Dose and Risk Assessment

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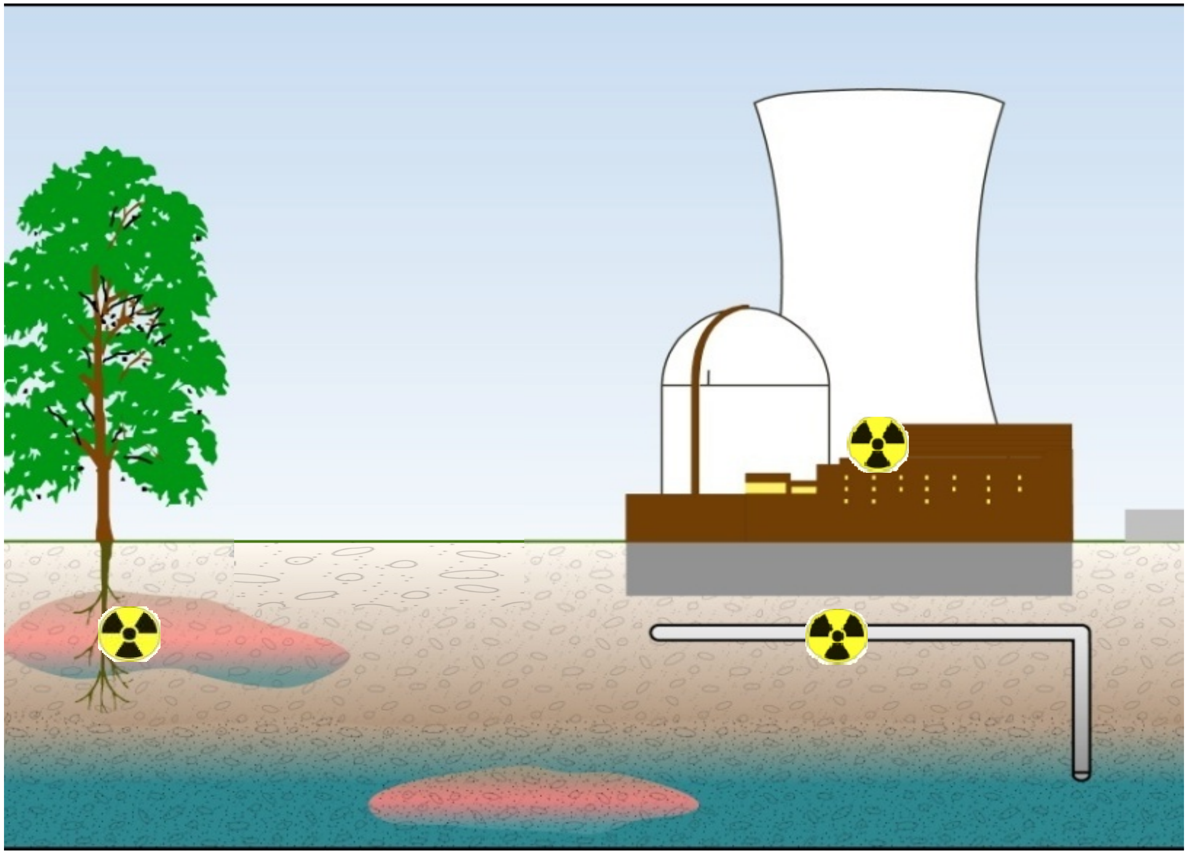
Dose and Risk Assessment

- Introduction to dose and risk assessment and radionuclide transport in the environment
- Overview of pathway analyses and data requirements
- Dose conversion coefficients and risk coefficients (slope factors)
- Developing dose- and risk-based cleanup criteria
- Overview of selected dose and risk assessment codes and models
  - Presentation of different codes and models and their applicability
  - Demonstration of NNL ReCLAIM screening assessment tool
  - Demonstration of RESRAD family of codes

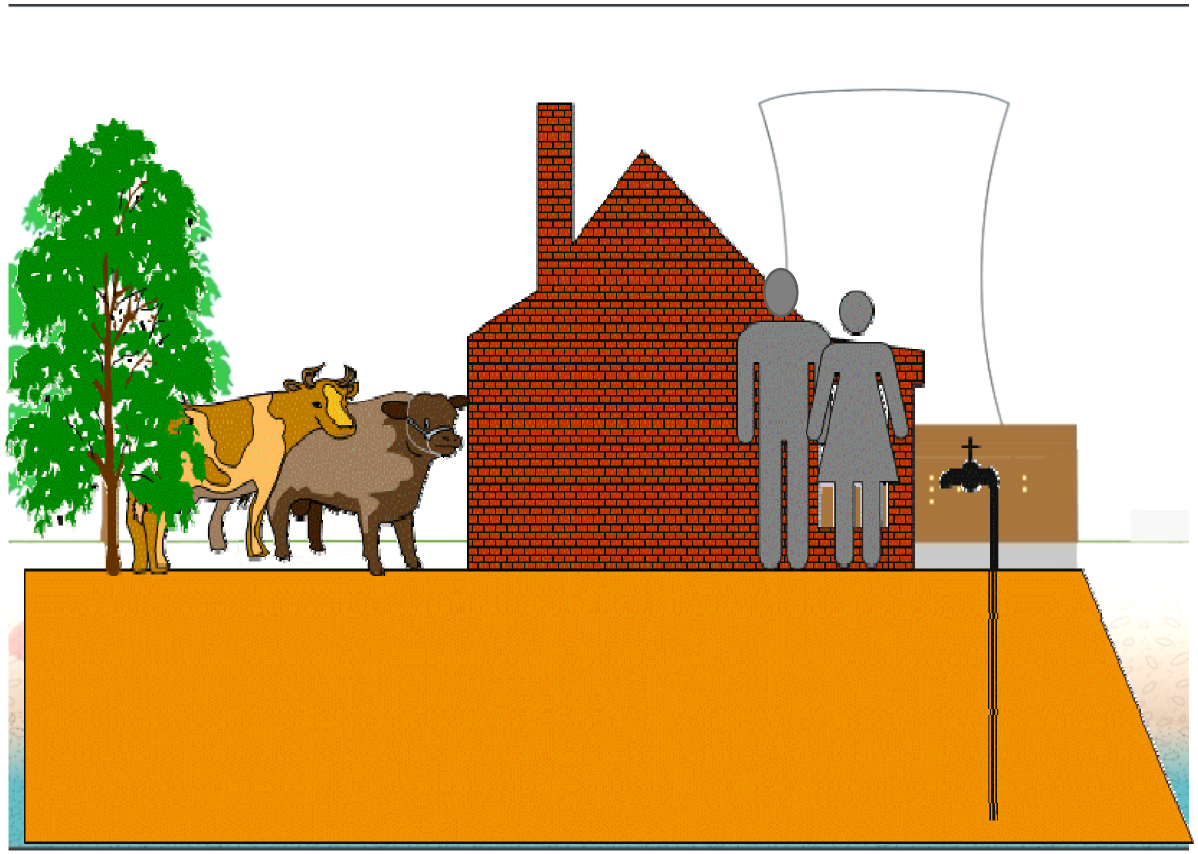
Dose Assessment for the Derivation of Site-Specific Cleanup Guidelines

- Determine exposure scenario(s)
- Determine exposure pathway(s)
- Gather data
- Understand calculations
- Calculate guidelines
- Conduct cleanup

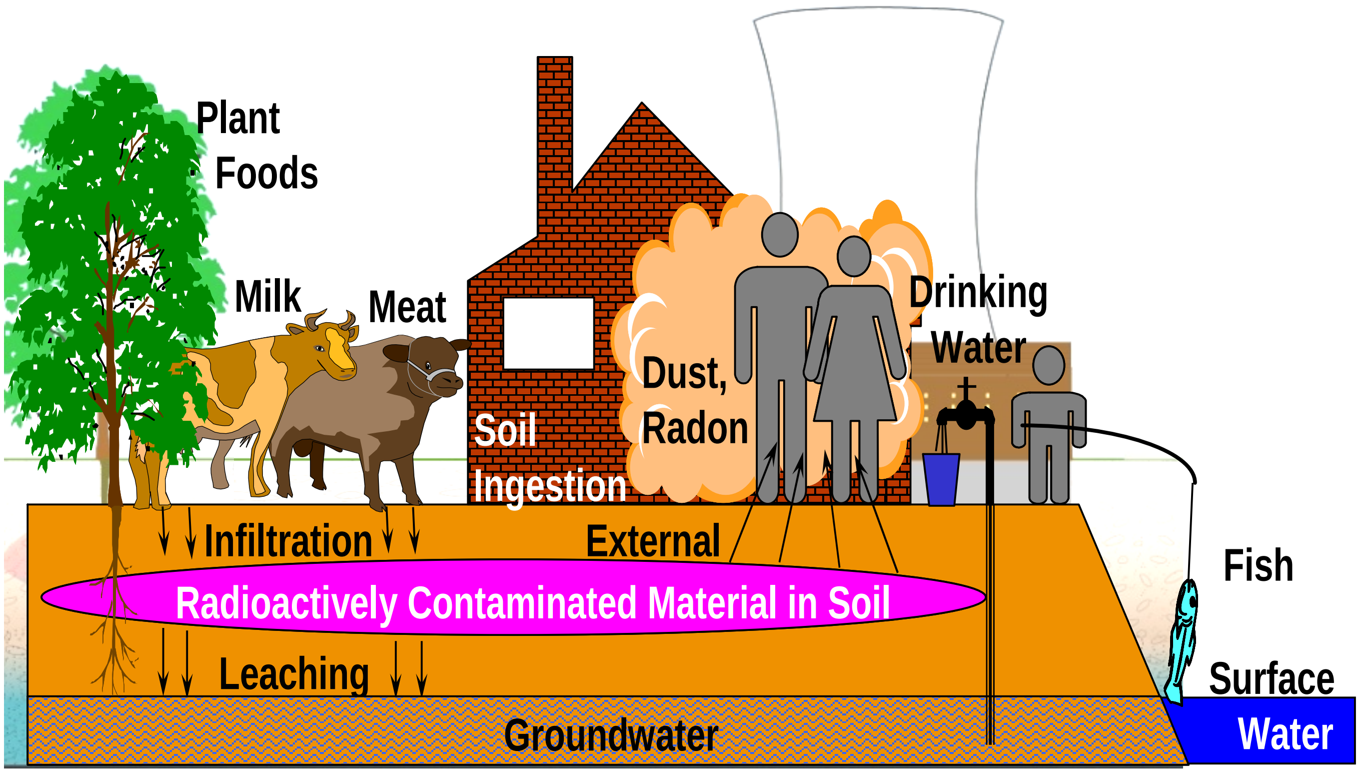
Identify Potential Contamination



Determine Exposure Scenarios



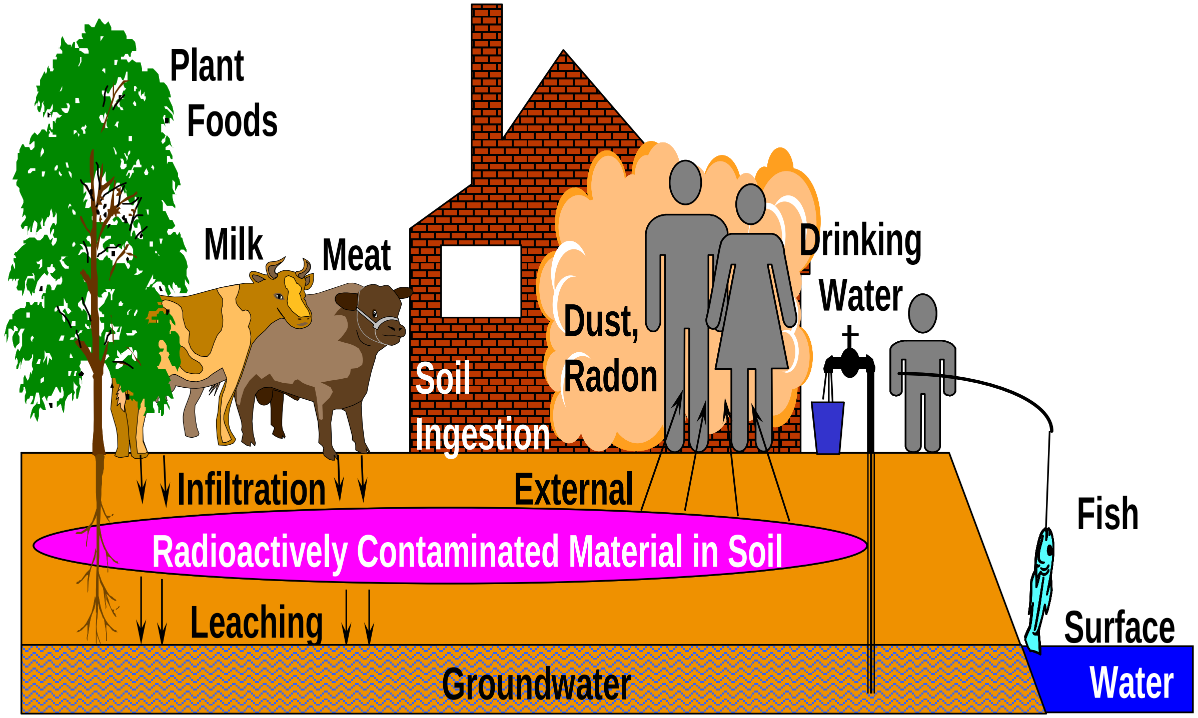
Determine Exposure Pathways



Gather Data

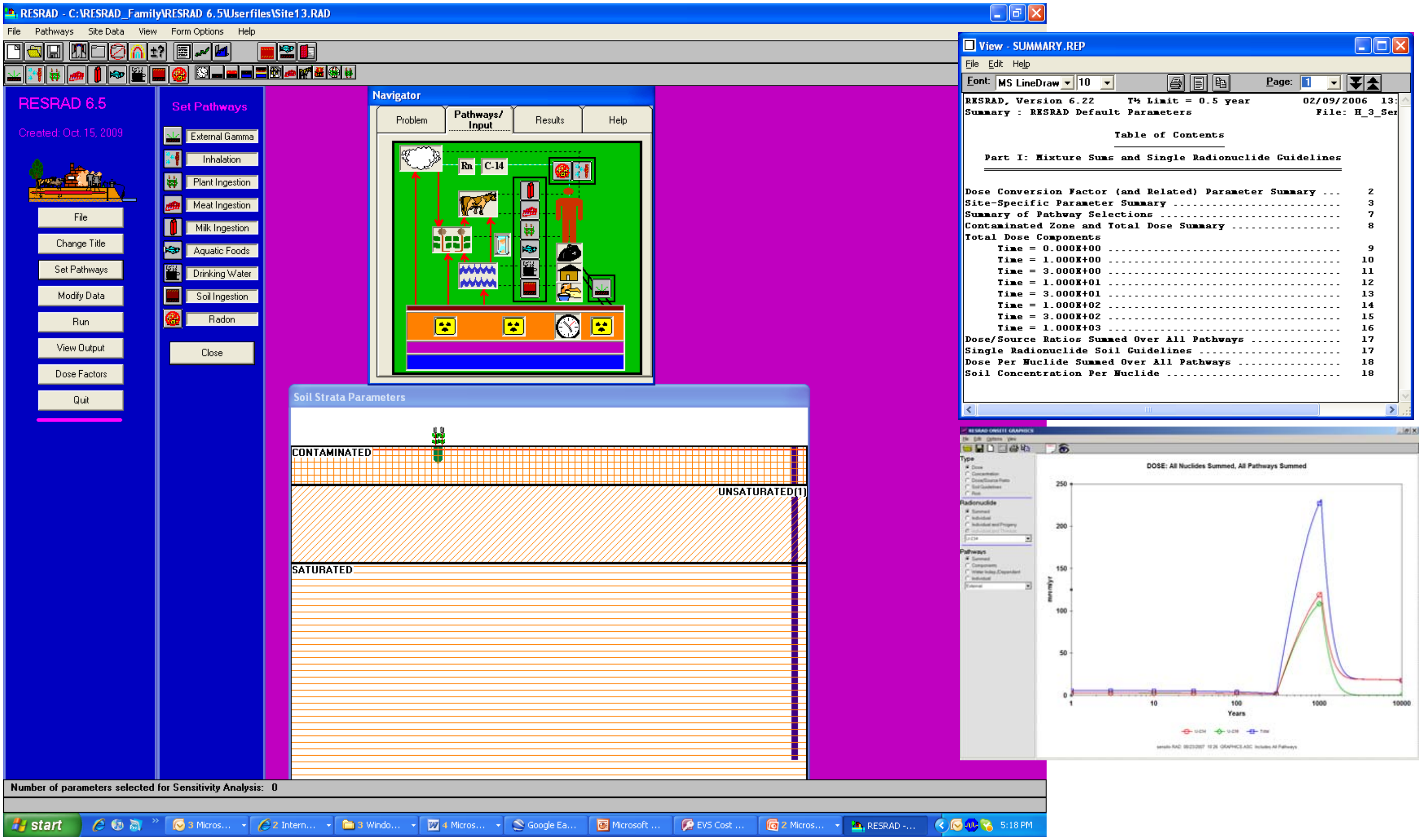
Environment
(precipitation, groundwater)

Scenario
(land use, time, diet, shielding)

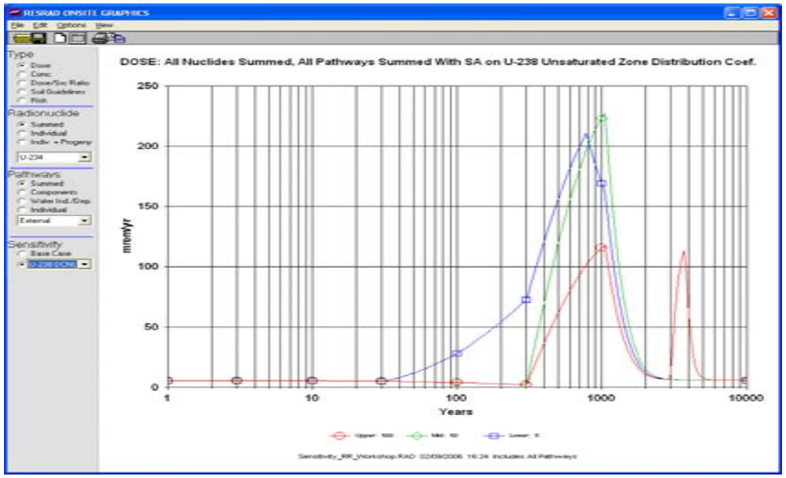


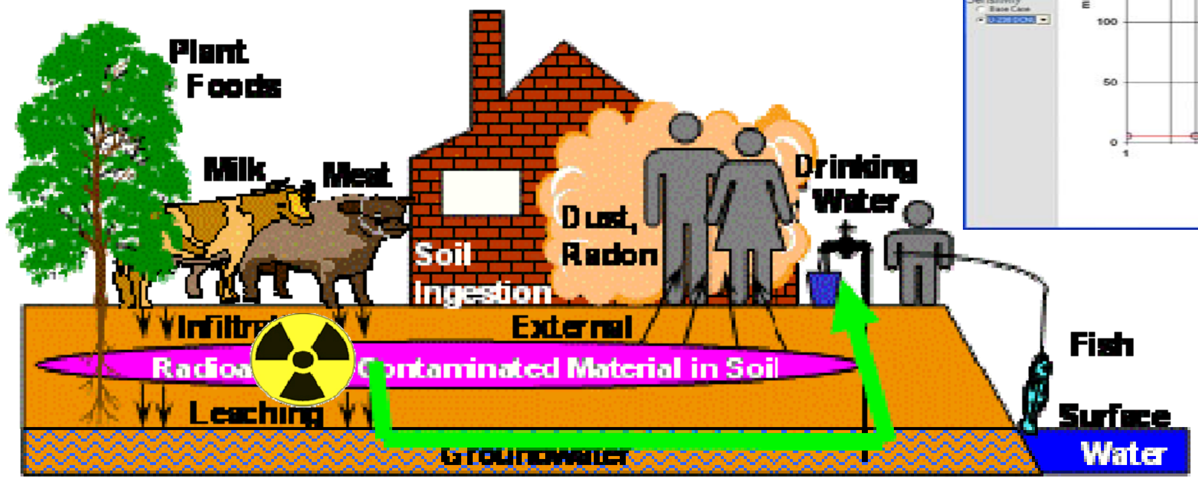
Contamination
(size, nuclides, concentration, release)

Perform Calculations



Understand Calculations





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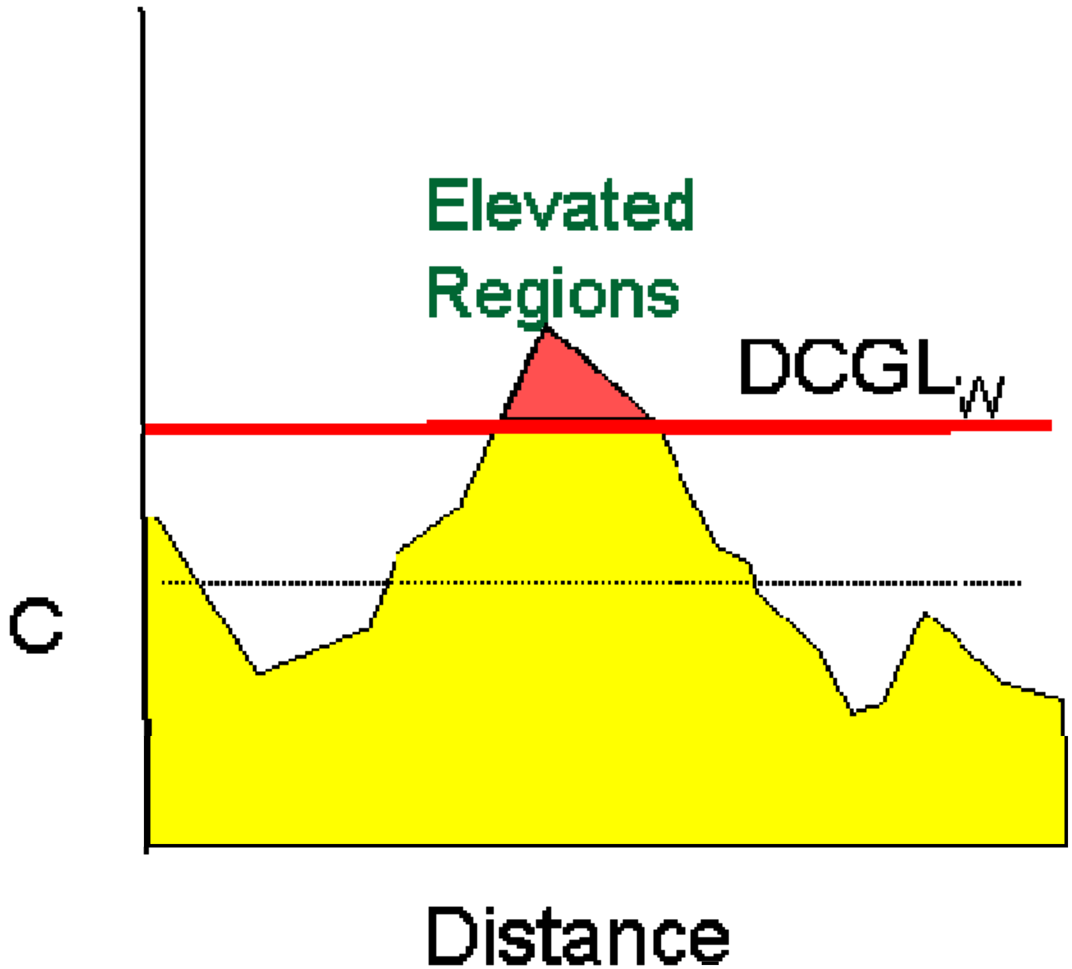
Calculate Cleanup Guidelines

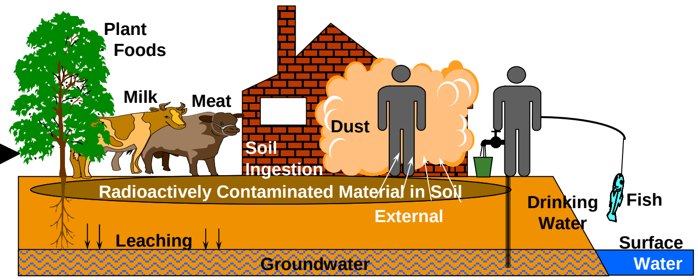


Generate Operational Guidelines

Dose Limit

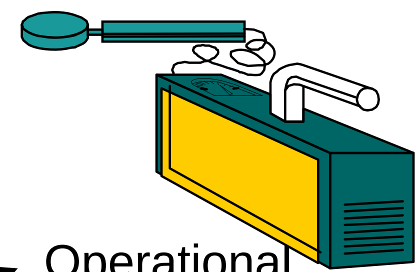
(1 mSv/yr)

Regulations



Single Radionuclide DCGLs

Pathway Analysis



Operational DCGLs

(compliance demonstrated with MARSSIM)

$$\sum_{s=1}^{S} \sum_{r=1}^{R} \frac{Con_{s,r}}{DCGL_{s,r}} \leq 1$$

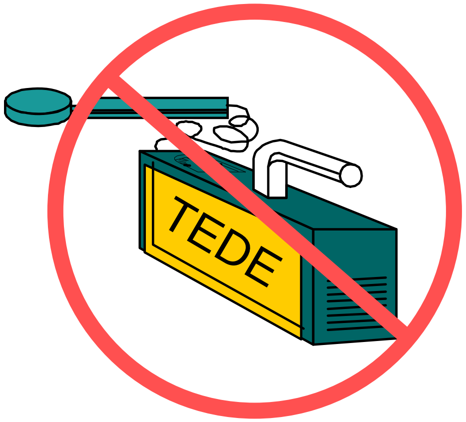
Sum of Ratios

Field Implementation

Cleanup

Why Perform a Dose Assessment?

- There is not a "TEDE meter" available
  - Time of decommissioning
  - 1,000 years after decommissioning
- Requires the use of mathematical models to estimate TEDE



Why Perform a Dose Assessment?

- Example Regulation:
  10 CFR 20, Subpart E

  "A site will be considered acceptable for unrestricted use if the residual radioactivity that is distinguishable from background radiation results in a TEDE to an average member of the critical group that does not exceed 25 mrem (0.25 mSv) per year, including that from groundwater sources of drinking water, and that the residual radioactivity has been reduced to levels that are as low as reasonably achievable (ALARA)."

PART 20—STANDARDS FOR PROTECTION AGAINST RADIATION

Subpart E—Radiological Criteria for License Termination.

Why Perform a Dose Assessment?

- Effective Dose Equivalent or Total Effective Dose Equivalent (TEDE)
  - External dose + 50-year committed effective dose equivalent
  - External + Inhalation + Ingestion
- External + Inhalation + Ingestion < 1 mSv/yr
  - 0.25 mSv /yr: NRC dose limit
- In Addition:

  "When calculating TEDE to the average member of the critical group the licensee shall determine the peak annual TEDE dose expected within the first 1,000 years after decommissioning"

Compliance Demonstration

- Soil Guideline or DCGL Development
  - Derive acceptable residual radioactive concentrations (DCGLs) for each radionuclide based on TEDE. Licensee must then prove the site meets the DCGLs. For multiple sources/radionuclides the “Sum of Fractions” must be less than 1.
- Dose Modeling
  - Uses actual or expected radionuclide concentrations to estimate TEDE. Site must be below 0.25 mSv/yr.

What is Dose Modeling?

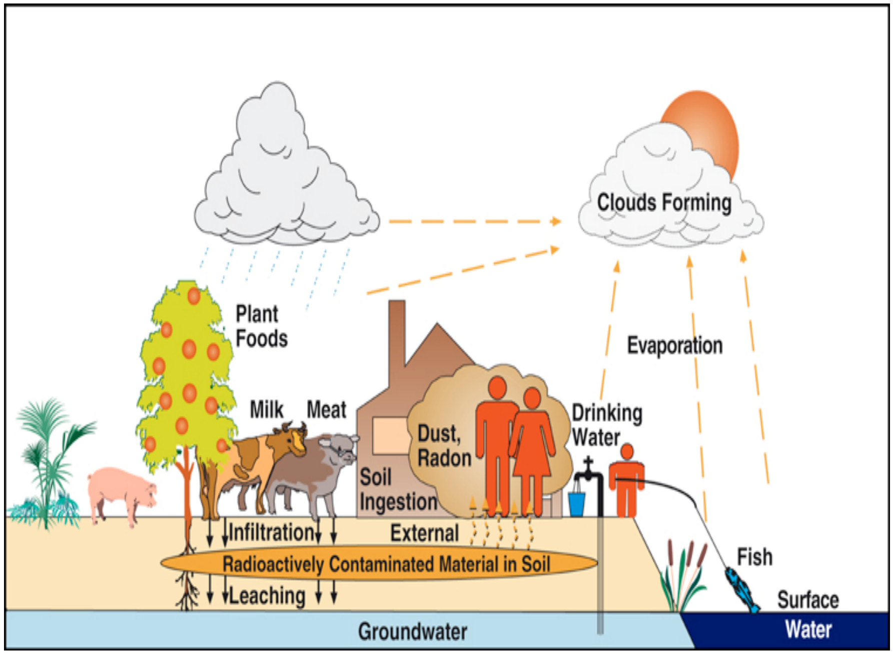
- Dose modeling involves using radiological assessment models to determine the dose to an individual from residual radioactive material
- A licensee would input final residual radioactive material concentrations into the model to predict the dose to the individual.
- Often this is called the "forward" calculation
  - Radionuclides → Environmental Pathways → Dose

What is a Soil Guideline or DCGL?

- ***D***erived ***C***oncentration ***G***uideline ***L***evel
- Uses computer codes to estimate residual radioactive material concentrations so that the dose to an individual is below the dose limit
- Often this is called the “backward” calculation
  - Dose Limit → Environmental Pathways → Concentration
- Derived separately for each radionuclide based on its maximum dose
- Requires the use of the “Sum of Fractions” if multiple radionuclides or sources are present

Example Software: RESRAD – A Regulatory Tool for Determining the Allowable RESidual RADioactivity in Site Cleanup

RESRAD, an internationally utilized model, successfully addresses the critical question "How clean is clean enough?"



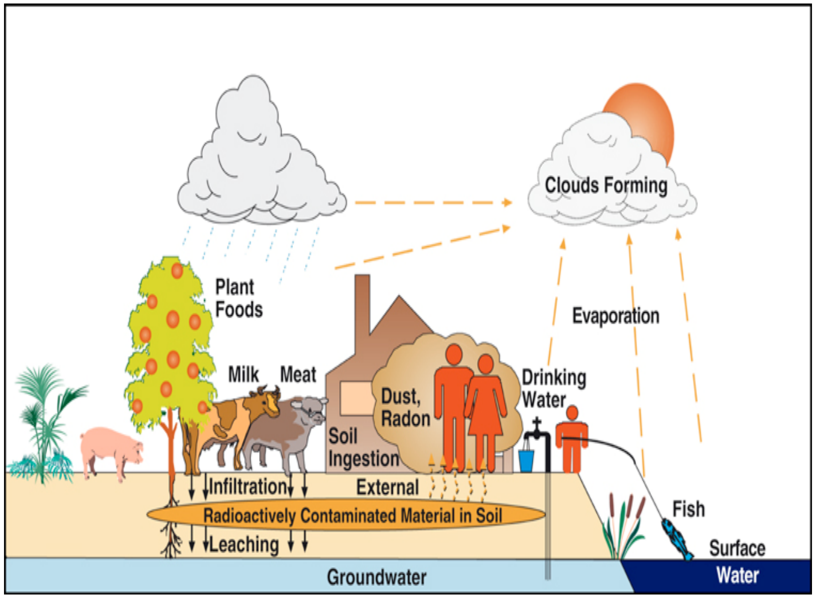
Accepted for use by government regulatory agencies

- *DOE (Designated by Order 5400.5)*
- *NRC (NUREG/CR-1757)*
- *EPA*
- *State agencies*

In use for about 20 years

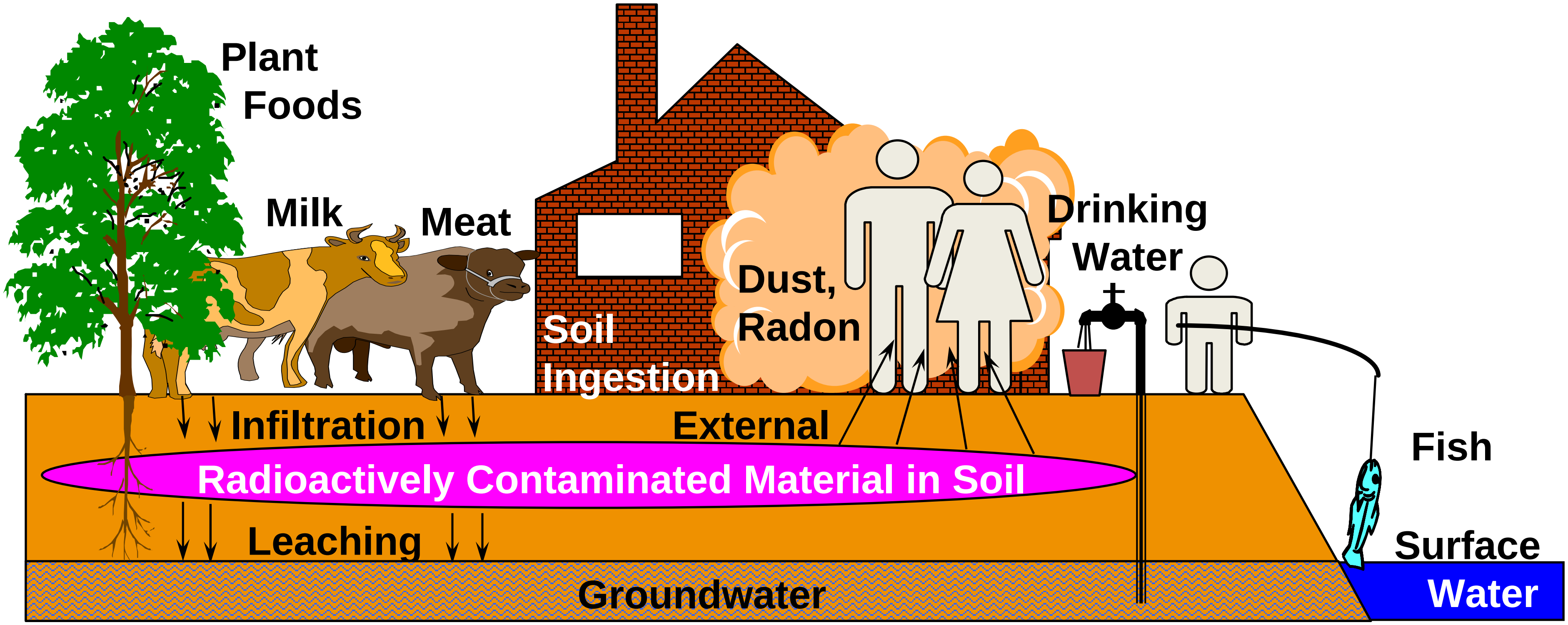
- *Evaluation of more than 300 cleanup sites*
- *More than 100 training workshops*
- *International recognition*

The RESRAD Code

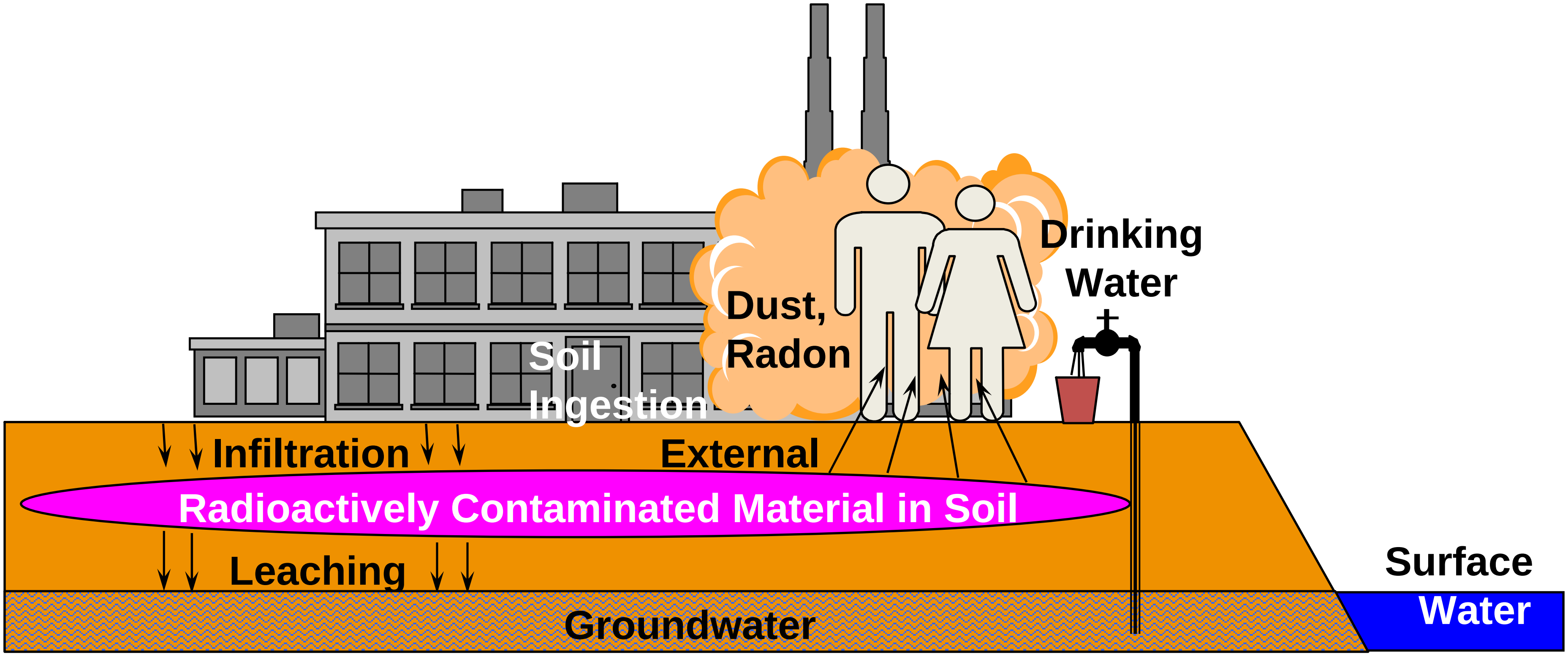


- Who: Individual
  - (not population)
- When: Peak over 1,000 years
  - (not average or lifetime)
- What: Radiological Dose or Cancer Risk Calculation
- How:
  - External, Inhalation, Ingestion Exposure Pathways
  - Water, Air, Soil, and Food Environmental Pathways
- Assumptions:
  - Contamination is originally in well characterized soil
  - Individual lives, works, or plays on top of contamination

