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U.S. NRC Staff Perspective on Use of Models/Codes for Risk-Informed Decision-Making in License Termination

Rateb (Boby) Abu Eid, Ph. D.

George Alexander, Ph.D.

Division of Decommissioning, Uranium Recovery Waste Management Programs (DUWP)

Office of Nuclear Material Safety and Safeguards (NMSS)

U.S. Nuclear Regulatory Commission

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Presentation Topics

- NRC Regulations & Key Guidance for Compliance with the Radiological Criteria for License Termination;
- NRC Decommissioning Processes;
- NRC's Risk-Informed and Performance-Based Approach;
- Models/Codes Used for Demonstration of Compliance with the Safety Criteria; and
- Summary & Conclusion.

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NRC Regulations & Key Guidance

License Termination Standards for Unrestricted Use (10 CFR 20.1402)

- Total Effective Dose Equivalent (TEDE) d 0.25 mSv/a and As Low As is Reasonably Achievable (ALARA)
- Average member of the critical group
- All pathways
- Period of performance - 1000 years

License Termination Standards for Restricted Use (10 CFR 20.1403)

- d 0.25 mSv/a TEDE and ALARA, with institutional controls in effect
- Legally enforceable institutional controls
- If institutional controls fail, doses do not exceed 1 mSv/a, or 5 mSv/a, under specific circumstances
- Financial assurance - independent third party
- Licensee and NRC public input/outreach requirements

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NRC Regulations & Key Guidance (Cont'd)

Alternate Criteria for License Termination (10 CFR 20.1404)

- **> 0.25 mSv/a, but < 1 mSv/a TEDE, with institutional controls in effect**
- **Similar requirements for license termination under restricted conditions**
- **Licensee must demonstrate doses to public from all man-made sources other than medical will be < 1 mSv/a and ALARA**
- **Unusual, site-specific circumstances**

Principle Guidance Documents

- NUREG-1700 – Standard Review Plan for Evaluating Nuclear Power Reactor License Termination Plans
- NUREG-1757 – Consolidated Decommissioning Guidance
- NUREG-1575 – Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)
- NUREG-1748 – Environmental Review Guidance for Licensing Actions Associated with NMSS Programs

