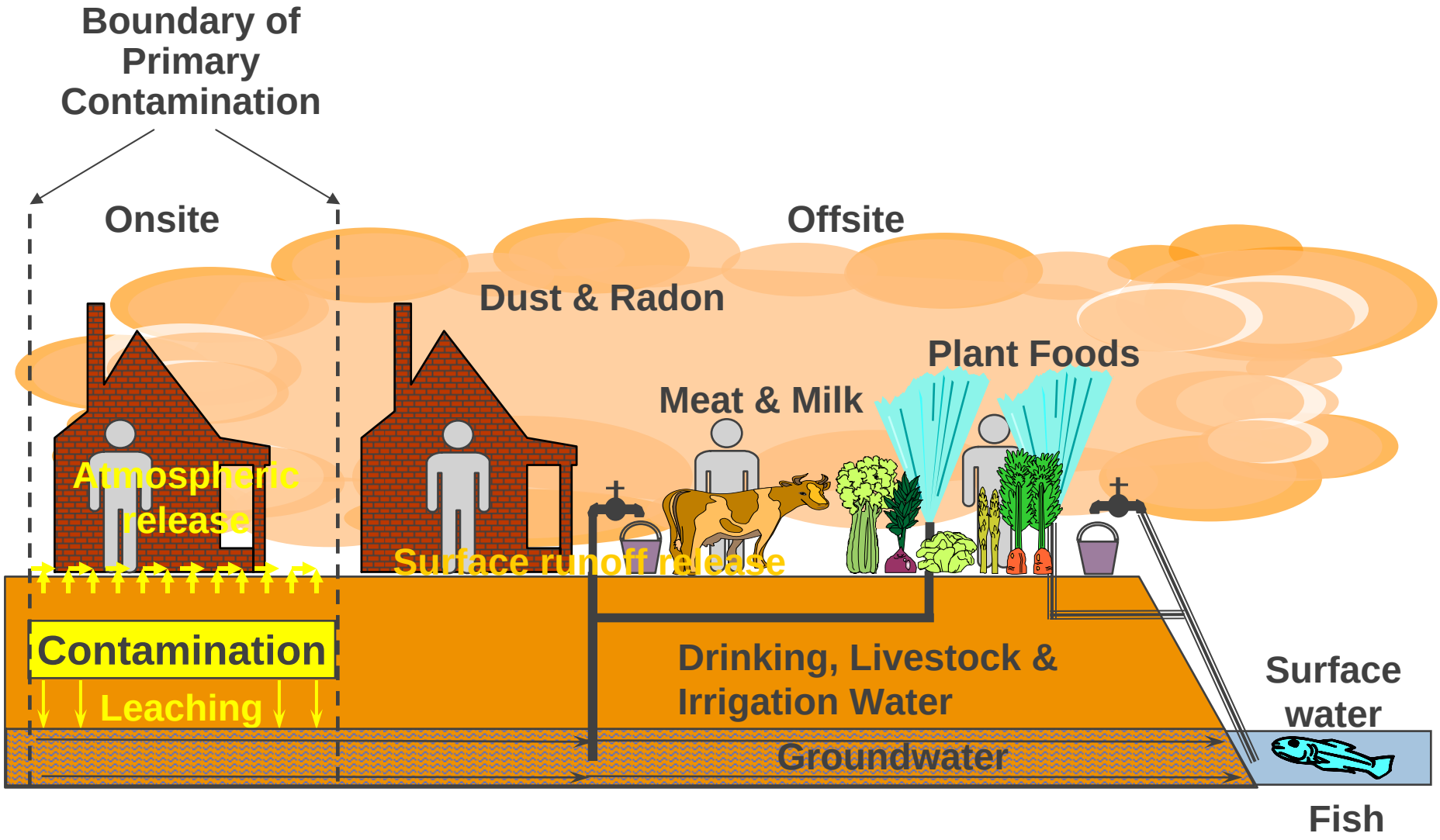
Major Features in RESRAD-OFFSITE

- Transport Pathways
  - Air dispersion (Gaussian Plume) model
  - Groundwater transport model
    - 1-D advective, 1-D dispersive transport in unsaturated zone
    - 1-D advective (straight or curved flow path), 3-D dispersive transport in saturated zone
- Additional impacted areas
  - Choice of 2 dwelling locations (onsite, offsite)
  - 4 agriculture areas
  - Well and surface water body can be at different locations
  - Accumulation in offsite soil and surface water body
- Improved User Interface
  - Graphical map user interface
  - Both deterministic and probabilistic analysis

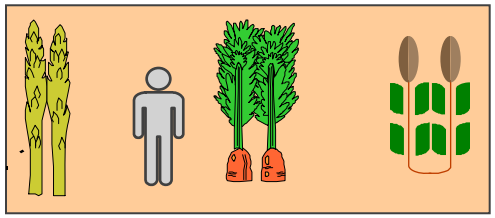
Environmental Pathways and Exposure Locations in RESRAD-OFFSITE Code