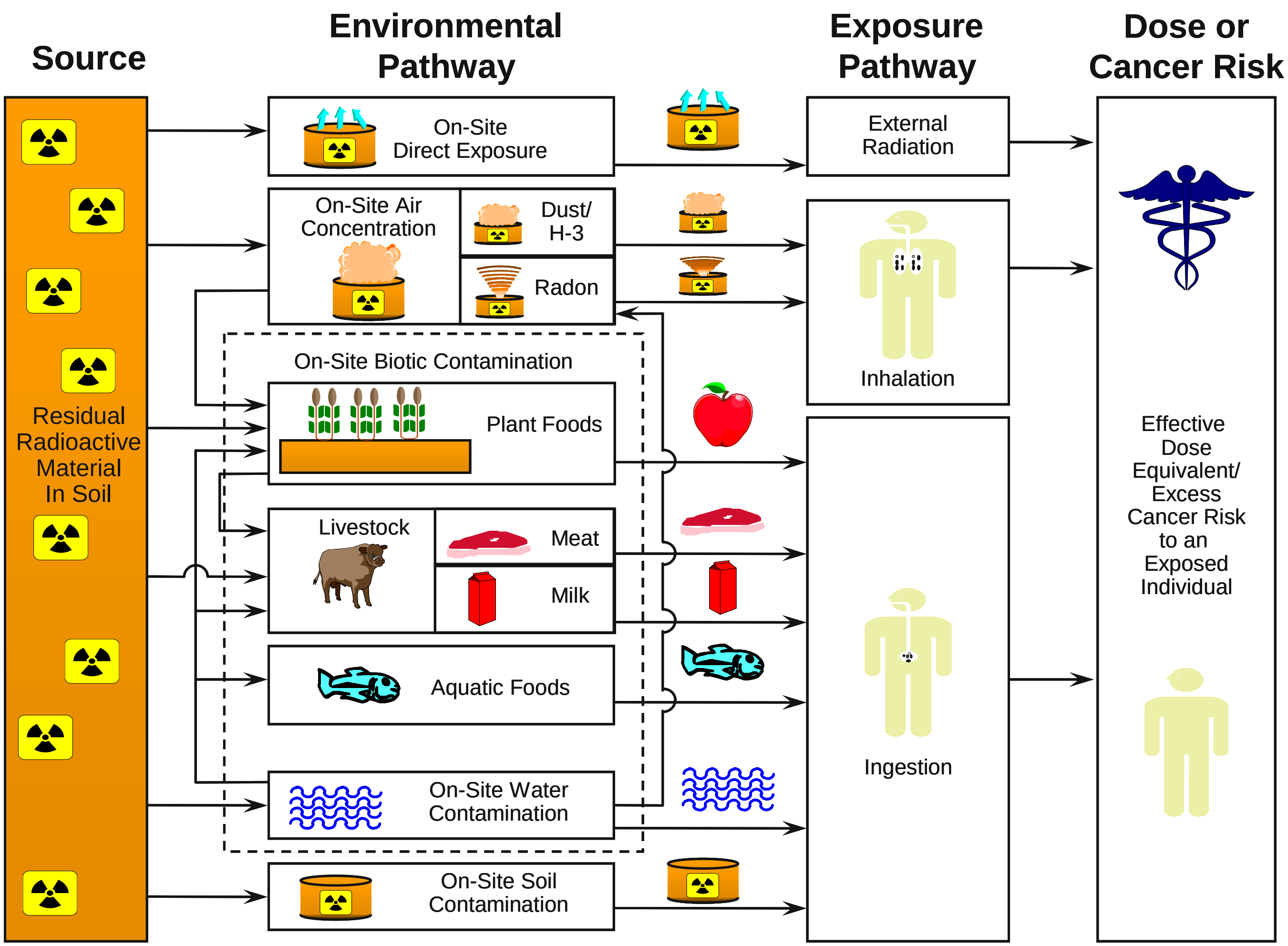
Exposure Pathways Considered in RESRAD: (Resident Farmer Scenario)



Exposure Pathways Considered in RESRAD: (Industrial Use Scenario)

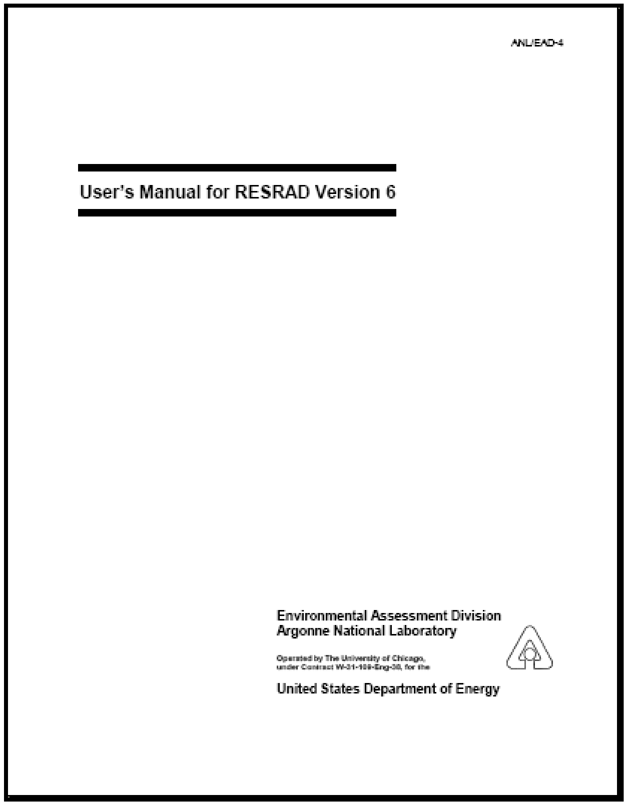


RESRAD Contains an Array of Parameters for Pathway Analysis in Performing Comprehensive Risk Assessment



Documentation of the RESRAD Computer Code

- Chapters:
  - Pathway analysis
  - Derivation of soil guidelines
  - User's guide for RESRAD
  - Verification & Validation
- Appendices include detailed discussions on
  - Pathway models
  - Source factors
  - Distribution coefficients
  - Estimation of off-site doses
  - Special tritium and carbon-14 models
  - Uncertainty analysis


ANL/EAD-4

User's Manual for RESRAD Version 6

Environmental Assessment Division
Argonne National Laboratory

Operated by The University of Chicago,
under Contract W-31-109-Eng-38, for the

United States Department of Energy

Supporting Documentation

- Parameters
  - Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil [4/93]
  - Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes [11/00]
  - A Compilation of Radionuclide Transfer Factors for the Plant, Meat, Milk and Aquatic Food Pathways and the Suggested Default Values for the RESRAD Code [8/93]
- Testing
  - Verification of RESRAD [6/94]
  - RESRAD Benchmarking Against Six Radiation Exposure Pathway Models [10/94]
  - Evaluation of Area Factor for Finite Area Sources for Inhalation Dose Calculations [7/98]

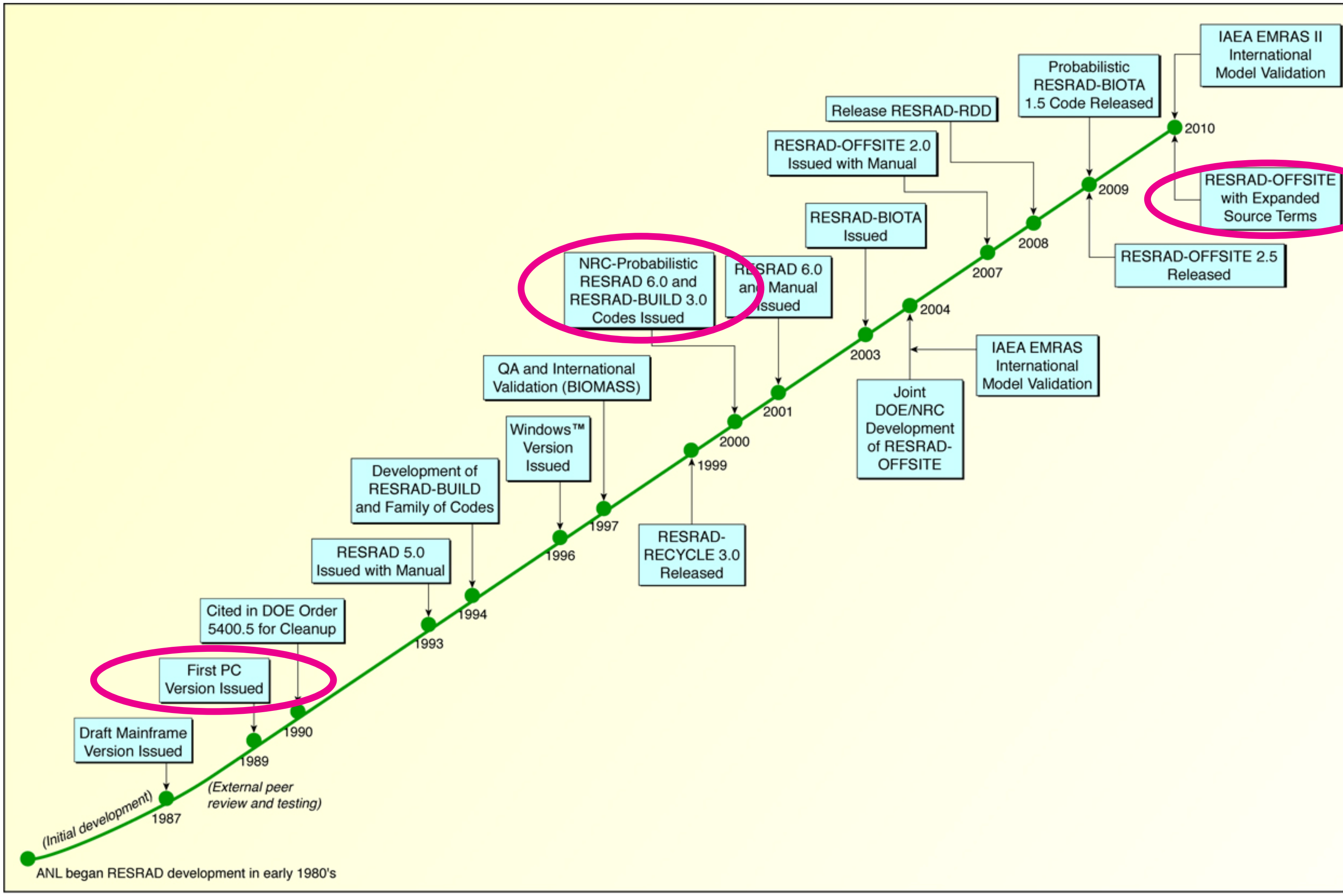
Definitions

- **Verification**
  - Refers to the task or procedure by which a mathematical solution to an arbitrarily complex problem is tested for internal mathematical consistency and accuracy
- **Validation**
  - Refers to the task or procedure by which the mathematical model is tested against accurately measured, independent sets of field or laboratory observations made over the range of conditions for which application of the model is intended

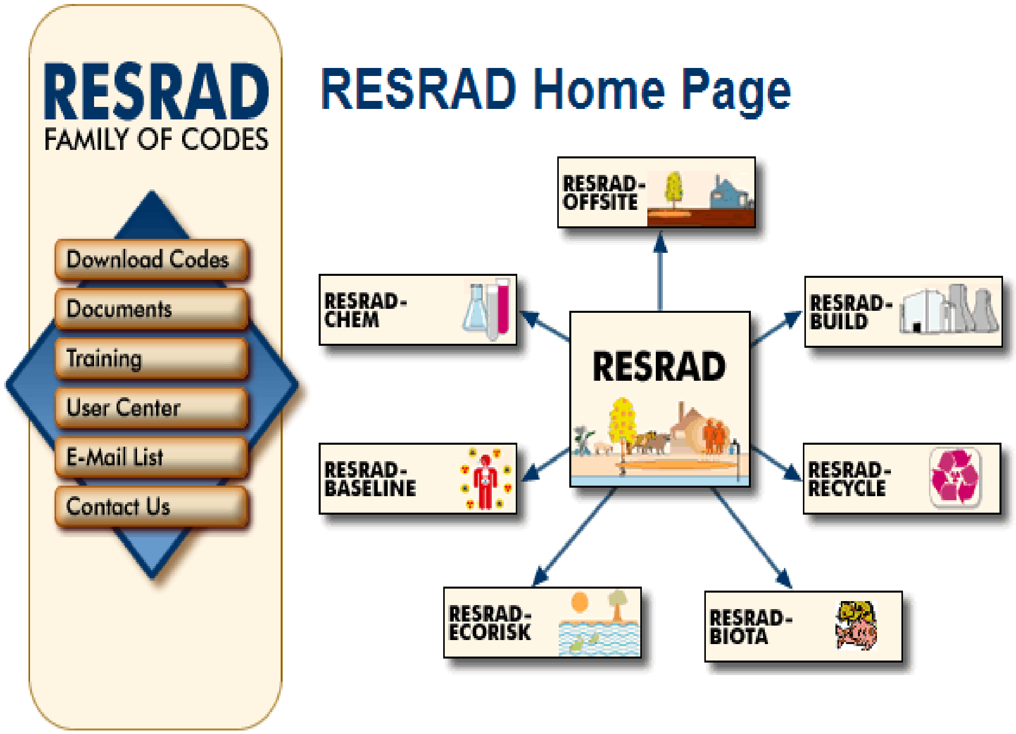
RESRAD Validation

- Conducted leaching experiment (batch and column tests) to validate leaching model
- Participating in international code-comparison exercises – VAMP, BIOMOVS II, BIOMASS and EMRAS – in some cases, using Chernobyl data

Development History Since Early 1980s



RESRAD Family of Codes Support National D&D and Cleanup Efforts

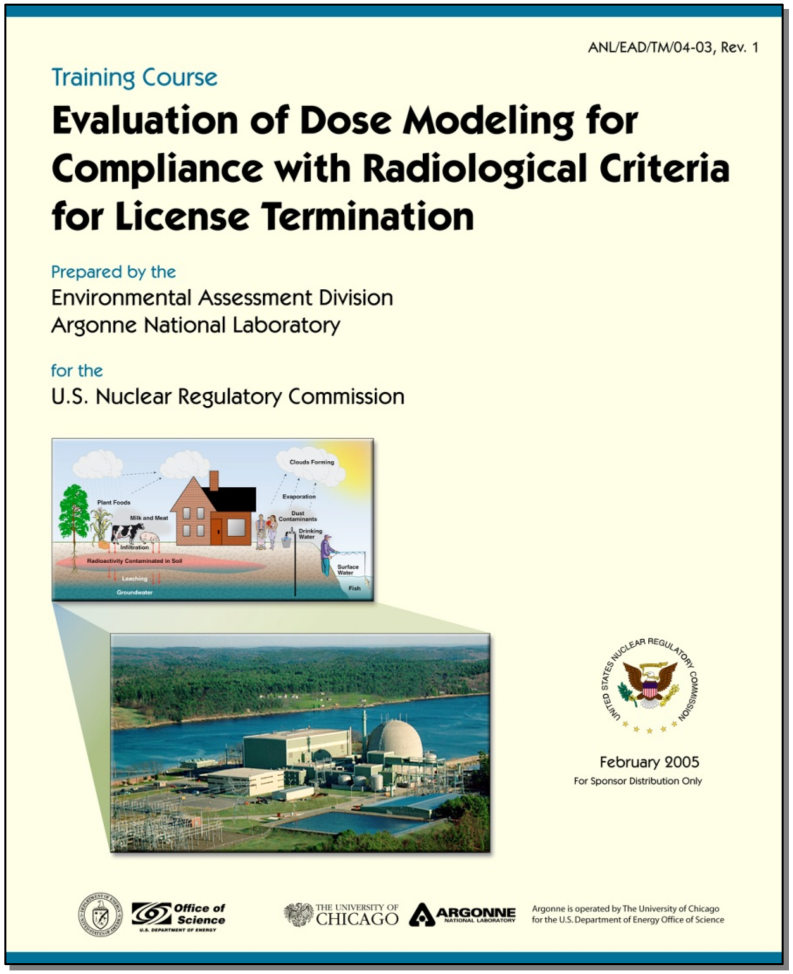


- Software Download
- Supporting Documentation
- Update News
- Training Workshops
- User Feedback

http://www.evs.anl.gov/resrad

Application of RESRAD Codes − Demonstrating Compliance with NRC’s License Termination Rule (10 CFR 20, Subpart E)

- RESRAD is accepted for demonstrating compliance
  - Methodology described in NUREG 1757 on Decommissioning Guidance
  - Site-specific vs. screening dose analysis
  - Has been applied in many license termination applications



International Atomic Energy Agency

Dose and Risk Assessment Demonstrations

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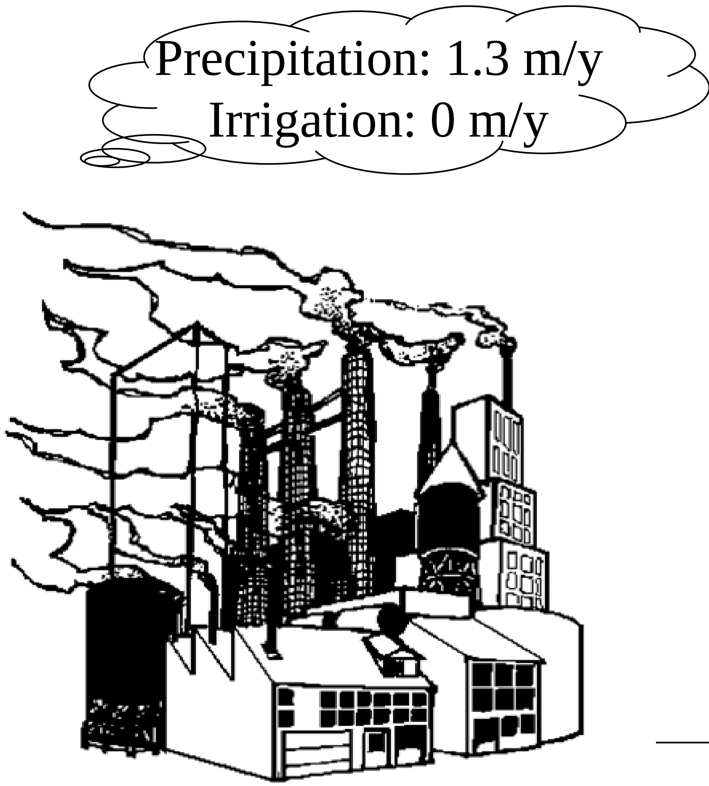
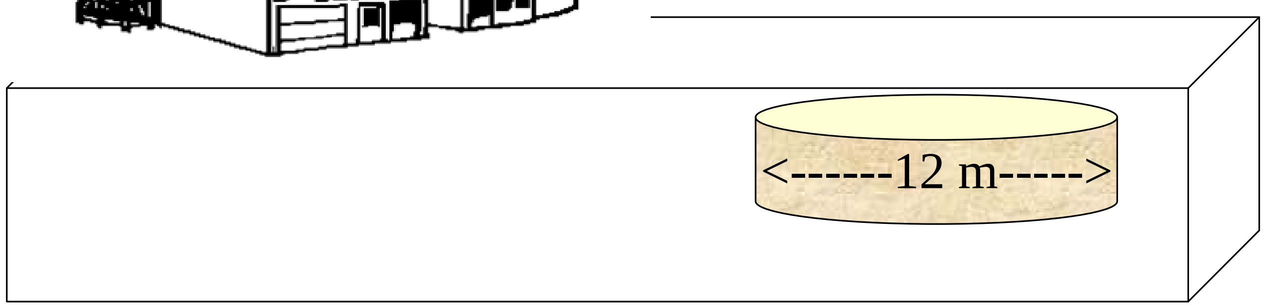
Demonstration

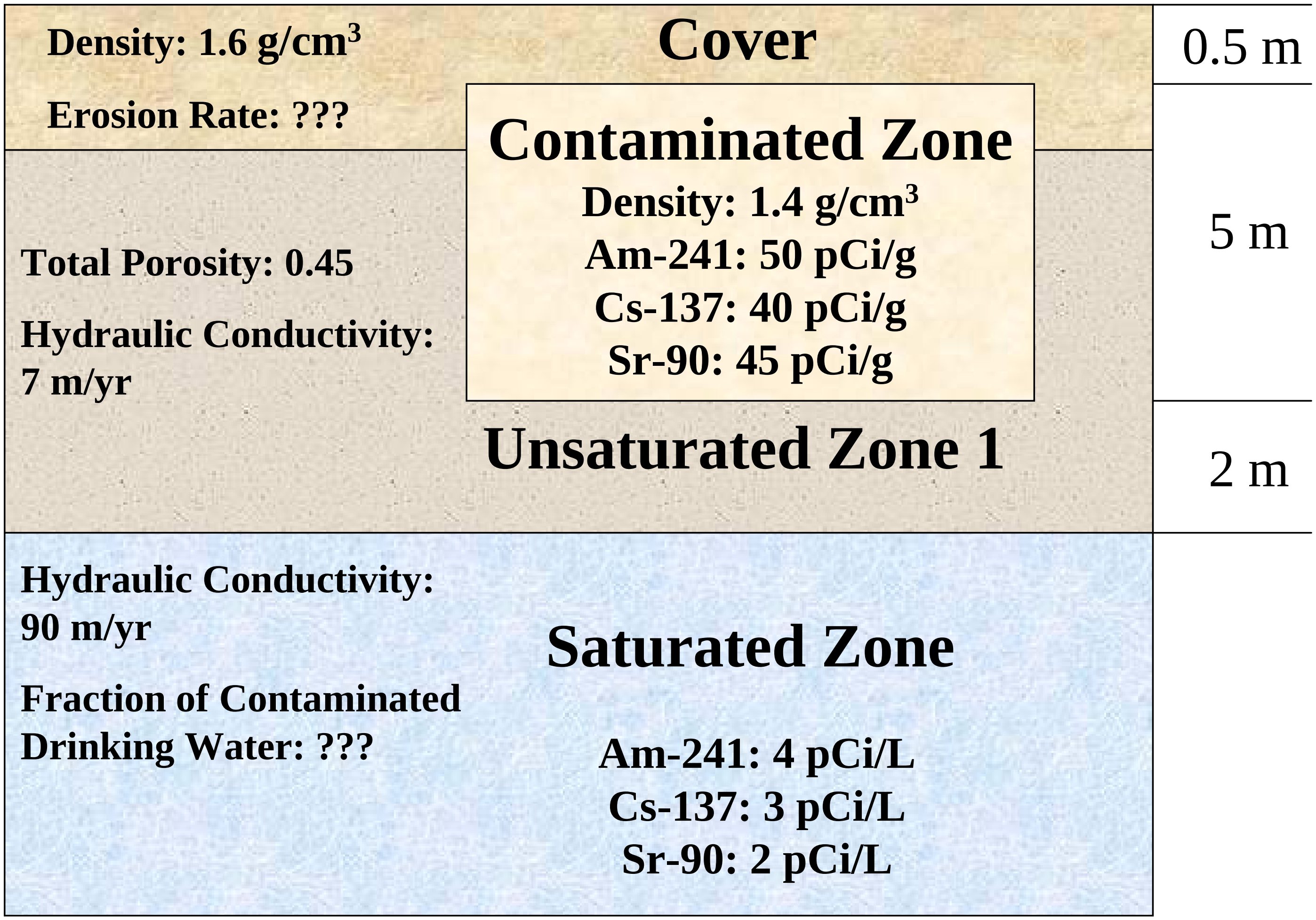


Current Scenario/Site History

RESonant **RAD**iological Industries is a former general manufacturer of small sources. Residues from plant operations were placed in a waste disposal pit until the plant ceased operations in 1969. Today, the site is vacant except for a single maintenance worker who checks the site 5 times weekly. This worker spends approximately 2 hours per visit at the site, and is indoors about 1 hour of that time. Drinking water is provided by a well located downgradient of the contaminated zone.



Demonstration

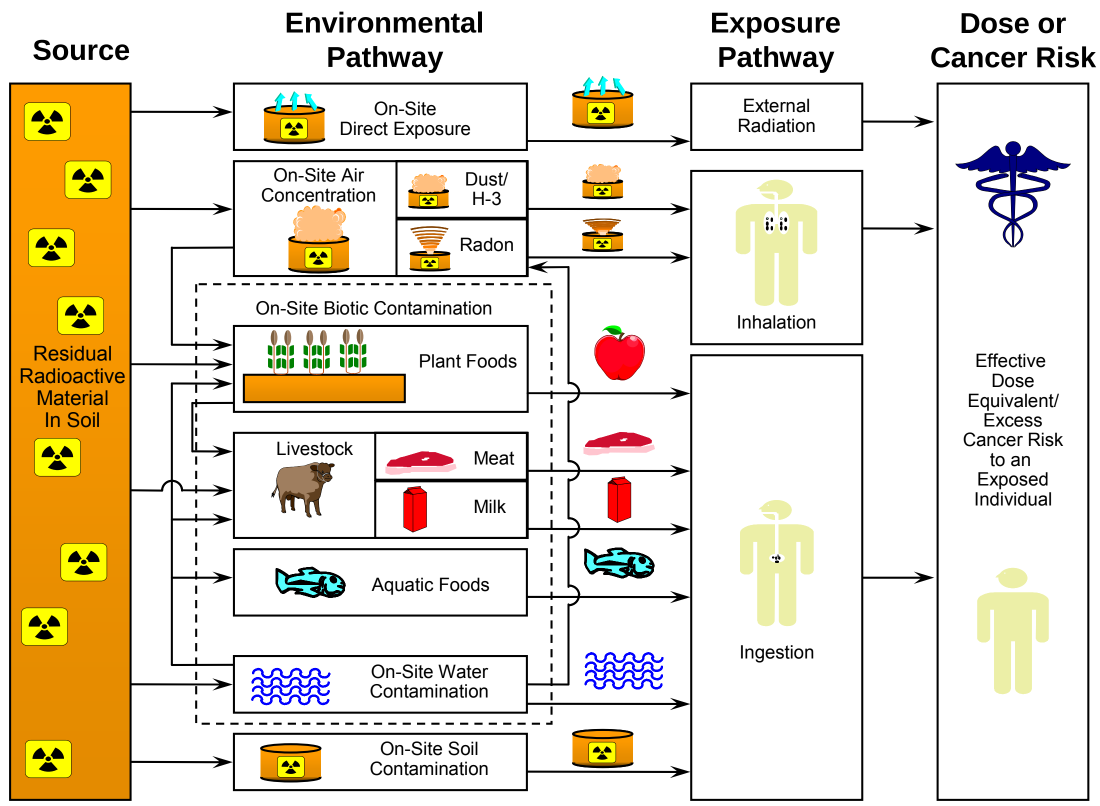


RESRAD (onsite)

Methodology

RESRAD Pathways

- Nine major environmental pathways are available in RESRAD
  - External (Ground)
  - Inhalation
    - Particulates
    - Radon
  - Ingestion
    - Soil
    - Water
    - Plant
    - Meat
    - Milk
    - Aquatic Foods



Demonstrating Compliance Using Derived Concentration Guideline Levels (DCGLs)

- RESRAD derives single radionuclide soil concentration limits (guidelines)
- $$\text{Contamination Limit}(t)[\text{Bq/g}] = \frac{\text{Dose Limit}\,[\text{mSv/yr}]}{\text{Dose per Unit Contamination}(t)[\frac{\text{mSv/yr}}{\text{Bq/g}}]}$$
- Look at the times of :
  - maximum total dose over all contamination
  - maximum dose for each individual radionuclide
- Example:
  - Given Dose Limit = 0.25 mSv/yr
  - Calculate Dose per Unit Contamination for given scenario = 0.0025 mSv/yr for a 1 Bq/g contamination
  - Derive Contamination Limit = 0.25 / 0.0025 = 100 Bq/g

Data Requirements

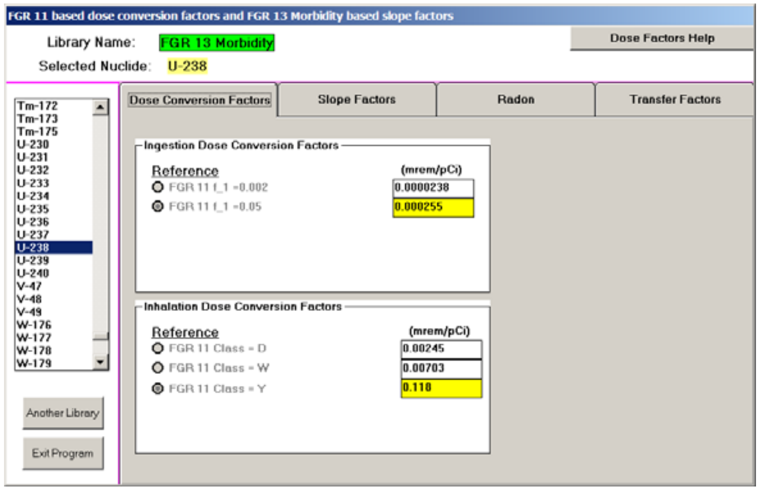
- Contamination:
  - Size, contaminants, shielding, release
- Environment:
  - Precipitation, groundwater, wind
  - Nuclide specific:
    - How does the nuclide travel relative to water?
    - How is the nuclide incorporated into food relative to soil?
- Scenario:
  - Land use, diet
- Dose Conversion Factors
  - Hazard per unit of exposure
- Radionuclide Information
  - Decay rates, decay products

Calculation of the Dose to Source Ratio

- Dose =
  - Sum over exposure pathways (ingestion, inhalation, external)
  - Sum over environmental pathways (water, soil, air, food)
  - Sum over potential radionuclides accounting for decay and ingrowth of original contaminant

Dose Conversion Factors (DCFs)

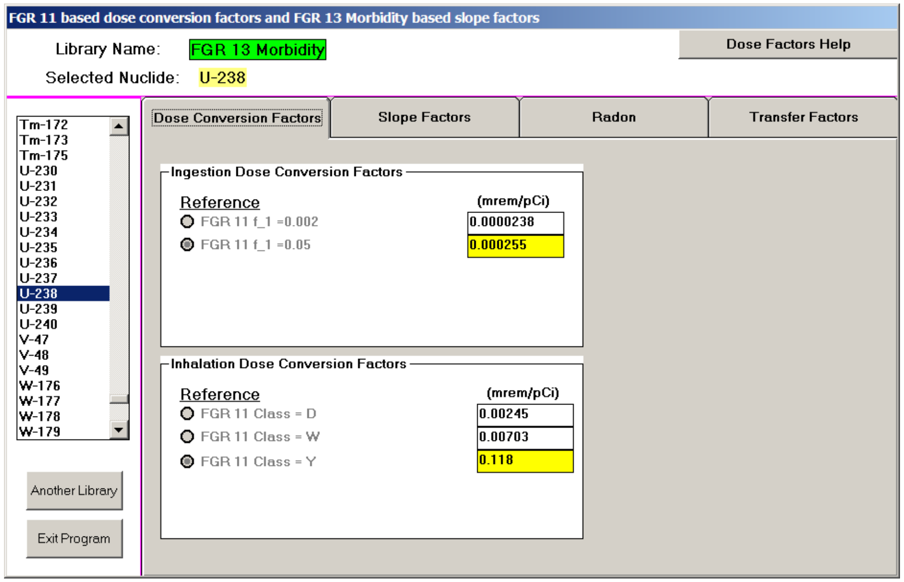
- External exposure pathway:
  - Infinite depth volume factors (mSv/yr per Bq/g)
- Inhalation pathway:
  - Inhalation factors (mSv/Bq)
- Ingestion pathways:
  - Ingestion factors (mSv/Bq)



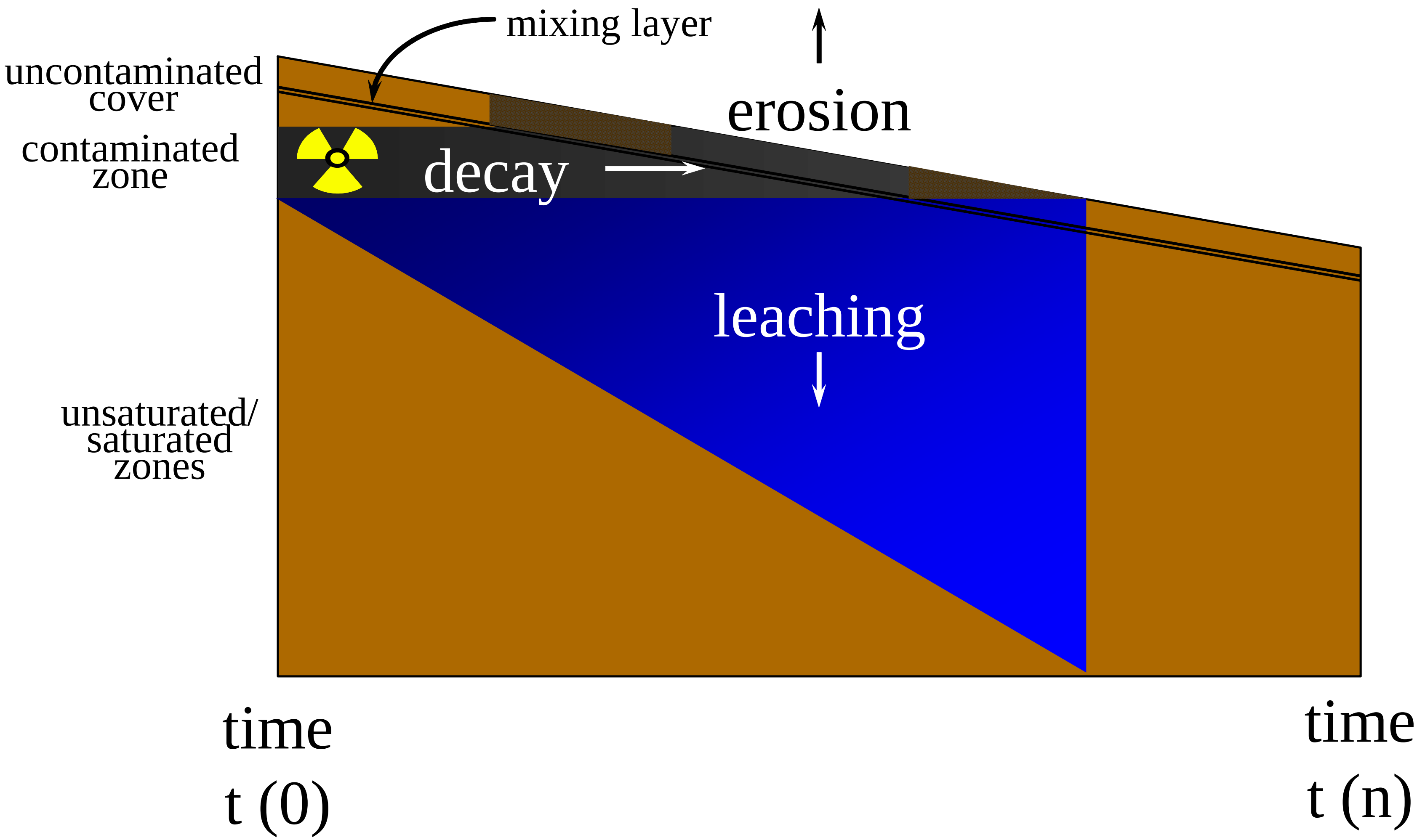
- References: External DCFs - Federal Guidance Report No.12 (1993)
  - Inhalation/Ingestion DCFs - FGR No.11 (1988)

Dose Conversion Factor/Risk Factor Libraries

- Using the Dose Conversion Factor Editor
  - Users can modify DCFs
    - Select a more appropriate DCF
    - Create a new DCF
  - Users can modify slope factors
    - HEAST 2001
    - FGR 13 Morbidity
    - FGR 13 Mortality
    - User Specified

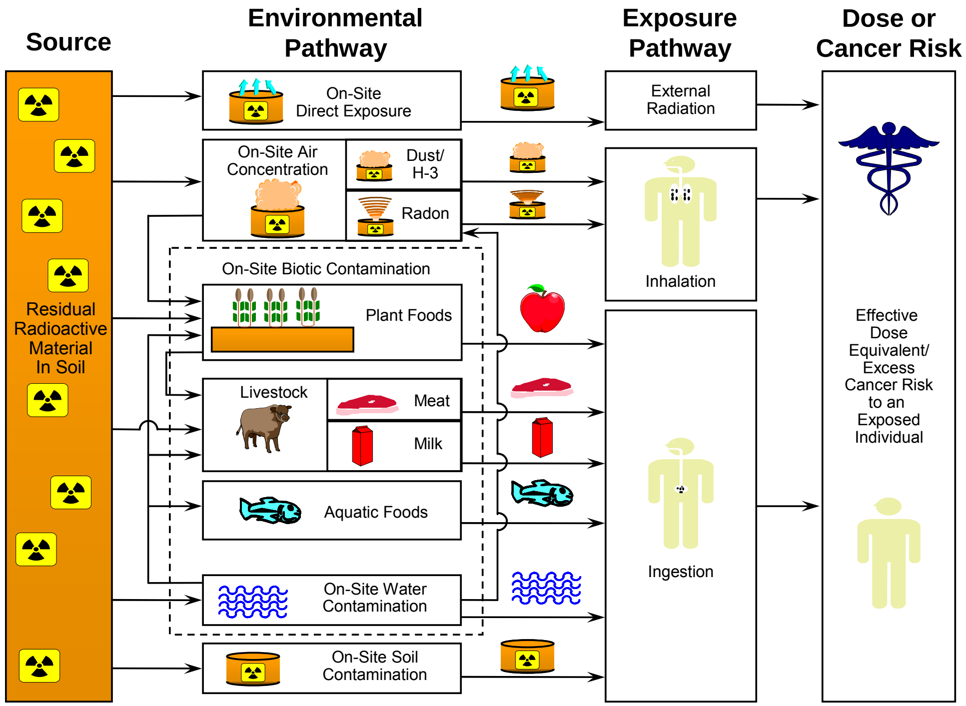


Factors Affecting Source Loss



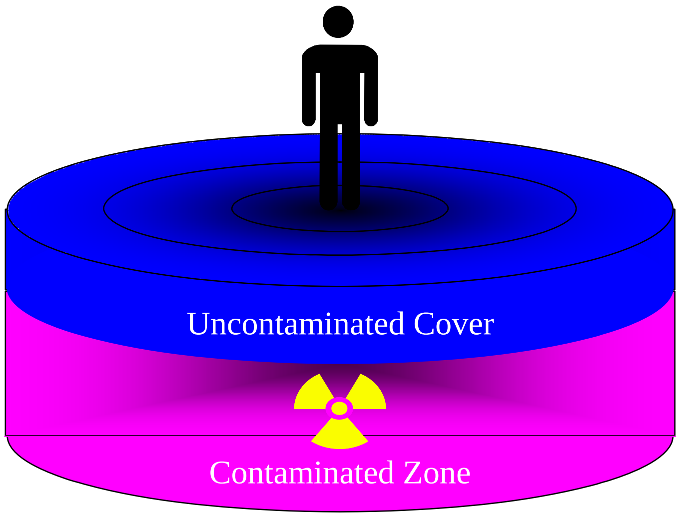
Environmental Transport Factors (ETFs)