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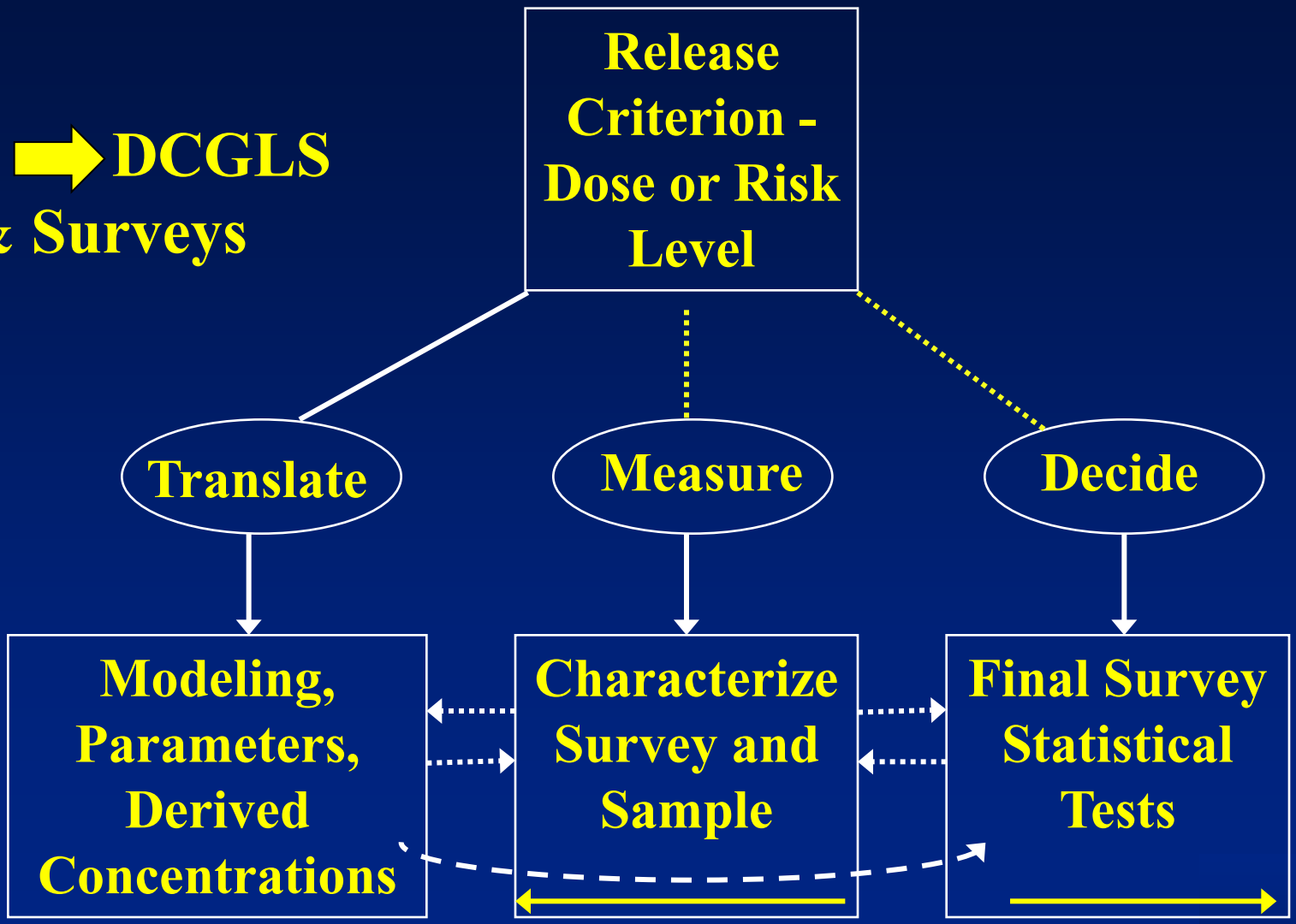
NRC Decommissioning Process

Dose ➡ DCGLS & Surveys



MARSSIM

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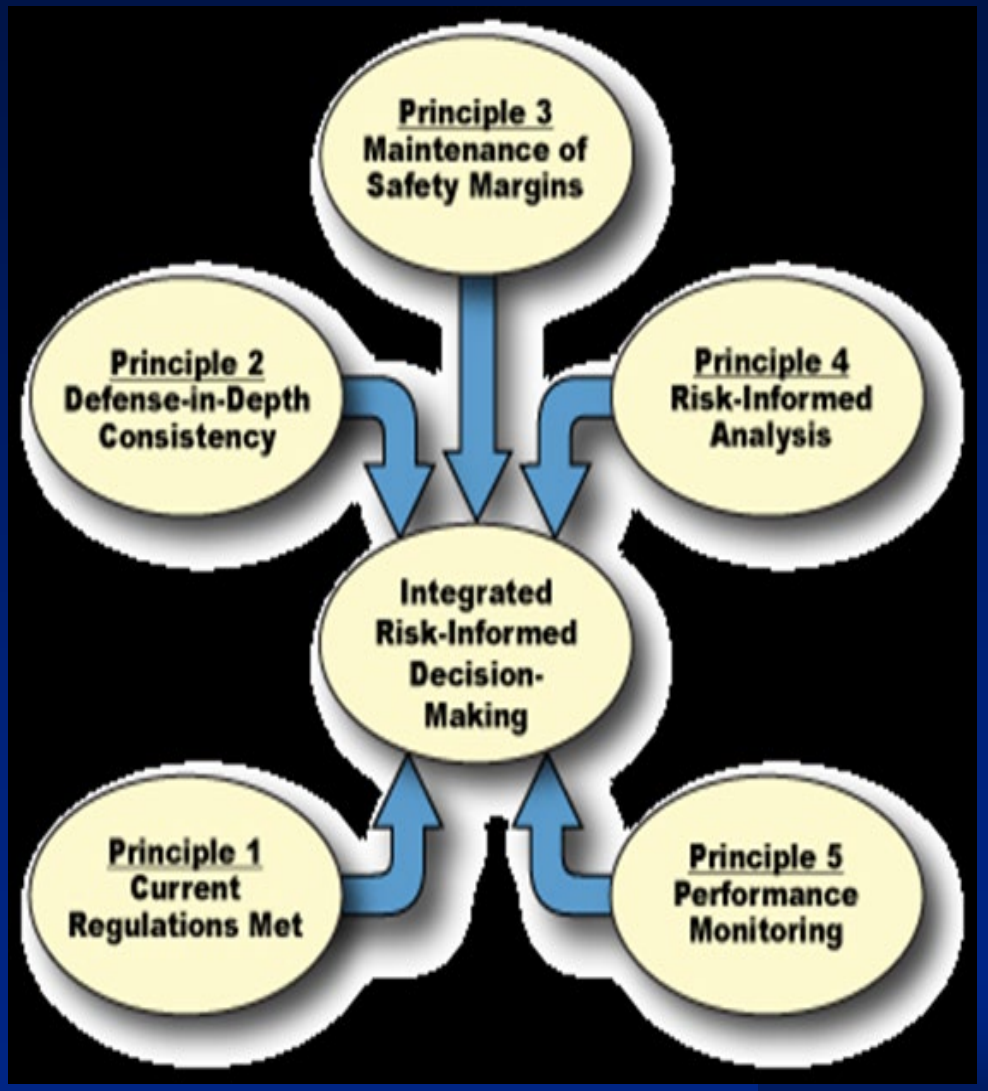
Risk-Inform & Probabilistic Simulation and Uncertainties