Areas of Secondary Contamination – RESRAD-OFFSITE

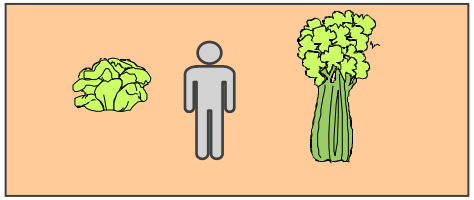
Primary contamination

Fruit, grain, non-leafy vegetables



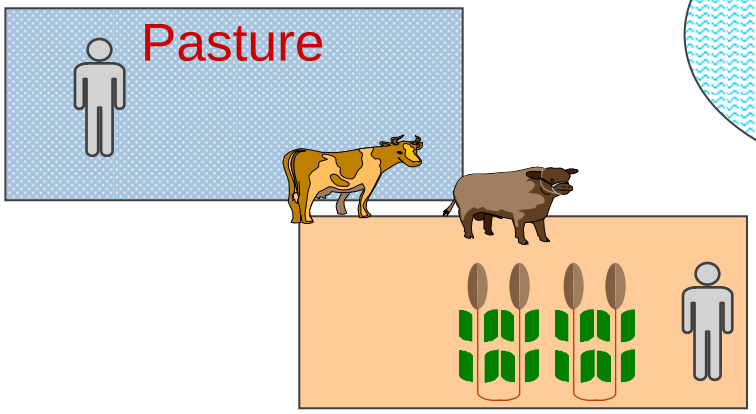
Well

Surface water body

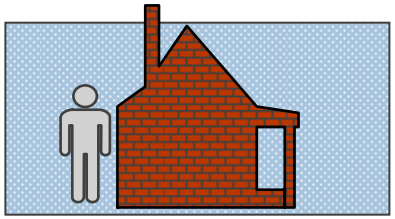


Leafy vegetables

Pasture

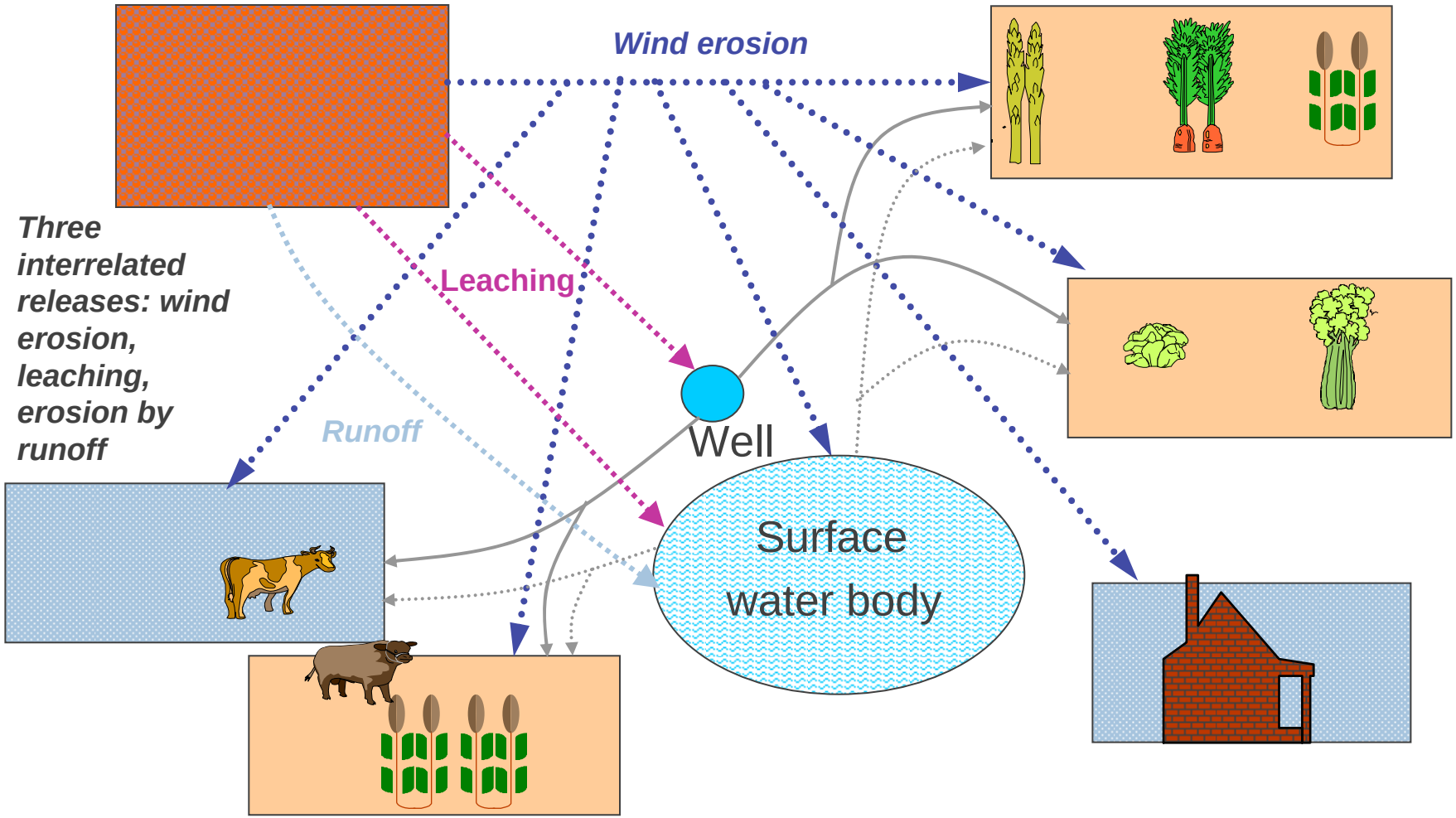


Livestock grain



Offsite dwelling

Transport to Areas of Secondary Contamination



Computational Scheme

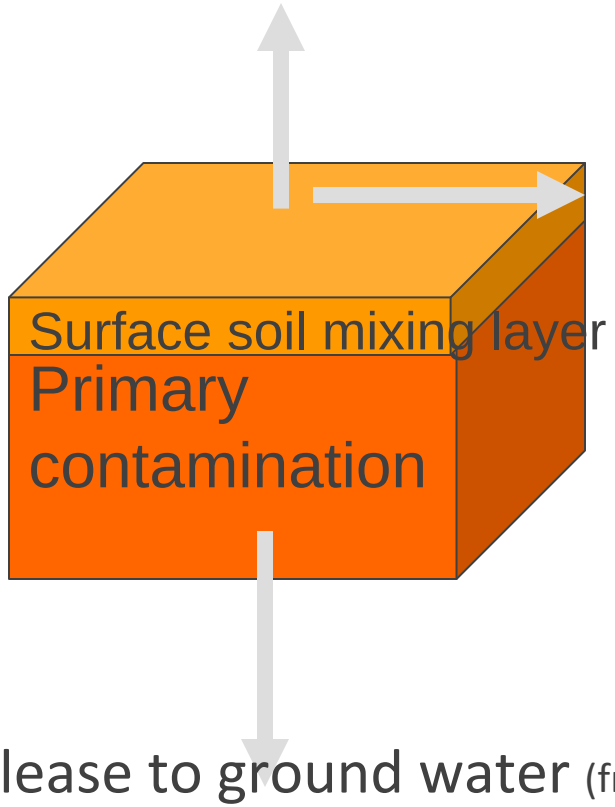
- Maintain mass balance for the source term
  - Calculate release rates (fluxes) at a series of time
- Develop analytical expressions for transport and accumulation
  - Track radioactive decay and ingrowth of progenies
  - Allow for different transport rates between parent and progenies
- Evaluate some of the analytical expressions with numerical formulations
  - Allow subdivision of each transport zone to increase precision
- The accuracy of predictions is affected by the choice of the series of evaluation times

RESRAD-OFFSITE Code Methodology

- Primary contamination
  - Source characterization and releases
- Atmospheric transport
- Groundwater transport
- Accumulation in offsite locations
- Exposure pathways

Releases from the Primary Contamination

Release to atmosphere (from the contaminated mixing layer)

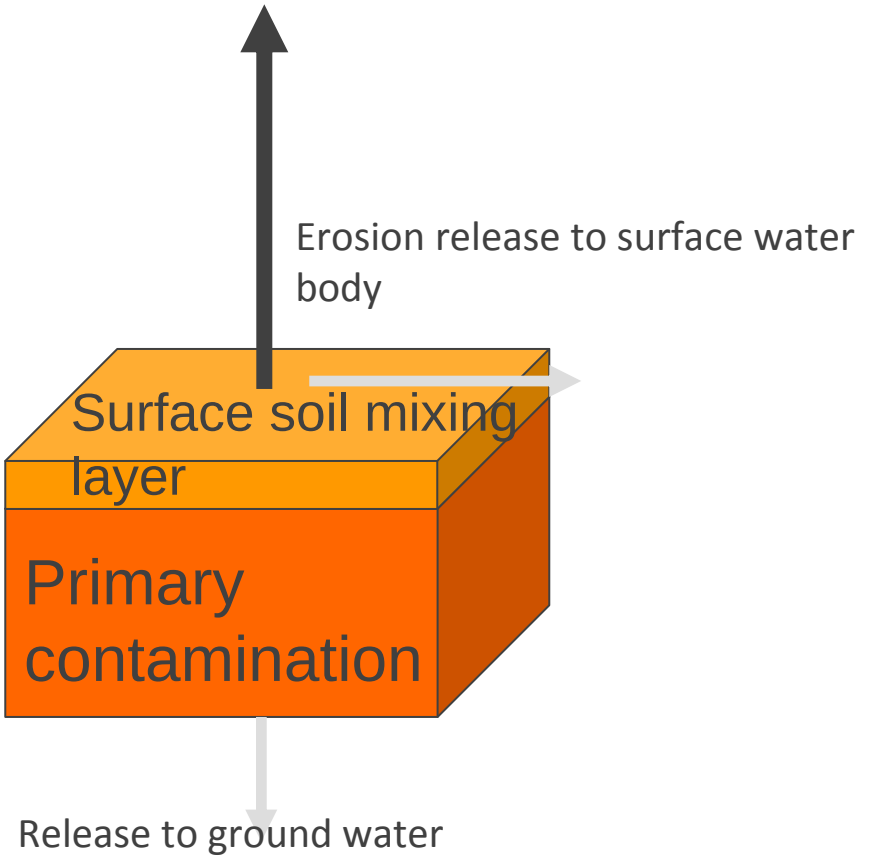


Erosion release to surface water body (from the contaminated mixing layer)

Release to ground water (from the contaminated mixing layer and primary contamination)

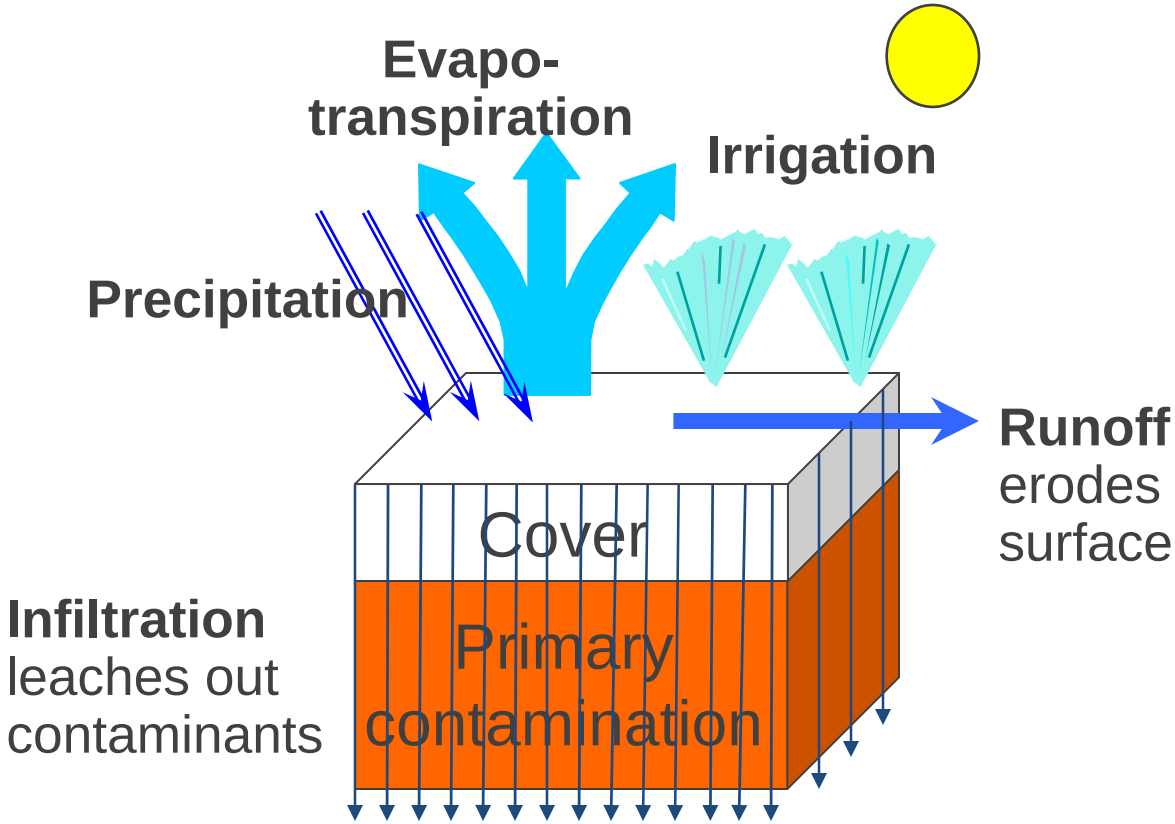
Release to Atmosphere

Release to atmosphere

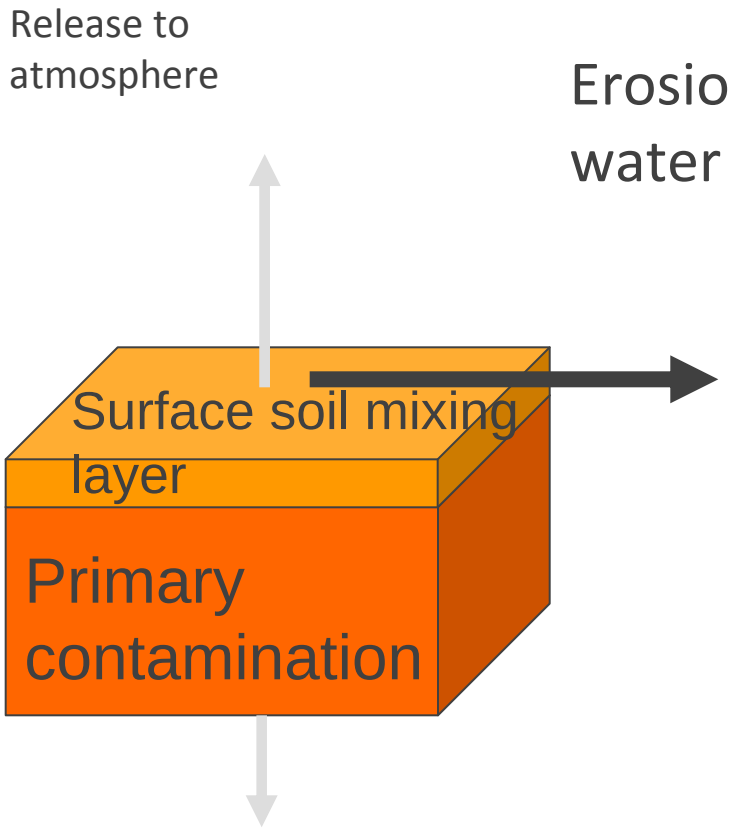


- Associated with the release of dust
  - Proportional to the quantity of particulates (dust) released
  - Proportional to concentration in mixing layer