- Mathematical representation of the environmental pathways
- ETFs for
  - External
  - Inhalation
  - Ingestion
    - Water
    - Soil
    - Plant
    - Meat
    - Milk
    - Aquatic Organisms



Environmental Transport Factors: External Ground

- Appendix A: RESRAD Users Manual
- $ETF_{i1}(t) = FO_1 \times FS_{i1} \times FA_{i1} \times FCD_{i1}(t)$
  - FO_1 = occupancy and shielding factor
  - FS_{i1} = shape factor
  - $FA_{i1}(t)$ = nuclide-specific area factor
  - $FCD_{i1}(t)$ = depth and cover factor



Occupancy and Shielding Factor

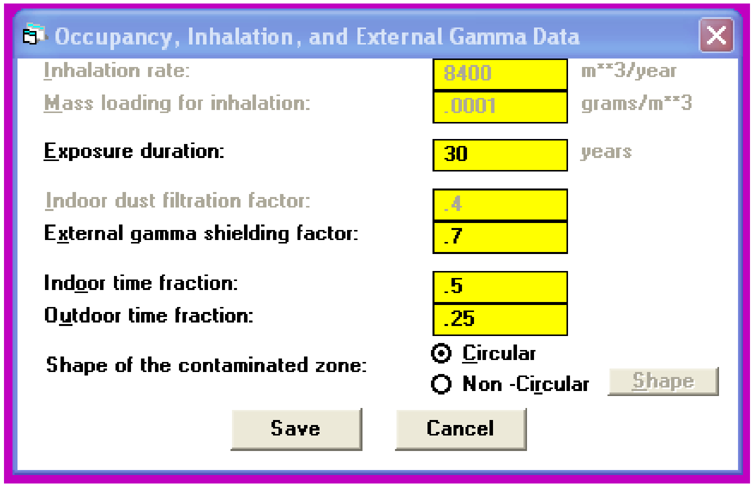
- Comprised of
  - $f_{otd;}$: Fraction of time spent outdoors
  - f_{ind} : Fraction of time spent indoors
  - F_{sh}: External gamma shielding factor

$$FO_1 = f_{otd} + \left(f_{ind} \times F_{sh}\right)$$

- Default Case

$$FO_1 = 0.25 + \left(0.5 \times 0.7\right) = 0.6$$

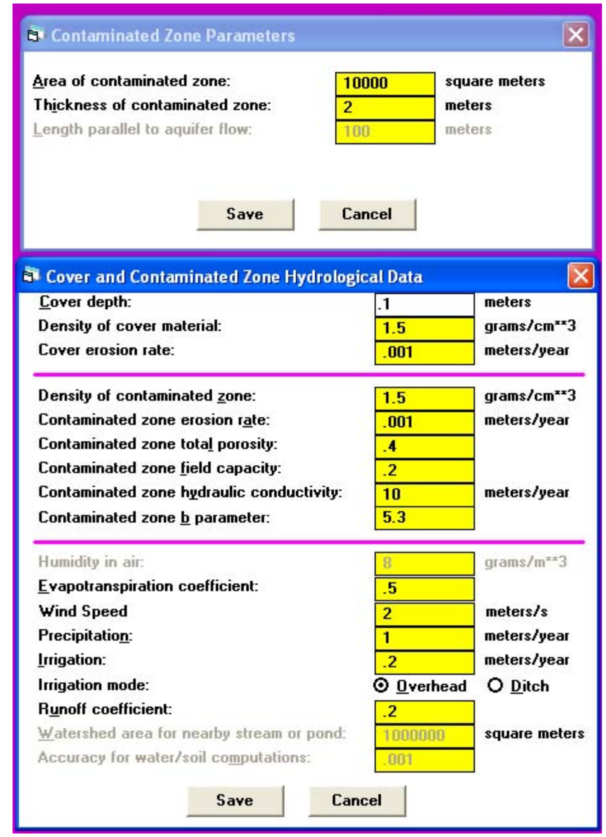
- Important Note!
  - F_{sh} = 0; completely shielded
  - F_{sh} = 1; no shielding



Depth and Cover Factor

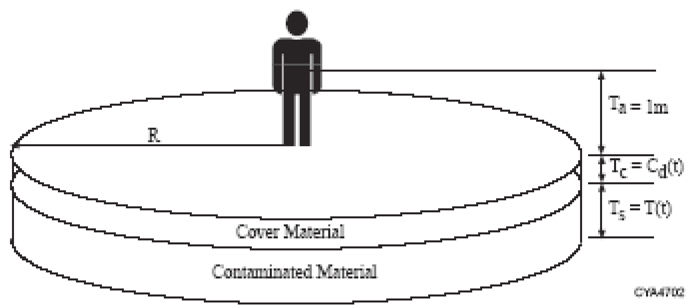
- Allows users to enter
  - Any contaminated zone thickness, and density
  - Any one cover thickness and density
- Based on a regression analysis of FGR 12 DCFs
- FCDs are radionuclide-dependent

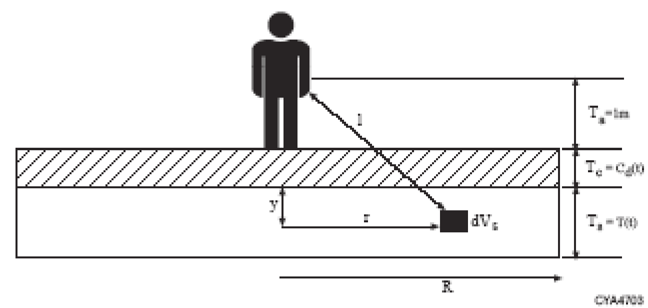
$$FCD_{i1} = \frac{DCF_i^{FGR}\left[T_c = C_d, T_s = T(t)\right]}{DCF_i^{FGR}\left[T_c = 0, T_s = \infty\right]}$$



Area Factor

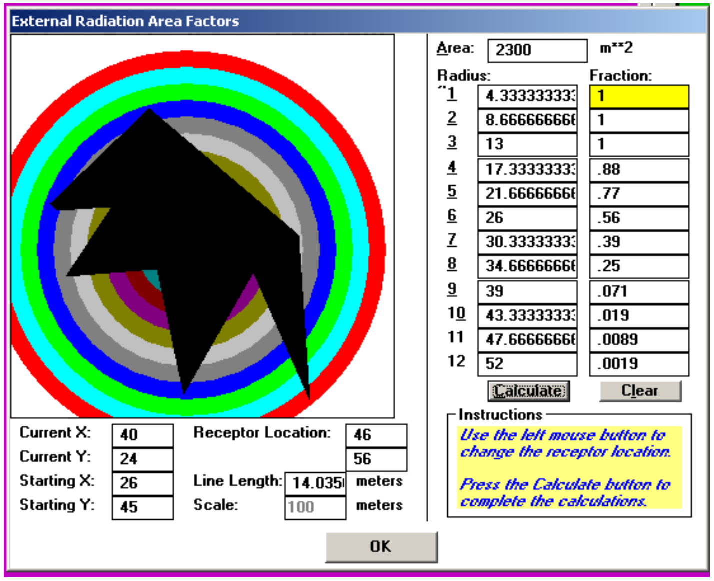
- Radionuclide-specific factor to correct an infinite geometry (FGR 12) to finite geometry (site-specific)
- Performs point-kernel integration on the dose
- Uses ICRP-38 photon spectra
- Benchmarked against MCNP





Shape Factor: Non-Circular Shapes

- RESRAD allows users to construct non-circular shaped sources
- Allows users to place receptors anywhere on the source
- Biggest Impact on long rectangular sources
  - Roads
  - Railroad right-of-way
- Primarily affects the External Pathway



Environmental Transport Factors: Inhalation Pathway

- Appendix B: RESRAD Users Manual

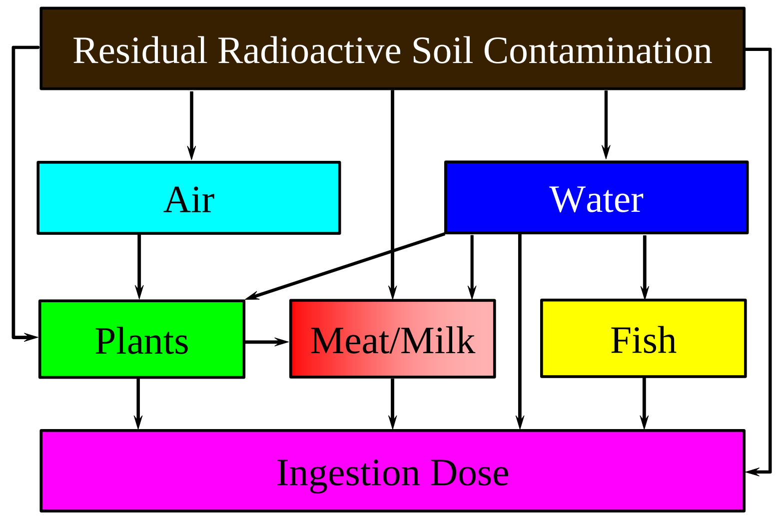
- $ETF_{i2} = ASR_2 \times FA_2 \times FCD_2(t) \times FO_2 \times FI_2$

- ASR_2 = mass loading factor (air/soil concentration ratio)
- FA_2 = area factor
- $FCD_2(t)$ = cover and depth factor
- FO_2 = occupancy factor
- FI_2 = annual intake of air (breathing rate)

Ingestion Pathways

- Water independent
  - Excludes dose derived from contaminated well or surface water
  - Leaching from the contaminated zone still applies
  - For plant, meat and milk; does not include the contribution from radionuclides in water used for
    - irrigation
    - livestock feed

- Water dependent
  - Dose derived from contaminated well or surface water
  - For plant, meat and milk; the contribution from nuclides in water used for irrigation and for livestock feed



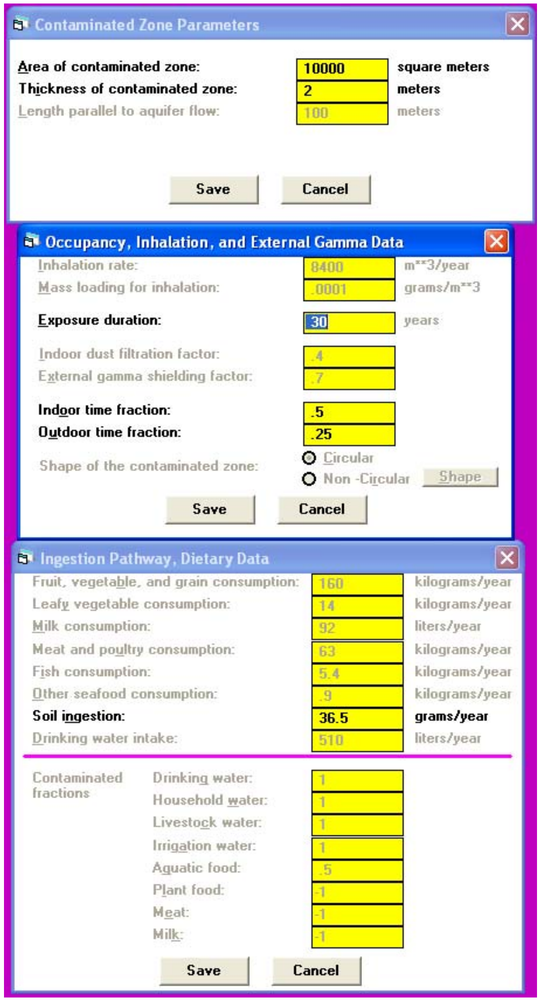
Environmental Transport Factors: Soil Ingestion

- Appendix F: RESRAD Users Manual

- Models the incidental ingestion of soil

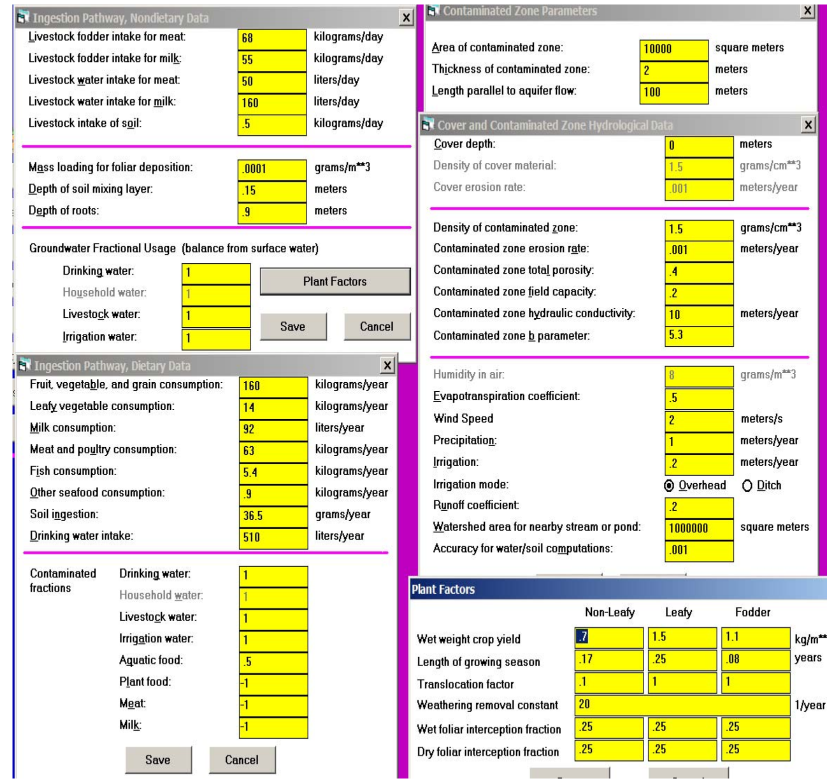
- $$ETF_{j8} = FSI \times FA_8 \times FCD_8(t) \times FO_8$$

- FSI = annual intake of soil
- FA_8 = area factor
- $FCD_8(t)$ = cover and depth factor
  - Same model as inhalation pathway
- FO_8 = occupancy factor
  - Total time spent on the site
  - Indoor time fraction + outdoor time fraction

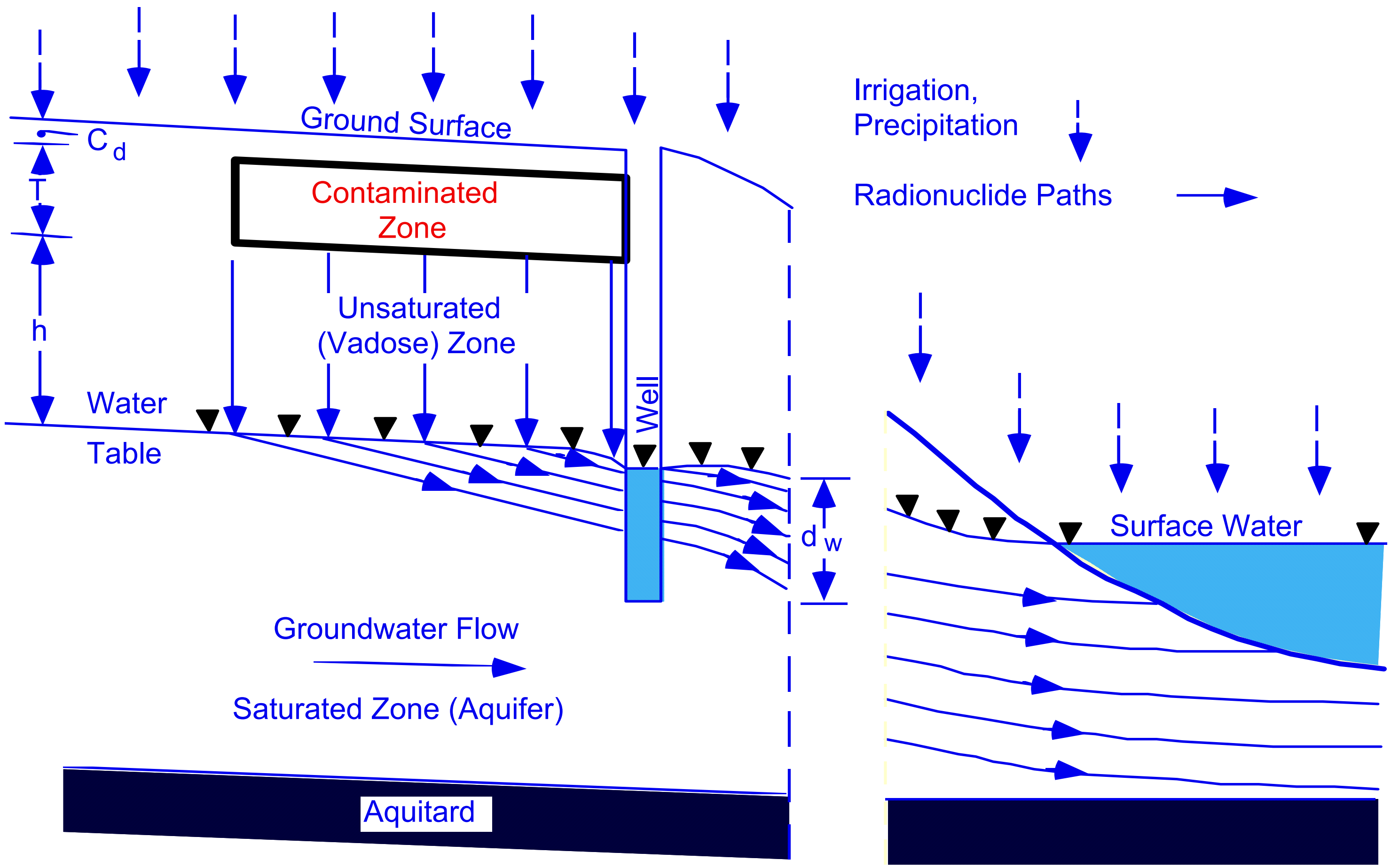


Environmental Transport Factors: Plant, Meat, and Milk Pathways

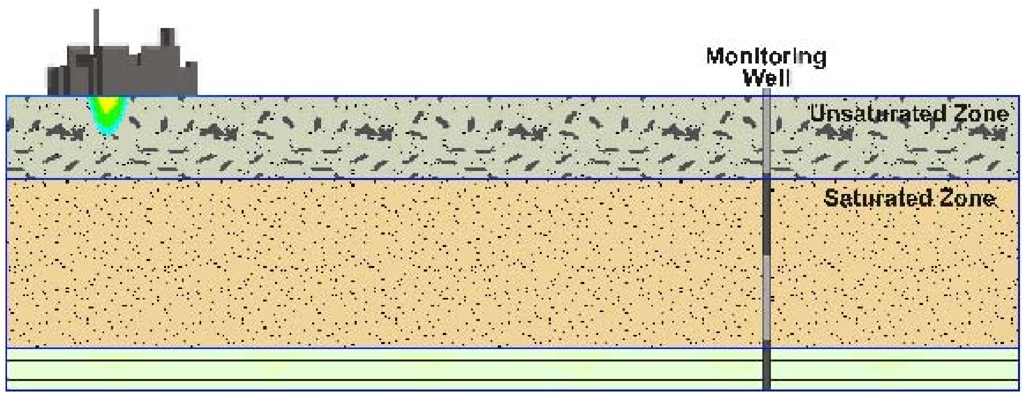
- Appendix D: RESRAD Users Manual
- $ETF_{ij,pq} = FA_p \times FCD_{pq}(t) \times \sum_k DF_{pk} \times FSR_{ij,pqk}(t)$
- Where
  - DF = dietary factor (annual consumption rate)
  - FSR(t) = food/soil concentration ratio
  - FA = area factor
  - FCD(t) = cover and depth factor



Water Pathway Factors



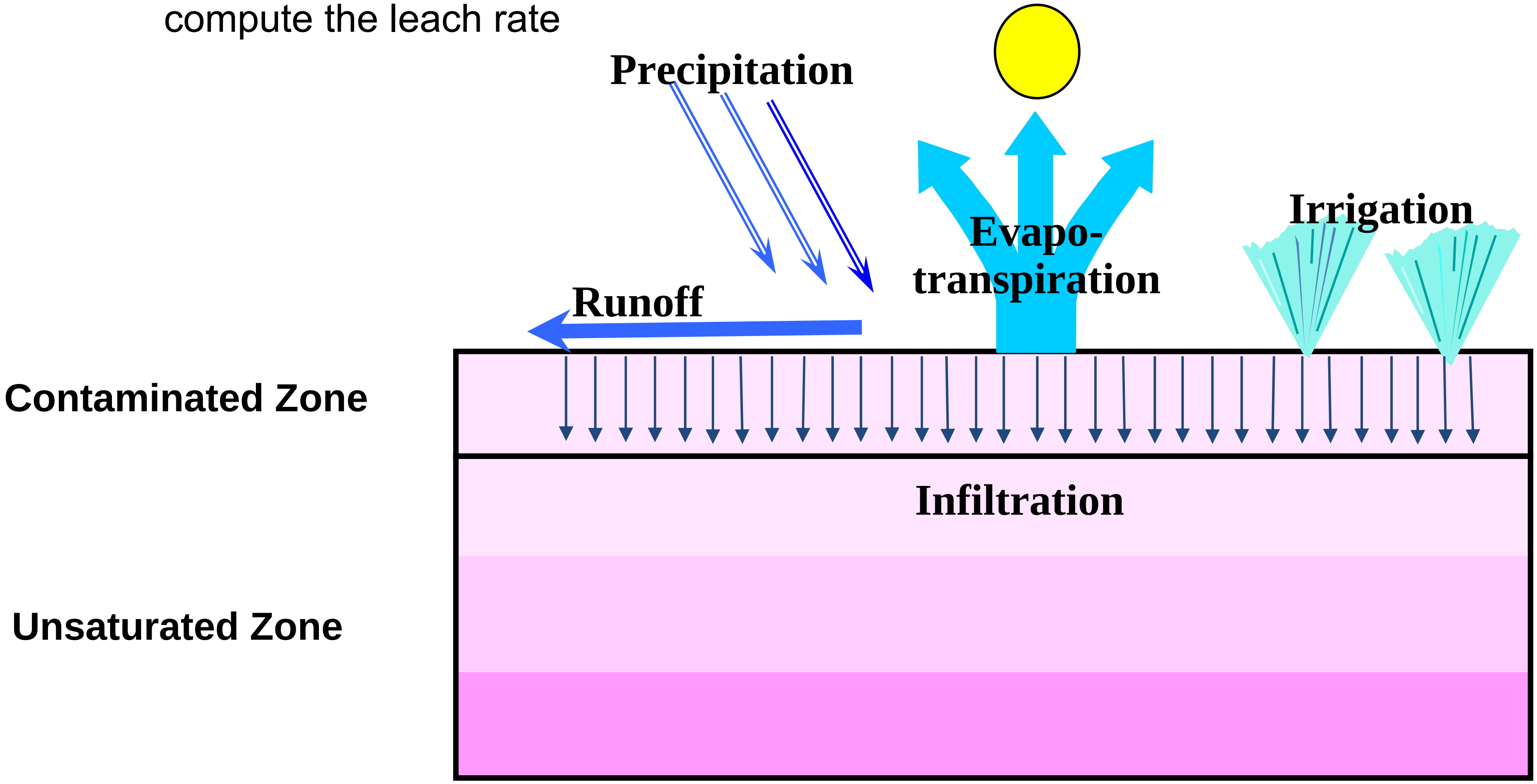
Computer Model of Contaminant Transport



Concentration above 40.0 pCi/L at 1/15/1990

Leaching Model

- Rate-controlled leaching model
  - If not specified, the leach rate will be computed using a sorption-desorption ion-exchange model
    - The distribution coefficient in the contaminated zone will be used to compute the leach rate



Leaching Model

$$L_i = \frac{I}{\theta^{(cz)} T R_{d_i}^{(cz)}}$$

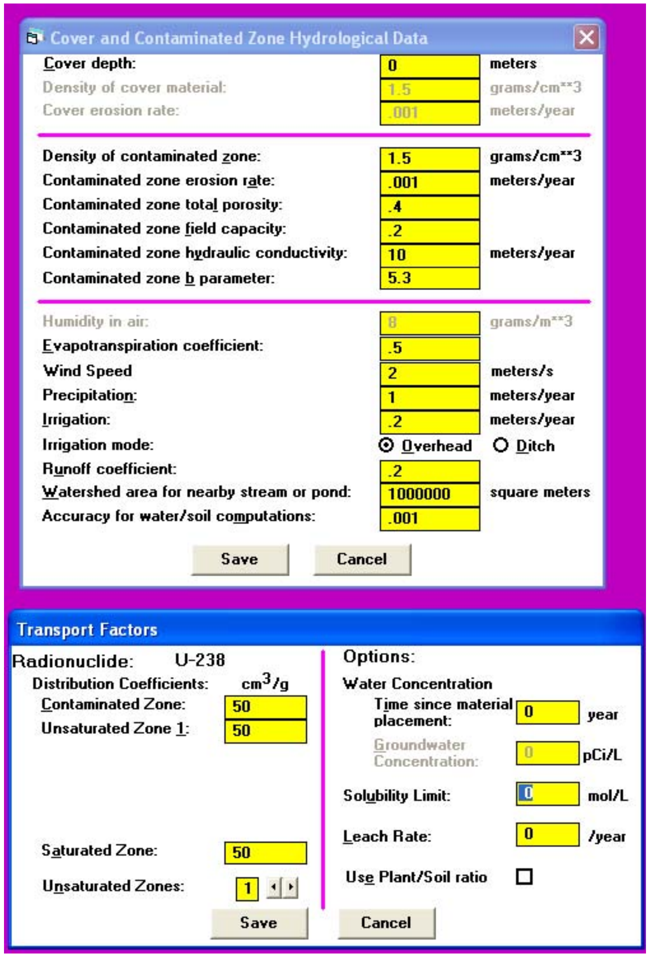
$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr}]$$

$$\theta = P_t R_s$$

$$R_{d_i} = 1 + \frac{\rho_b K_{d_i}}{\theta}$$

$$R_s = \left(\frac{I}{K_{sat}}\right)^{\frac{1}{2b+3}}$$

- Note: $R_s \leq 1$
  - $K_{sat} \geq I$



Leaching Model

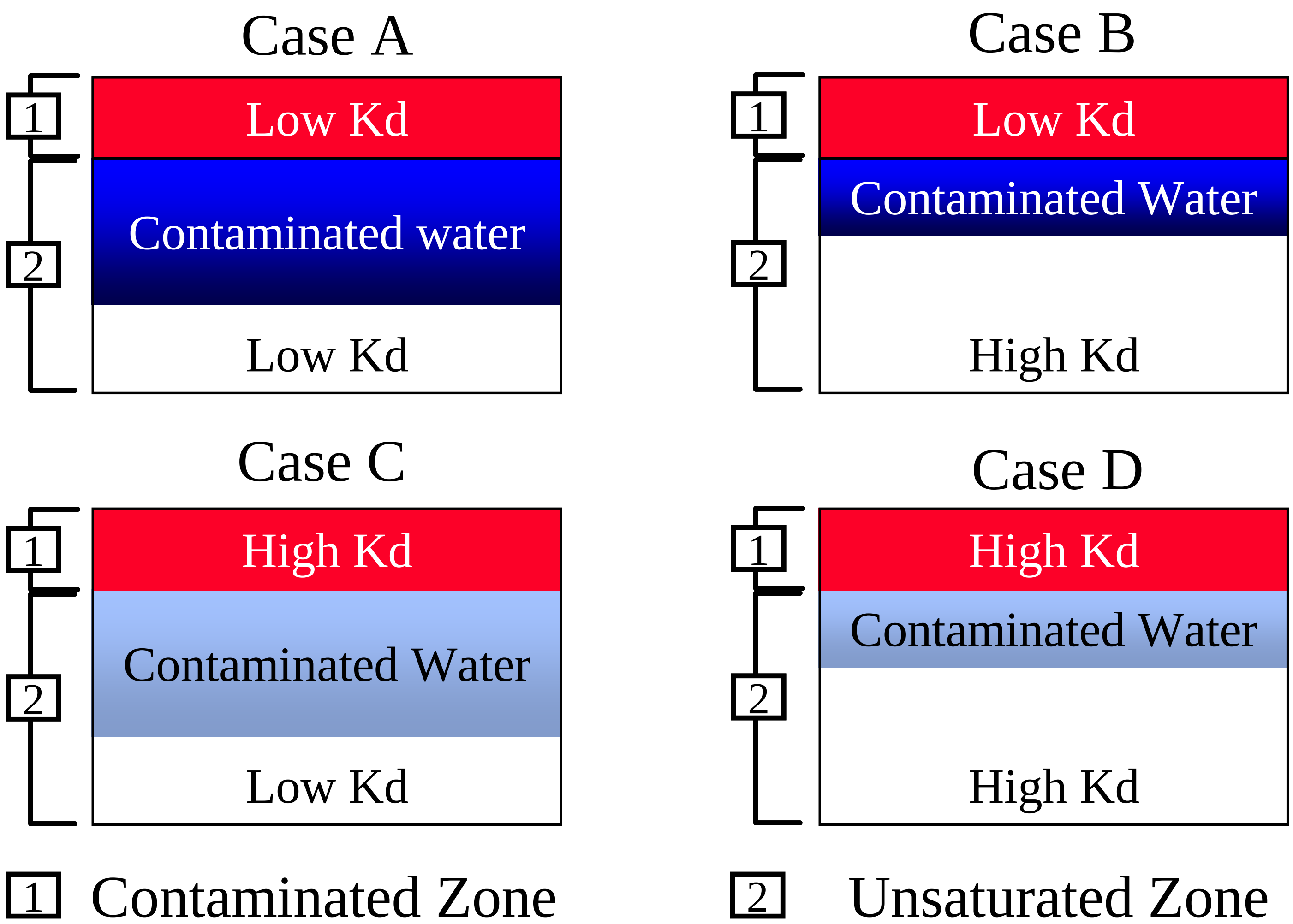
- Radionuclide-specific K_d
- Hydraulic conductivity (m/yr)
  - 33 [Silty Clay]
  - to 5,500 [Sand]
- Soil-specific “b” parameter
  - 4.0 [Sand]
  - to 11.4 [Clay]
- Field capacity
  - Lower limit of volumetric water content
- See Data Collection Handbook for more information

TABLE E.2 Representative Values of Saturated Hydraulic Conductivity, Saturated Water Content, and the Soil-Specific Exponential Parameter

Texture	Hydraulic Conductivity, K_{sat} (m/yr)	Saturated Water Content, θ_{sat}	Soil-Specific Exponential Parameter, b
Clay	4.05×10^1	0.482	11.40
Clay loam	7.73×10^1	0.476	8.52
Loam	2.19×10^2	0.451	5.39
Loamy sand	4.93×10^3	0.410	4.38
Sand	5.55×10^3	0.395	4.05
Sandy clay	6.84×10^1	0.426	10.40
Sandy clay loam	1.99×10^2	0.420	7.12
Sandy loam	1.09×10^3	0.435	4.90
Silty clay	3.26×10^1	0.492	10.40
Silty clay loam	5.36×10^1	0.477	7.75
Silty loam	2.27×10^2	0.485	5.30

Source: Data from Clapp and Hornberger (1978).

Effect of K_d on Leaching and Transport



Thank You!!