- Risk 3Qs: "*what can go wrong?*," "*how likely it is?*," and *what its consequences might be?*"
- The conceptual models used to assess risk and inputs describing the source, its release and transport, and receptor' exposure pathways are uncertain.
- Probabilistic simulation is used as a process to explicitly representing this uncertainty by describing models and associated inputs as probability distributions.



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Risk-Informed Performance-Based NRC's Concept for Regulatory Compliance

- A risk-informed performance-based (RIPB) regulation is an approach in which risk insights, engineering analysis and judgment (including the principle of defense-in-depth and the incorporation of safety margins, and performance history are used;
- RIPB main pros:(1) focus attention on the most important activities, (2) establish objective criteria for evaluating performance, (3) develop measurable or calculable parameters for monitoring system and licensee performance, (4) provide flexibility to determine how to meet the established performance criteria, and (5) focus on the results as the primary basis for regulatory decision-making.

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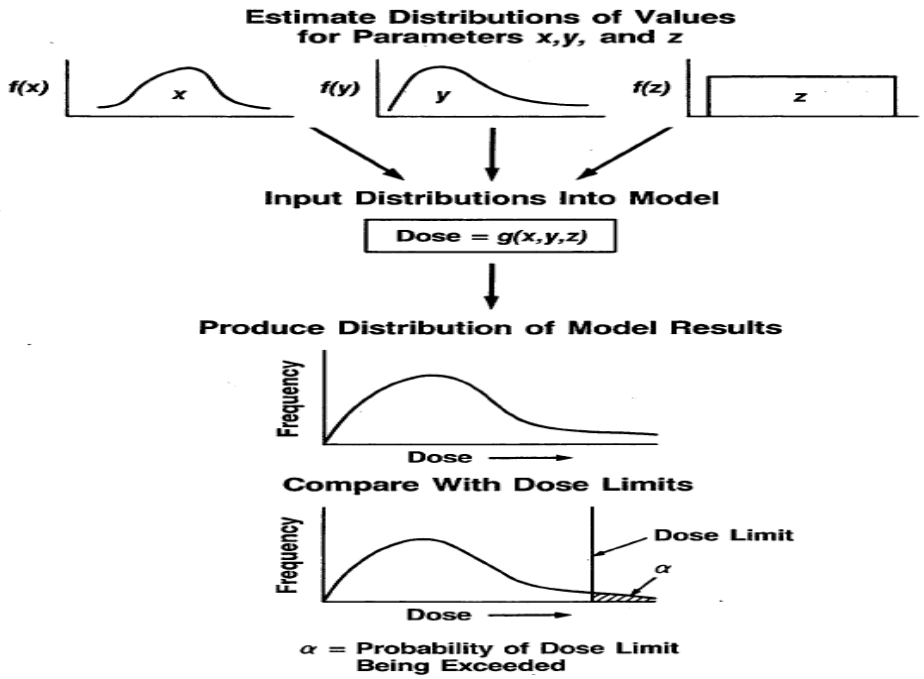
Risk-Informed - Probabilistic Dose Assessment Approach & Uncertainty Analysis