Surface Hydrology

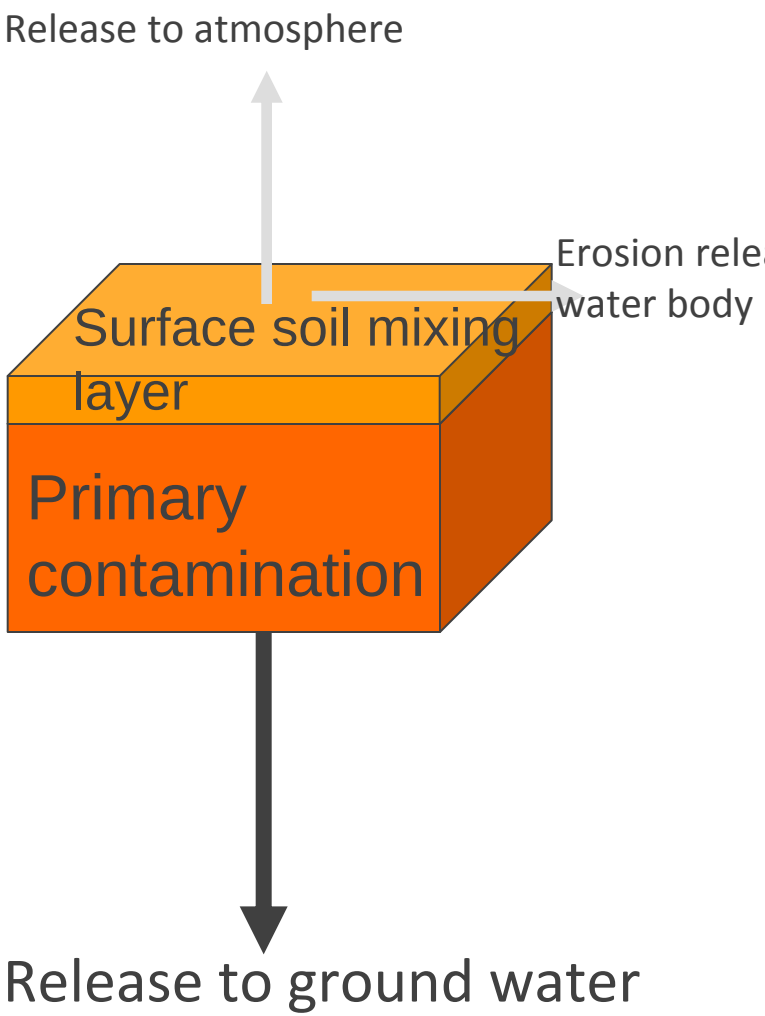


Surface Erosion Release



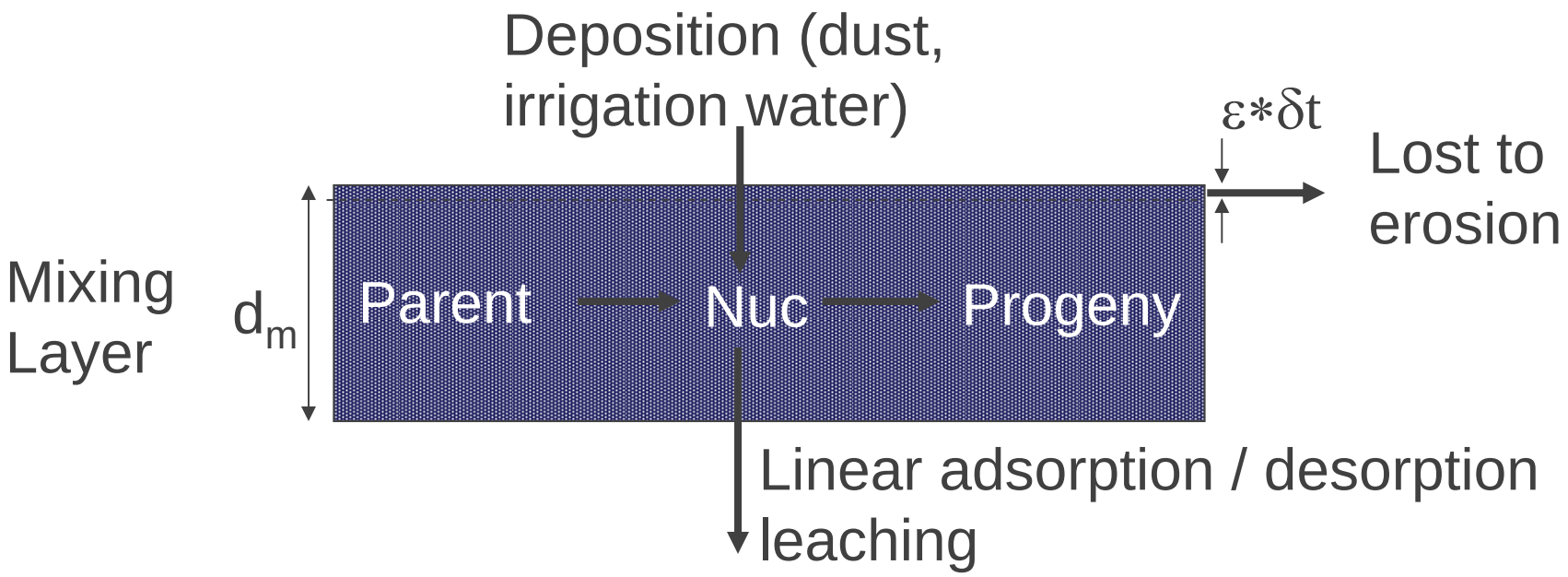
- Due to erosion of surface soil
- Proportional to the quantity of particulates eroded by runoff
  - Proportional to concentration in mixing layer

Release to Ground Water



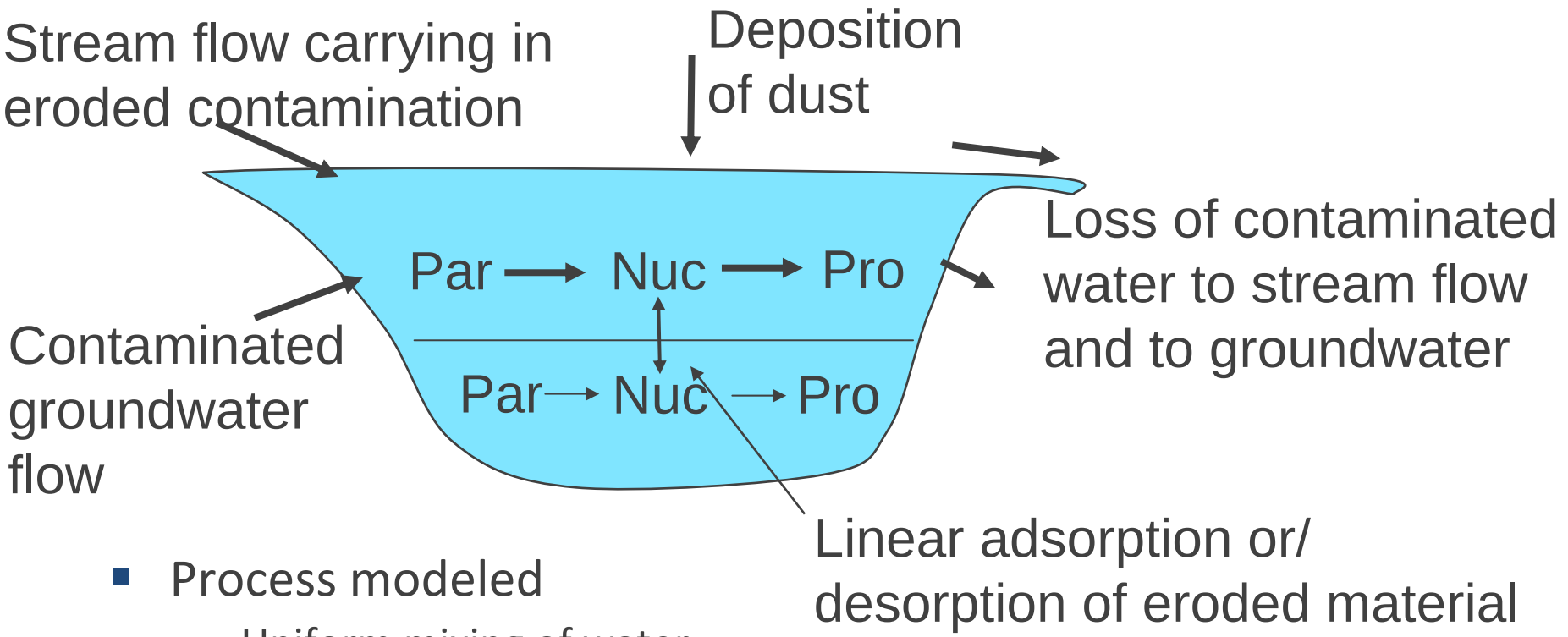
- Currently modeled as a rate controlled release
  - Proportional to current inventory in the primary contamination and mixing layer

Process Modeled for Accumulation in Offsite Soil



- Process modeled
  - Uniform mixing within mixing layer
  - Loss due to surface erosion
  - Linear adsorption/desorption
  - Radiological transformations
  - Time dependent deposition

