United States Nuclear Regulatory Commission

Dose Assessment for Decommissioning

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General Components of Dose Analyses

- Develop source term
- Define land-use scenarios and exposure pathways
- Develop conceptual model
- Develop mathematical model/select computer codes
- Define input parameter values
- Carry out analyses
- Perform sensitivity/uncertainty analyses

Develop Source-Term

- Identify the radionuclides of concern
  - Use site characterization and HSA
- Describe the physical/chemical form(s) of the contaminated media*
- Recognize there is a distinction between source-term for calculating doses vs deriving acceptable concentration limits
  - For calculating doses:
    - Delineate the spatial extent of the residual radioactivity *
  - For calculating concentration limits:
    - Assume unit concentrations or activities

* *anticipated at the time of the Final Status Survey and site release*

Define Land-Use Scenarios and Exposure Pathways

- Each exposure scenario should address the following questions:
  - how does the residual radioactivity move through the environment?
  - where can humans be exposed to the environmental concentrations?
  - what are the exposure group's habits that will determine exposure?
- The ultimate goal of dose modeling is to estimate the dose to a specific receptor
- Two example scenarios are:
  - Building occupancy
  - Resident farmer

Building Occupancy Scenario

- Used for residual radioactivity on indoor building surfaces
- Assumptions:
  - Light-industrial indoor worker
  - Passive activities
- Pathways include:
  - external exposure
  - inhalation of (re)suspended removable residual radioactivity
  - inadvertent ingestion of removable residual radioactivity

Resident Farmer Scenario

- Used for residual radioactivity in soils and sediments
- Key Assumptions:
  - Large portion of diet grown on the site
  - Individual spends portion of time both indoors and outdoors
- Pathways include:
  - external exposure from soil
  - inhalation to (re)suspended soil
  - ingestion of soil
  - ingestion of drinking water from aquifer
  - ingestion of plant products grown in contaminated soil and using aquifer to supply irrigation needs
  - ingestion of animal products grown onsite (using feed and water derived from potentially contaminated sources)
  - ingestion of fish from a pond filled with water from the aquifer

Additional Scenario Examples

- Urban construction
- Residential (subset of the residential farmer)
- Recreational User
- Maintenance Worker
- Drinking water (offsite impacts)

Develop Conceptual Models

- A conceptual model is a simplified representation of the site
  - the potential release and migration of radionuclides
  - key features and processes controlling the migration of radionuclides
- Decide among possible competing interpretations of the site data
- Determine the level of detail needed to describe the key features and processes

Additional Consideration in Developing A Conceptual Model

- The analysis need not incorporate all the physical, chemical, and biological processes
- A conceptual model can be simple if it provides satisfactory confidence in site performance
- A generic representation is acceptable if it provides a conservative assessment of the performance of the site

Develop Mathematical Model/Select Computer Codes

- The mathematical model/computer code must appropriately represent the conceptual model
- Determine whether to perform a conservative screening analysis or more realistic site-specific analysis
- Determine whether the analysis will be deterministic or probabilistic
- Determine whether existing computer codes are suitable
  - Commonly used codes:
    - DandD
    - RESRAD
    - RESRAD-Build