- For questions on the RESRAD Family of Codes, please contact:

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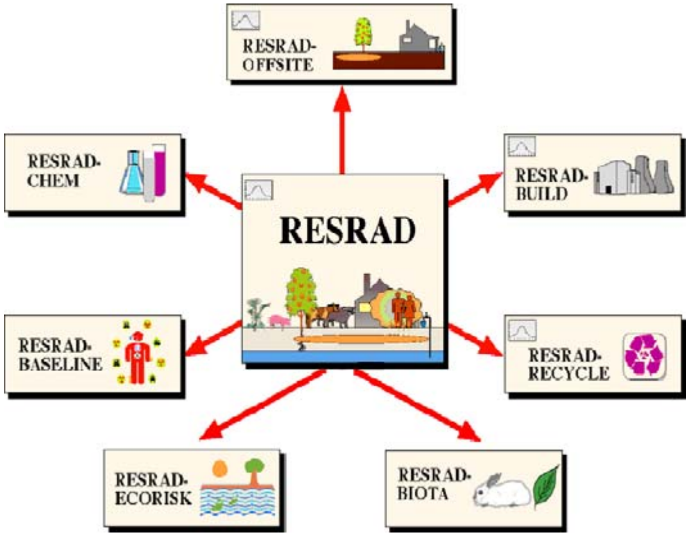
Argonne National Laboratory
RESRAD Program Manager
Phone: 630-252-5589
FAX: (630) 252-5880
E-mail: RESRAD@anl.gov

http://www.evs.anl.gov/RESRAD



IAEA
International Atomic Energy Agency

Dose and Risk Assessment Extensions

Sensitivity Analysis & Expectations
Offsite Assumptions
Probabilistic Analysis
Demonstration of Extensions

June 2010 | Argonne National Laboratory, USA

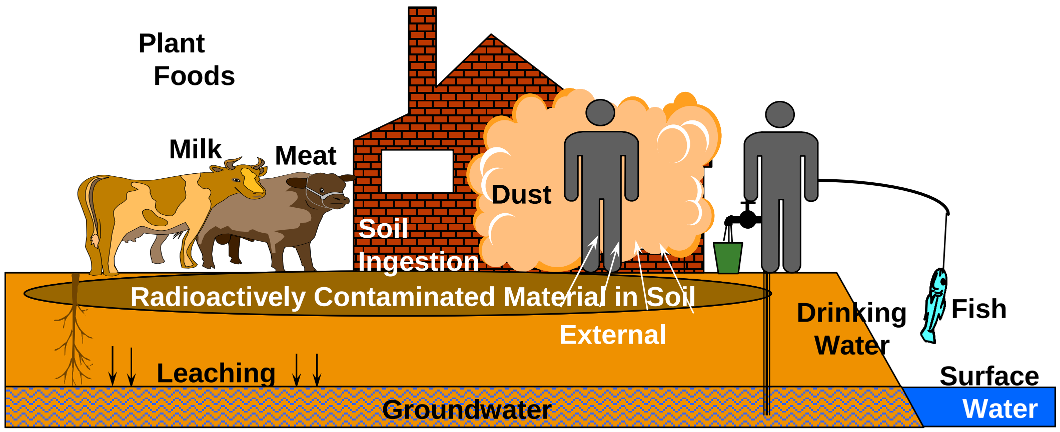
Levels of Conservatism Pile Up

- Determine exposure scenario
- Determine exposure pathway(s)
- Gather data
- Understand calculations
- Calculate guidelines
- Clean up

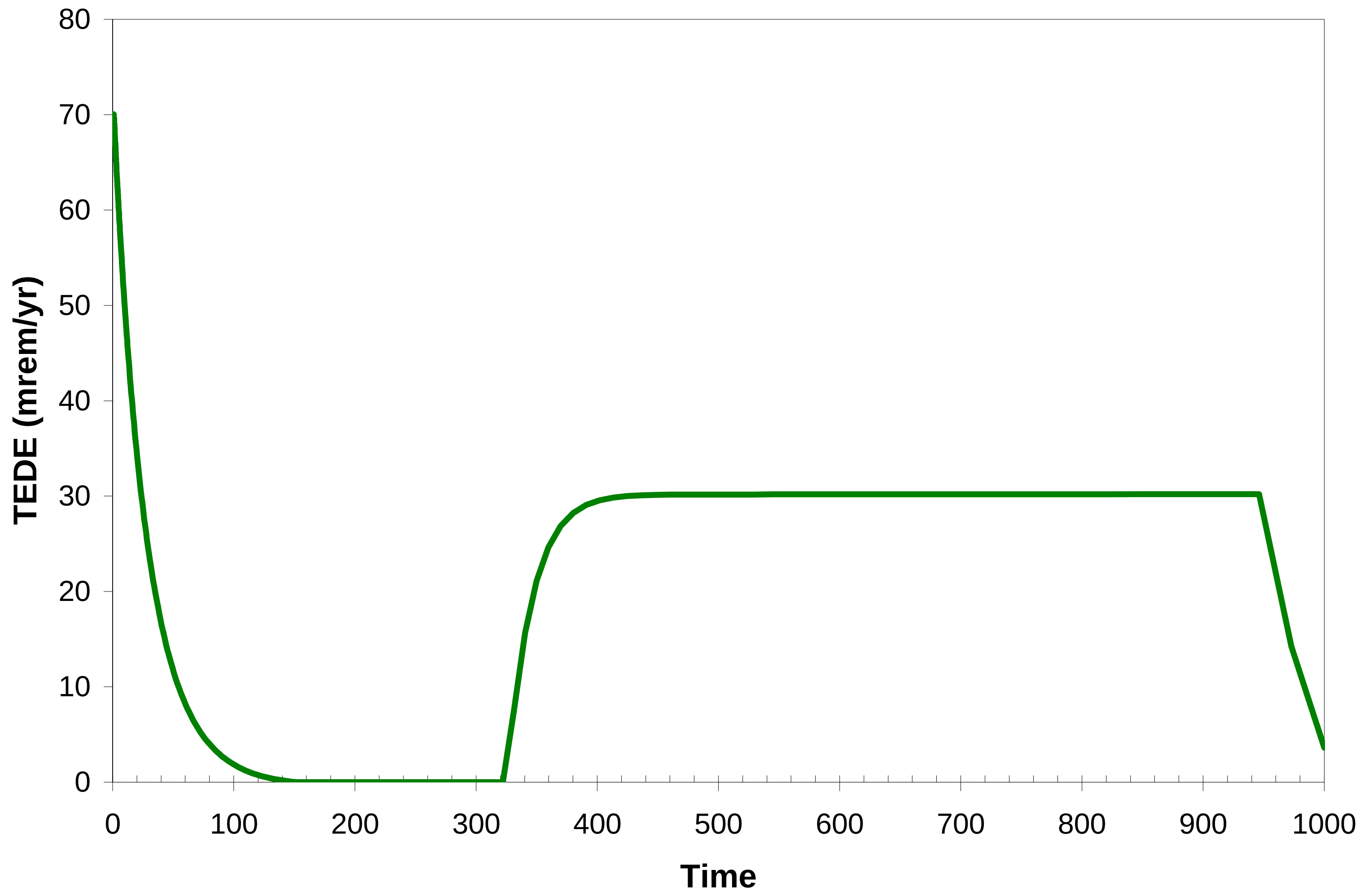
- Solution:
  - Use more realism in
    - Data (Sensitivity and Uncertainty) and
    - Scenario (Offsite)
  - But requires additional justification

An Example

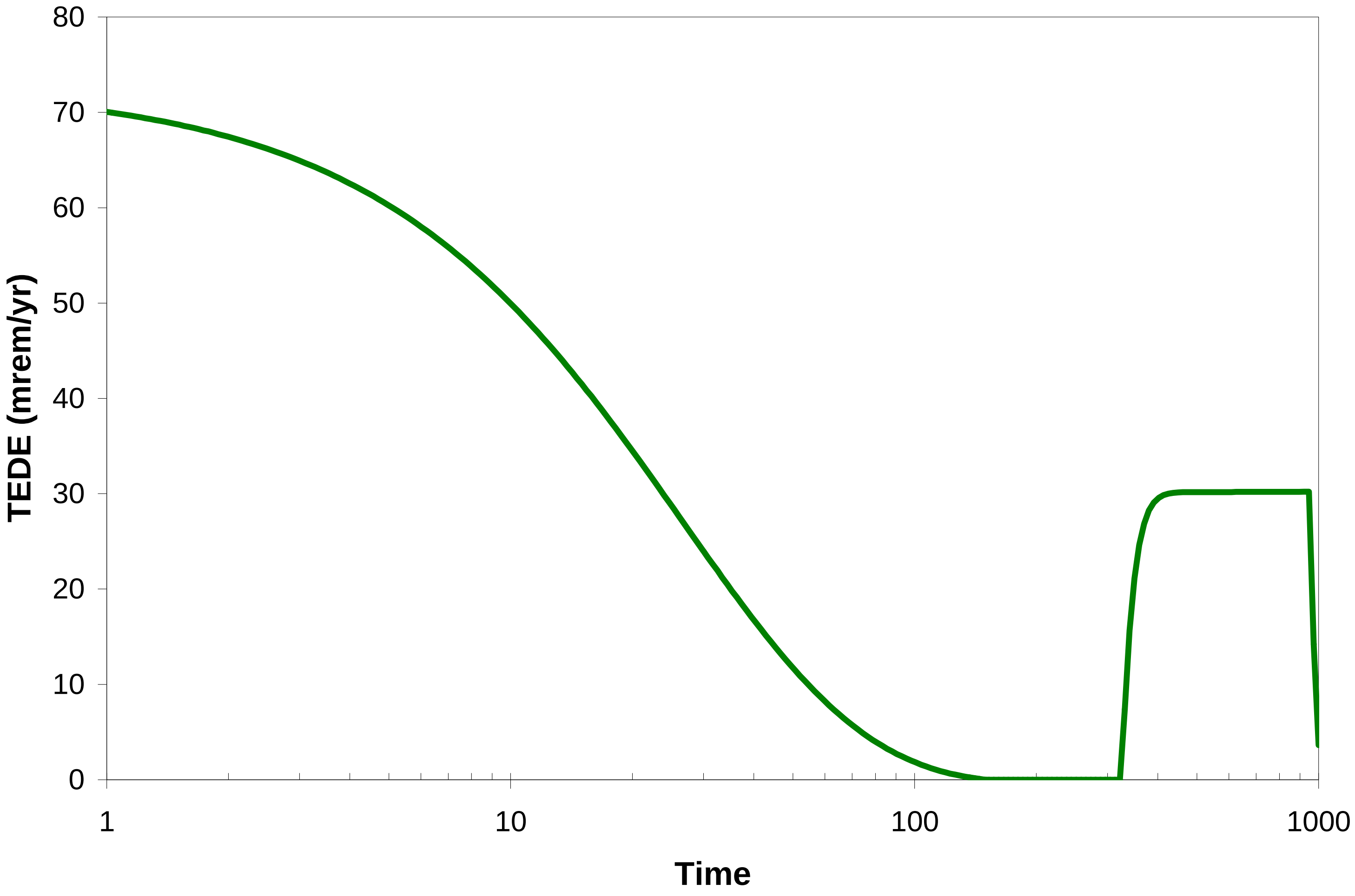
- An industrial site is contaminated with U-238 at 400 pCi/g and Cs-137 at 20 pCi/g. The contamination extends down to the first 15 cm of soil.
- Assuming unrestricted use, estimate the total effective dose equivalent to an individual for up to 1,000 years after license termination. Assume a residential farming scenario.



Total Effective Dose Equivalent (TEDE)

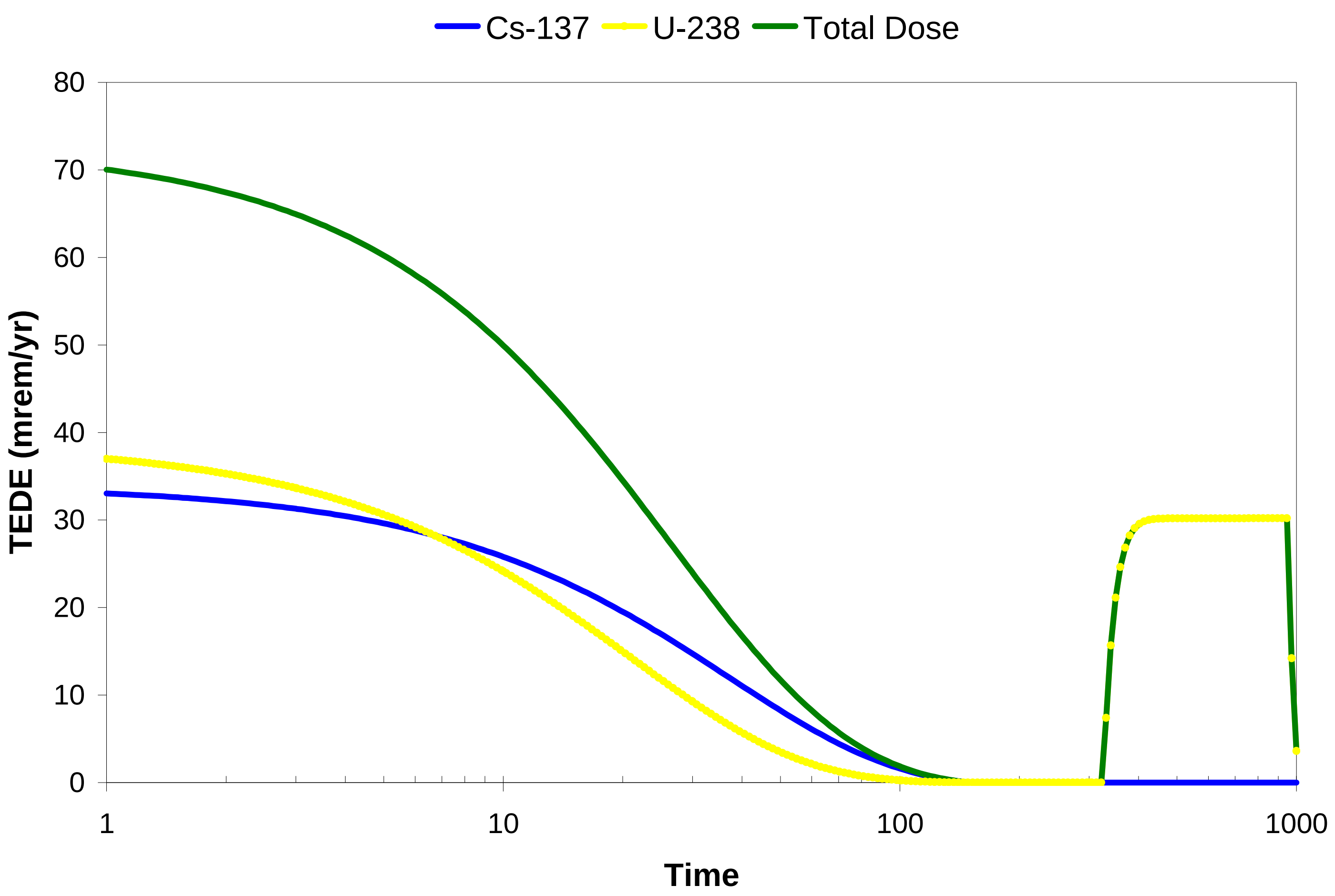


Total Effective Dose Equivalent (TEDE)



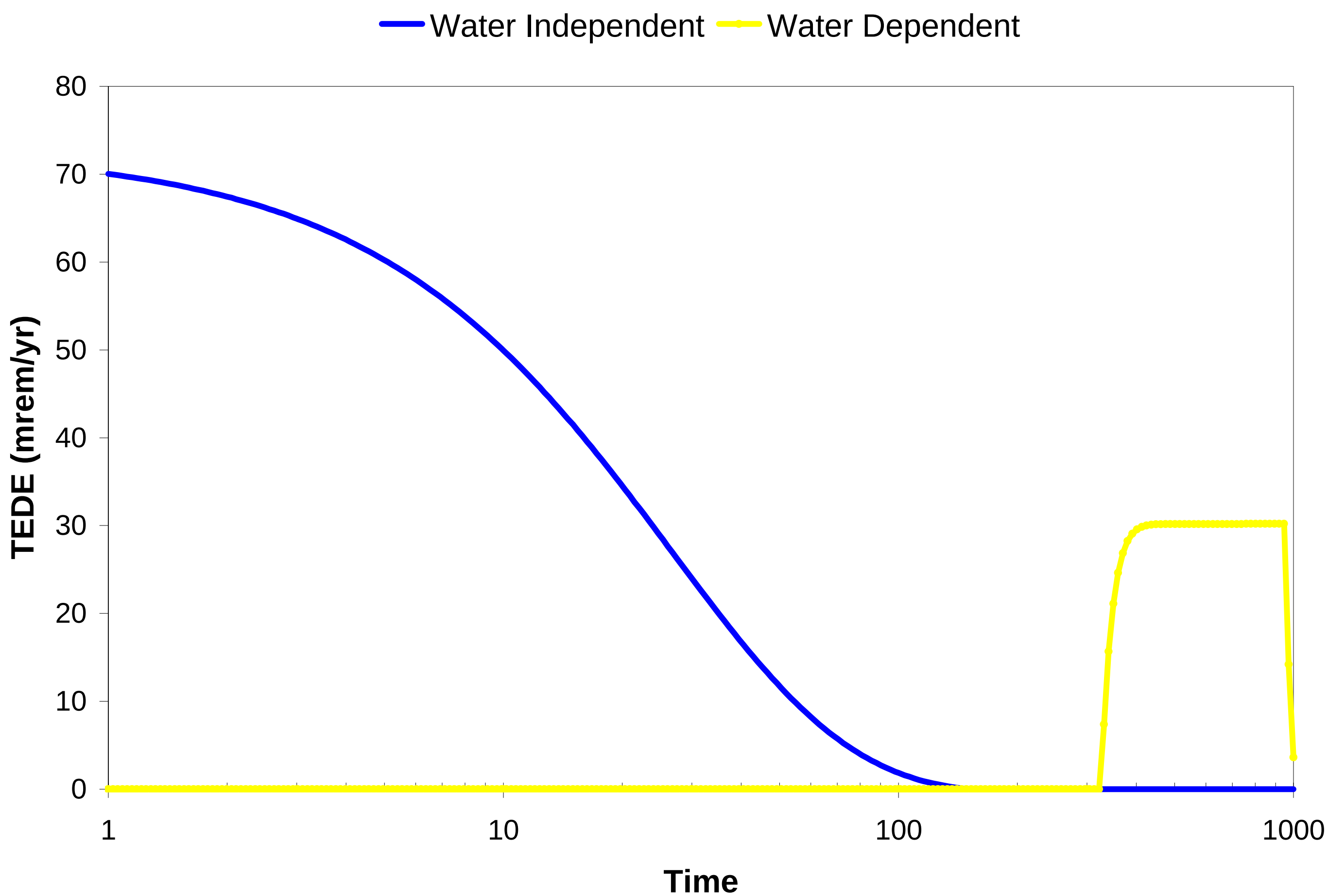
Which Radionuclides Contribute to the Dose

- Cs-137, U-238 or both?



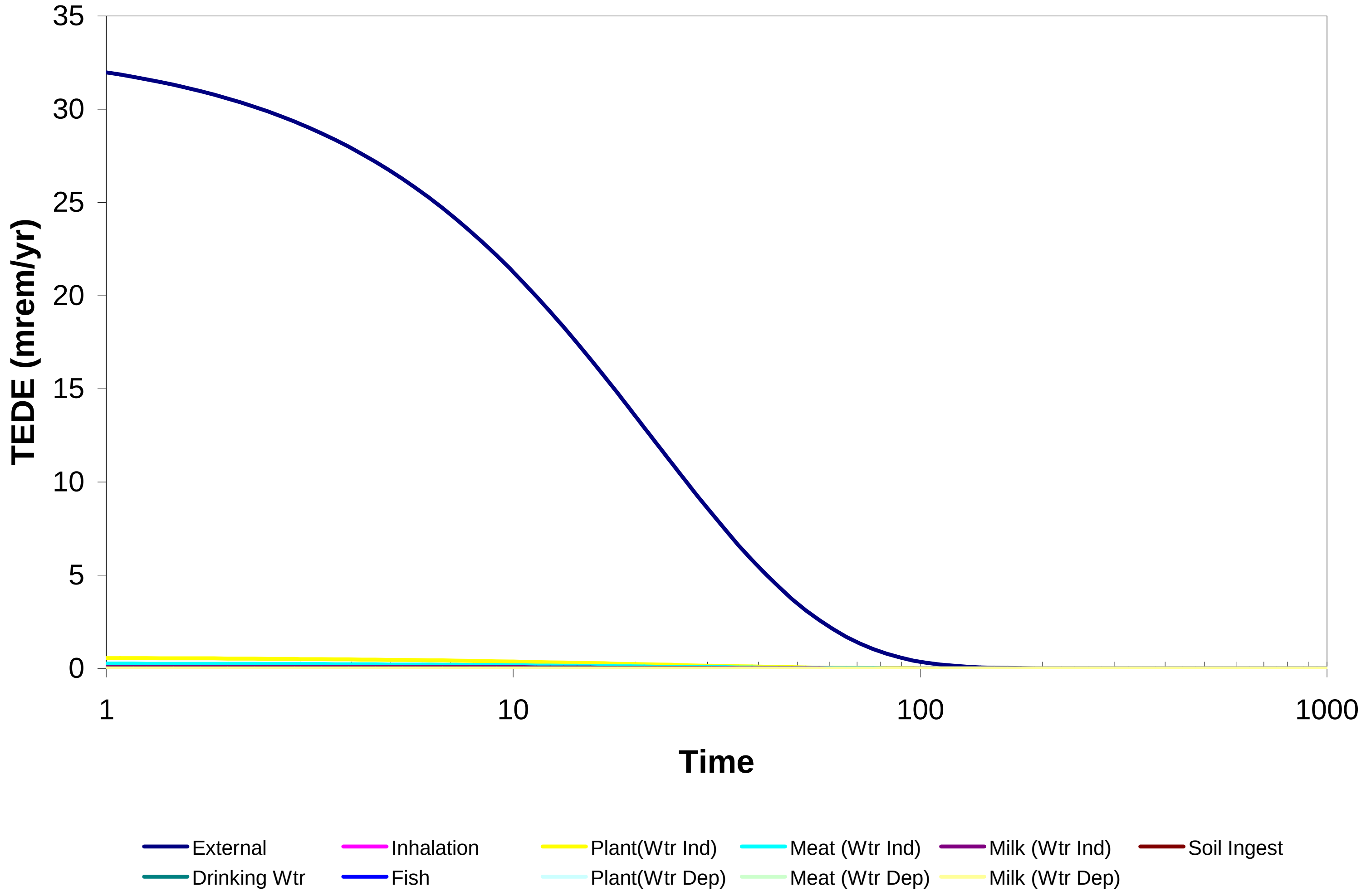
Which Pathways Contribute to the Dose?

- Water dependent or water independent?



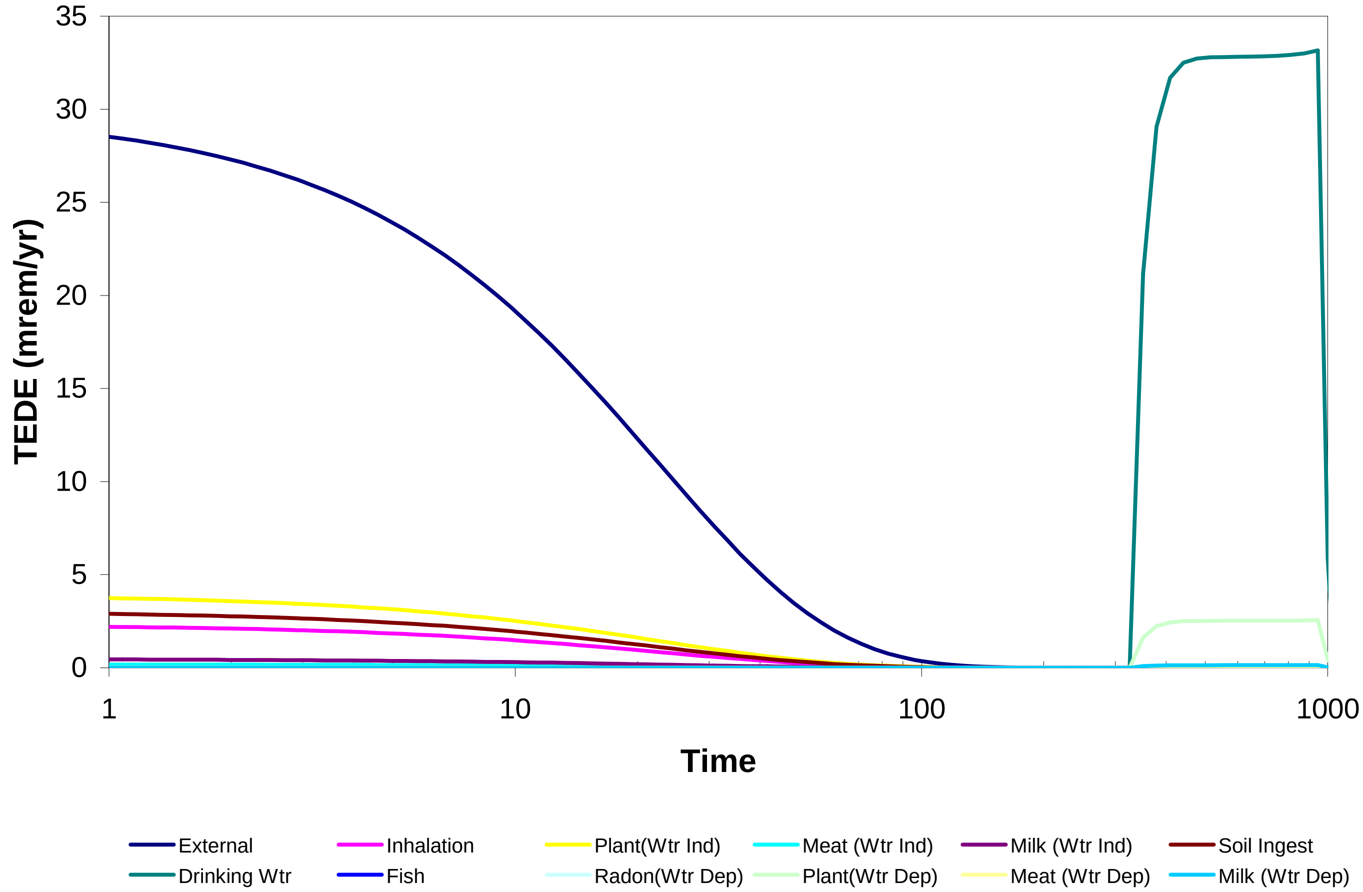
Components of TEDE

- Cs-137

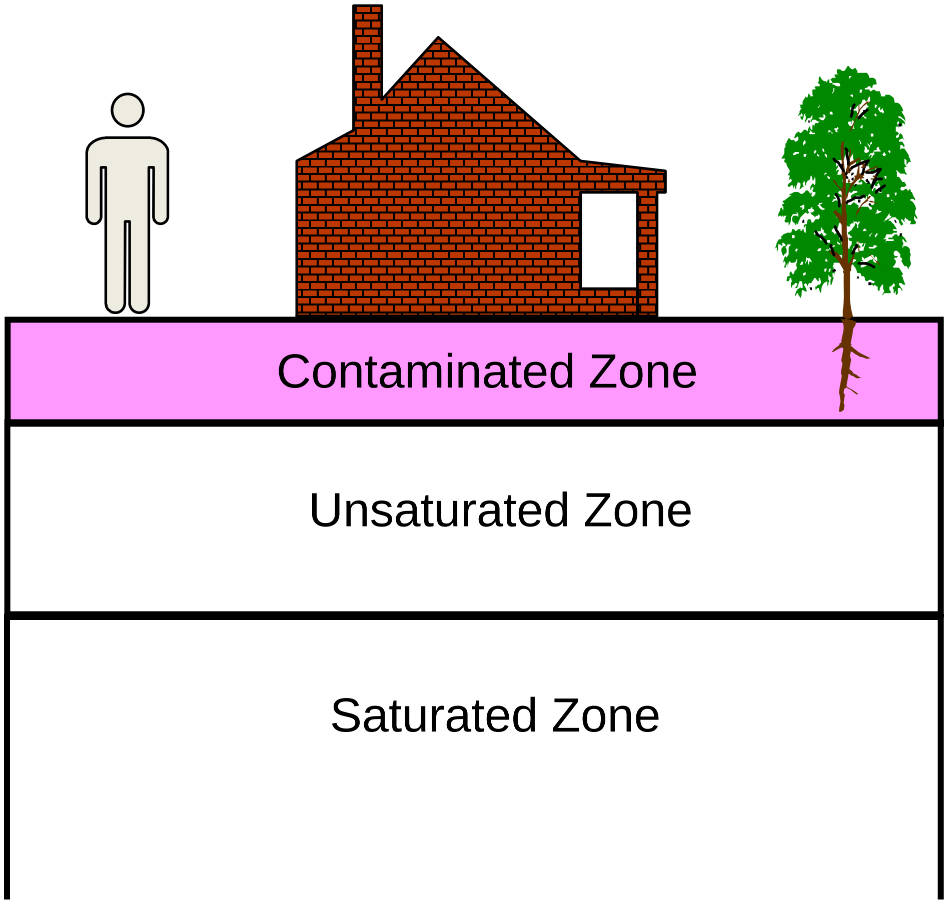


Components of TEDE

- U-238

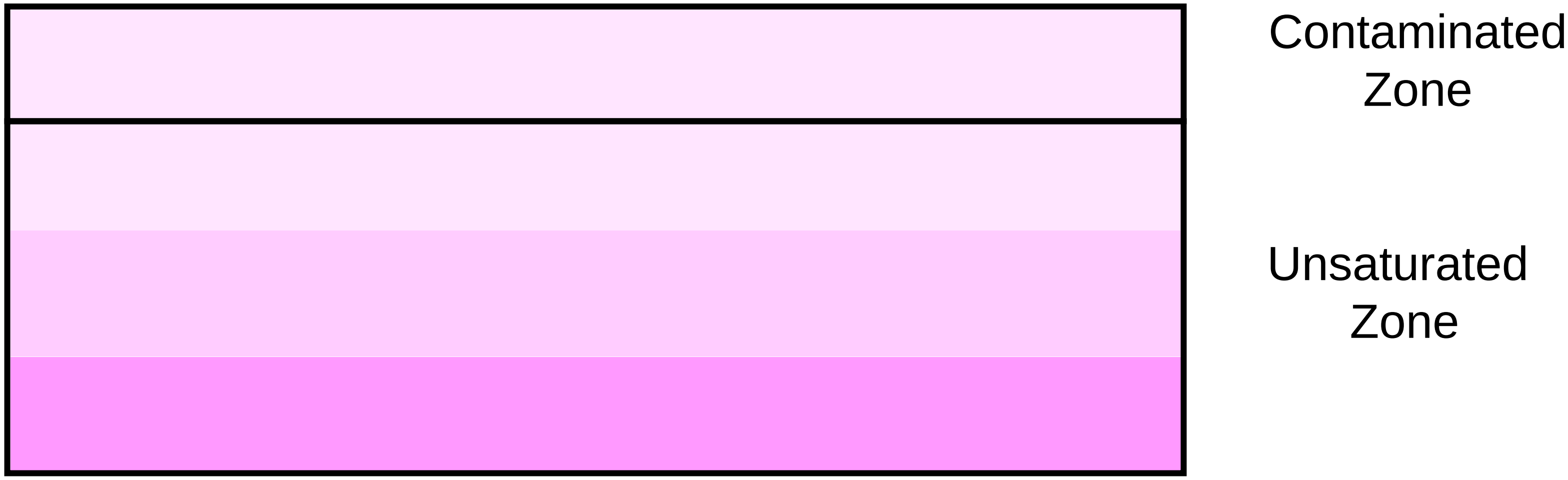


Water-Independent Components



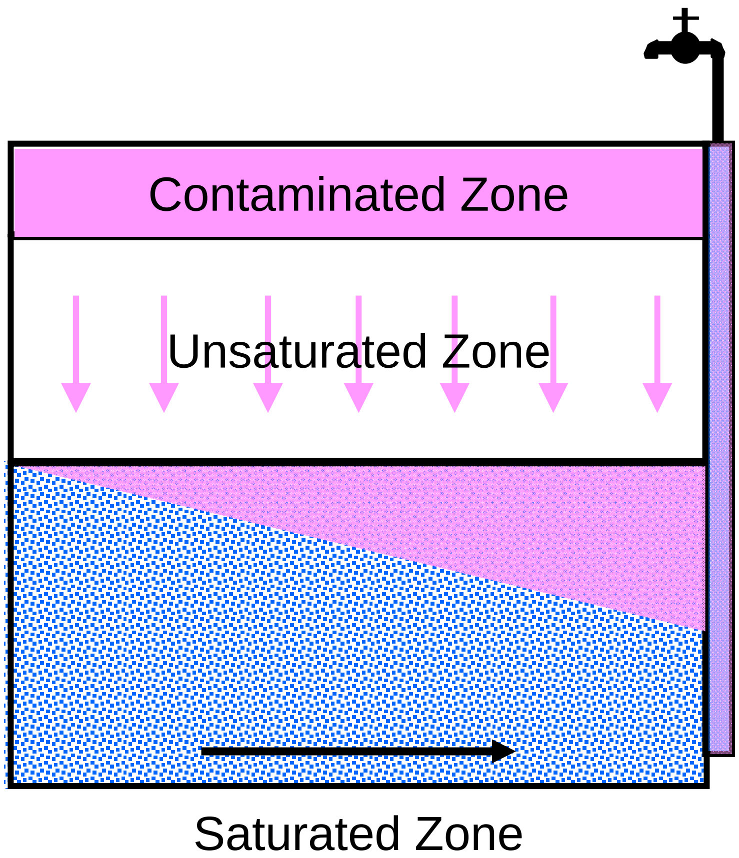
- External Pathway
  - Cover thickness
  - Contamination thickness
  - Erosion rates
  - Leach rates
  - Shielding factors
  - Time factors
- Ingestion Pathways
  - Cover thickness
  - Contamination thickness
  - Erosion rates
  - Leach rates
  - Ingestion rates
  - Depth of roots

RESRAD Leaching/Unsaturated Zone Transport Model



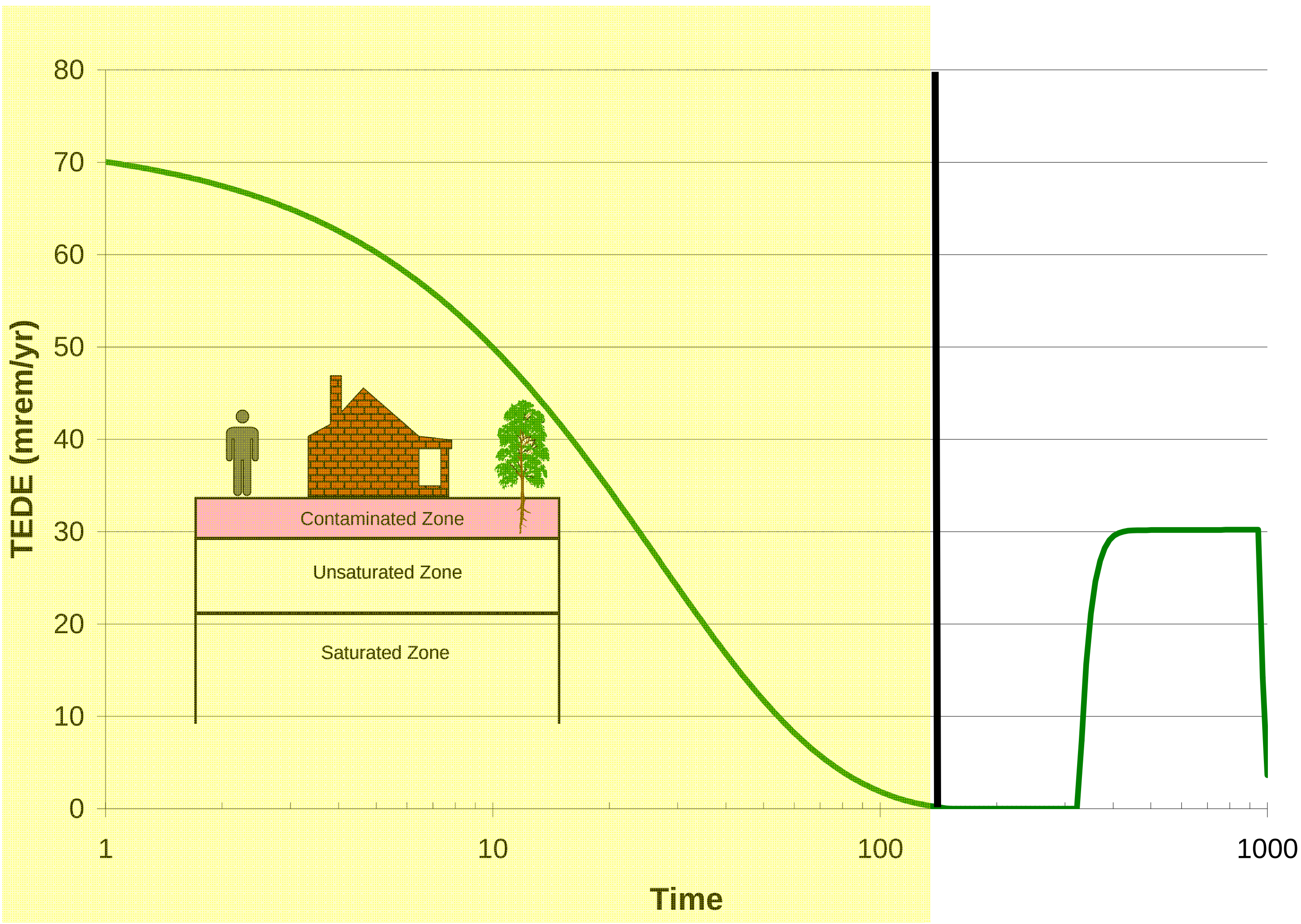
- Transport time in the “unsaturated zone” is a function of
  - K_d (distribution coefficient)
  - Saturation ratio
  - Thickness of unsaturated zone(s)
  - Infiltration rate
  - Effective porosity
- Leach-rate is a function of
  - K_d (distribution coefficient)
  - Total porosity
  - Saturation ratio
  - Infiltration rate

Radionuclide Transport

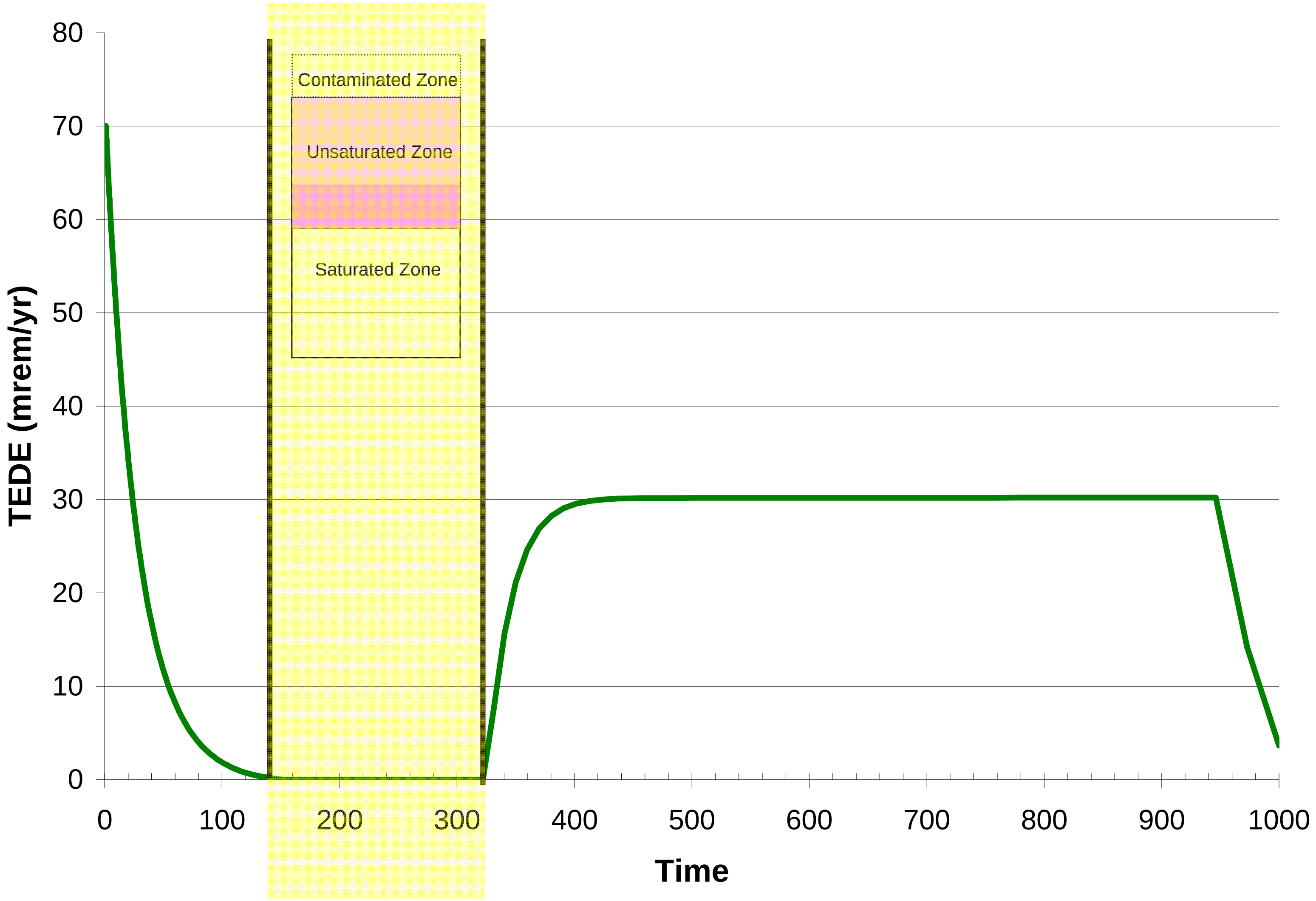


- Water-Dependent Pathway Parameters
  - Distribution coefficients
  - Area of contaminated zone
  - Well depth
  - Well pumping rate
  - Infiltration rate
  - Length parallel to aquifer flow
  - Ingestion rates