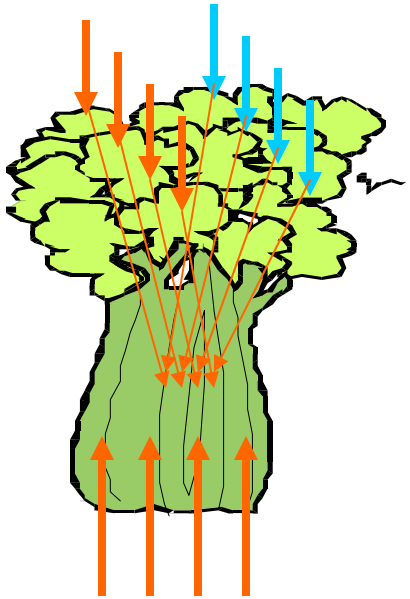
Process Modeled for Accumulation in Surface Water Body



- Process modeled
  - Uniform mixing of water
  - Radiological transformations
  - Linear adsorption desorption exchange with sediments eroded from primary contamination
  - Time dependent influx of contaminants
  - Loss with water leaving the surface water body

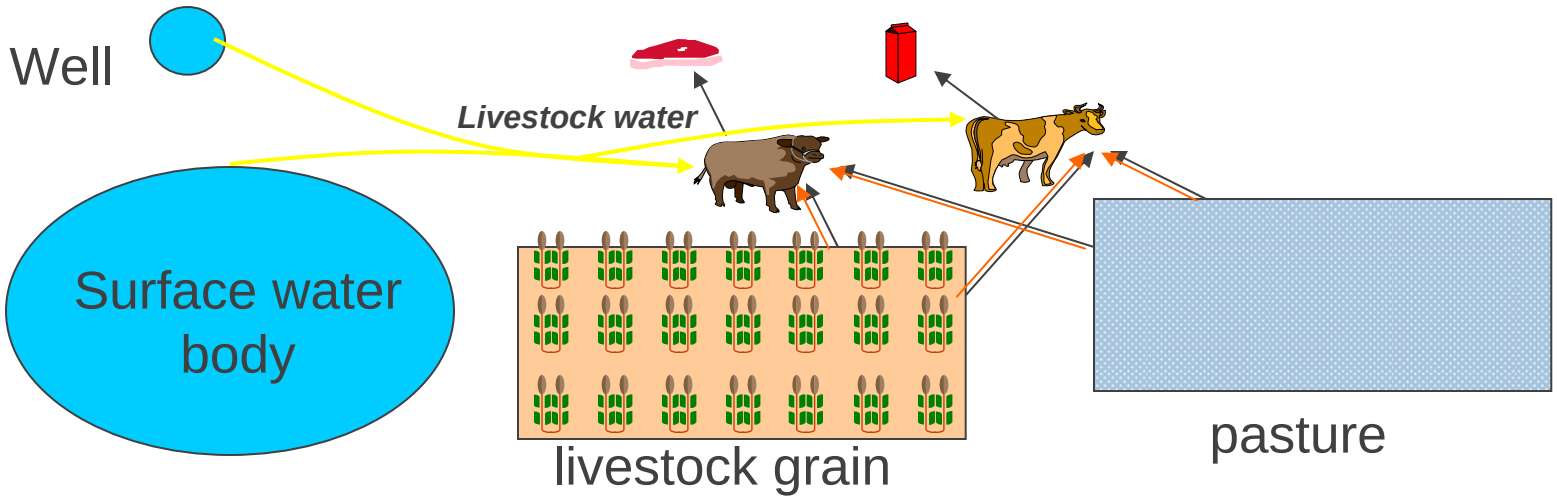
Process Modeled for Contamination of Plant Food

- Root uptake from soil
- Foliar interception of contaminated dust
- Foliar interception of contaminated irrigation
- Translocation of intercepted contamination to edible part of plant

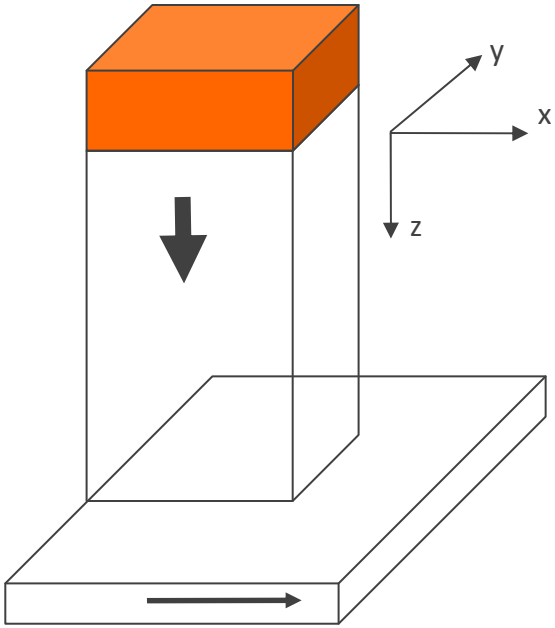


Contamination of Meat and Milk

- Ingestion of contaminated feed (grain, grass)
- Ingestion of soil with feed
- Ingestion of contaminated water
- Transfer to milk or accumulation in meat

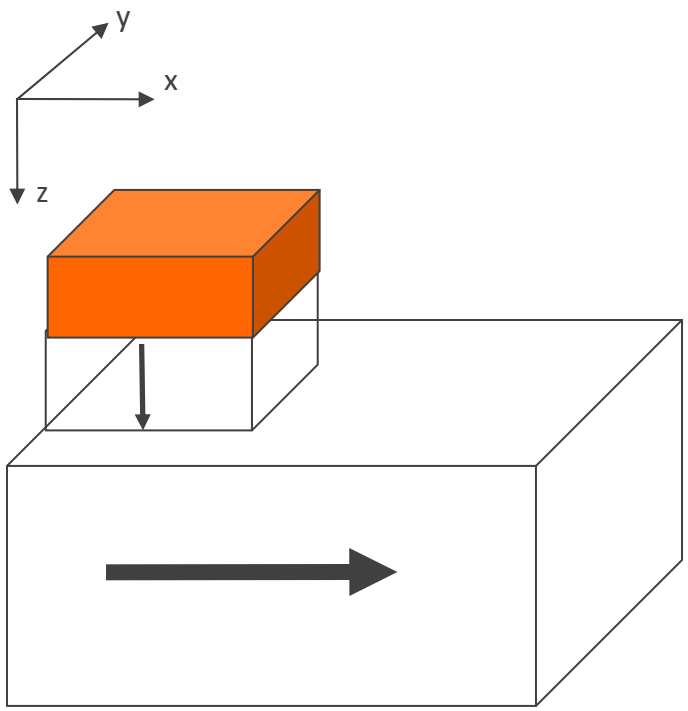


Processes Modeled for Unsaturated Zone Transport



- Vertical transport
  - Longitudinal (z) advection
  - Longitudinal (z) dispersion
  - Transformations during transport
  - Nuclide specific solute-soil interaction
    - Transport rate
    - Concentration in water

Processes Modeled for Saturated Zone Transport



- Longitudinal (x) advection
- Longitudinal (x) dispersion
- Nuclide specific solute-soil interaction
- Transverse (y, z) dispersion

Current RESRAD-OFFSITE Capabilities

- RESRAD-OFFSITE can be flagged to read in:
  - Releases and inventory of the primary contamination (deterministic run)
    - Flux to ground water
    - Flux to atmosphere
    - Flux to surface water
    - Inventory remaining in the primary contamination and mixing layers
  - Concentrations in surface water and well
- This feature allows the application of RESRAD-OFFSITE to various contamination situations, e.g.
  - waste disposed in soils,
  - emissions from effluent stacks, or
  - discharges from wastewater pipelines

New Features Are Being Implemented into RESRAD-OFFSITE

- Argonne National Laboratory is tasked by NRC to expand the source term model in RESRAD-OFFSITE so that the code can be used for waste disposal facility performance assessment
- The objectives of the NRC task are
  - to provide more release mechanisms for the user to choose from
- After the expansion of the source term model, RESRAD-OFFSITE can be applied directly to
  - evaluate different disposal methods

Extension of RESRAD-OFFSITE Capabilities

- The code currently includes the rate controlled release from the primary contamination and mixing layer
  - Release at any time is proportional to inventory at that time in the primary contamination and mixing layer
    - Release occurs over the entire depth of contamination
- The code is being modified to model transport (by water) within the contaminated zone and to provide 3 additional release options
  - "Solubility rate-controlled" release
    - A constant fraction of the source material is released over a user specified release duration
      - Release occurs over the entire depth of contamination

Extension of RESRAD-OFFSITE Capabilities - contd.