DandD Conceptual Model

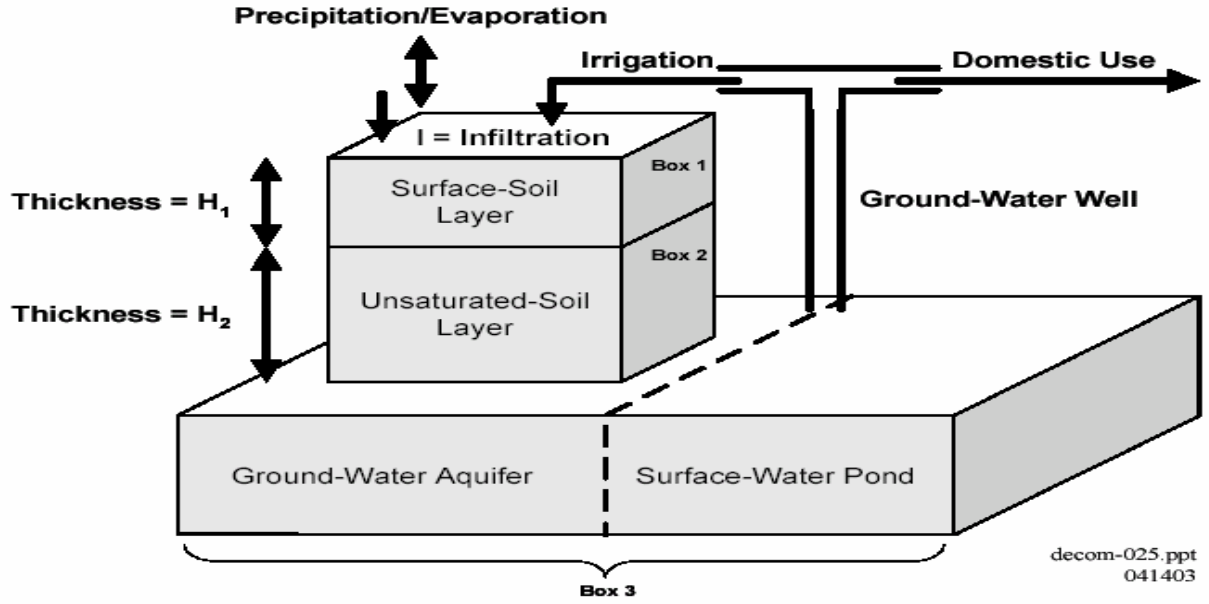
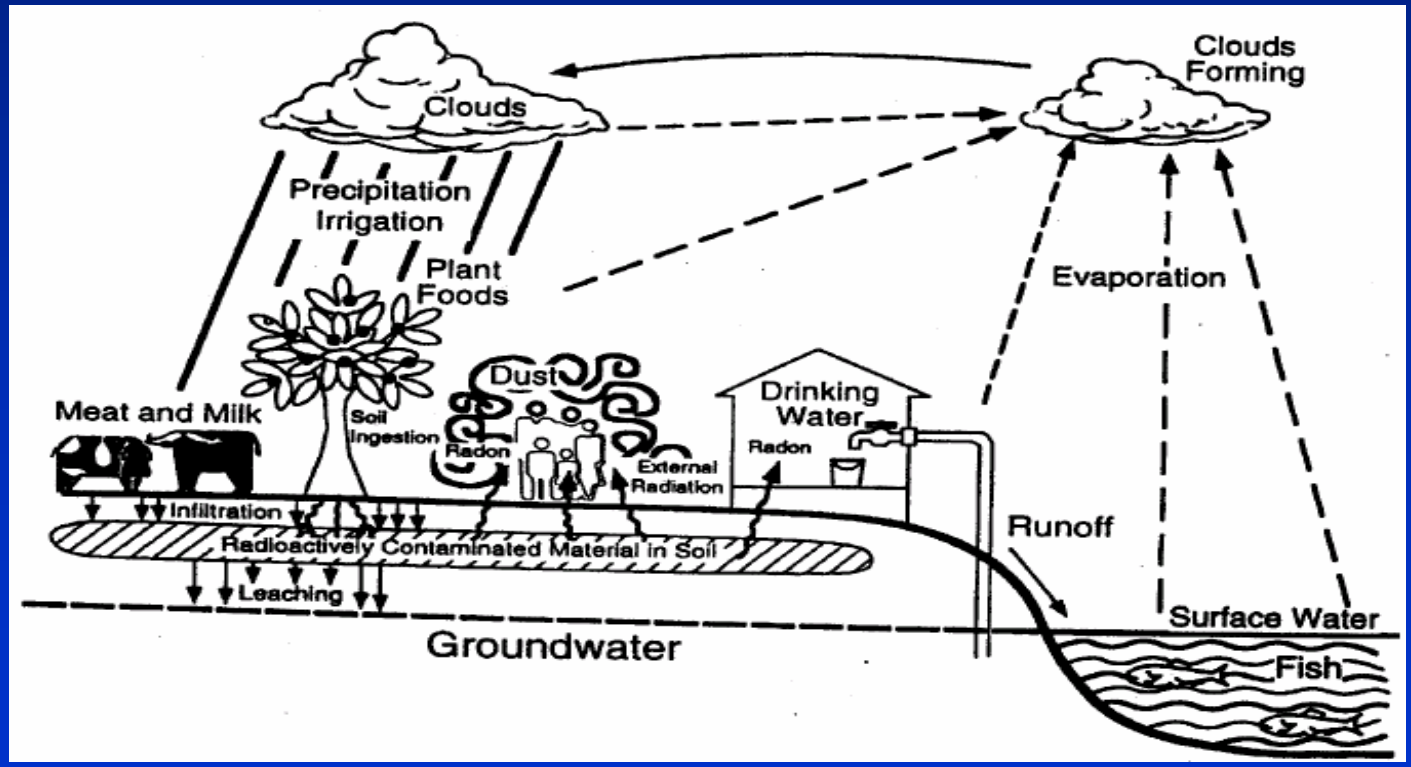