$$\text{Max}[\text{Mean}(t)] \leq \textit{Regulatory Limit}$$

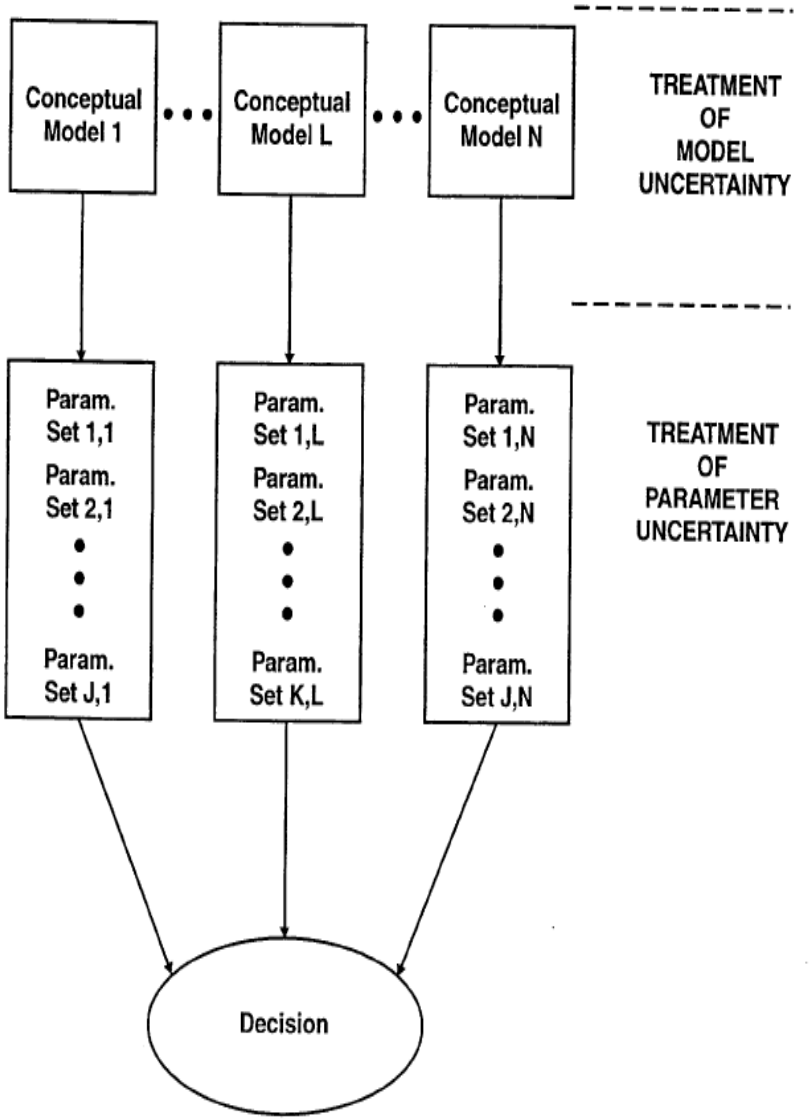
where:

$$\text{Mean}(t) = \frac{\sum_{k=1}^{N} \text{Dose}_k(t)}{N}$$

$\text{Dose}_k(t)$ = doses *at time t, for run k*

N = *number of Monte Carlo runs*

t = *time*



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Codes/Models Commonly Used in NRC License Termination Reviews

- D&D Code (Screening Analysis)
- RESRAD BUILD (building surface contamination)
- RESRAD ONSITE (onsite dose impact assessment)
- RESRAD –OFFSITE (offsite dose impacts using advanced atmospheric' transport, GW&SW models)
- GoldSim (stylized complex site specific analysis)
- Micro-shield (ɣ-direct exposure)