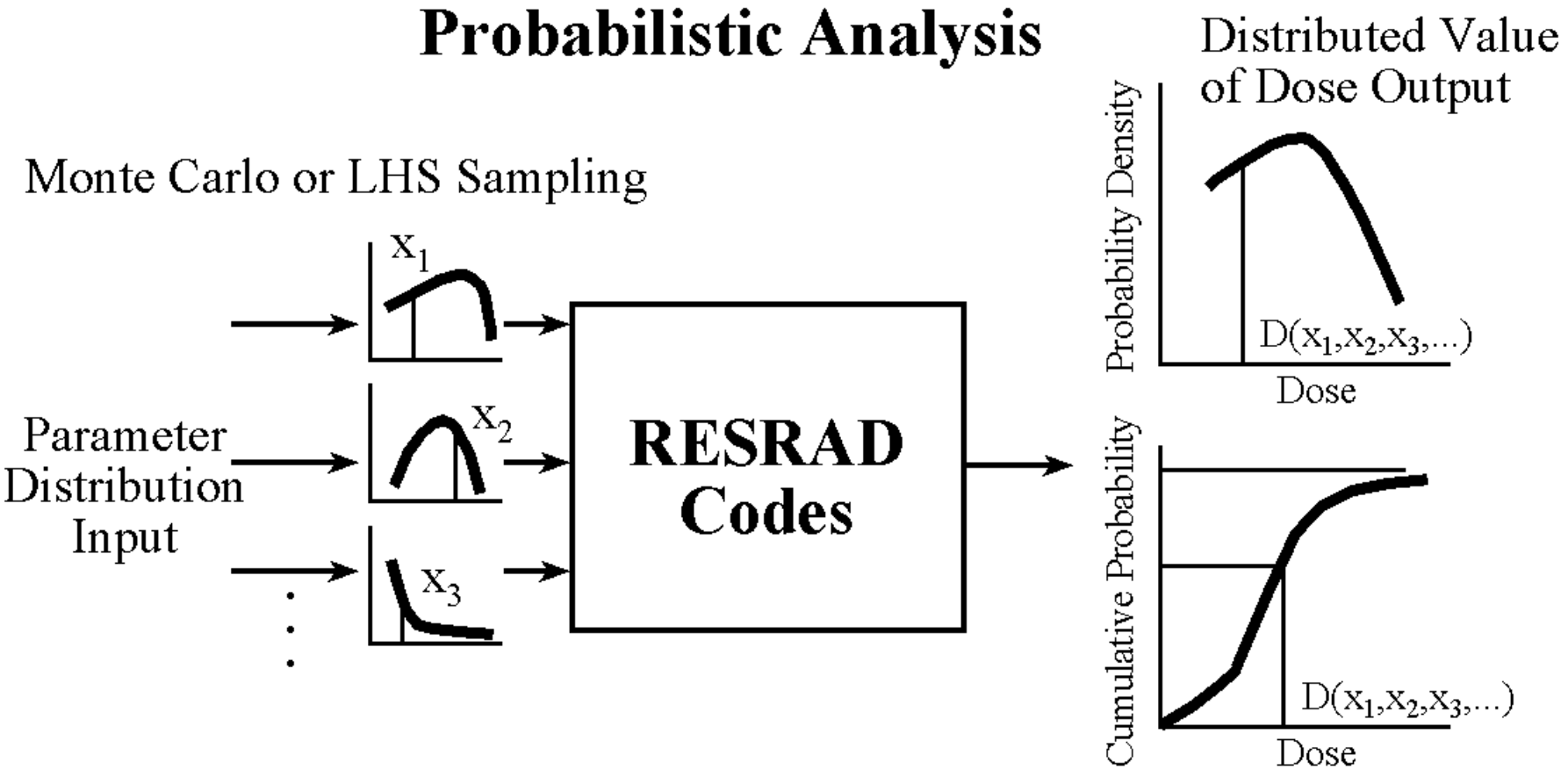
- "Solubility equilibrium" release
  - A user specified constant aqueous concentration of the isotope is released over time
    - Release occurs from the top of the contamination
- "Adsorption-desorption equilibrium" release
  - The aqueous concentration in the release is proportional to the concentration in soil
    - Release occurs from the top of the contamination

DCGL Derivation Using Probabilistic Analysis

Basic Components in Deriving DCGLs

- Source term assumptions
  - Media, radionuclide, characteristics of primary contamination
- Exposure scenario
  - Selection of appropriate exposure scenario
- Mathematical dose model
  - RESRAD/RESRAD-OFFSITE/RESRAD-BUILD
- Parameter values used in dose models

NRC's Use of Probabilistic Analysis in DCGL Derivation



Comparison of Deterministic and Probabilistic Calculations

- Deterministic
  - Calculations are performed one time in the main code
- Probabilistic
  - The number of times the calculations are performed by the main code is equal to the product of the number of observations and the number of repetitions
    - 5000 observations & 5 repetitions = 25000 calculations

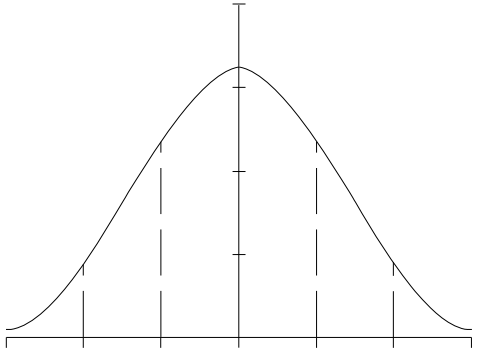
Comparison of Deterministic and Probabilistic Results

- Deterministic
  - One result, whether it be
    - the peak dose,
    - the peak risk,
    - or the temporal plot of dose (or risk)
- Probabilistic
  - As many results as there are observations
  - A distribution of the result
    - the distribution of the peak dose,
    - the distribution of the peak risk
    - or the temporal plot of the distribution of dose (or risk)

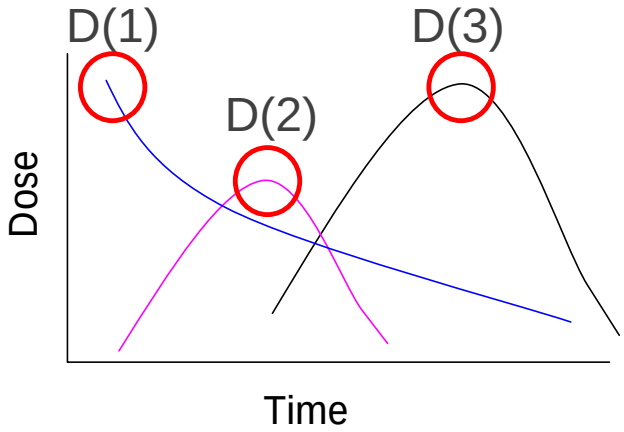
Comparison of Deterministic and Probabilistic Dose or Soil Guideline

- Deterministic
  - Based on the peak dose, (or peak risk)
- Probabilistic
  - Based on some measure of the distribution of the peak dose (or peak risk)
    - A percentile (e.g. 99%, 95%) of the distribution of the peak dose (or peak risk)
    - The mean of the peak doses
    - The peak of a percentile of the distribution of the dose over time
    - The peak of the mean doses over time

Probabilistic Terminology

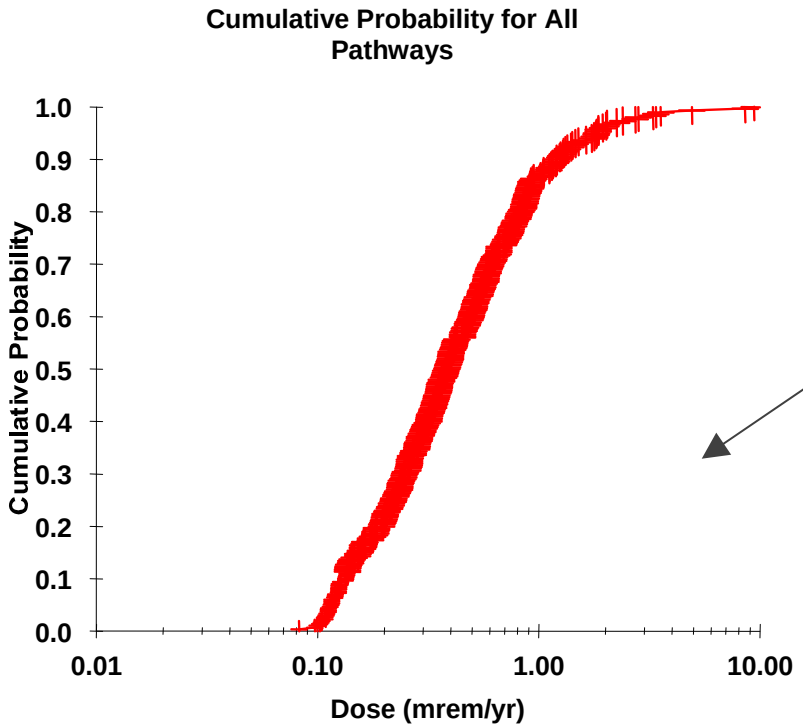


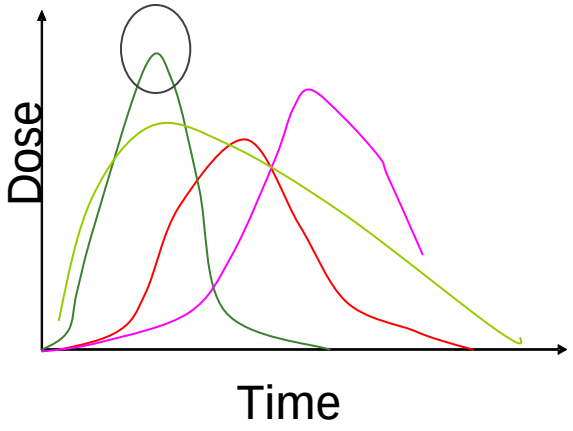
- Parameter sampling
- Parameter correlations
- “Peak of the mean” (NRC uses this)
- “Mean of the peaks”
- Parameter sensitivity
  - Deterministic
  - Probabilistic



Output Results

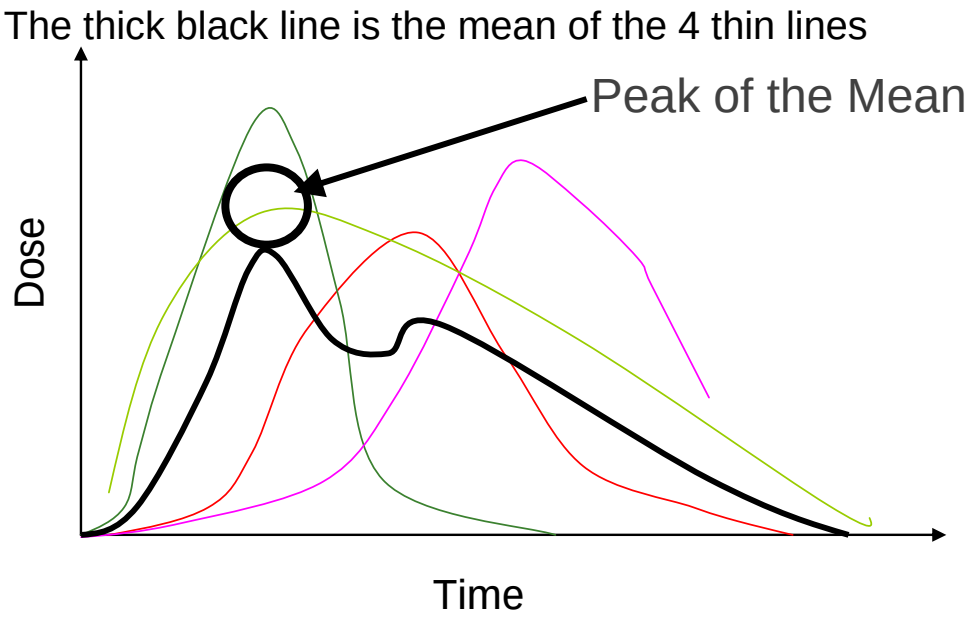
- Output from a probabilistic dose calculation is a probability distribution of dose.