Figure I.3 DandD Conceptual Model of the Ground-Water and Surface-Water Systems (from NUREG/CR–5621).

RESRAD Conceptual Model



Define Input Parameter Values

- Behavioral parameters – any parameter whose value depends on the receptor's behavior and the scenario
  - For a specific group of receptors, a parameter value could change as the scenario changes
  - Example: irrigation rate, fraction of water or food grown onsite
- Metabolic parameters – any parameter that represents the metabolic characteristics of the potential receptor
  - Independent of scenario or site
  - May differ for different age groups
  - Example: breathing rate, food consumption rate
- Physical parameters – parameter values related to the source or physical characteristics of the site
  - Example: porosity, density

Carrying-out the Analysis

- Screening
  - Use look-up tables
  - Perform analysis using DandD
- Site-specific
  - RESRAD
  - RESRAD-Build
  - More advanced models/codes

Derived Concentration Guideline Level (DCGL)

- The $DCGL_W$ is the concentration of a radionuclide which, if distributed uniformly across a survey unit, would result in an estimated dose equal to the applicable dose limit.

- The $DCGL_{EMC}$ is the concentration of a radionuclide which, if distributed uniformly across a smaller limited area within a survey unit, would result in an estimated dose equal to the applicable dose limit.

Screening DCGLs

- Simple sites with building surface and/or with surficial soil residual radioactivity
- Simple and conservative models/codes and parameters, under generic scenarios
- Screening DCGLs are expected to be more restrictive than the site-specific DCGLs.
- Screening analysis may save licensees time and effort, but it may require more remediation

Qualifications for Screening Values Building Surfaces

- The residual radioactivity on building surfaces should be surficial [less than 10 mm of penetration]
- Residual radioactivity on surfaces is mostly fixed
  - removable fraction no greater than 0.1
  - undetermined or higher than 0.1, the screening values should be decreased by a factor of 10.
- Not applicable to surfaces such as buried structures or equipment