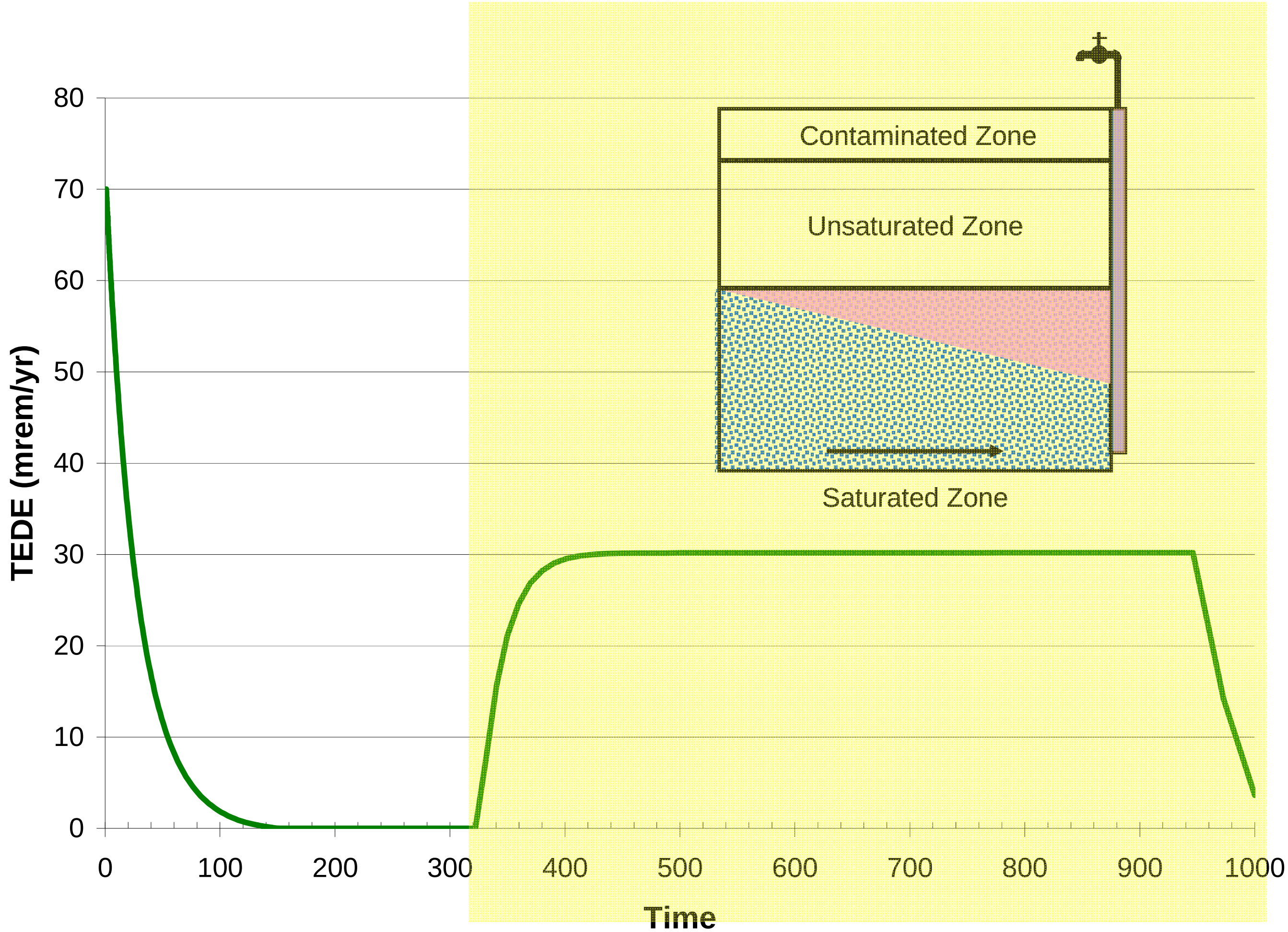
Characteristics of TEDE versus Time



Characteristics of TEDE versus Time

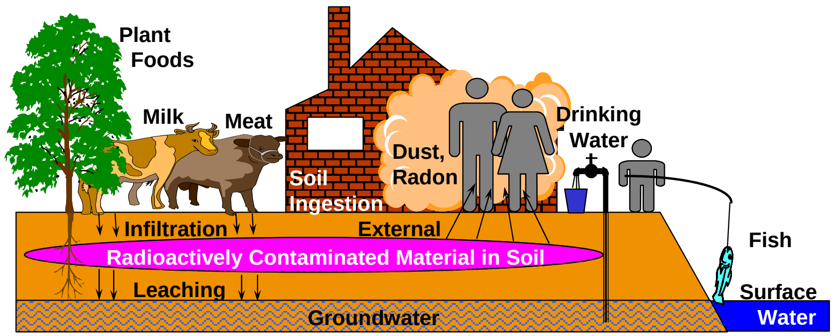


Characteristics of TEDE versus Time

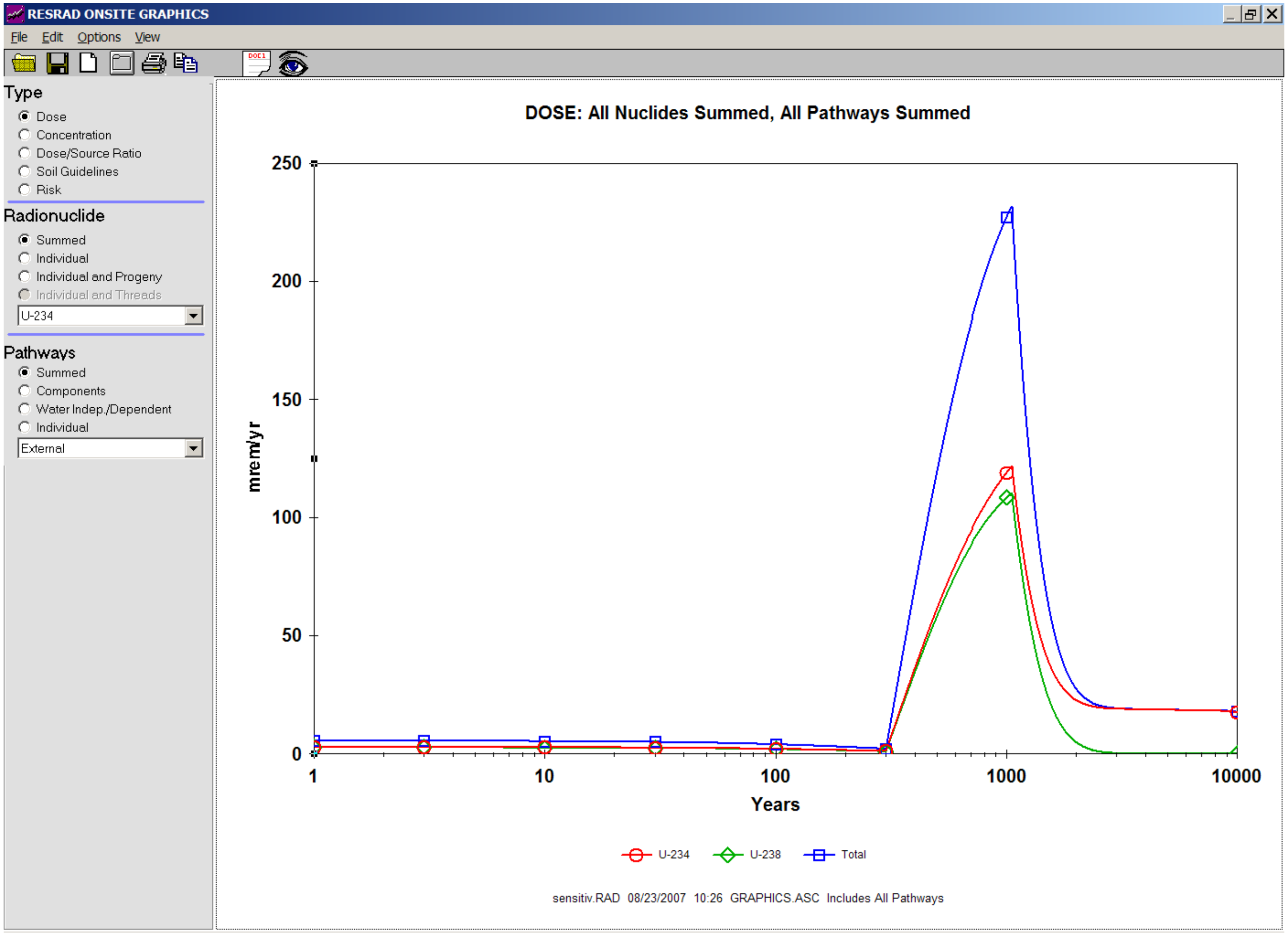


Sensitivity Analysis: An Example

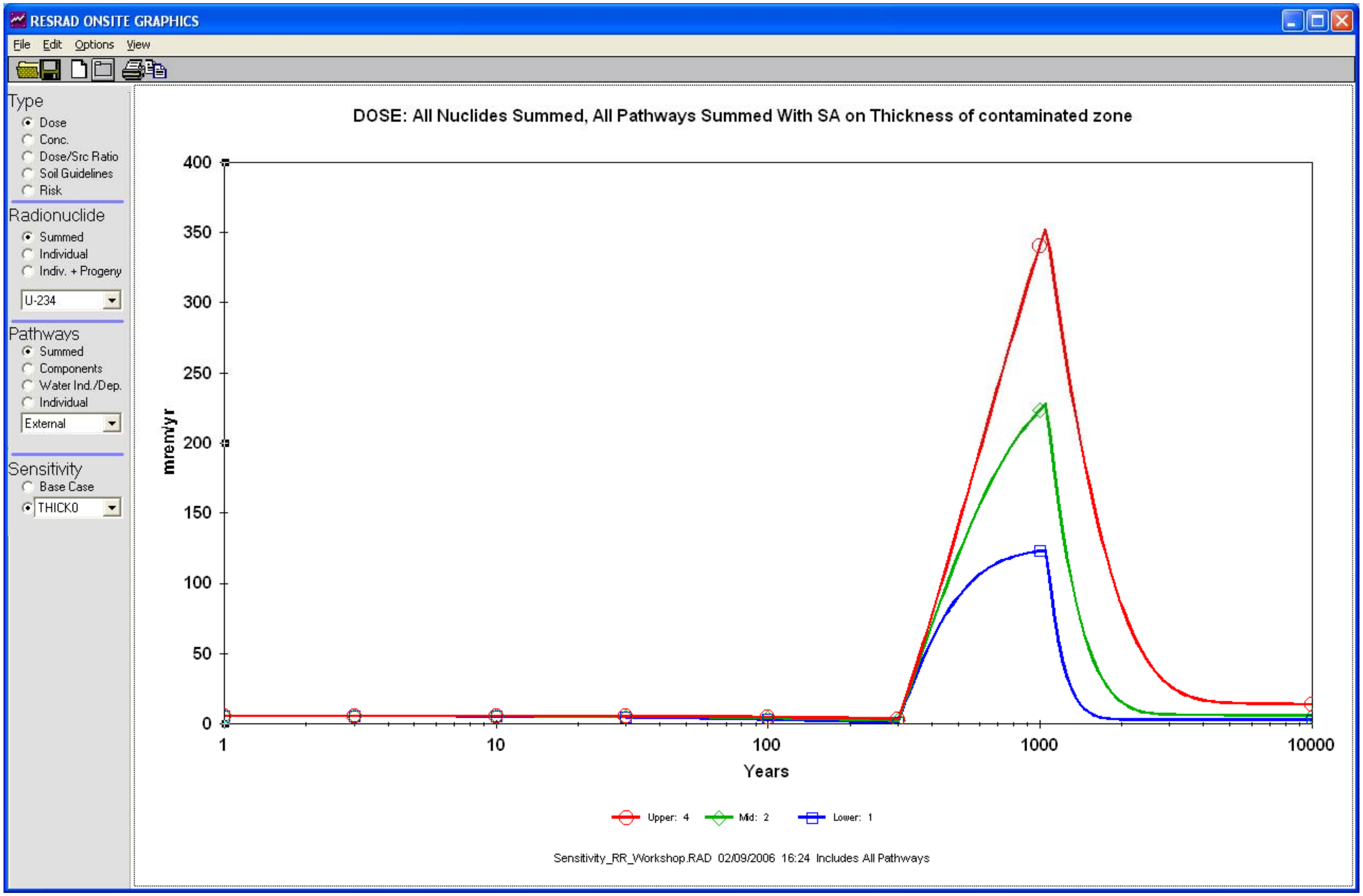
- Residential Farmer Scenario
  - U-238 and U-234 @ 100 pCi/g each
  - 0.5 m cover
  - No erosion of cover material
  - Water table drop rate set to 0
  - All other parameters set to default
  - Sensitivity analysis performed on
    - Thickness of contaminated zone
    - Precipitation rate
    - Distribution coefficient in the unsaturated zone



Base Case

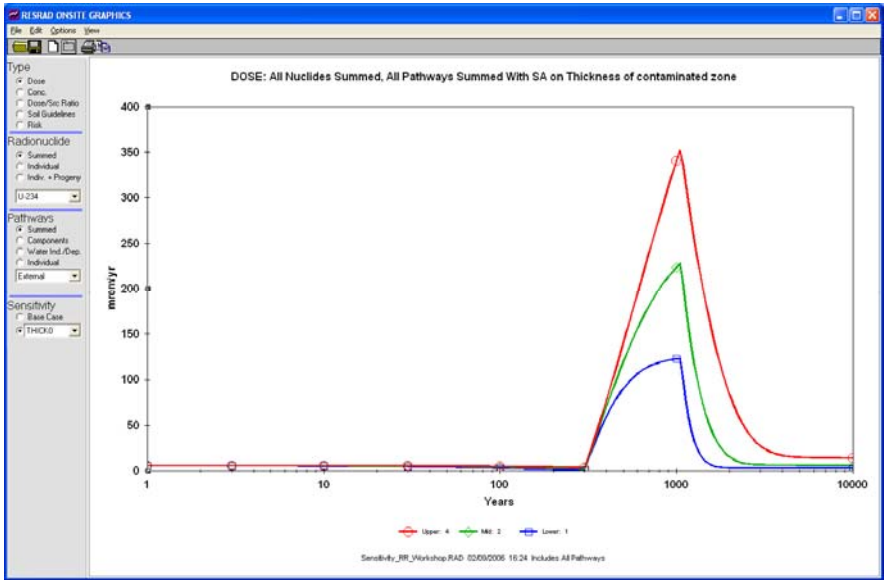

RESRAD ONSITE GRAPHICS
File Edit Options View
Type
Dose
Concentration
Dose/Source Ratio
Soil Guidelines
Risk
Radionuclide
Summed
Individual
Individual and Progeny
Individual and Threads
U-234
Pathways
Summed
Components
Water Indep./Dependent
Individual
External
DOSE: All Nuclides Summed, All Pathways Summed
mrem/yr
250
200
150
100
50
0
1
10
100
1000
10000
Years
U-234
U-238
Total
sensitiv.RAD 08/23/2007 10:26 GRAPHICS.ASC Includes All Pathways

Sensitivity on the Thickness of the Contaminated Zone

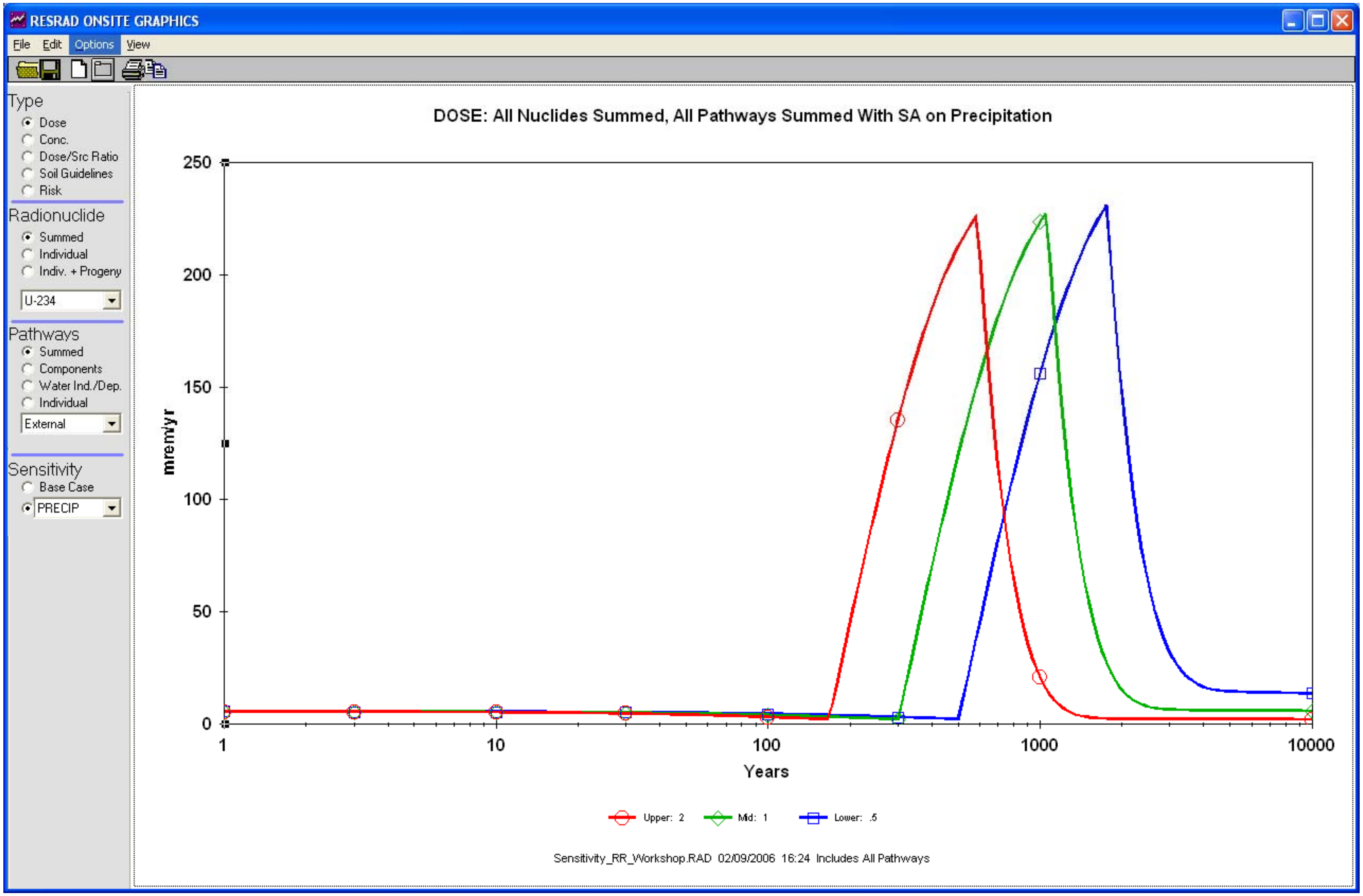


Summary of Results

- Thickness of Contaminated Zone
  - Peak dose occurs at the same point in time
  - Breakthrough time occurs at the same place
  - Dose is insensitive to the thickness at early times
  - The overall magnitude of the dose increases with increasing thickness
  - Longer tail with increased thickness
  - What other parameters may change when the thickness of the contaminated zone changes
  - Does the dose change “significantly?”

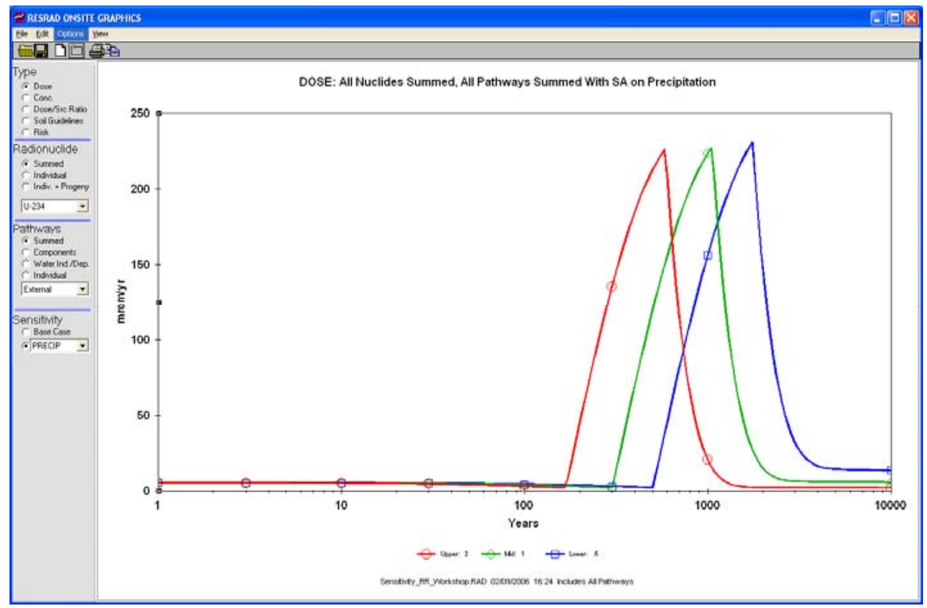


Sensitivity on the Precipitation Rate

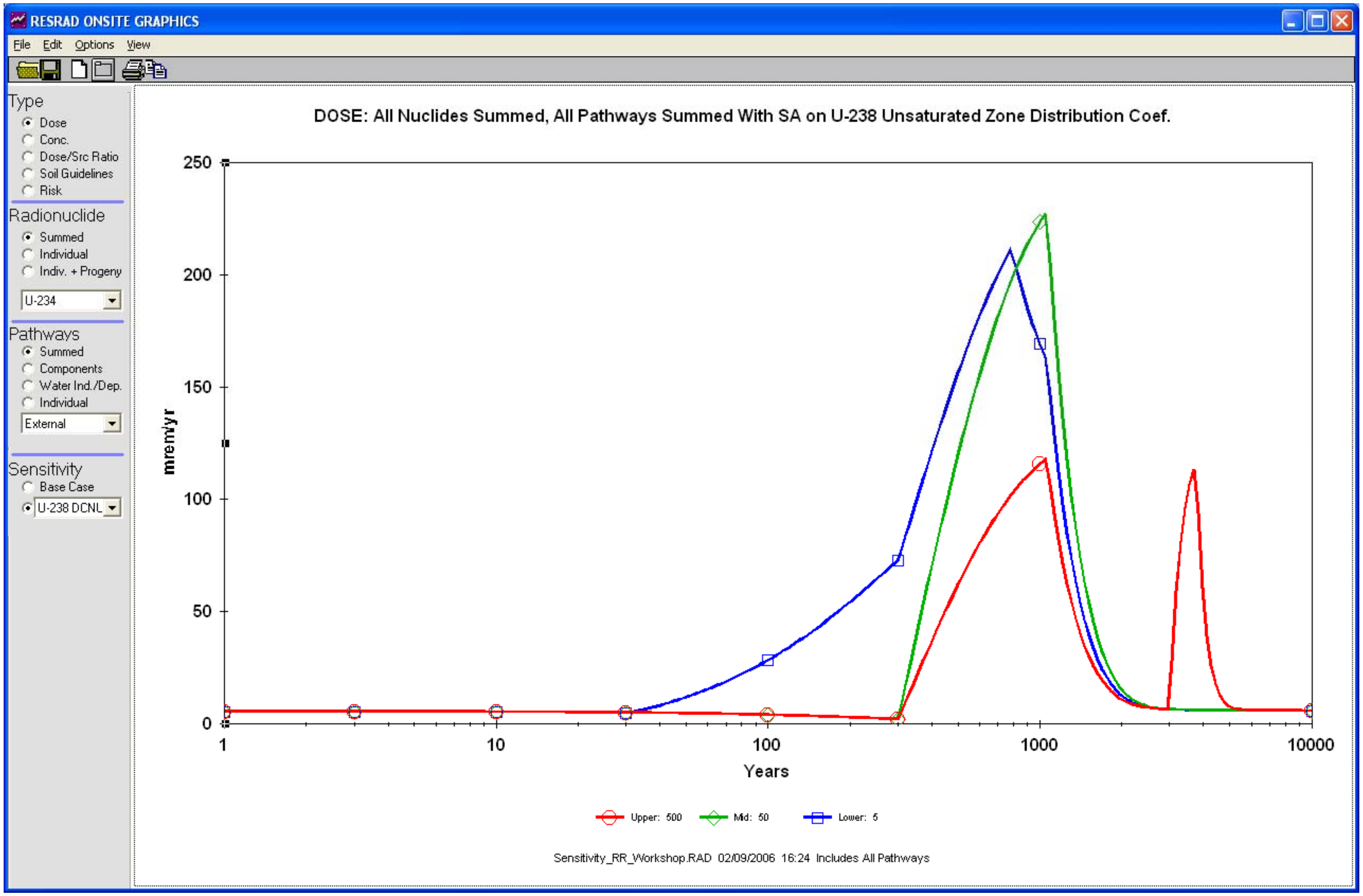


Summary of Results

- Precipitation Rate
  - Time of peak dose changes
  - Breakthrough time changes
  - Overall magnitude of the dose is about the same
  - Dose is insensitive to the precipitation rate in early times
  - Decreasing the precipitation rate pushes the peak past 1000 years
  - Would this be a cause for concern?
  - What other parameters may affect the precipitation rate?
  - Would the precipitation rate be considered "significant"?

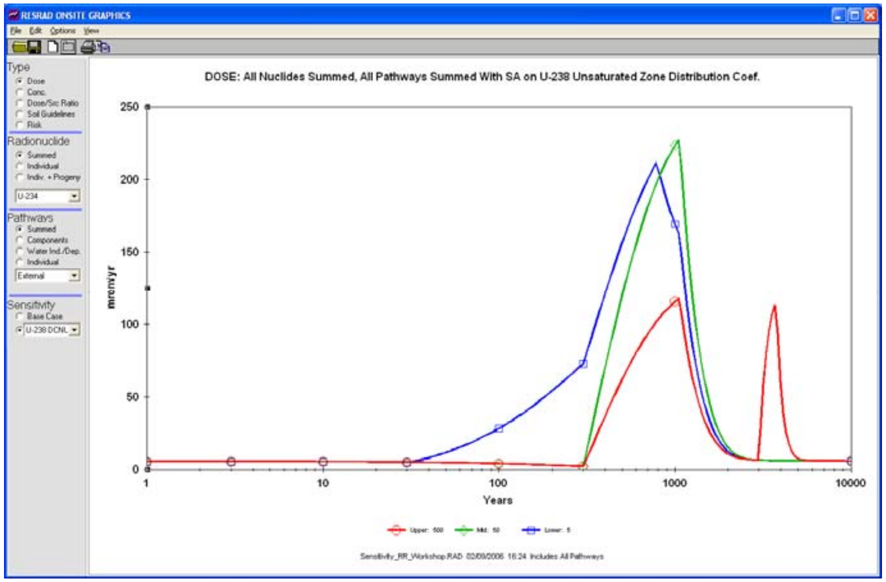


Sensitivity Analysis on the K_d of U-238 in the Unsaturated Zone

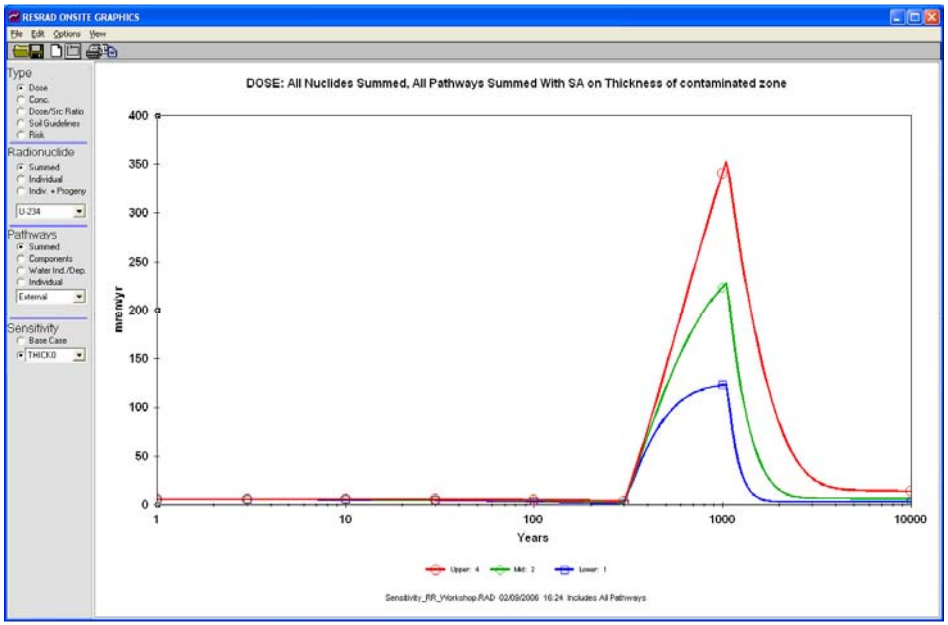


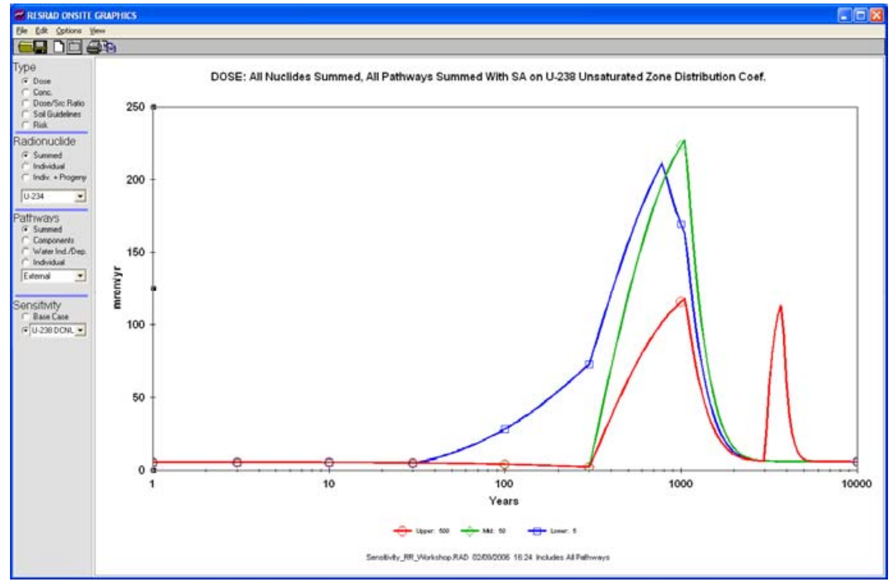
Summary of Results

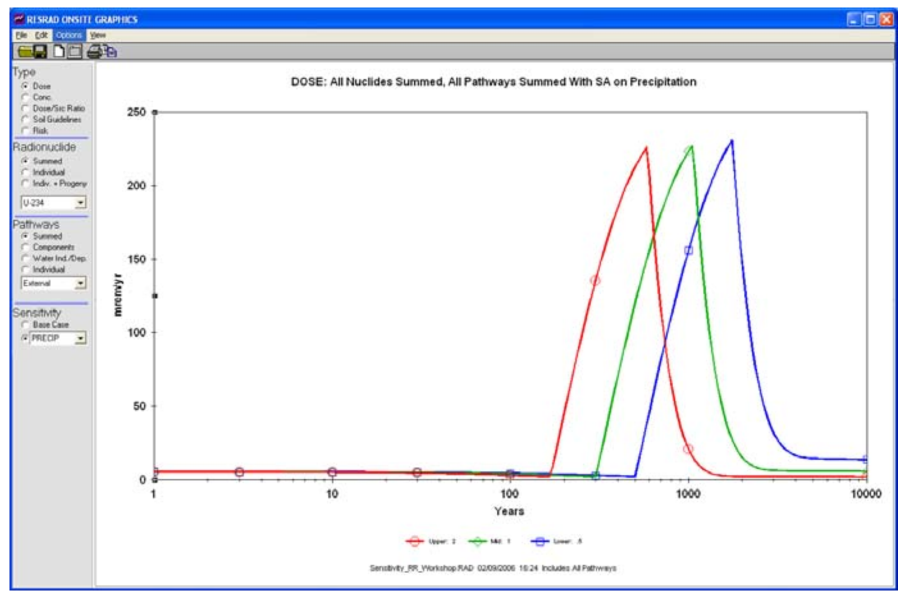
- Overall magnitude of the dose decreases for 1 out of 3 simulations and remains the same for the other 2 simulations
- Multiple breakthrough times and peak doses for one simulation
- One peak past the 1,000-year timeframe
- Are there other parameters that may be correlated to the K_d of U-238 in the unsaturated zone?
- How might they affect the results?
- Does changing the K_d in the unsaturated zone change the dose significantly?



What is Significant?

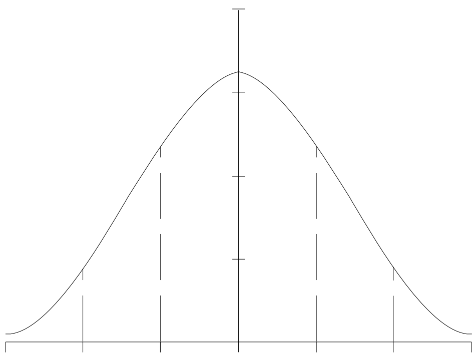


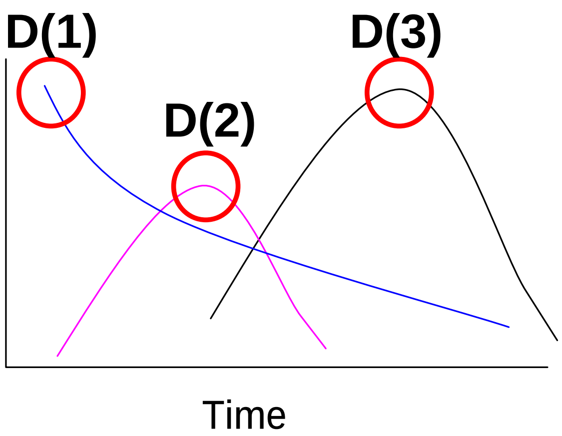




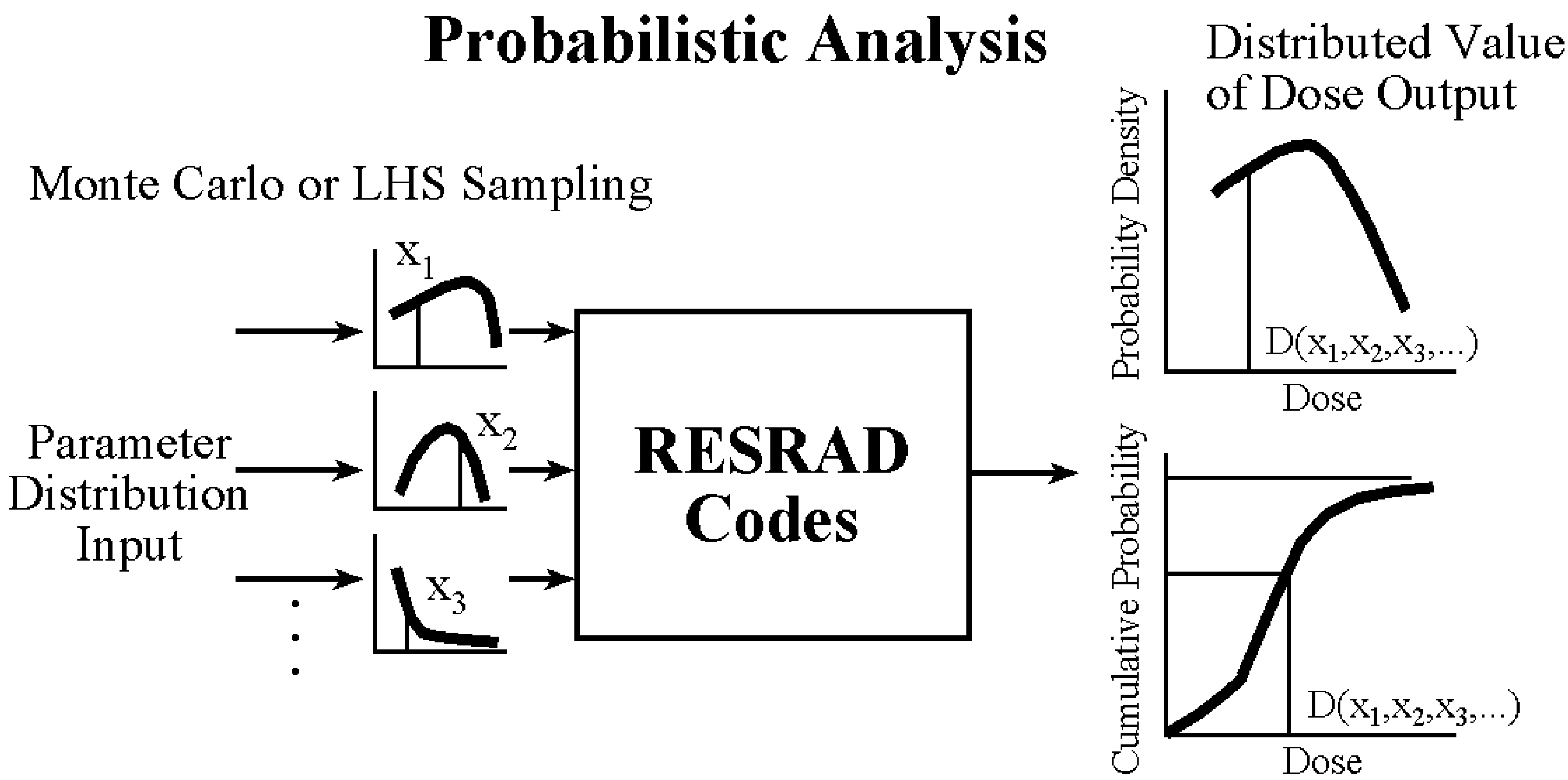
Probabilistic Methodology Overview

- Comparison of deterministic and probabilistic inputs and calculations
- Specifying distribution for inputs
- Inputs
  - Parameter sampling
  - Parameter correlations
- Outputs
  - Distribution of the peaks
    - Distribution free fractiles (quantiles)
    - Mean ("mean of the peaks")
  - "Peak of the means"
- Parameter sensitivity
  - Probabilistic
  - Deterministic





Probabilistic Analysis



Comparison of Deterministic and Probabilistic Inputs

- Deterministic
  - Single value for each input parameter
  - One set of inputs
- Probabilistic
  - A distribution for one or more parameters
    - A range of values with some way of specifying the probability of various parts of that range
  - Sample the distribution many times
    - Number of observations
    - Creates many sets of inputs

Comparison of Deterministic and Probabilistic Calculations

- Calculations are performed one time in the main code
- The number of calculations performed by the main code are equal to the number of observations
  - 100 observations = 100 RESRAD calculations
  - 1,000 observations = 1,000 RESRAD calculations

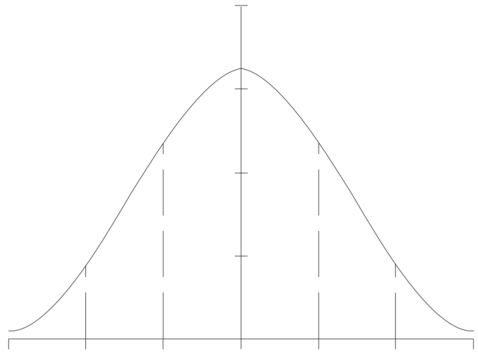
Comparison of Deterministic and Probabilistic Calculations