Probabilistic Results

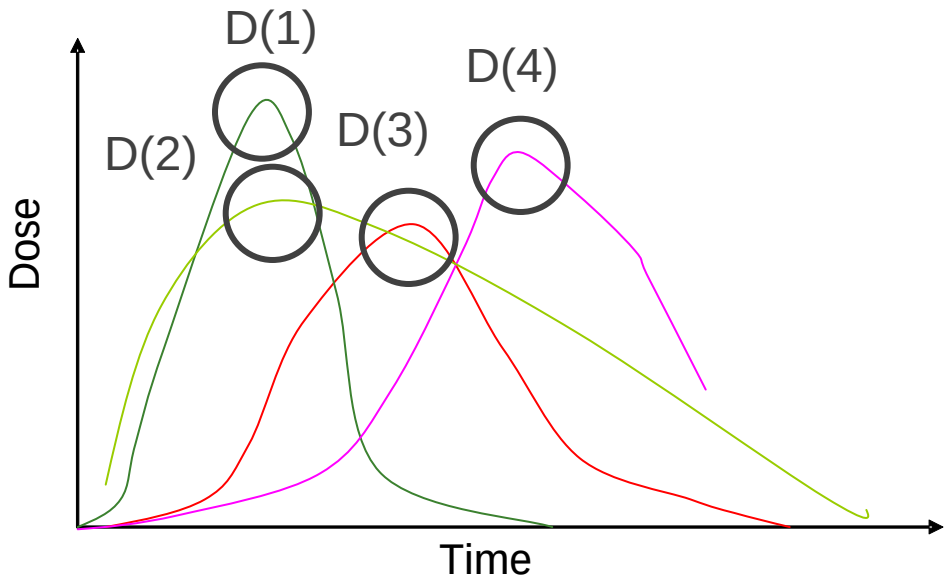
- Peak of the Mean
  - Arithmetic mean of the dose for all observations at a given time period
  - The point in time where the arithmetic mean is the maximum is the "peak of the mean" dose



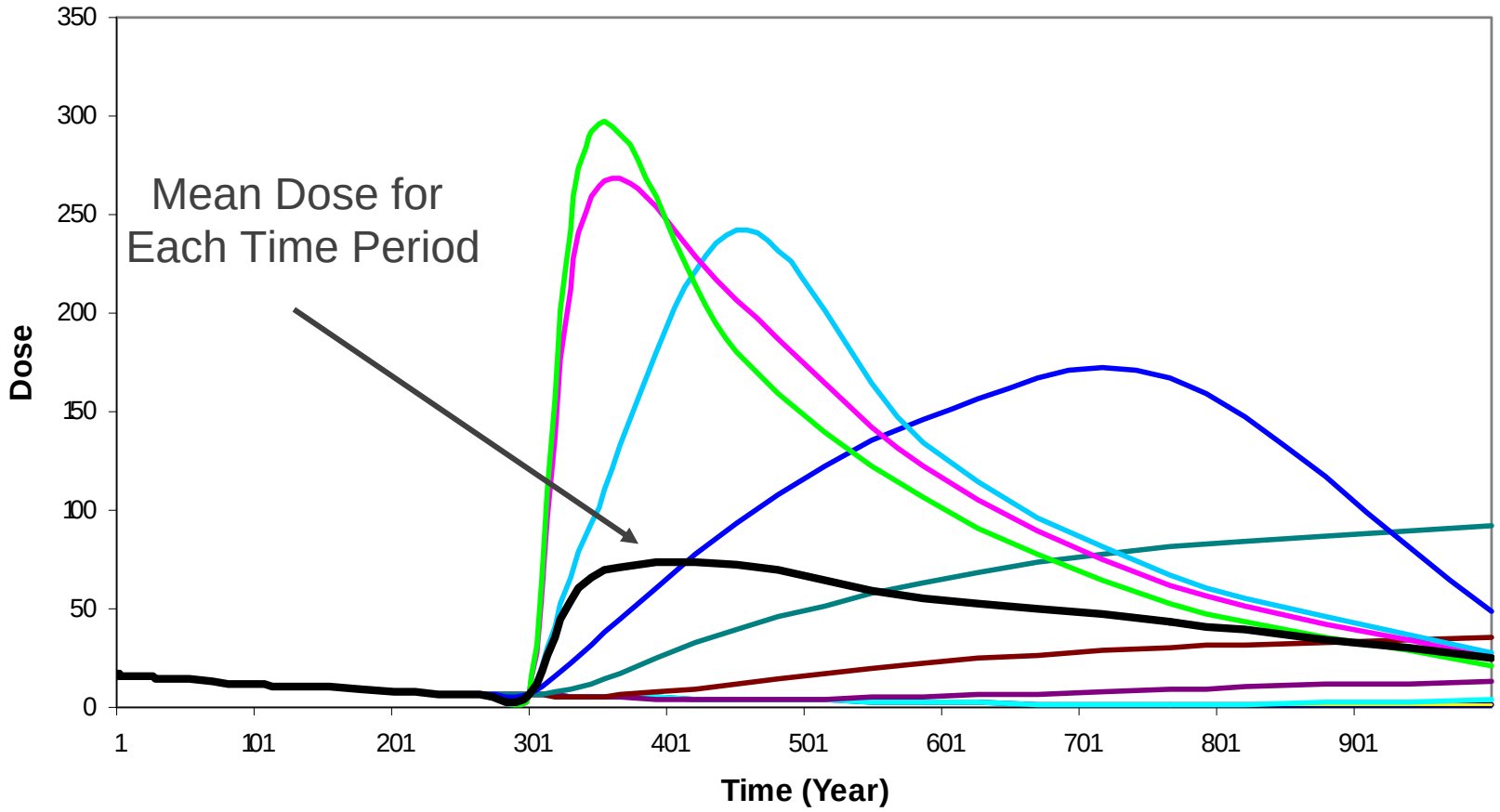
Probabilistic Results

- "Mean of the Peaks"
  - Arithmetic mean of the peak total dose from all pathways"
  - Peaks can occur different times

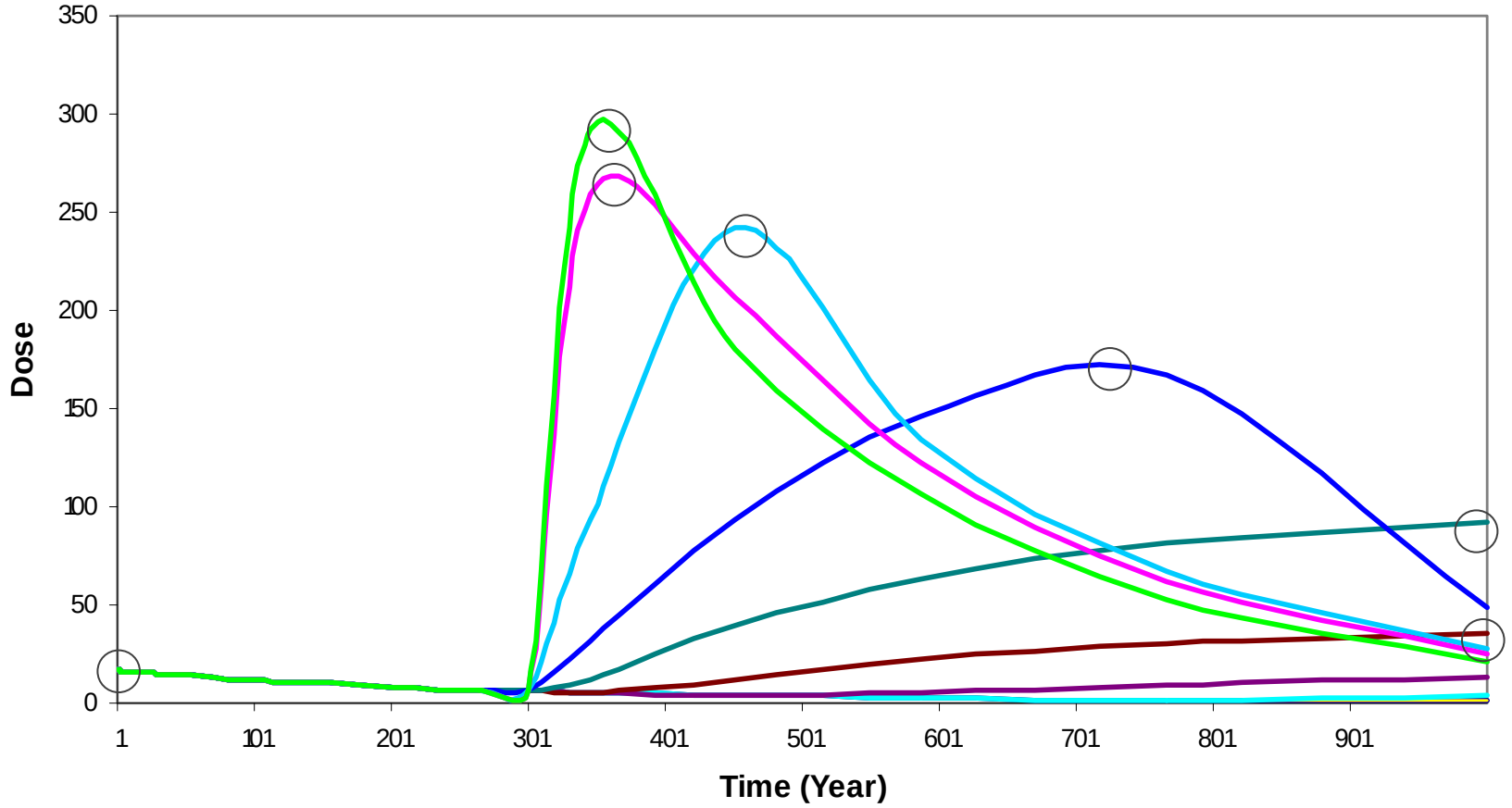
$$Mean\ of\ the\ Peaks = \frac{D(1) + D(2) + D(3) + D(4)}{4}$$