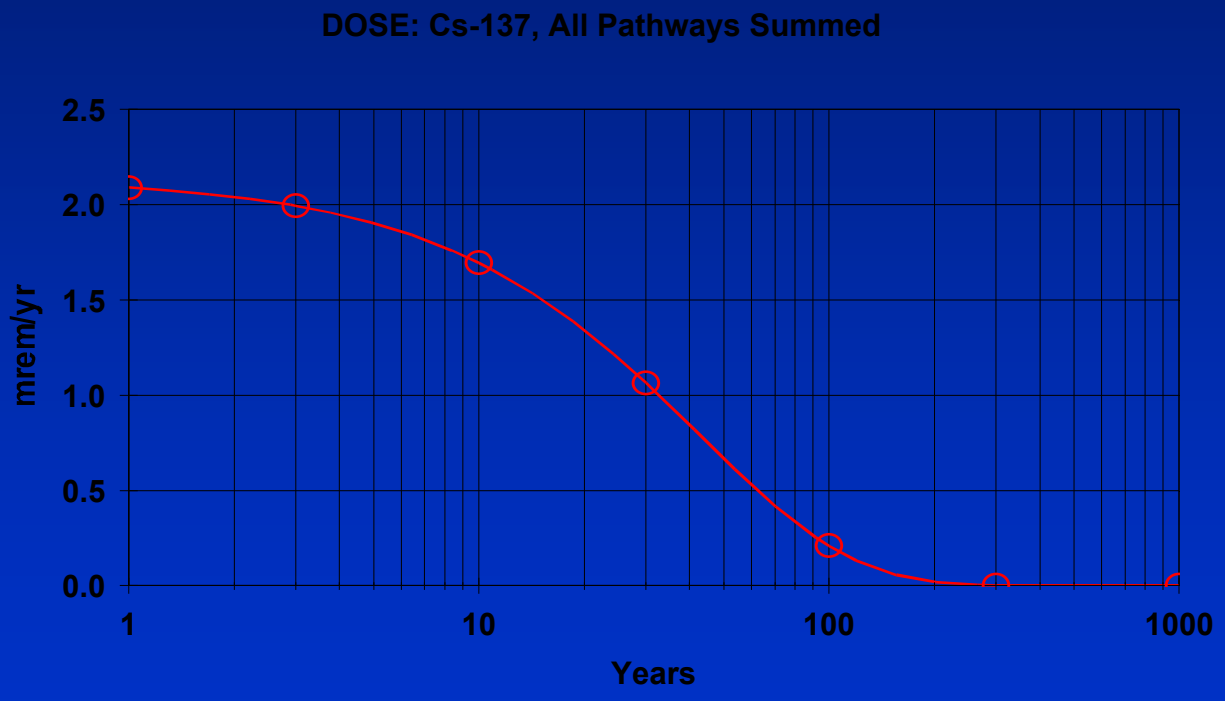
Qualifications for Screening Values Surface Soil

- The initial residual radioactivity is contained in the top layer of the surface soil
- The unsaturated zone and the ground water are initially free of residual radioactivity
- The vertical saturated hydraulic conductivity at the specific site is greater than the infiltration rate (e.g., there is no ponding or surface run-off)

Site Specific DCGLs

- Site conditions are not consistent with screening criteria
- Screening DCGLs are unnecessarily restrictive
- Site-specific DCGLs are derived using
  - exposure pathway scenarios
  - conceptual models/computer models
  - physical (site) input parameter values
  - behavioral/metabolic input parameter values