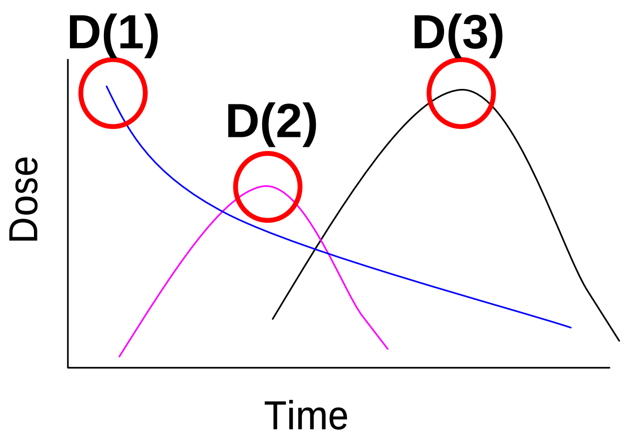
- One result, whether it be the peak dose, the peak risk, or a temporal plot of dose (or risk)

- As many results as there are observations
- A distribution of the result, whether it be of the peak dose, of the peak risk, or distribution of dose (or risk) over time

Probabilistic Terminology

- Parameter sampling
- Parameter correlations
- "Peak of the mean"
- "Mean of the peaks"
- Parameter sensitivity
  - Deterministic
  - Probabilistic

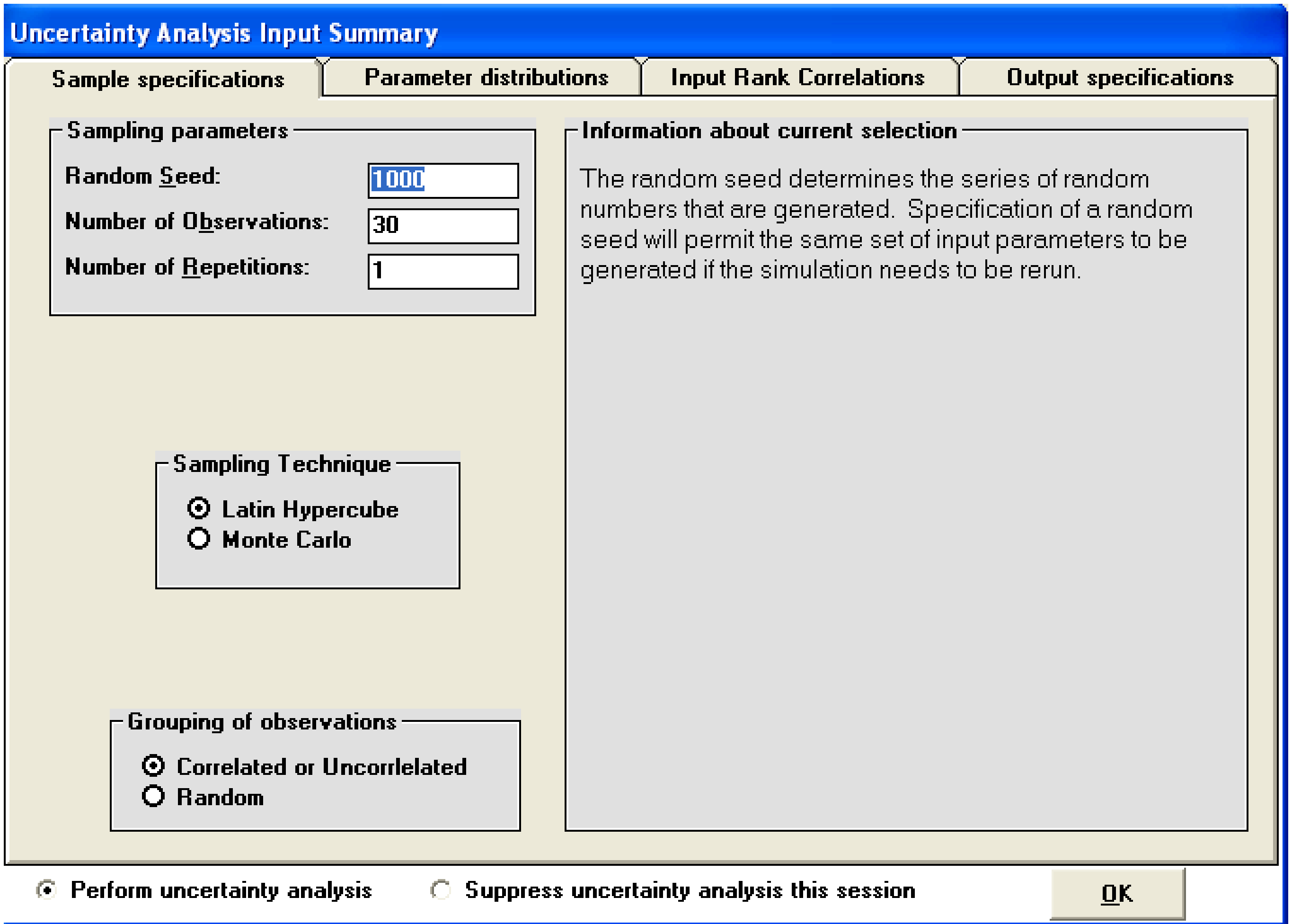




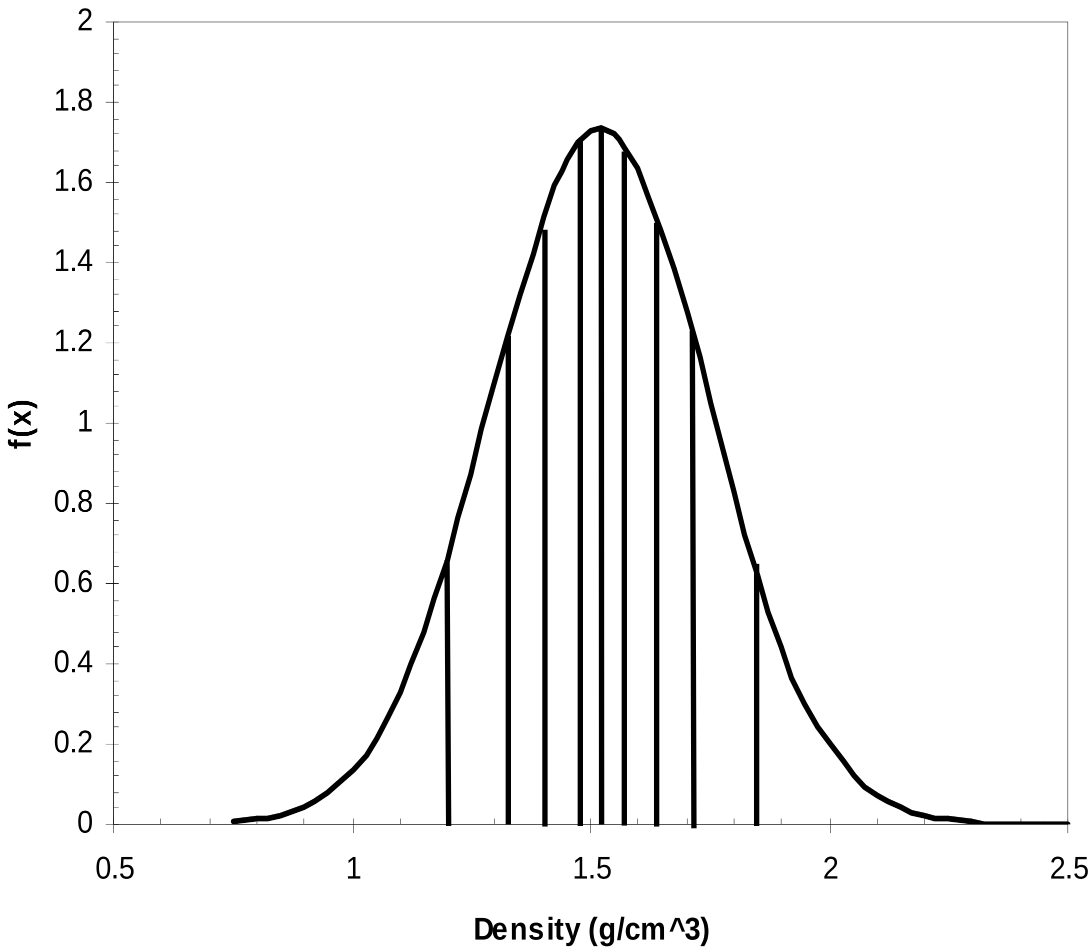
Probabilistic Dose Assessment

- Parameter distributions cannot be entered into the dose assessment model directly
- Parameter distributions are “sampled” to reflect the “true” distributions
- Many sampling routines have been developed

Probabilistic Specifications



Latin Hypercube Sampling

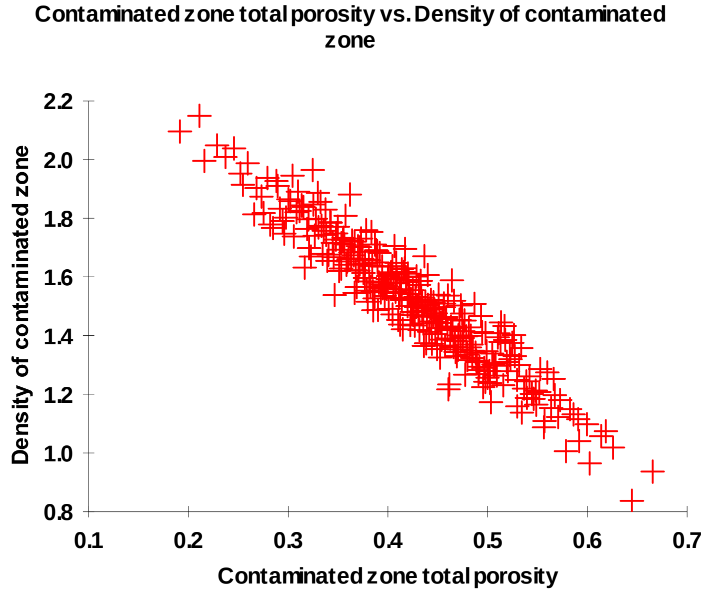


LHS Values

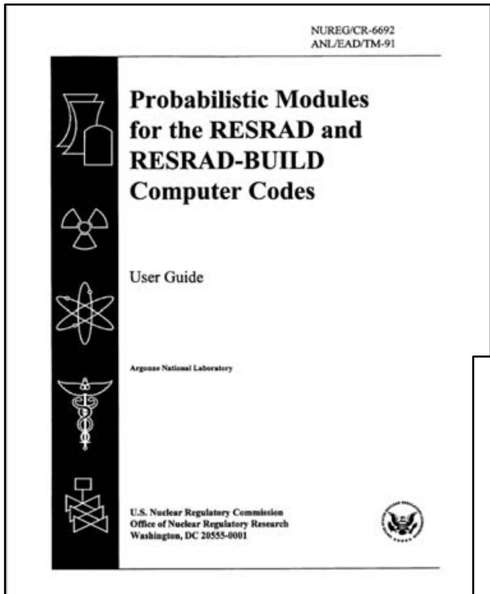
1.1923
1.30491
1.33396
1.41412
1.47631
1.5496
1.61538
1.64943
1.72338
1.95171

Parameter Correlations

- Some input parameters may be related to one another
  - Examples
    - As the density of the contaminated zone increases, the total amount of pore space in the soil decreases (negative correlation)
    - As the distribution coefficient of U-238 increases in the contaminated zone, the distribution coefficients of U-234 and U-235 increase as well (positive correlation)



Reports Available to Assist Analysts



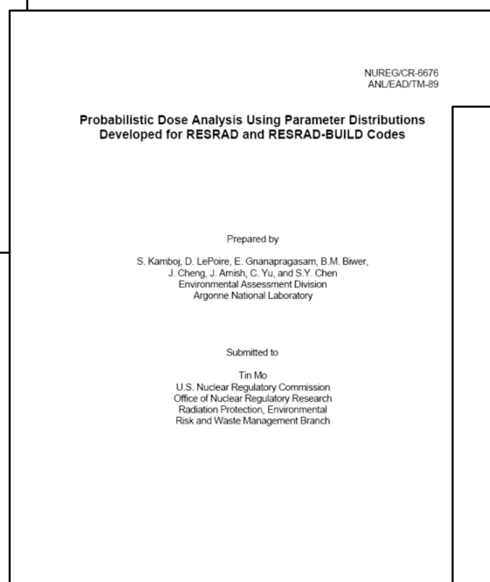
NUREG/CR-6692
ANL/EAD/TM-91

Probabilistic Modules for the RESRAD and RESRAD-BUILD Computer Codes

User Guide

Argonne National Laboratory

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001



NUREG/CR-6676
ANL/EAD/TM-89

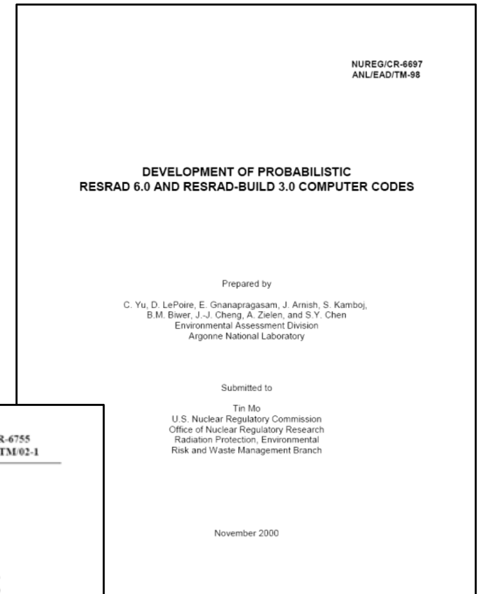
Probabilistic Dose Analysis Using Parameter Distributions Developed for RESRAD and RESRAD-BUILD Codes

Prepared by

S. Kamboj, D. LePoire, E. Gnanapragasam, B.M. Biwer, J. Cheng, J. Arnish, C. Yu, and S.Y. Chen
Environmental Assessment Division
Argonne National Laboratory

Submitted to

Tin Mo
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Radiation Protection, Environmental Risk and Waste Management Branch



NUREG/CR-6697
ANL/EAD/TM-98

DEVELOPMENT OF PROBABILISTIC RESRAD 6.0 AND RESRAD-BUILD 3.0 COMPUTER CODES

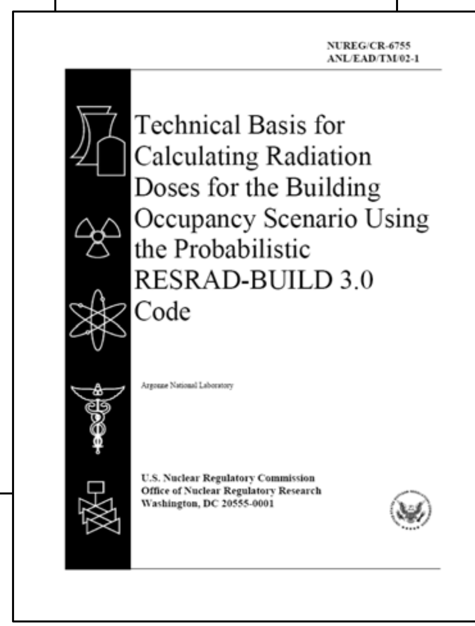
Prepared by

C. Yu, D. LePoire, E. Gnanapragasam, J. Arnish, S. Kamboj, B.M. Biwer, J.-J. Cheng, A. Zielen, and S.Y. Chen
Environmental Assessment Division
Argonne National Laboratory

Submitted to

Tin Mo
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Radiation Protection, Environmental Risk and Waste Management Branch

November 2000



NUREG/CR-6755
ANL/EAD/TM/02-1

Technical Basis for Calculating Radiation Doses for the Building Occupancy Scenario Using the Probabilistic RESRAD-BUILD 3.0 Code

Argonne National Laboratory

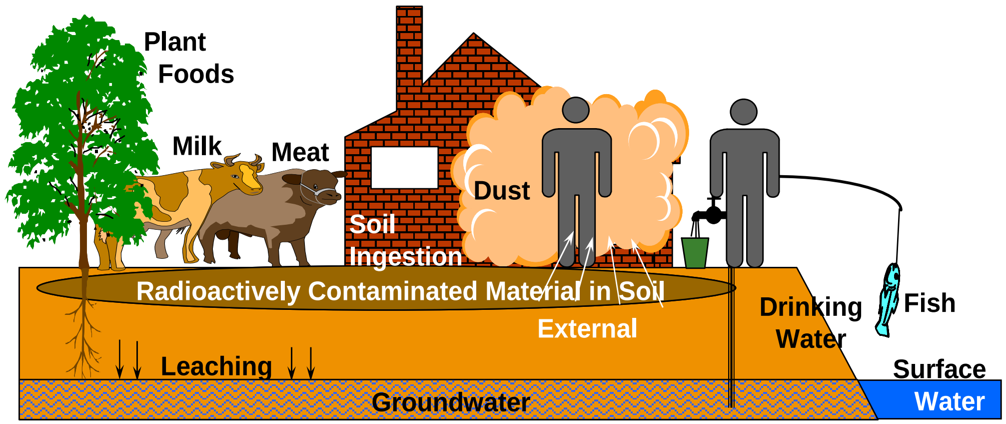
U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

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"

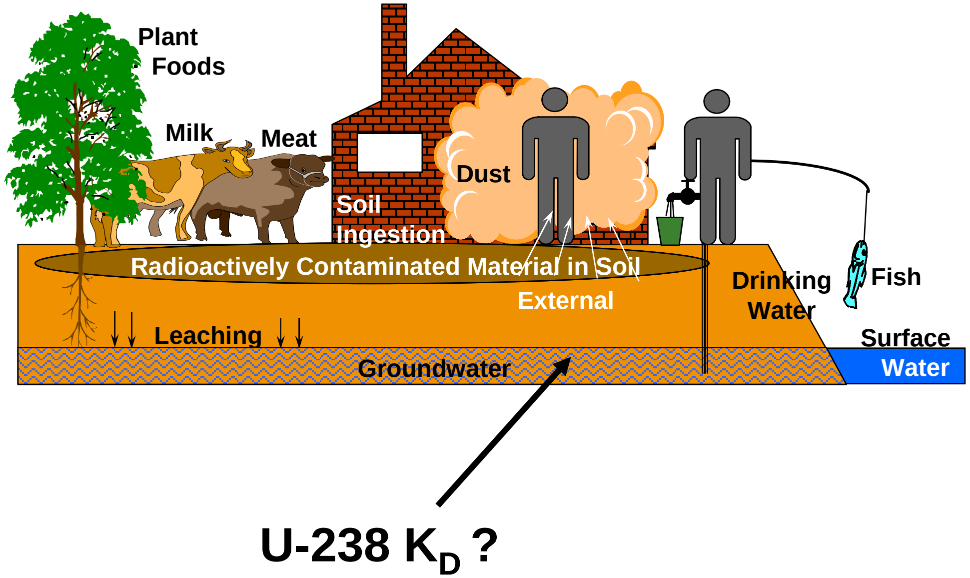
Probabilistic Dose Modeling Example

- Describe nuances of probabilistic dose modeling with a simple example
  - "Peak of the Mean"
  - "Mean of the Peaks"
- All pathways active
- One radionuclide



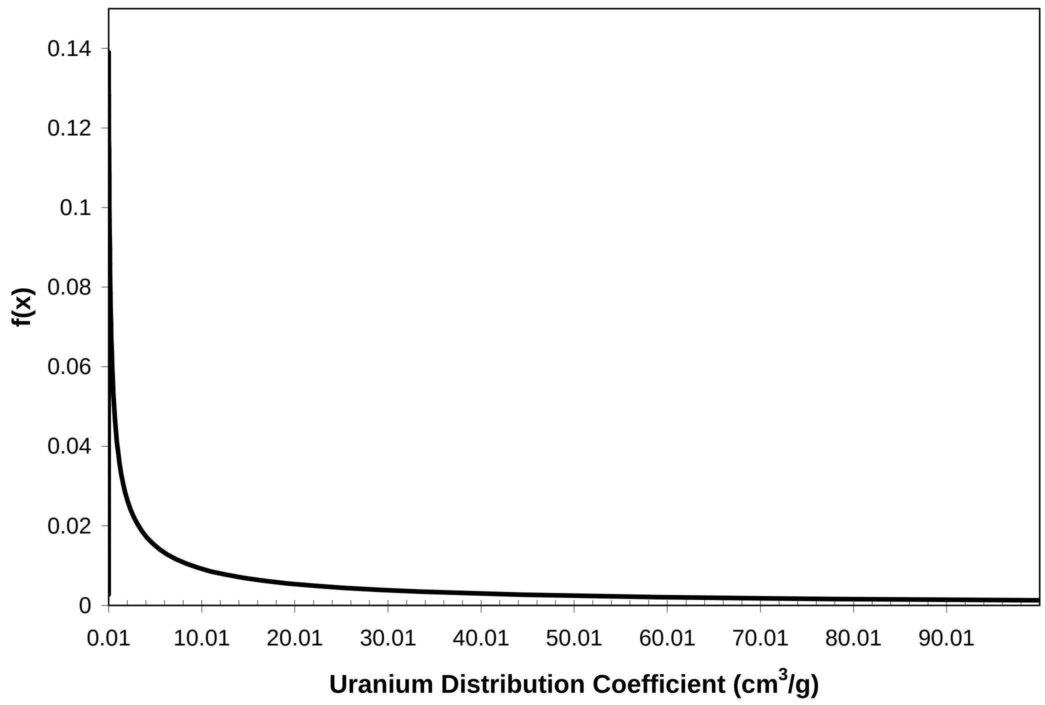
Probabilistic Dose Modeling Example

- Consider case of soil contaminated with U-238
- Perform uncertainty analysis on saturated zone K_D
- For other parameters use RESRAD defaults
- Walk through simple case with few (11) samples

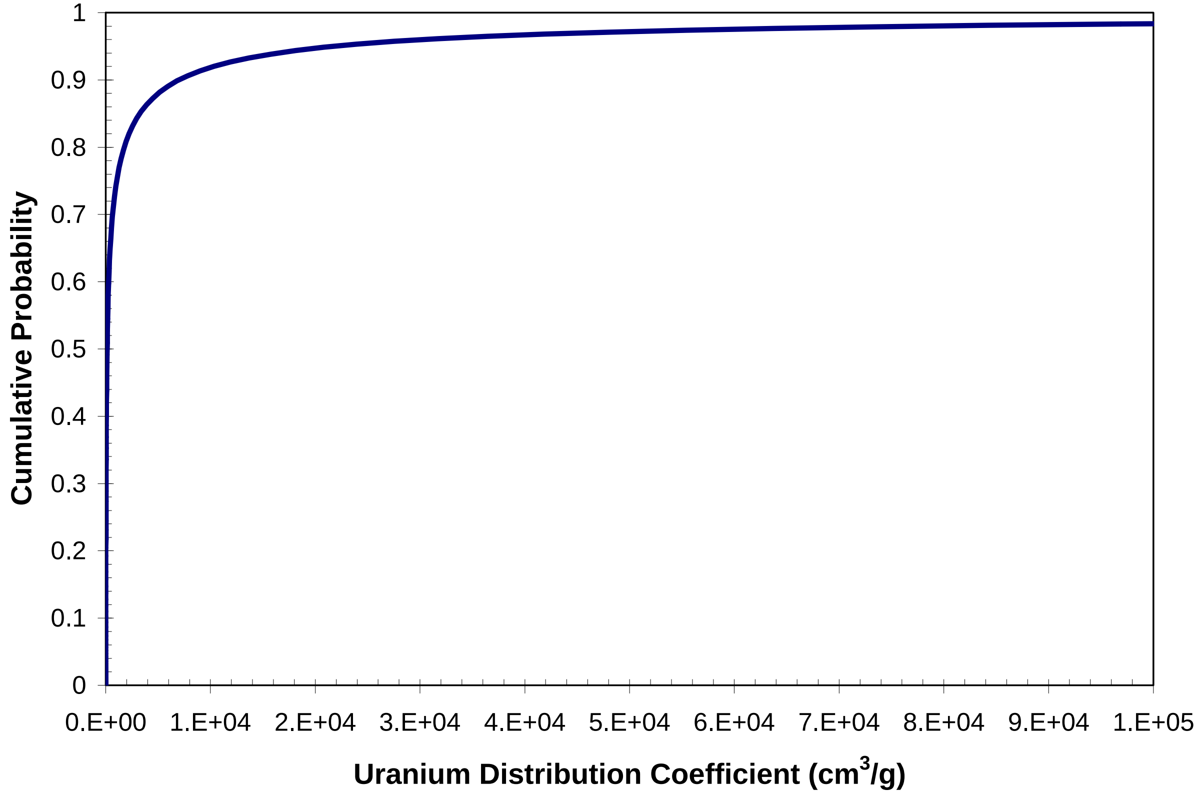


Probability Distributions for the K_D of U-238 in the Saturated Zone

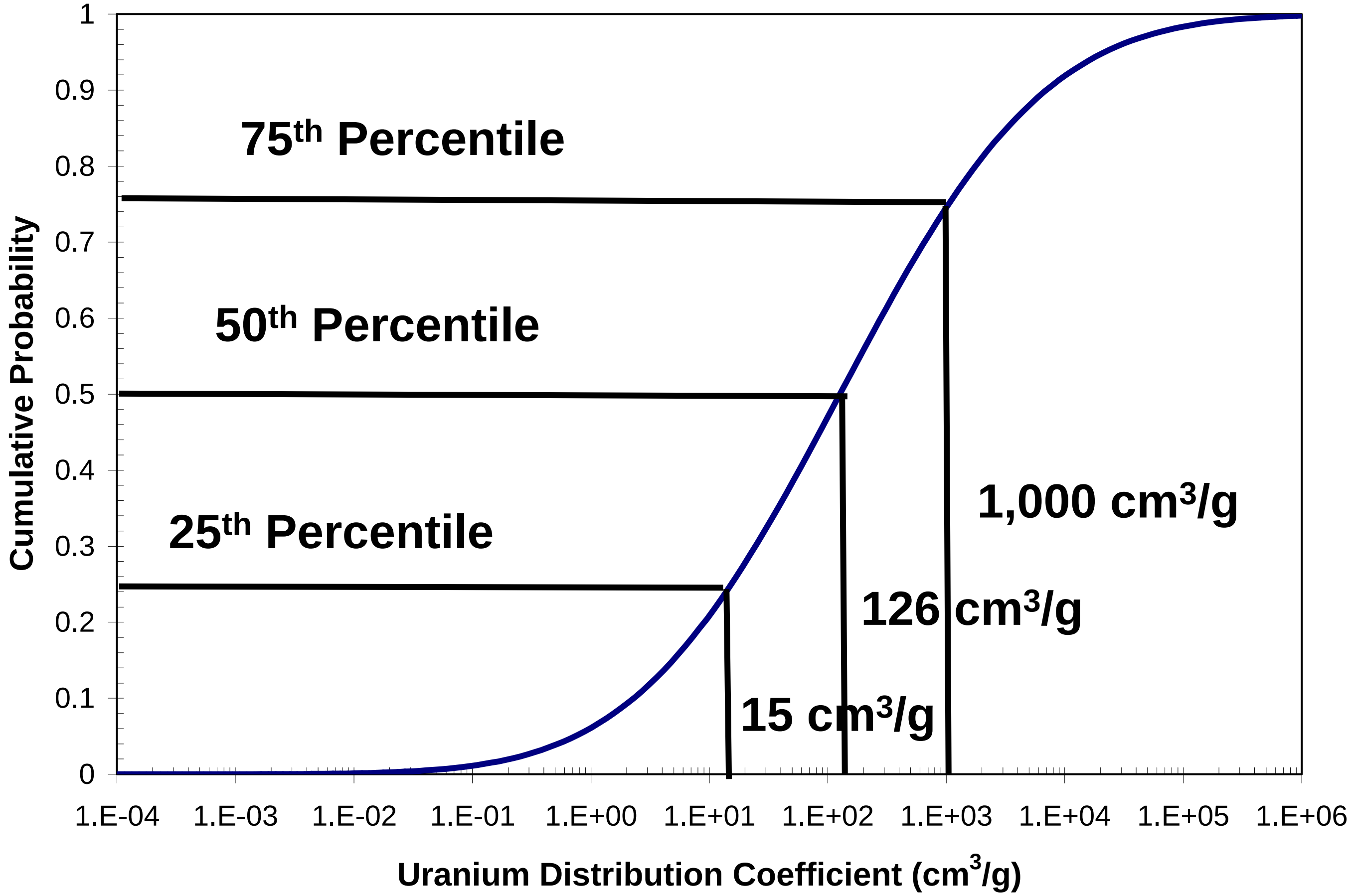
- K_D of U-238
  - Lognormal distribution
    - μ=4.84
    - σ=3.13



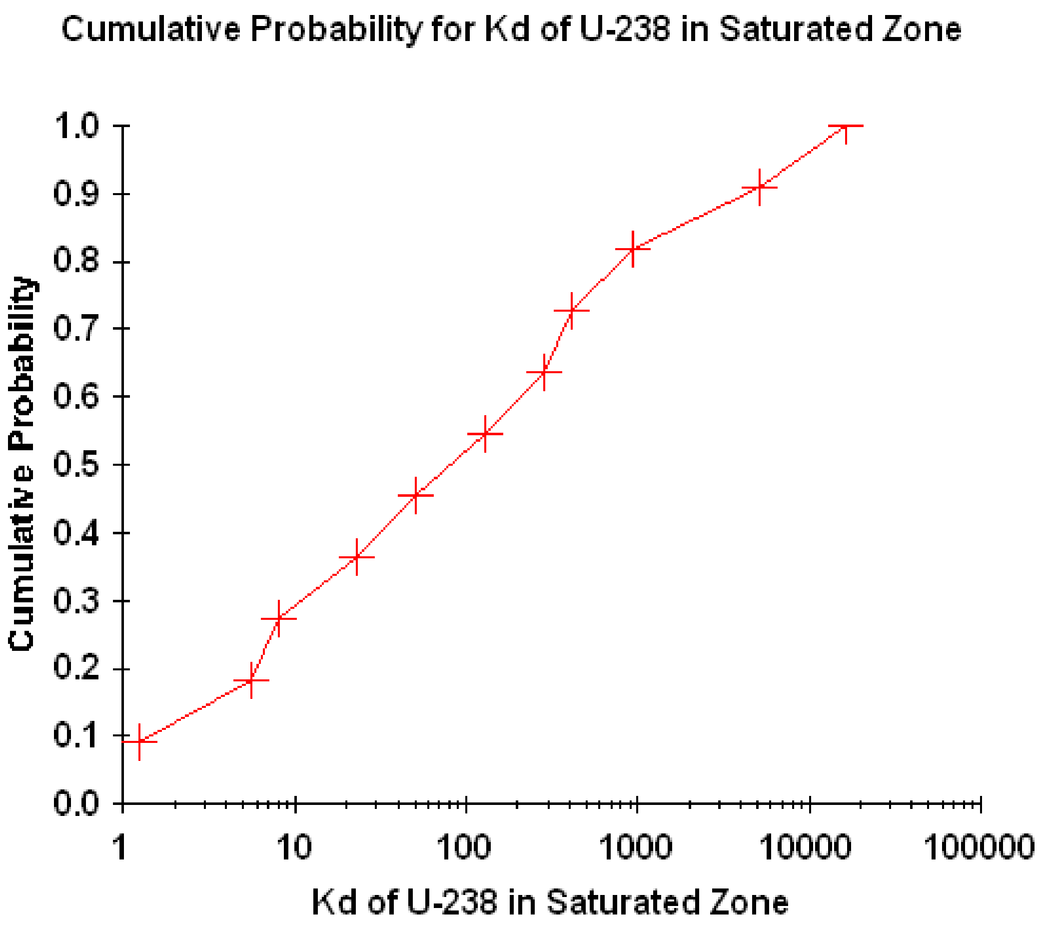
Cumulative Probability Distributions of the K_D in the Unsaturated Zone



Cumulative Probability Distributions of the K_D in the Unsaturated Zone



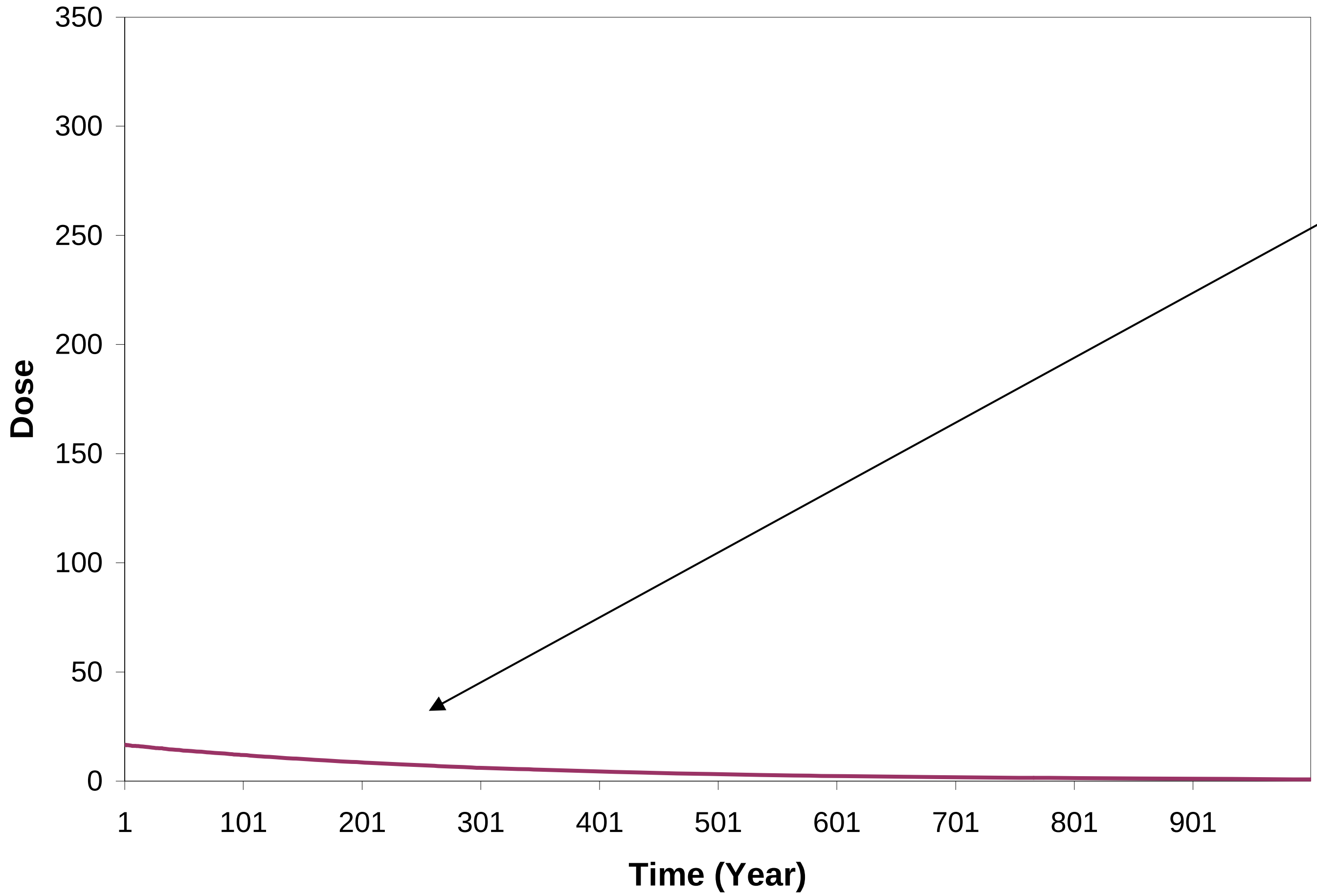
LHS Sampling of the U-238 K_D: 11 Observations



Sampled U-238 Saturated Zone K_D's

16216	
5198	
934	**81st Percentile**
418	
282	
127	**54th Percentile**
51	
23	
8	**27th Percentile**
6	
1	

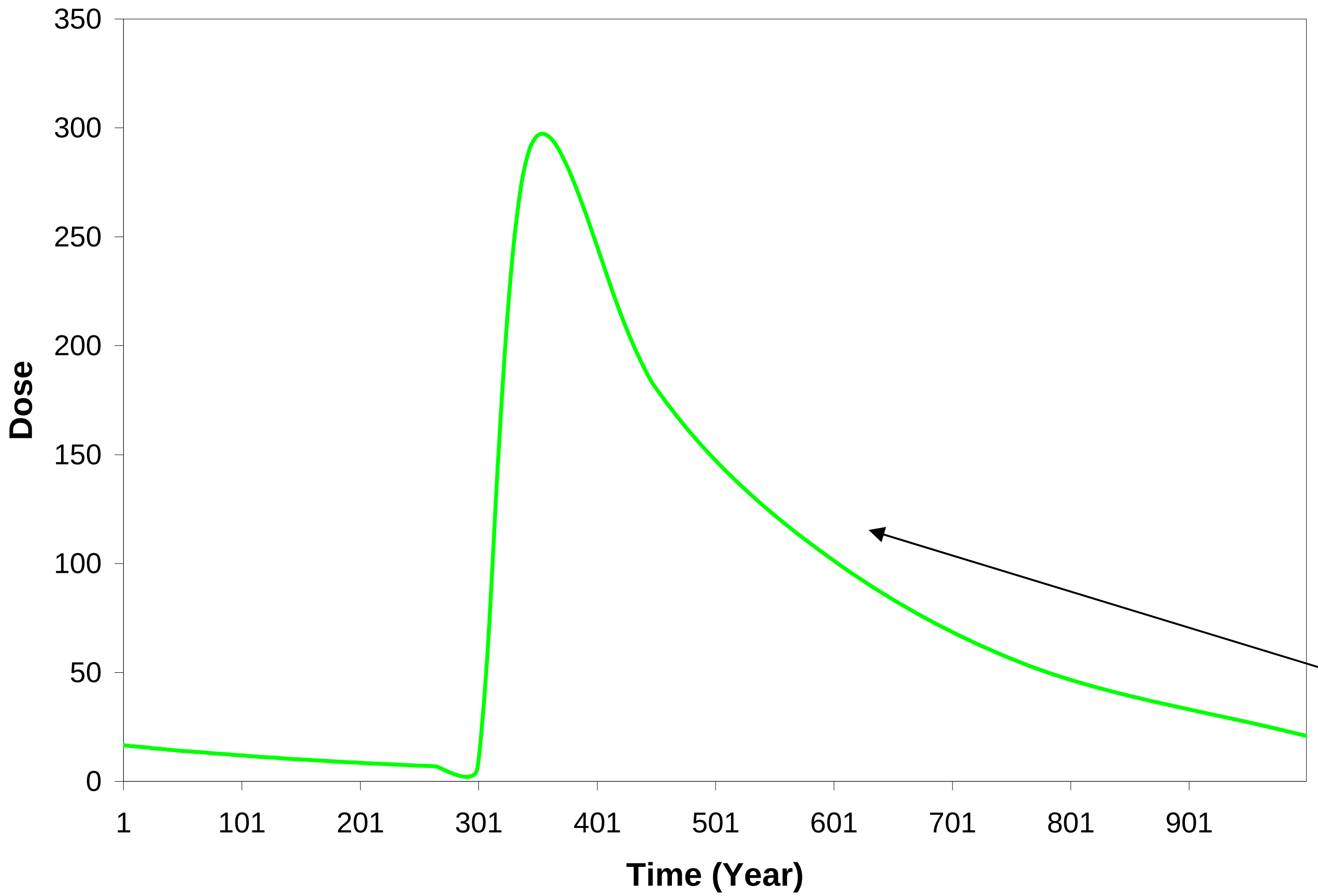
Temporal Plot of Dose with a Largest Sampled K_D in the Saturated Zone