Peak of the Mean Approach



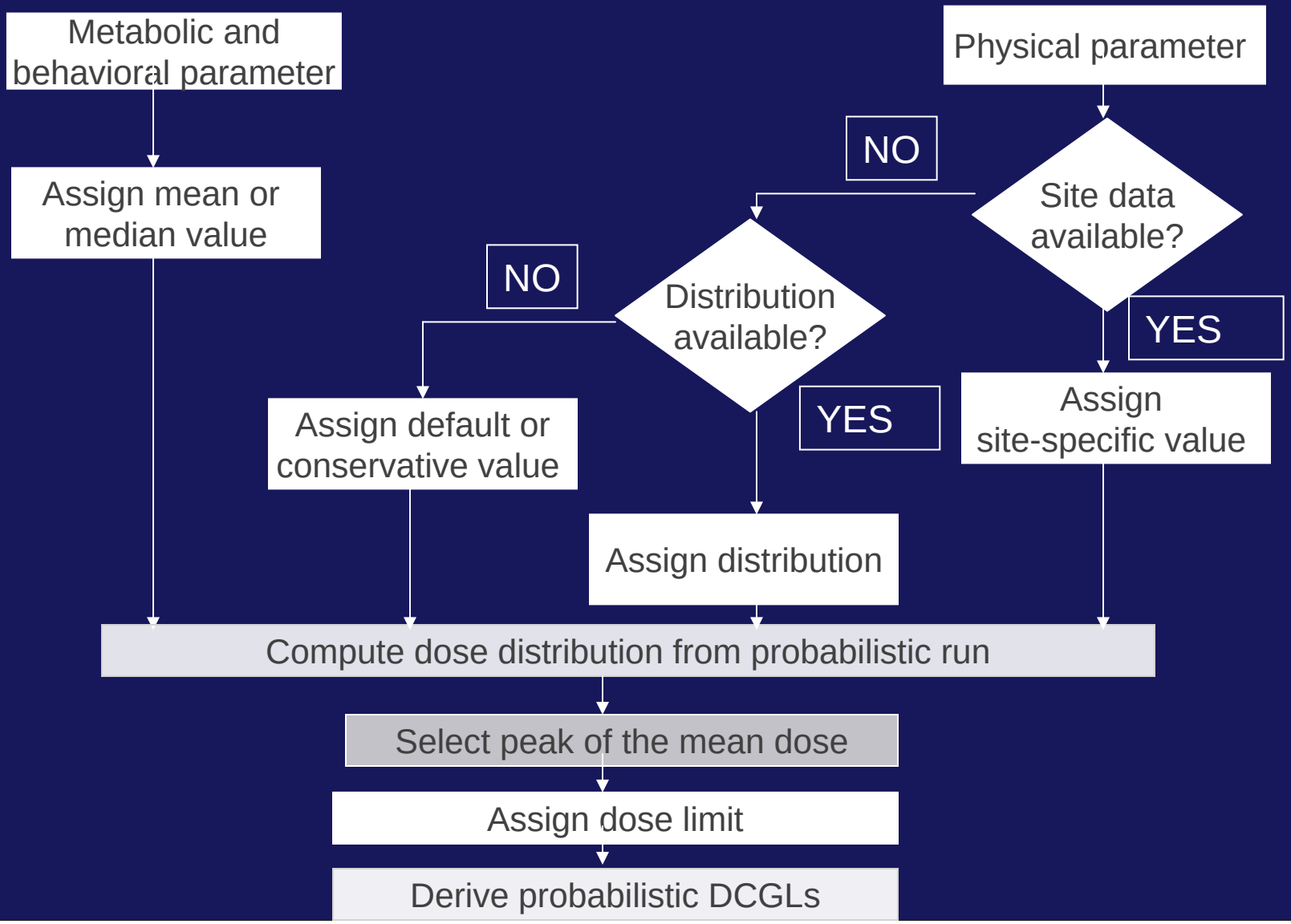
Mean of the Peak Dose: Identify the Peak Dose for Each



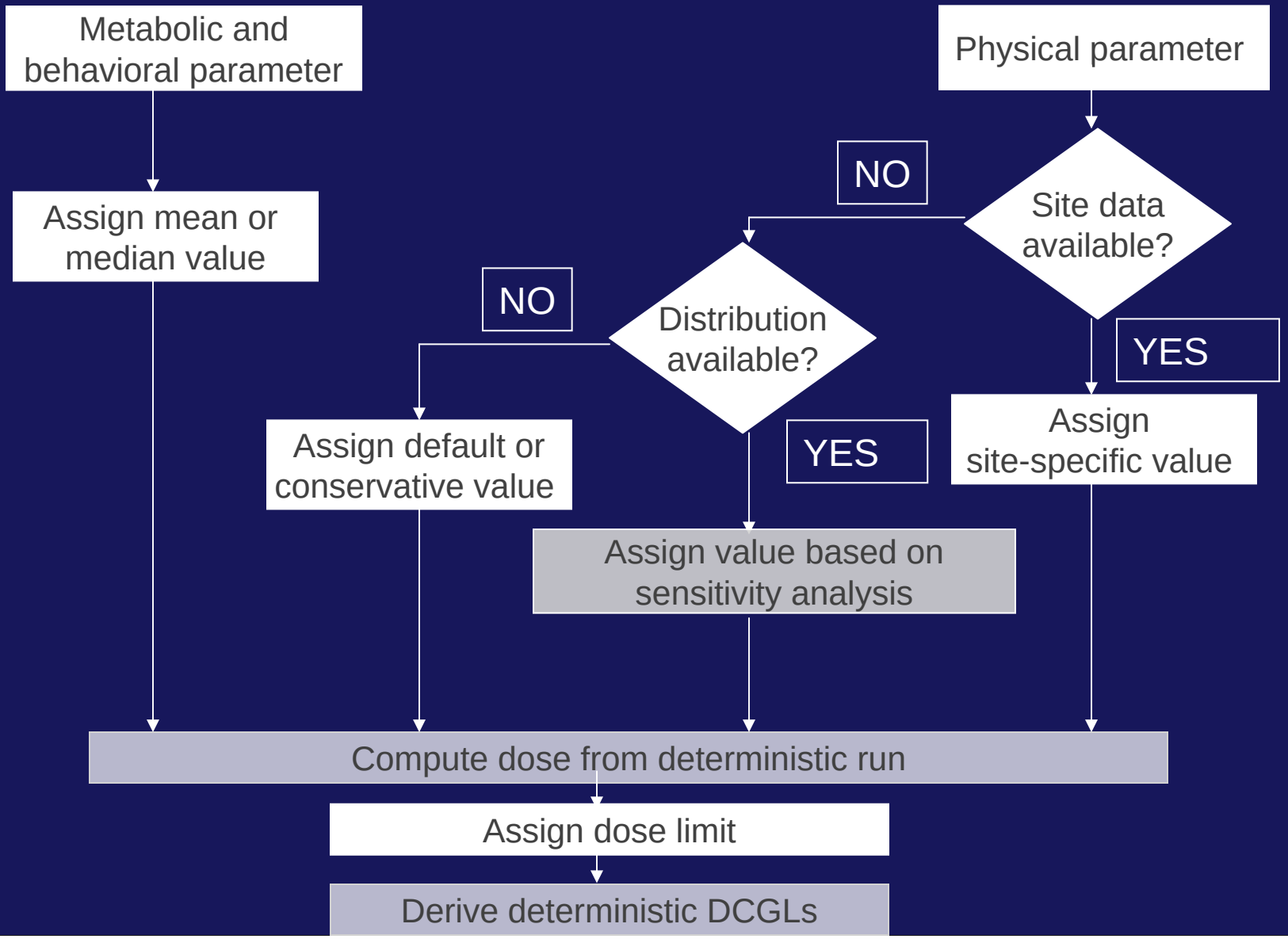
Peak of the Mean of the Doses at Graphical Times

- "Mean of the Peak" doses is always greater than or equal to the "Peak of the Mean" doses at graphical times
- When using the Peak of the Mean dose at graphical times,
  - Use sufficient graphical time points to capture all the peaks from each individual sample
  - Linear spacing of graphical time points will give better coverage over the entire time horizon
  - These are the defaults in RESRAD-OFFSITE