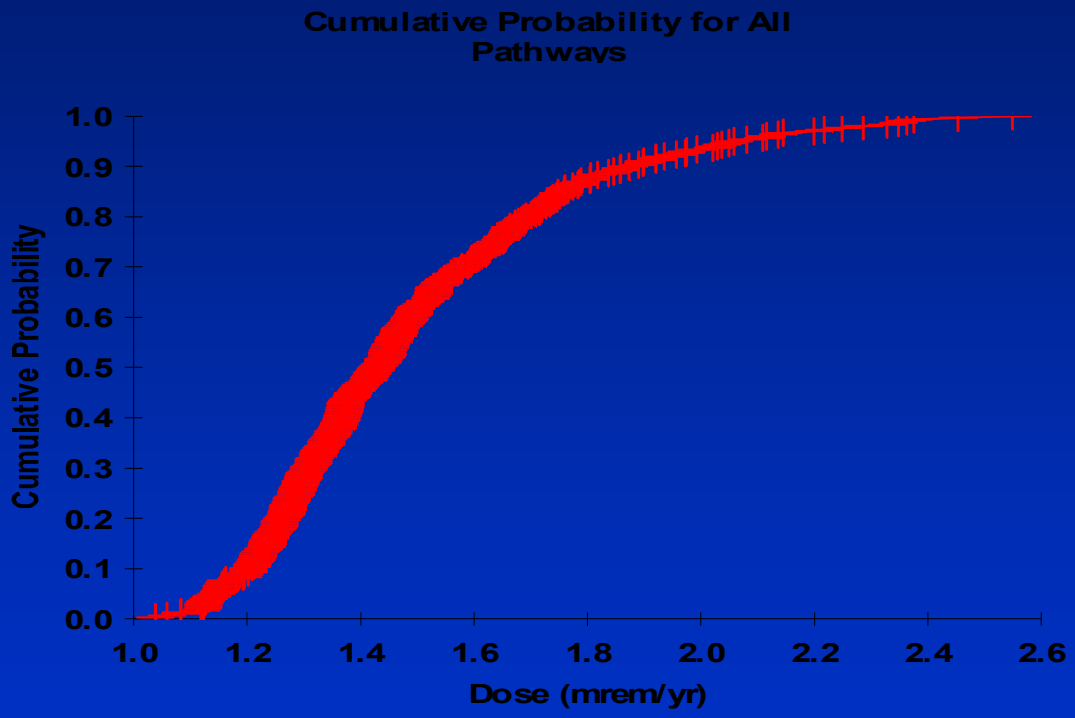
Example



Peak dose = 2.0895; DCGL = 25/2.0895 = 11.965 pCi/g

What is an Uncertainty Analyses?

- There are three primary sources of uncertainty in a dose assessment
  - uncertainty in the models
  - uncertainty in scenarios
  - uncertainty in the parameters
- The primary emphasis in an uncertainty analysis should be to identify the important assumptions and parameter values that influence decisions about the site


Cumulative Probability for All Pathways
Cumulative Probability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Dose (mrem/yr)

What is a Sensitivity Analyses?

- Sensitivity analysis identifies parameters and assumptions that have the largest effect on the result
- Sensitivity analysis provides a tool for understanding and explaining the influence of these key assumptions and parameter values on the variability of the estimated dose

Key Issues in Addressing Uncertainty

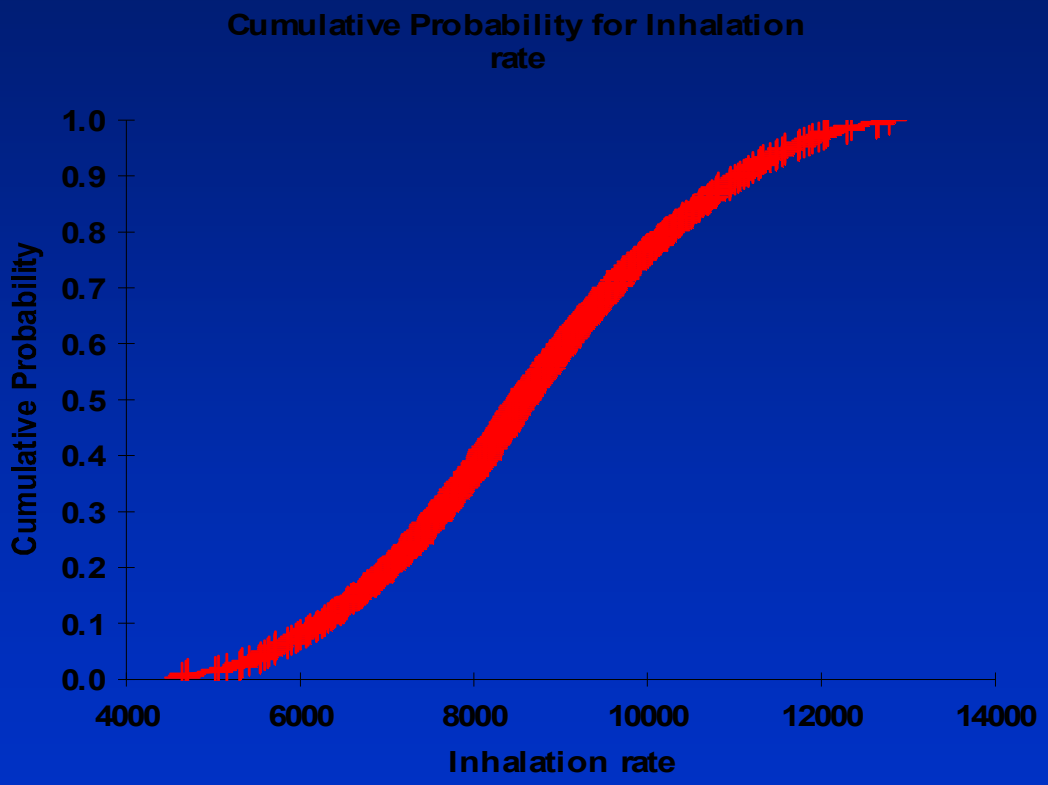
- Considering alternative conceptual models and scenarios
- Determining appropriate parameter distribution and ranges, and the associated correlation between parameters
- Specifying the metric of the dose distribution to use in determining compliance with the dose limit