Sampled U-238 Saturated Zone K_D's

16216
5198
934
418
282
127
51
23
8
6
1

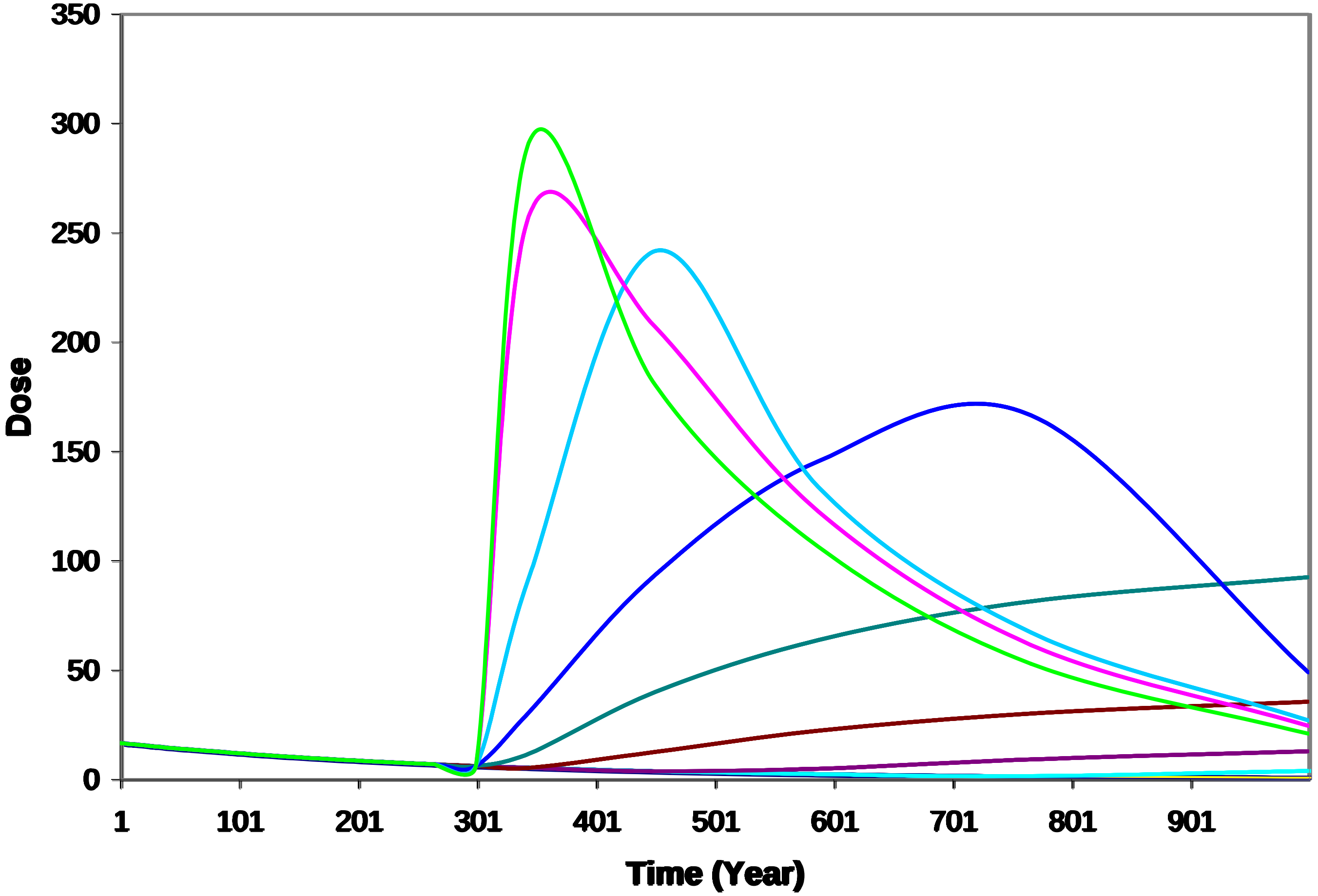
Temporal Plot of Dose with a Smallest Sampled K_D in the Saturated Zone



Sampled U-238 Saturated Zone K_D's

16216
5198
934
418
282
127
51
23
8
6
1

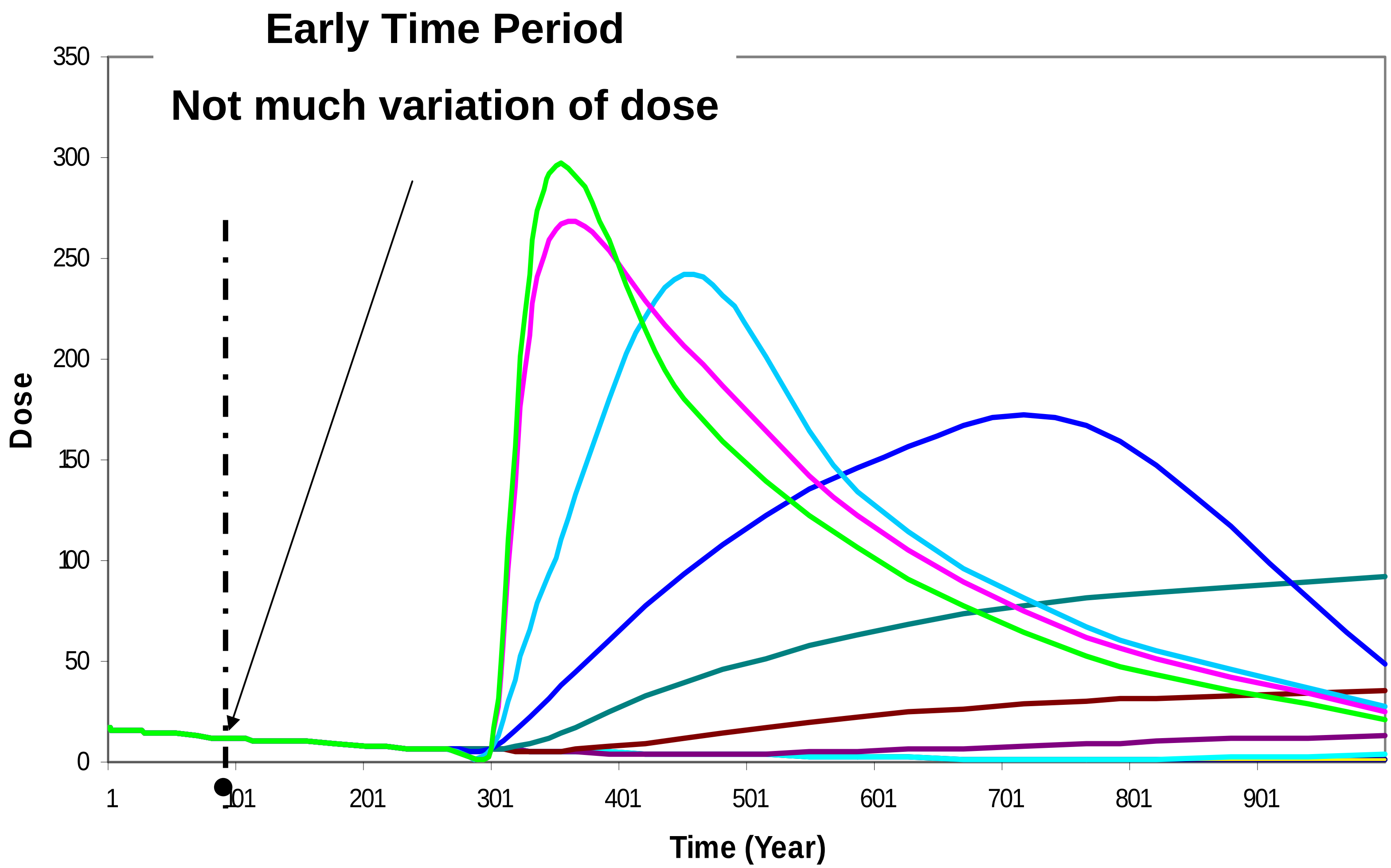
Change in the Temporal Dose Profile as the K_D in the Saturated Zone Changes



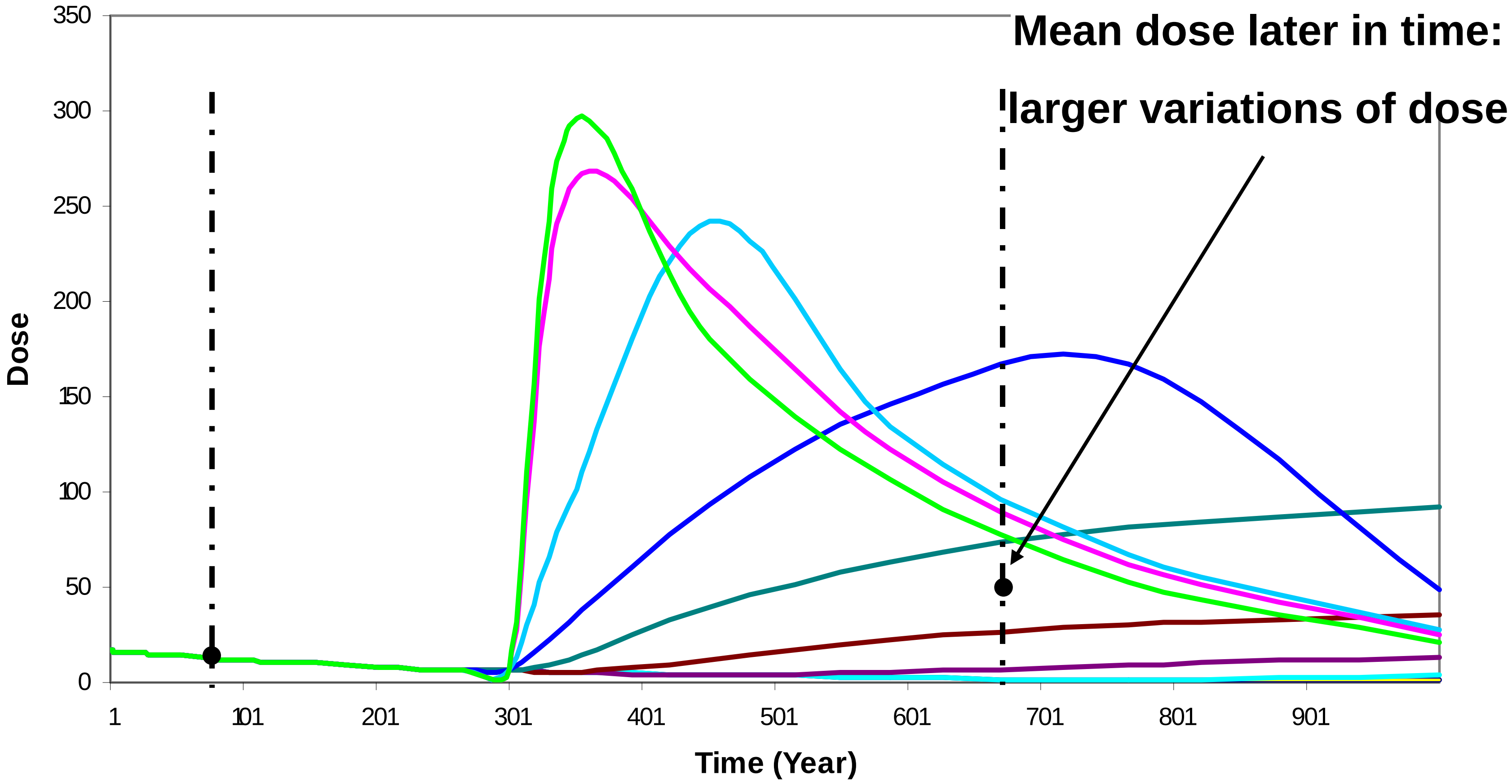
Sampled U-238 Saturated Zone K_D's

16216
5198
934
418
282
127
51
23
8
6
1

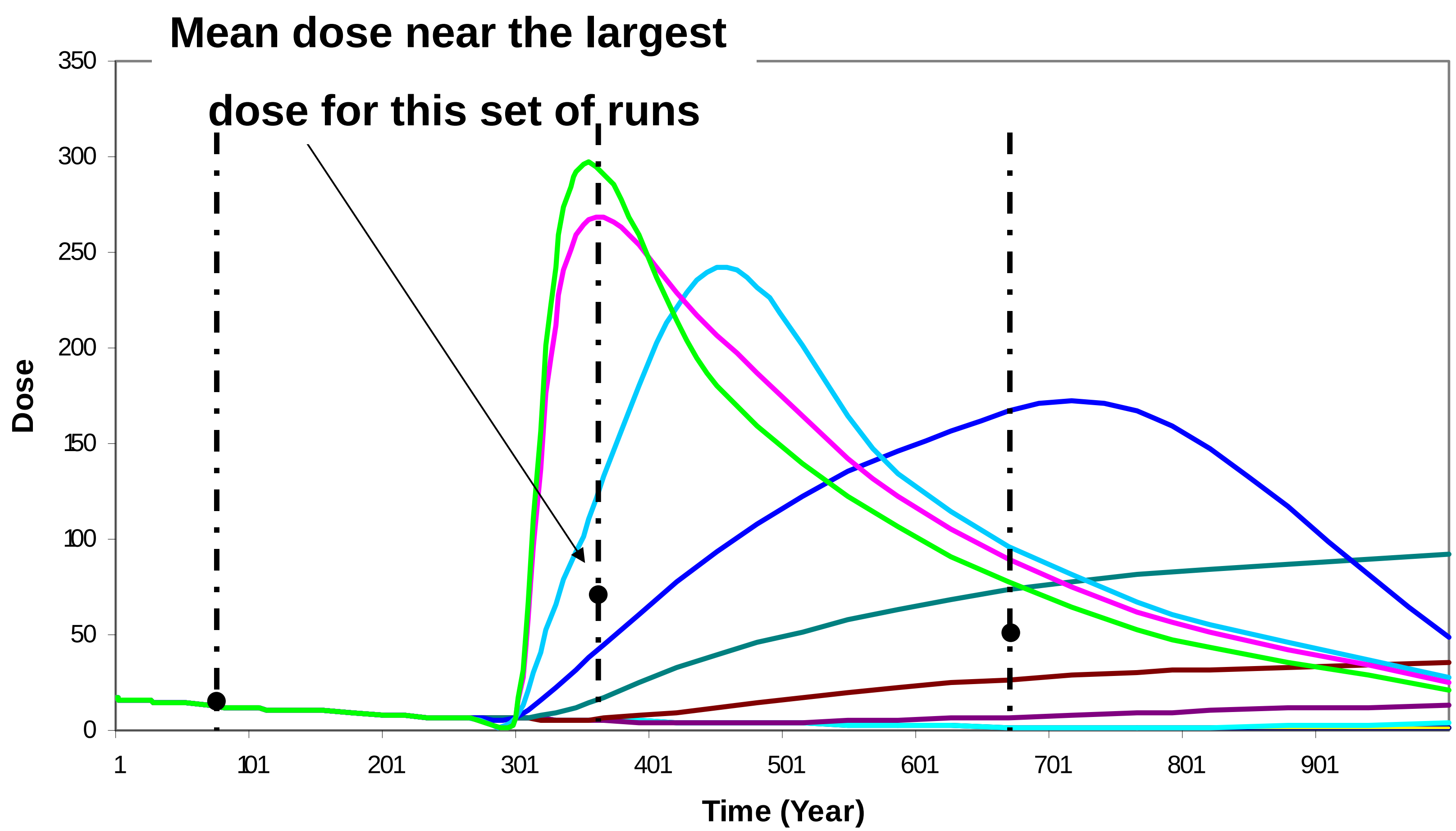
Peak of the Means Approach



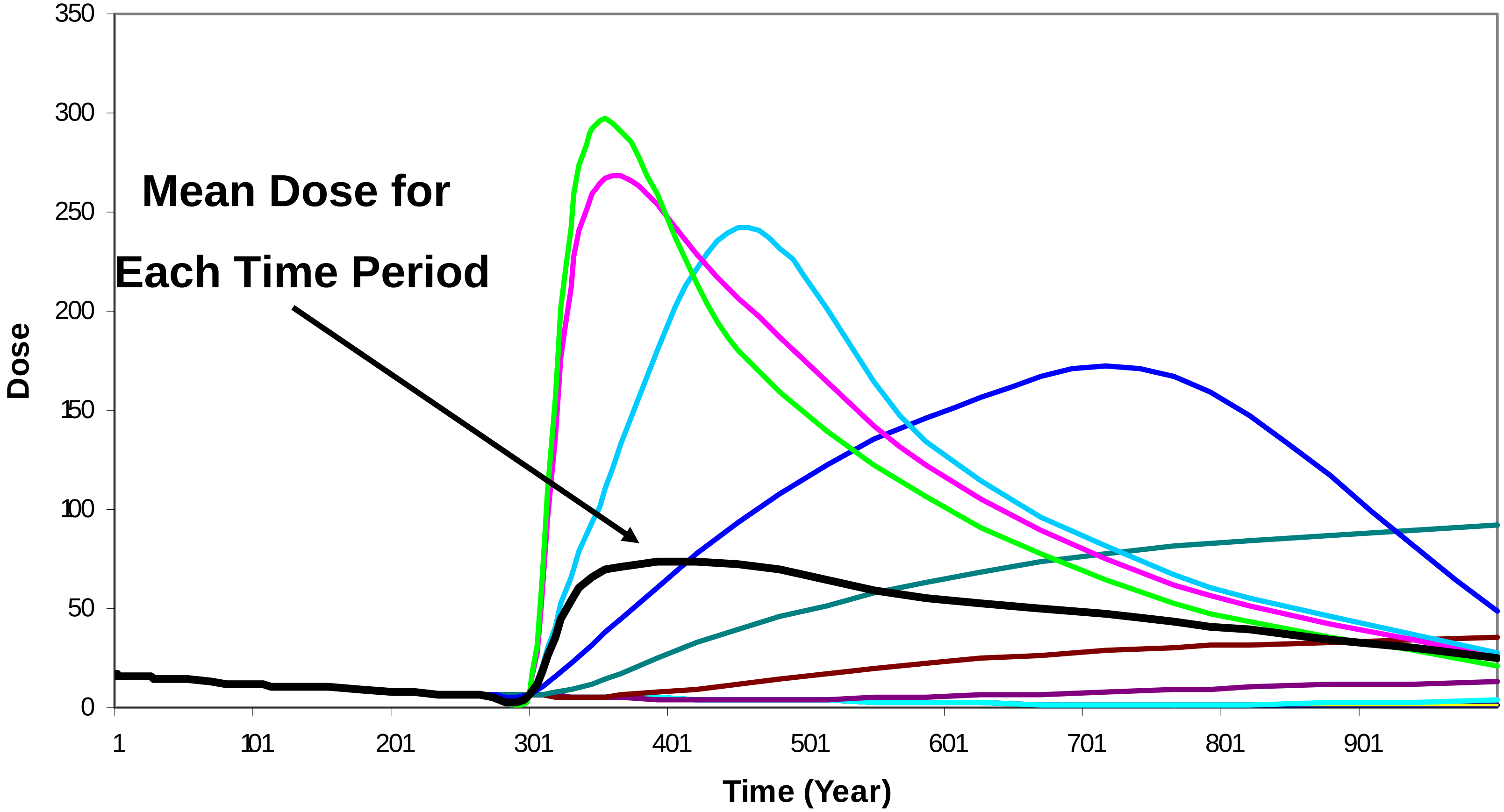
Peak of the Means Approach



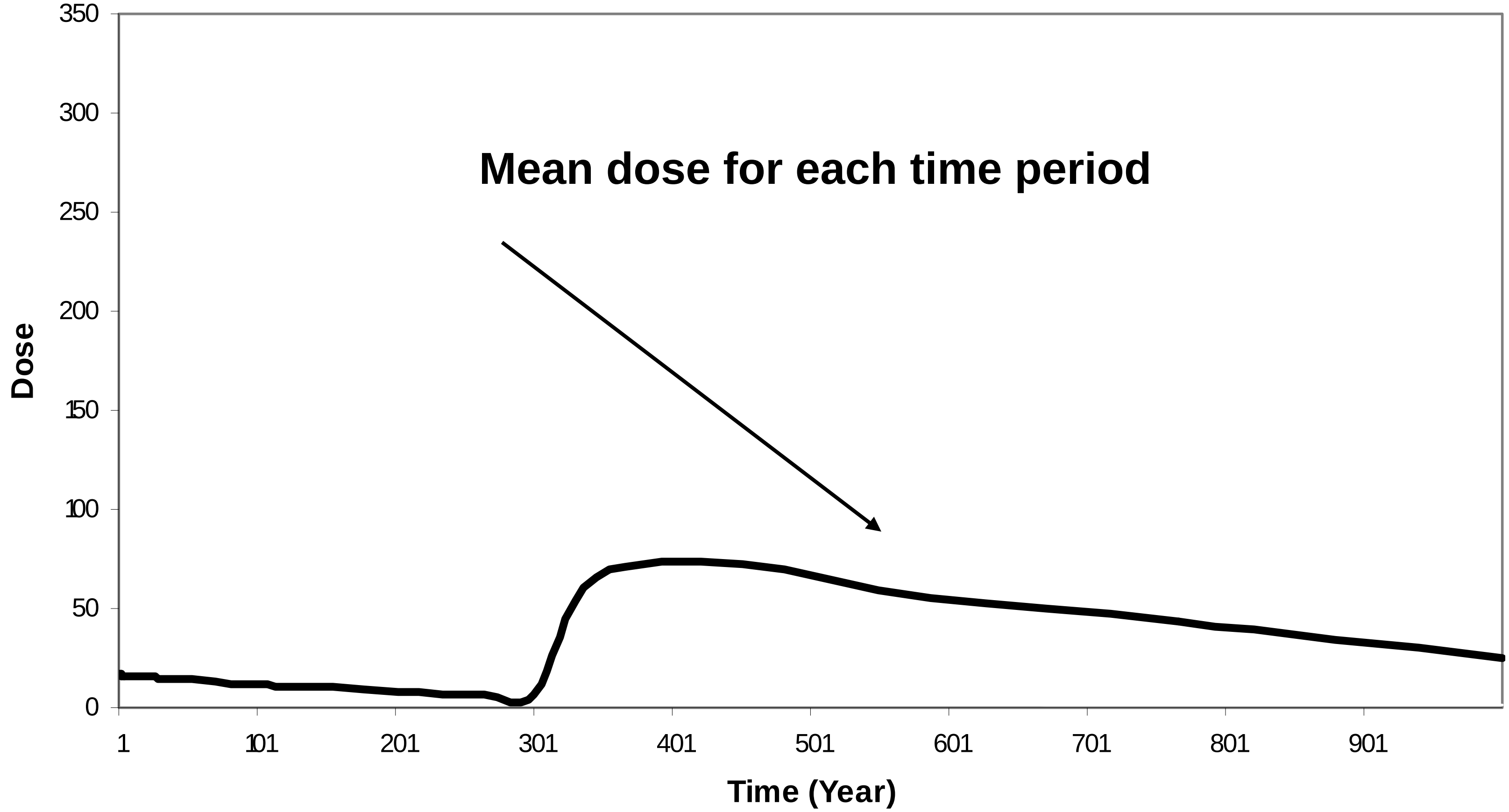
Peak of the Mean Approach



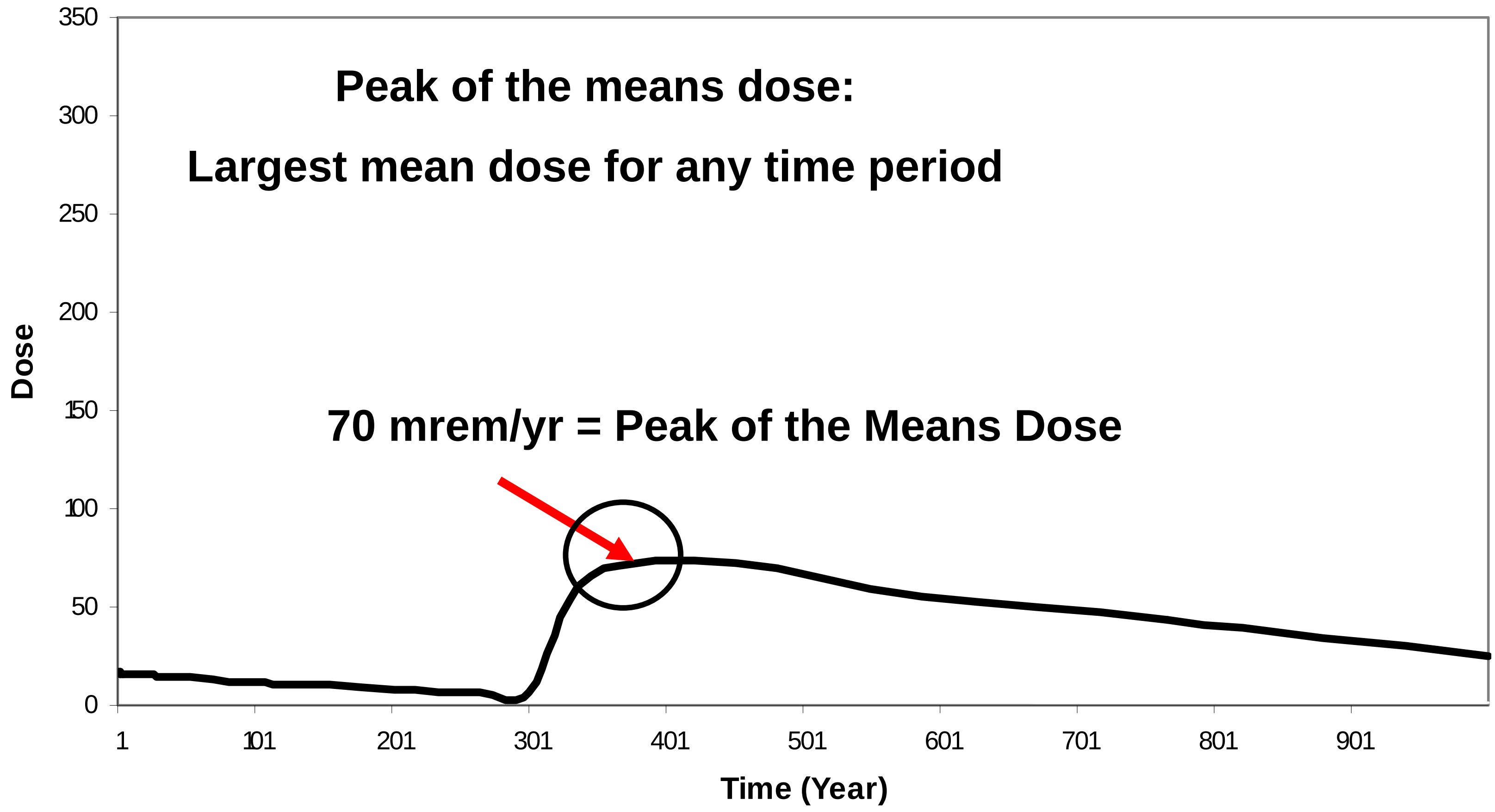
Peak of the Means Approach



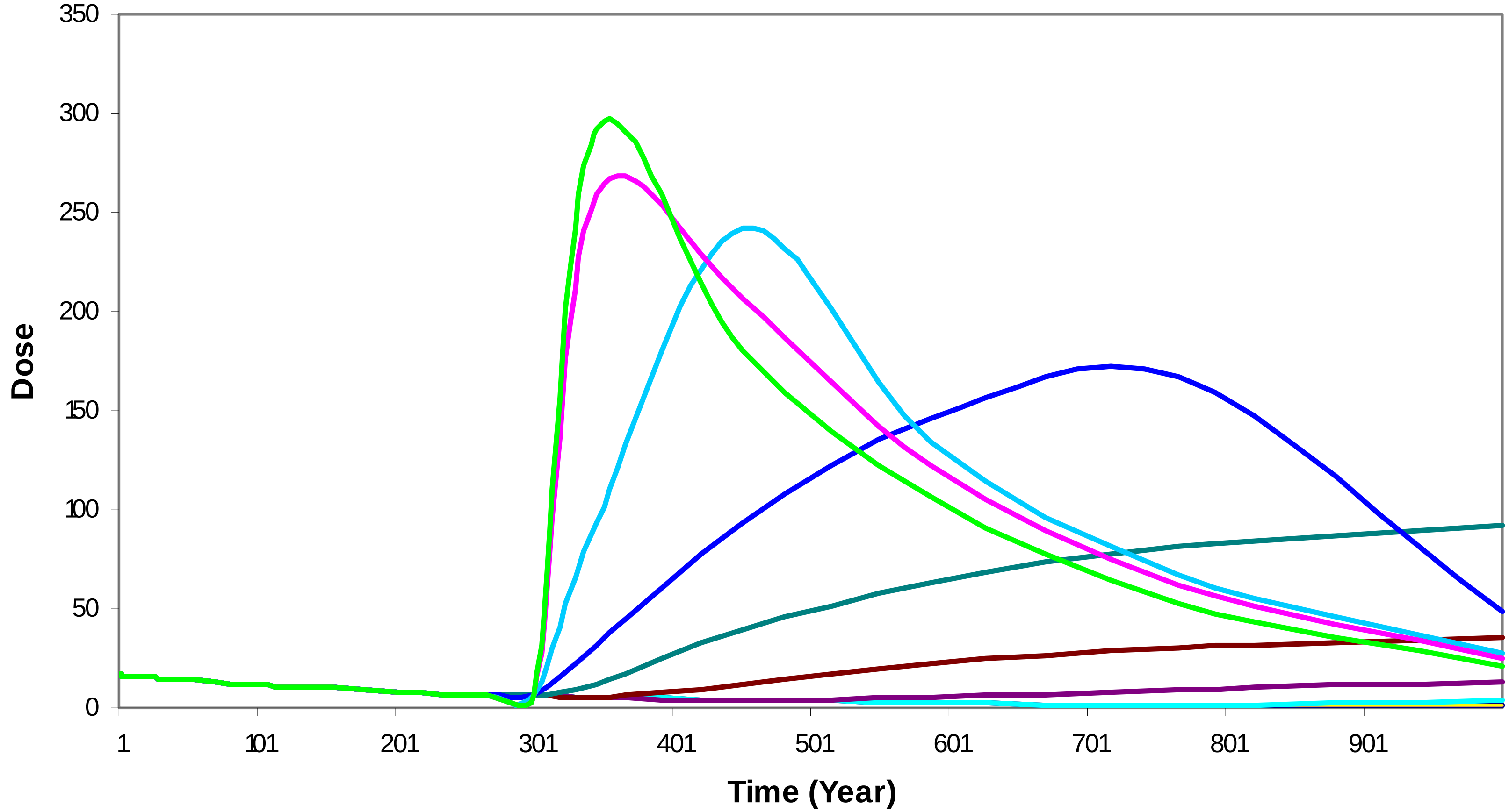
Peak of the Means Approach



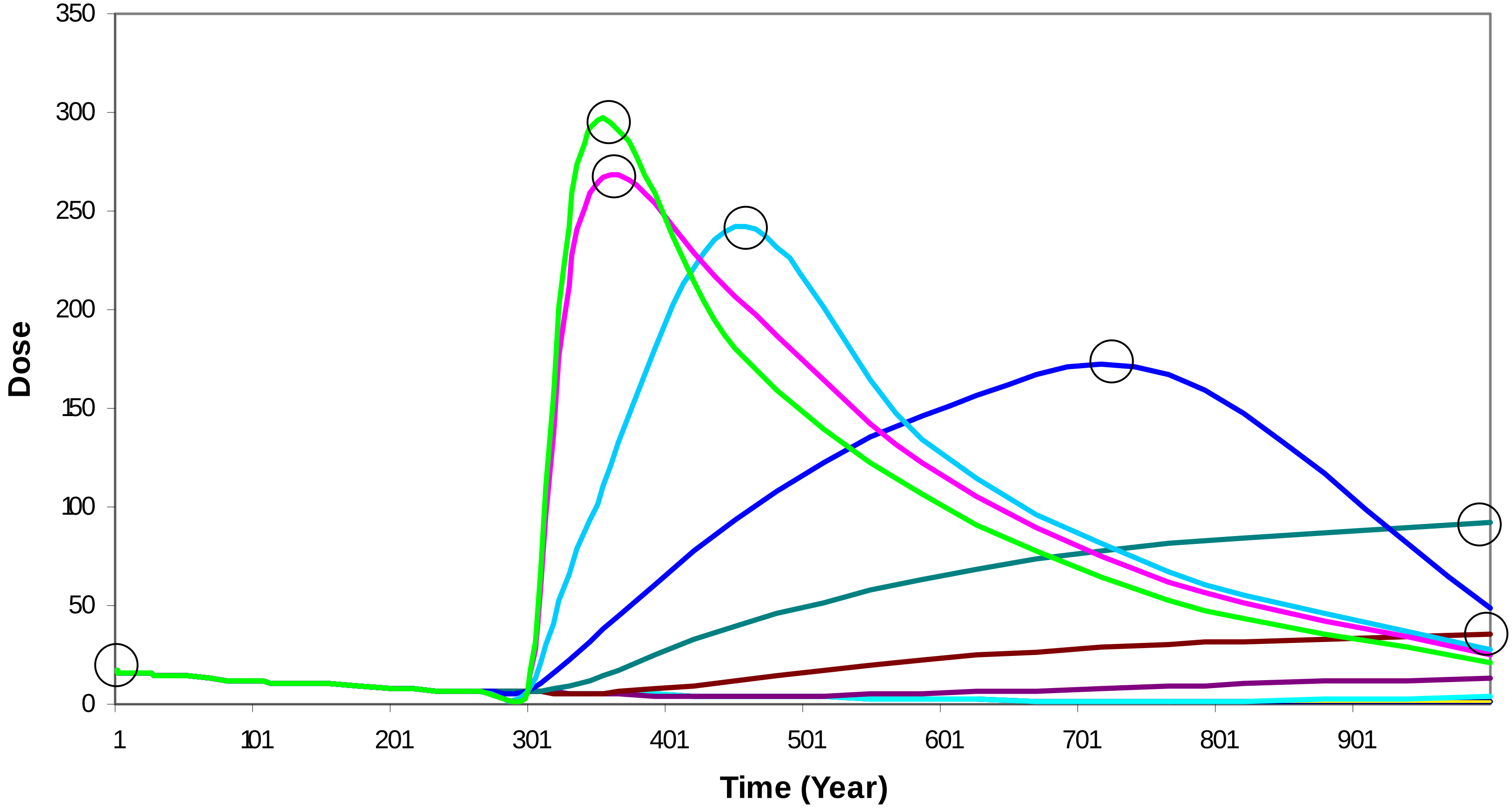
Peak of the Means Approach: Finding the Peak



Mean of the Peaks Approach: Original Results



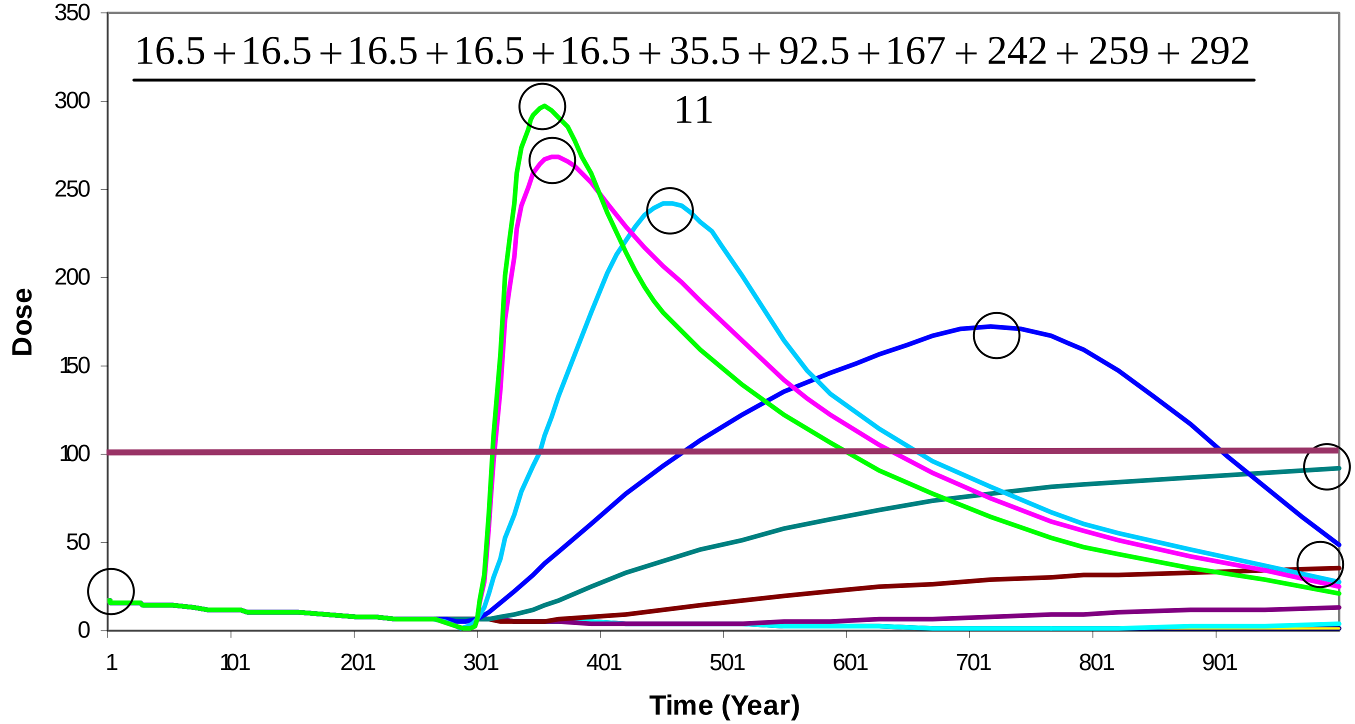
Mean of the Peaks Dose: Identify the Peak Dose for Each