Probabilistic Analysis



Reasonably Conservative Deterministic Analysis



Parameter Values for Reasonably Conservative Deterministic Analysis

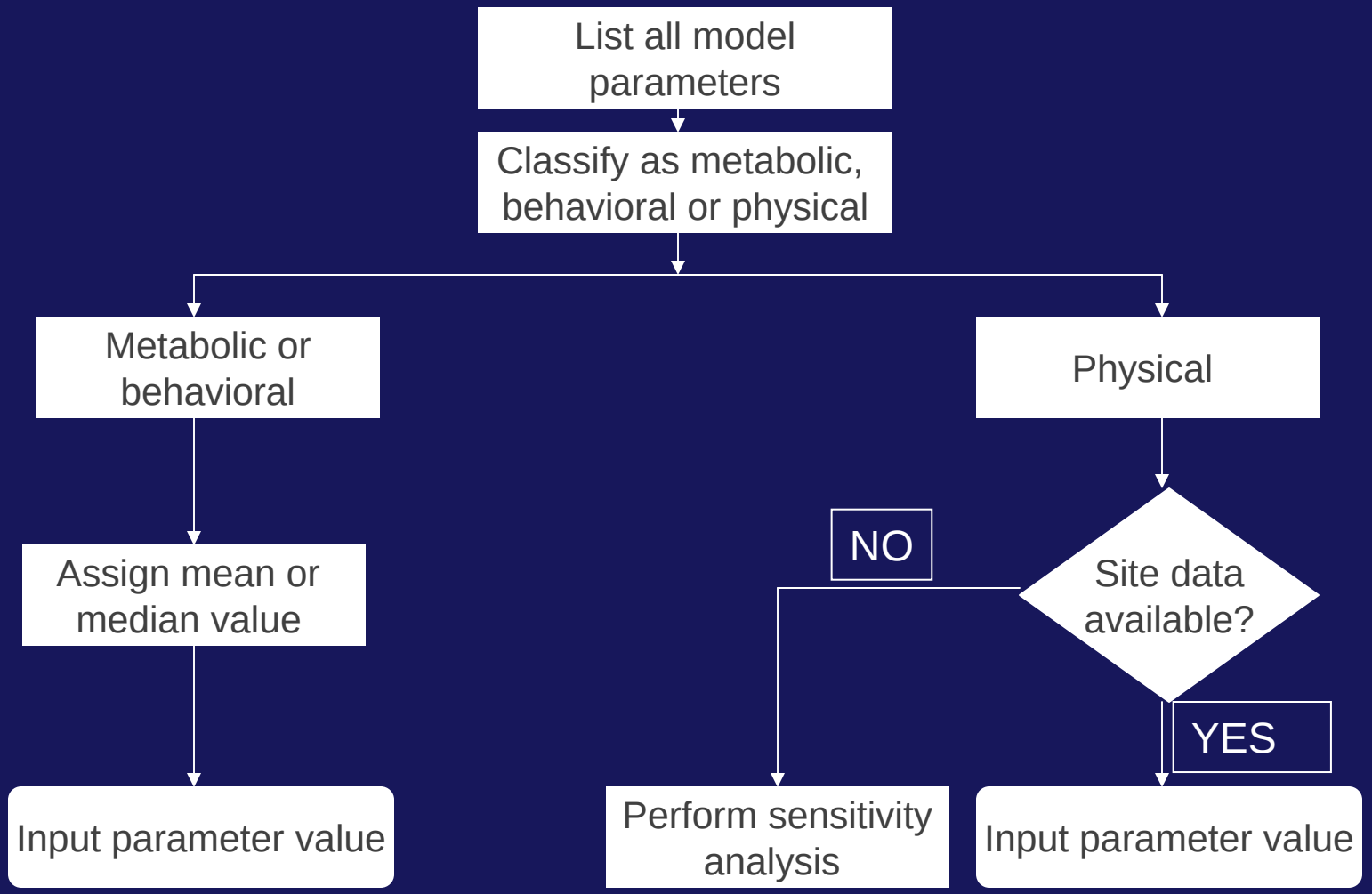
- Objective
  - Select reasonably conservative values

- Method
  - List model parameters
  - Classify parameters (metabolic, behavioral, and physical)
  - Identify sensitive parameters
  - Determine parameter value
  - Use as input in a deterministic analysis

Parameter Types

- Metabolic
  - Parameter that represents a metabolic characteristic of the potential receptor and is independent of scenario
- Behavioral
  - Parameter that depends on the receptor's behavior and the scenario definition
- Physical
  - Parameter that is source- or site-specific

Parameter Value Selection Process



Why Find the Sensitive Parameters?

- To justify the use of default values for some of the parameters
  - The parameters that have an insignificant influence on the variability of the dose

- To identify the parameters for which additional data needs to be collected in order to decrease the variability in the dose
  - The parameters that have a significant effect on the variability of the dose

Finding the Sensitive Parameters in RESRAD-OFFSITE

- There are many ways to do this in RESRAD-OFFSITE
  - One input parameter at time using the “single parameter” sensitivity feature”
  - One input parameter at time using the probabilistic feature
  - Multiple input parameters at the same time using the probabilistic feature and regression analysis

Probabilistic or Uncertainty Analysis

- Probabilistic Analysis, all parameters simultaneously
  - Can use sufficient number of observations to cover the entire range of the selected parameters and the range of their interactions
  - Considers the interaction of the parameters
  - Can not see the temporal effects of the different values of a selected parameter
    - Temporal plots are not available for the individual observations
    - All the parameters are varied simultaneously
  - More difficult to understand and visualize the results

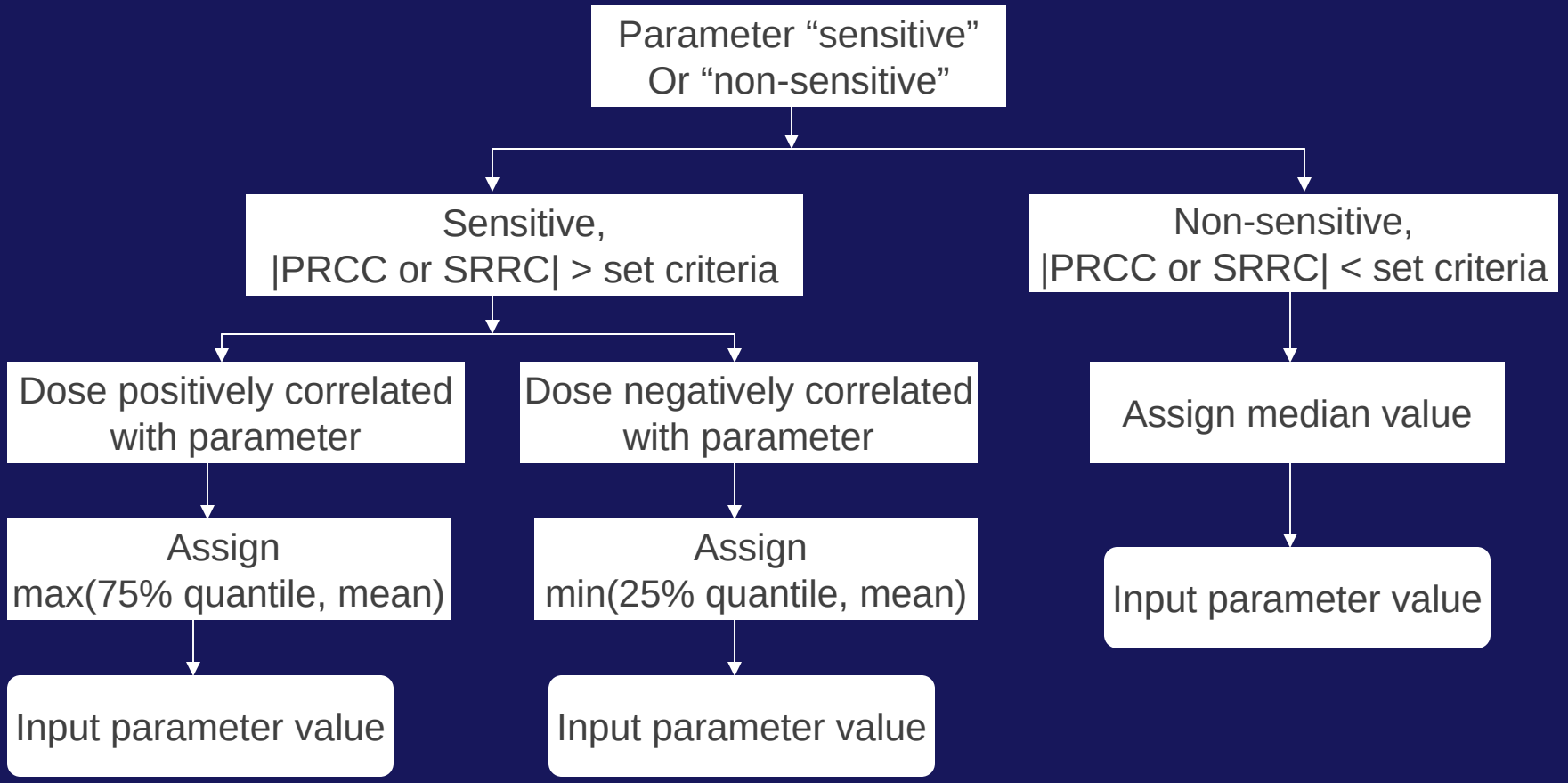
Sensitivity Analysis

Factors	Deterministic	Probabilistic
Data needs	1) Baseline parameter values 2) Ranges of parameter values	Distributions of parameter values
Calculation Procedures	1) Calculate peak dose at parameter's base values 2) Calculate peak dose at parameter's low and high value by keeping the other parameters at their base values 3) Repeat (1) and (2) for all parameters	1) Sampling each parameter based on distribution 2) Generate numerous input data sets of the sampling data 3) Calculate peak dose for each input data set
Parameter Sensitivity	Percent change in the peak dose as defined by normalized dose difference	SRRC quantifies contributions to radiation dose from each individual parameter
Results	NDD for each individual parameter	SRRC for each individual parameter Easy to identify few most sensitive parameters
Advantages	Study the influence of a single parameter	Consider variation in more than one parameter simultaneously
Limitations	Provides point (local) sensitivity and does not evaluate the effects of simultaneous changes in a large number of input parameters	It is hard to identify less sensitive parameters in the presence of a few more sensitive parameters

Approaches for Determining Parameter Sensitivity

Approaches	Advantages	Disadvantages
Scatter plots	**Visual display of the relationship**	**Differentiate between the sensitivity of parameters**
PCC	**Linear relationship and unique contribution**	**Nonlinear relationships**
SRC	**Linear relationship and shared contribution**	**Nonlinear and correlated parameters**
PRCC	**Nonlinear monotonic relationship and unique contribution**	**Non-monotonic relationship**
SRRC	**Nonlinear monotonic relationship and shared contribution**	**Correlated parameters**

Parameter Value Selection (cont.)



Some Observations about Finding the Sensitive Parameters

- Scatter plots are useful in finding the sensitive parameters when there are a few important inputs
  - Can “see” the effect
    - Can have a high confidence that the effect is real
- Must use regression coefficients when the interaction between sensitive parameters masks the effect in 2 dimensional scatter plots
  - Use the coefficient of determination to select the coefficient to be used
    - Standardize regression coefficient
    - Standardized rank regression coefficient
    - Code does this for you
  - Can not “see” the effect, hence the reluctance to use this method

Some Observations about Finding the Sensitive Parameters – cont.

- Confirm that the selected sensitive parameters account for all the variability in the dose
  - Narrow the distribution of the insensitive parameters and rerun with uncertainty on the sensitive parameters
    - Retains the samples for the sensitive parameters and the grouping of samples from the initial run
  - Compare the two cumulative distribution plot

Caution on Interpreting Probabilistic Results and Blindly Using Output Correlations

- "He uses statistics like a drunk uses a lamp post….for support rather than illumination"