Approaches in Uncertainty Analysis

- Deterministic
  - single value for each parameter
  - demonstrate that the estimated dose is an overestimate
- Probabilistic
  - parameter values selected from a probability density function
  - multiple runs performed (Monte Carlo analysis)

Input Parameter Distributions

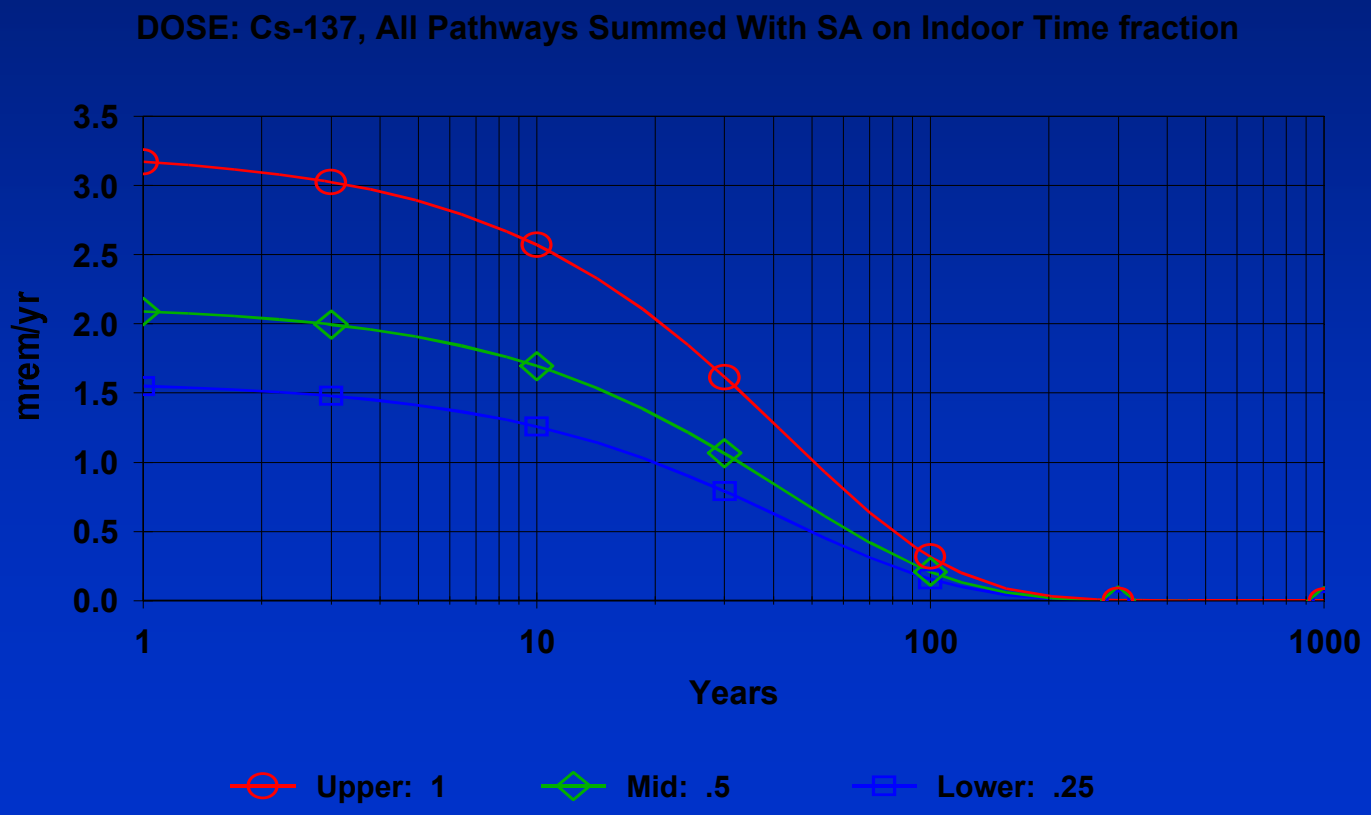
- Avoid assigning overly restrictive ranges
- Unreasonably large ranges may not account for what is known about a parameter and also may lead to “risk dilution”
- The distributions used in the analysis should characterize the degree of belief that the true but unknown value of a parameter lie within a specified range of values for that parameter