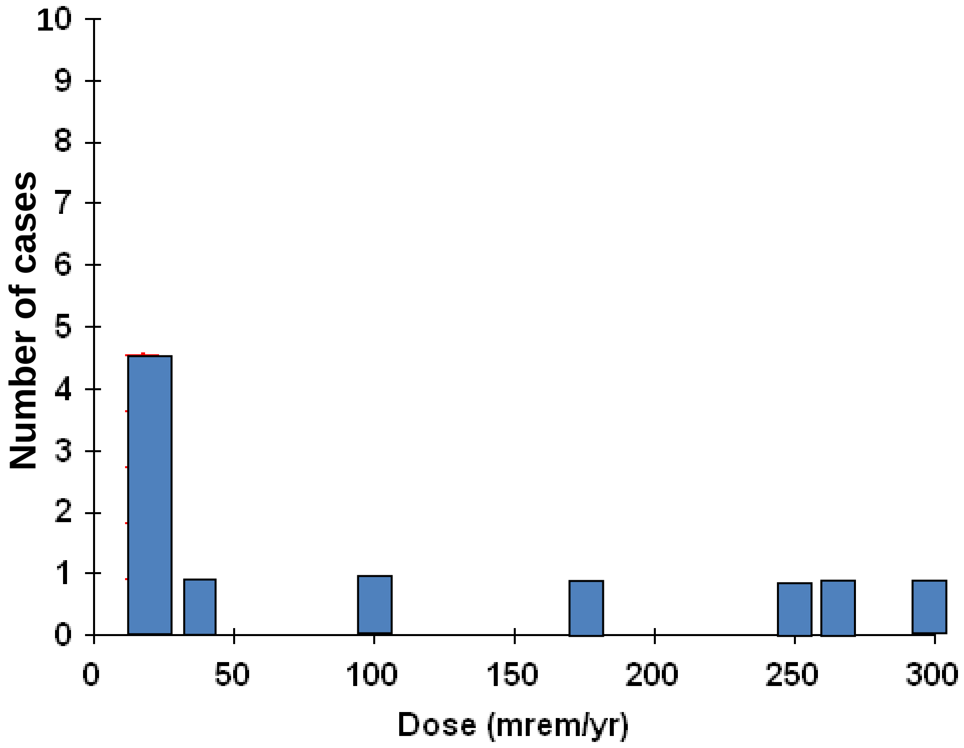
Mean of the Peaks Approach: Calculate the Average Dose Using the Peak Values

Mean of the Peaks Dose $= \dfrac{16.5+16.5+16.5+16.5+16.5+35.5+92.5+167+242+259+292}{11}$ **mrem/yr**

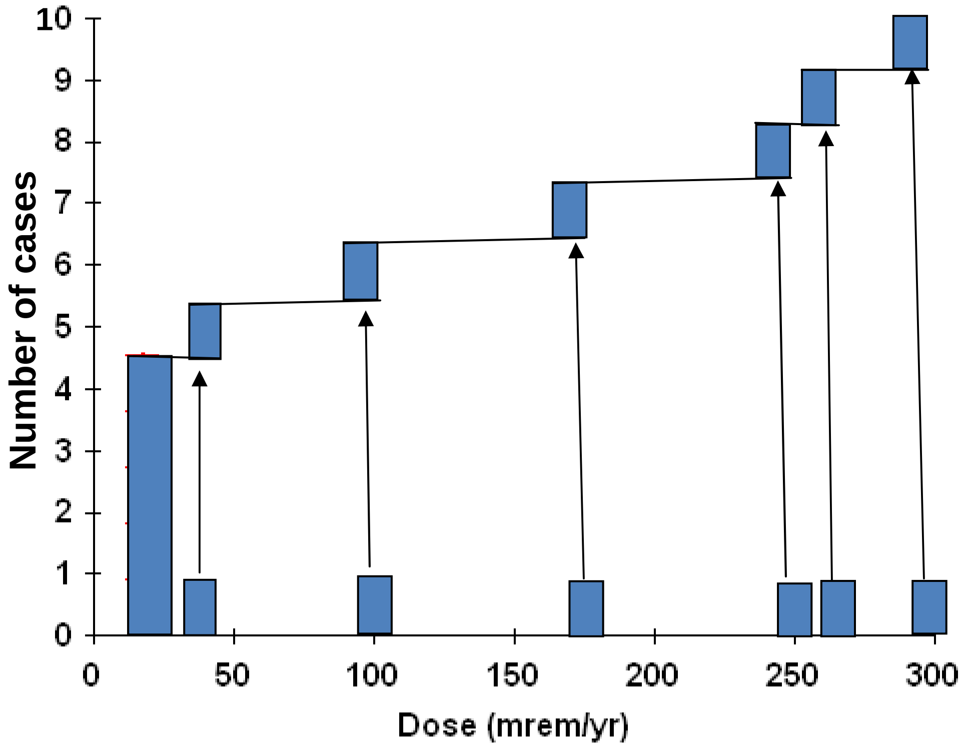
$=$ **106 mrem/yr**



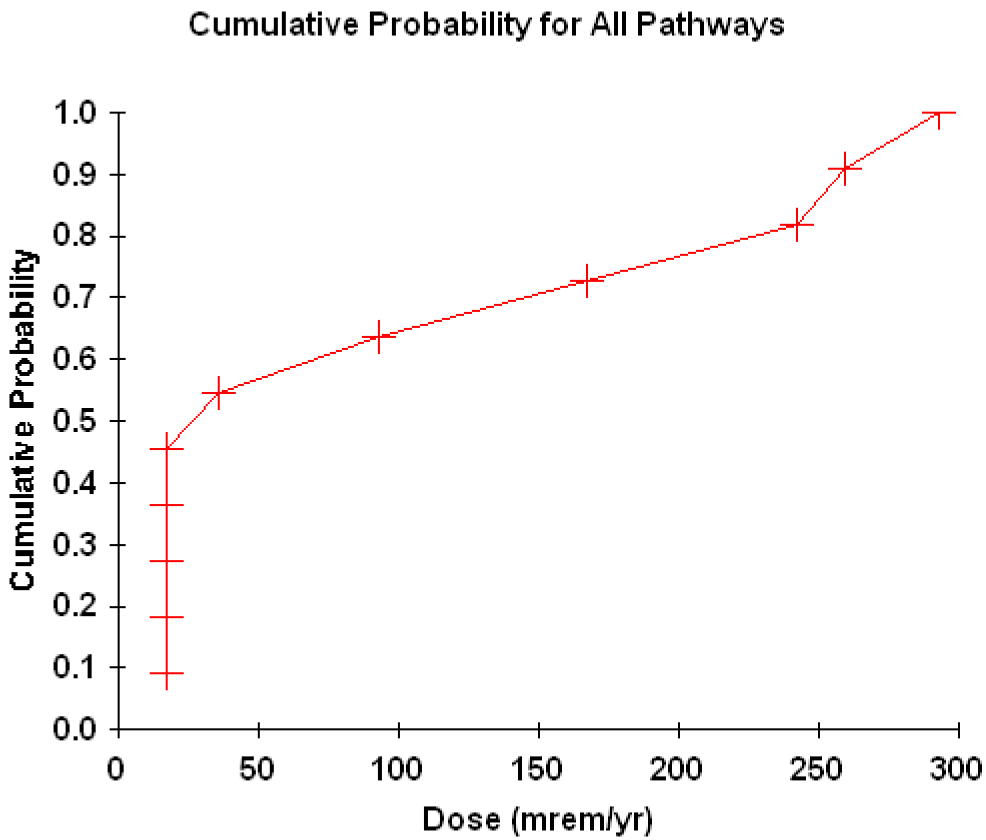
The Resultant Distribution of Dose



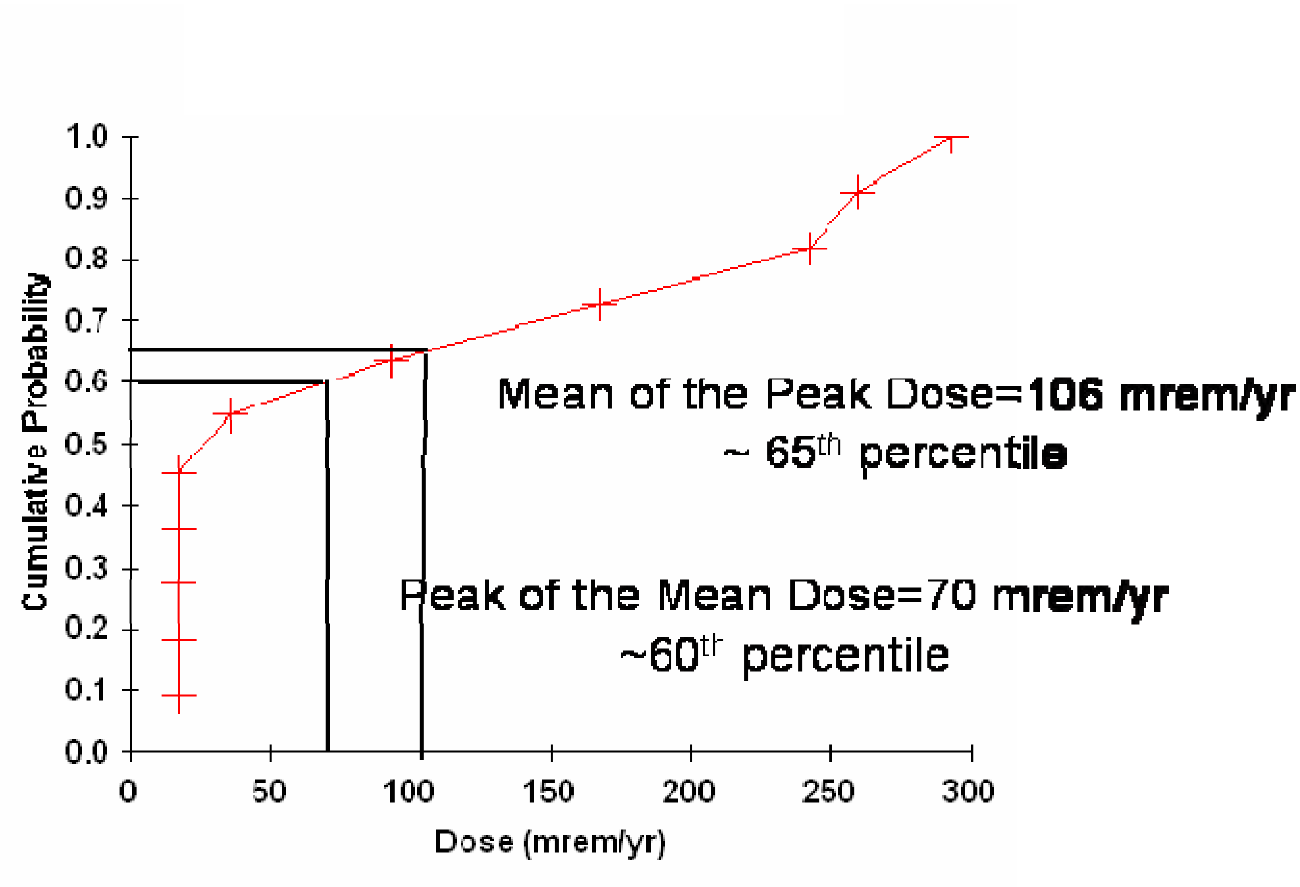
Forming the Cumulative Probability Distribution



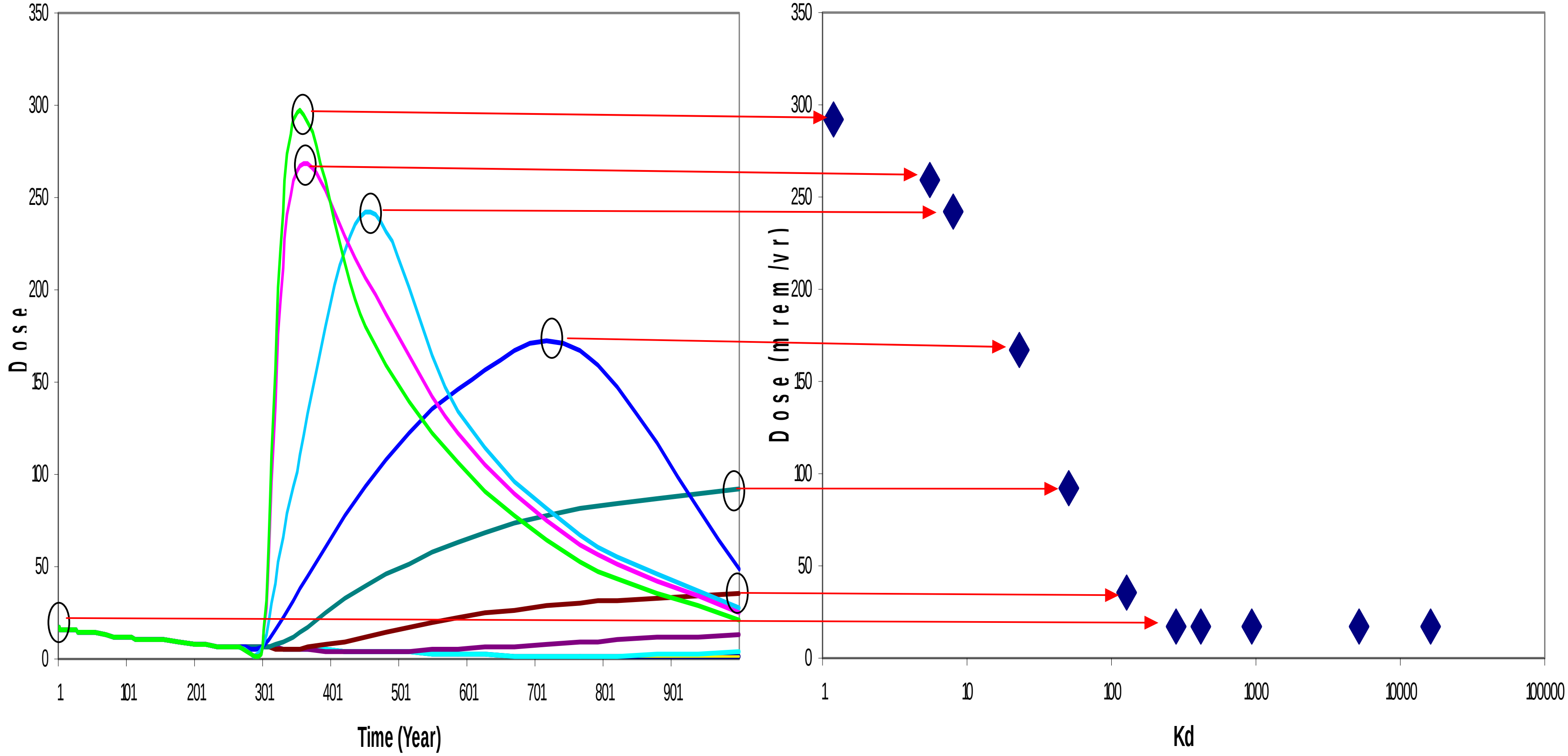
Forming the Cumulative Probability Distribution



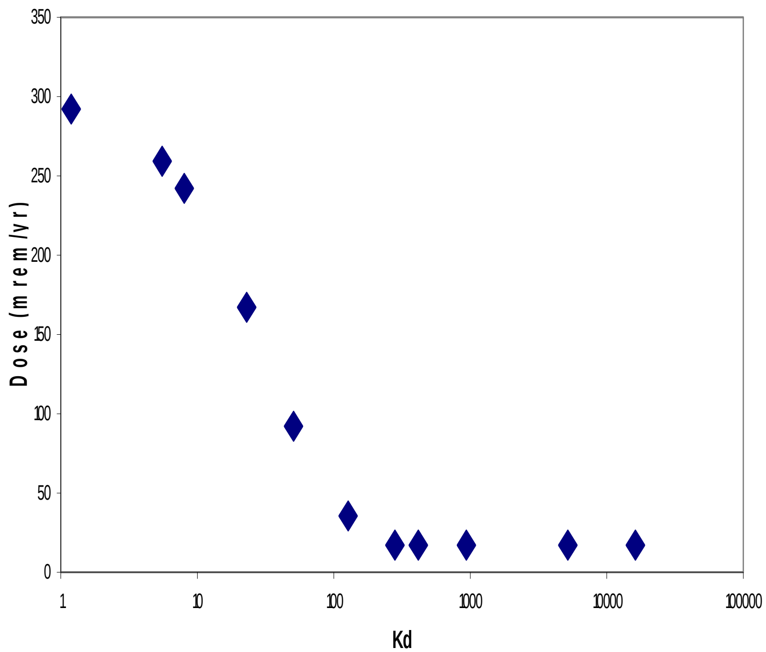
Resultant Cumulative Probability Distribution

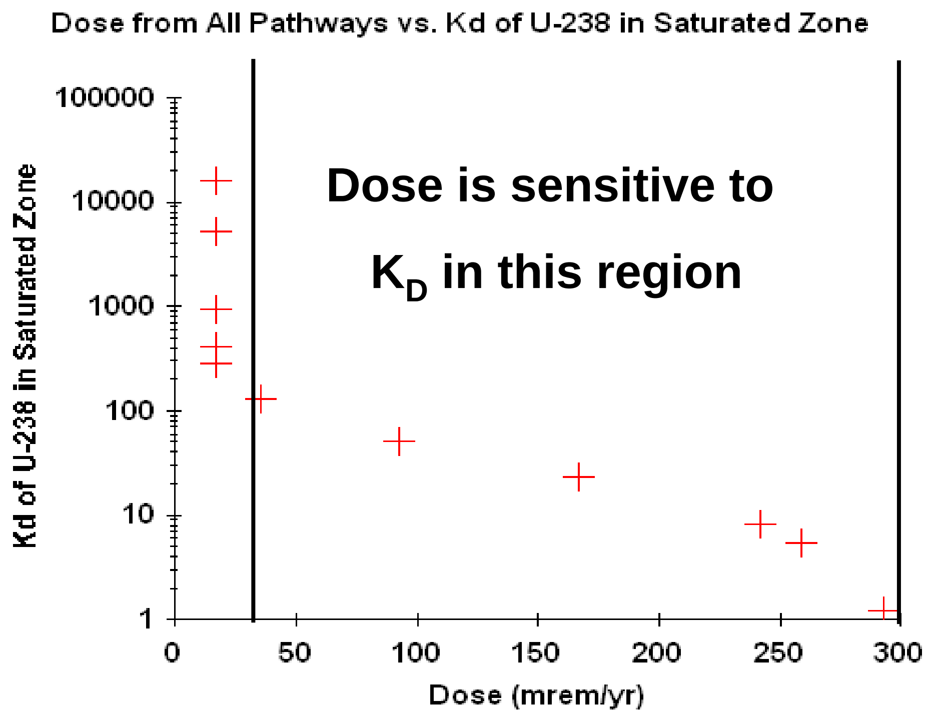


Relationship (Correlation) between Peak Dose and K_D



Scatter plot of Correlation (as Seen in RESRAD)

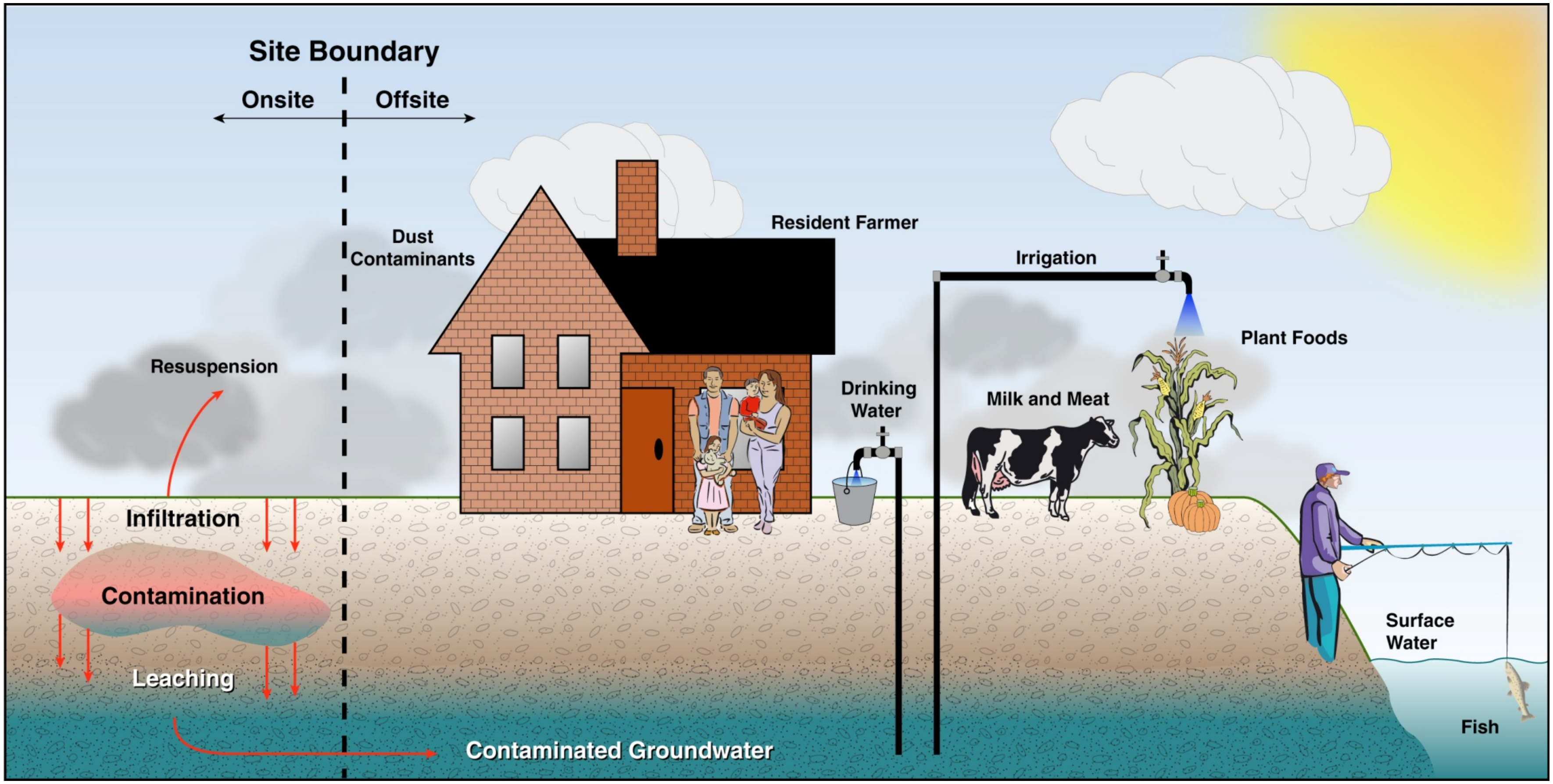




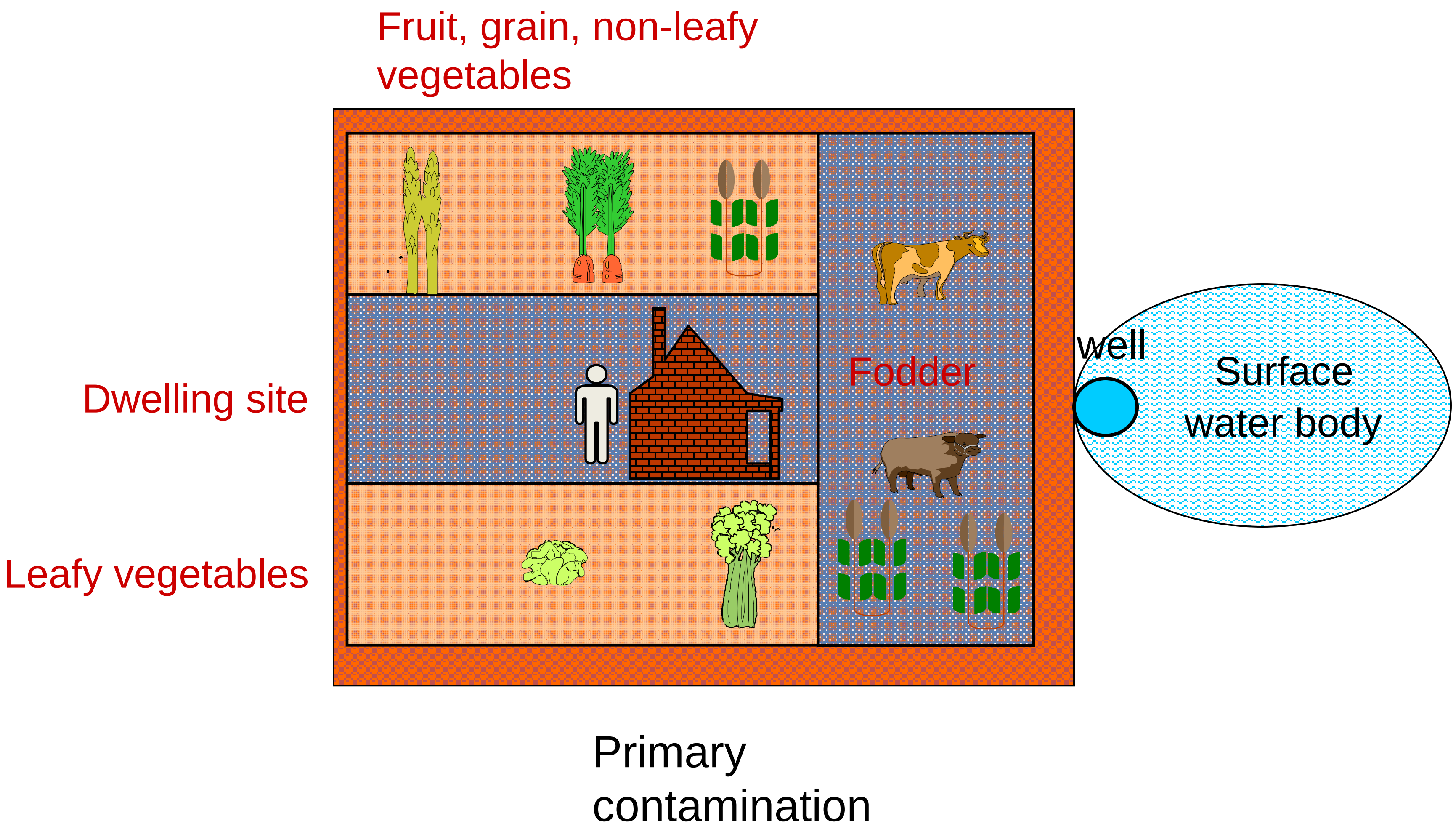
Comparison of Results

- "Mean of the Peaks" dose is always greater than or equal to the "Peak of the Means" dose
  - Peak of the Means Dose = 70 mrem/yr
  - Mean of the Peaks Dose = 106 mrem/yr
- When would the "Mean of the Peaks" dose and the "Peak of the Means" dose be equal?
  - The peak dose for each observation would have to occur at the same time

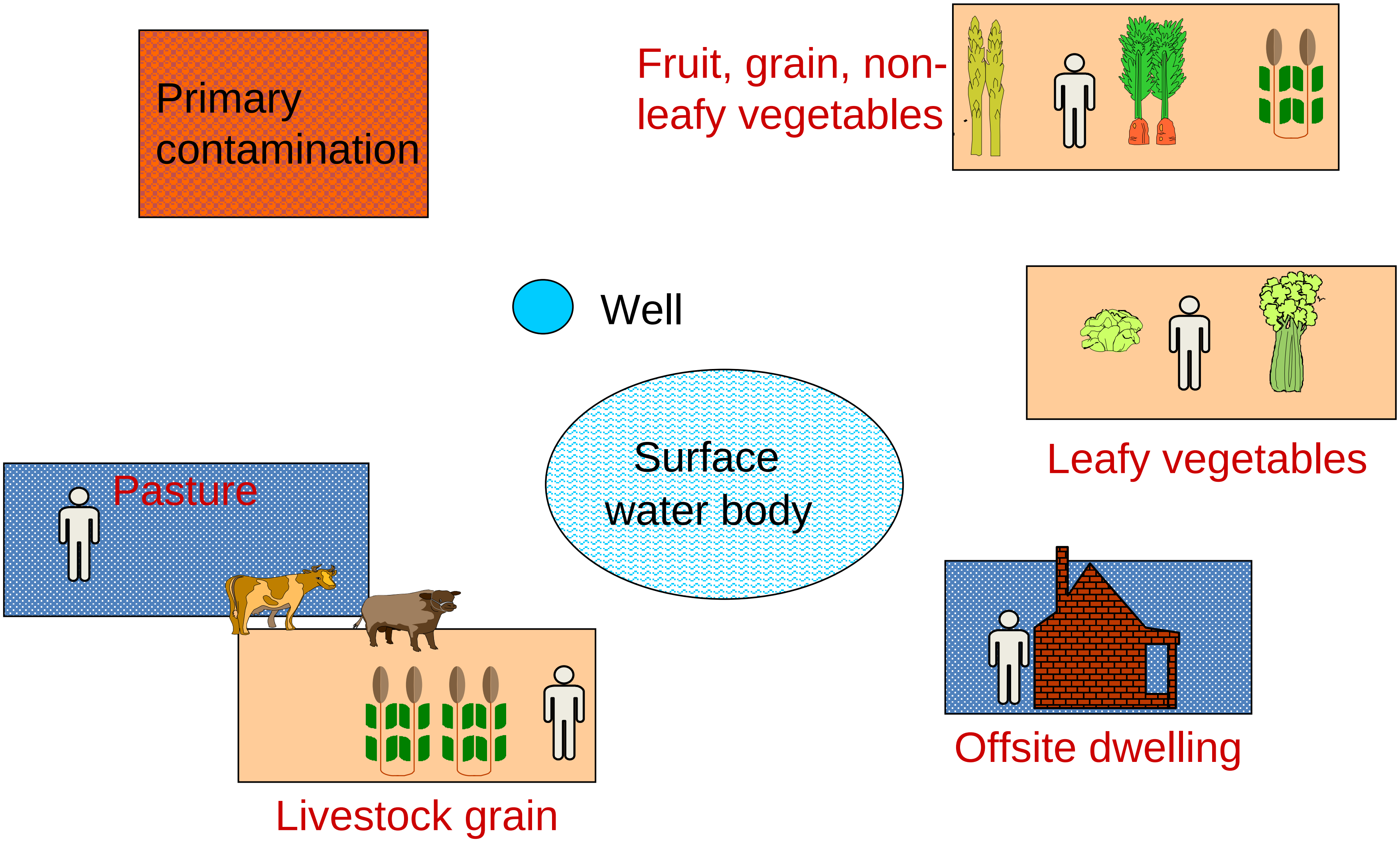
RESRAD-OFFSITE – Extending the Analysis Beyond the Contaminated Sites



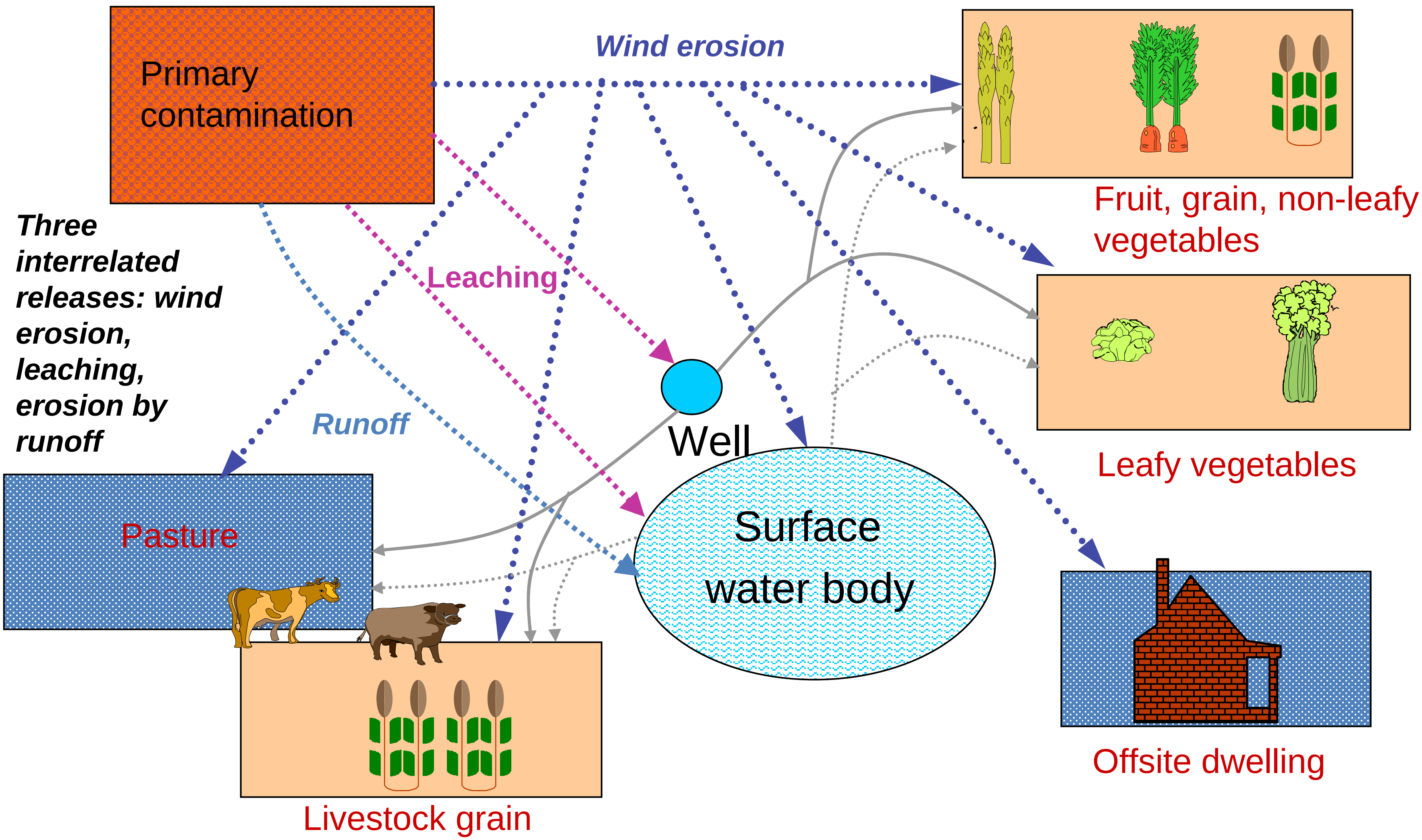
Area of Primary Contamination



Areas of Secondary Contamination



Transport to Areas of Secondary Contamination



Major New Models/Features in RESRAD-OFFSITE

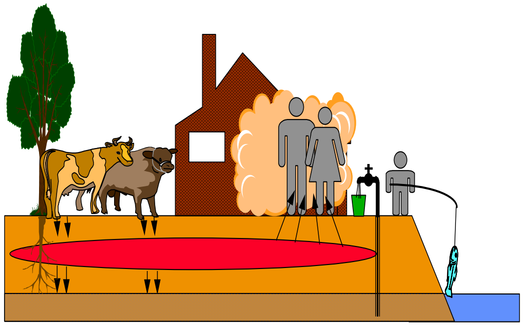
- Transport Pathways
  - Air dispersion (Gaussian plume) model
  - Groundwater transport model
    - 1-D advective, 1-D dispersive transport in unsaturated zone
    - 1-D advective (straight or curved flow path), 3-D dispersive transport in saturated zone
- Additional Impacted Areas
  - Choice of two dwelling locations (onsite, offsite)
  - Four 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

Input of Intermediate Contaminant Fluxes and Concentrations

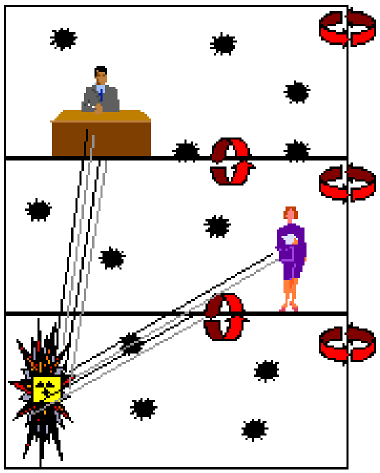
- RESRAD-OFFSITE can be flagged to read in:
  - Releases and inventory of the primary contamination (deterministic run)
    - Flux to groundwater
    - Flux to atmosphere
    - Flux to surface water
    - Inventory remaining in the primary contamination and mixing layers
  - Concentrations in surface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

Comparison of RESRAD and RESRAD-BUILD

- RESRAD (for soil contamination) and RESRAD-BUILD (for building contamination) codes address different contamination sources and uses:
  - Soil contamination that might lead to foodstuffs and water contamination through movement by natural processes



  - Building contamination in man-made products and air-flows thath might lead to exposure during normal building occupancy or D&D activities



Review of Extensions

- Sensitivity Analysis should always be used to gain understanding of the case and results ("Risk Informed")
- Probabilistic Analysis allows use of more realistic parameter values – conservatism set in level of results used to determine cleanup criteria
- RESRAD-Offsite allows use of more realistic scenarios – scenarios and parameters should be justified
- Probabilistic and Offsite allows more flexible and realistic assumptions but these assumptions require more effort to justify and collect