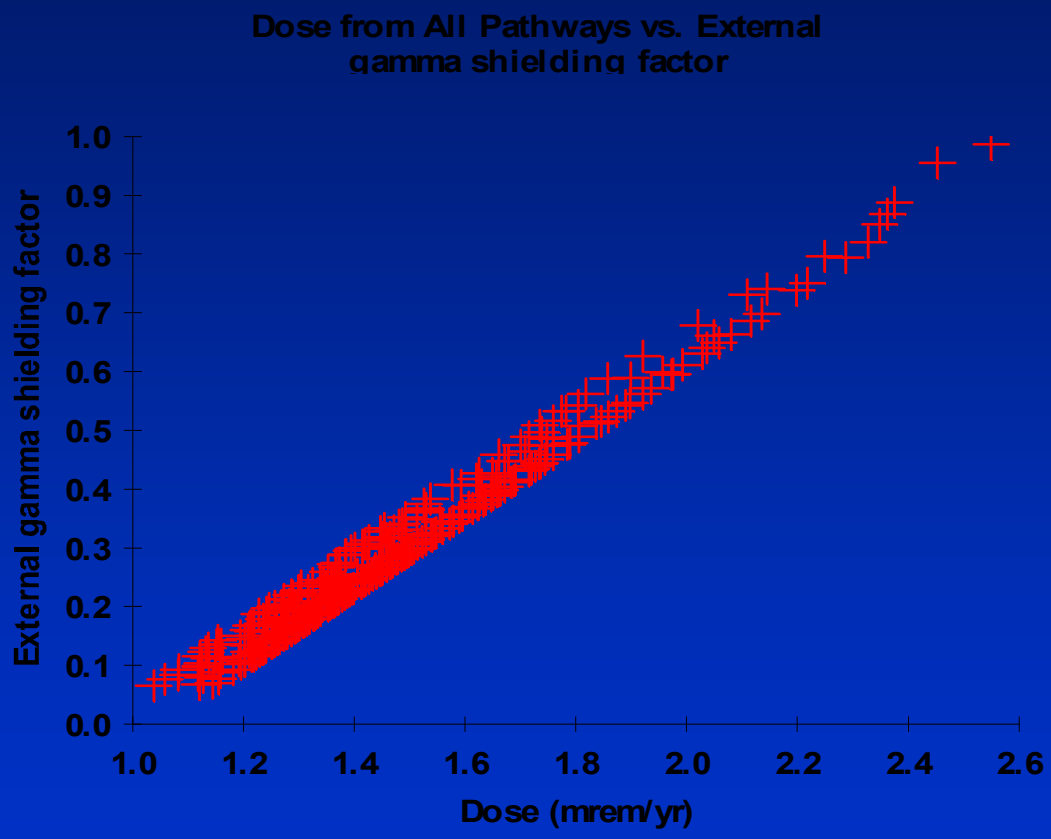

Cumulative Probability for Inhalation rate
Cumulative Probability
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
4000
6000
8000
10000
12000
14000
Inhalation rate

Sensitivity Analyses

- Deterministic sensitivity analysis
  - Calculates the change in the output result (peak dose) with respect to a small change in the independent variables, one at a time (dY/dX)
- Multivariable sensitivity analysis
  - Sensitivity of multiple parameters are considered at the same time.
  - Allows consideration of the influence of parameters that could be masked by other parameters
  - Can be evaluated using scatter plots or regression analysis

Example Single Parameter Sensitivity Analysis




Dose from All Pathways vs. External gamma shielding factor
External gamma shielding factor
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
Dose (mrem/yr)