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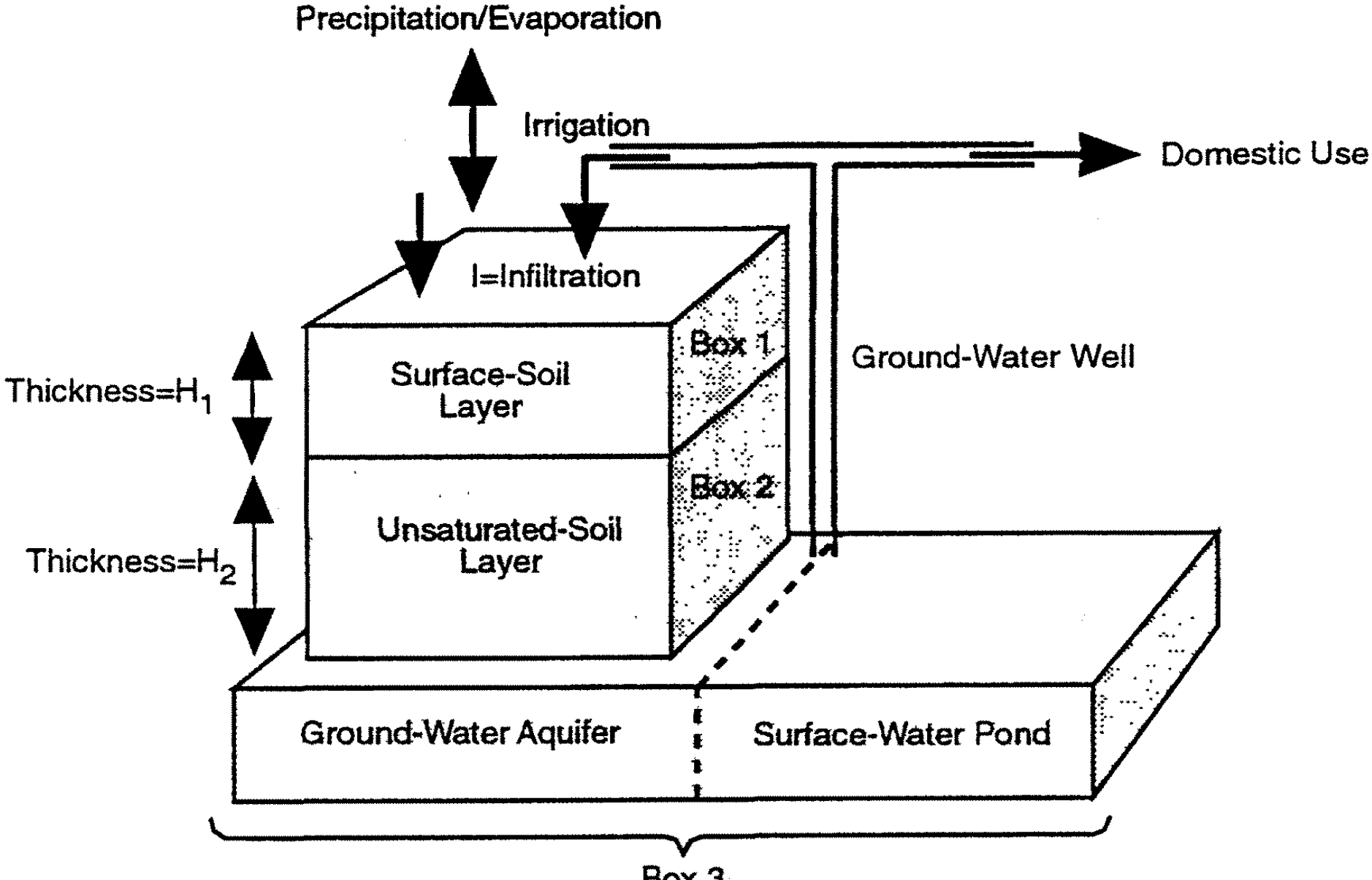
D&D Code Simple Models for Screening Analysis



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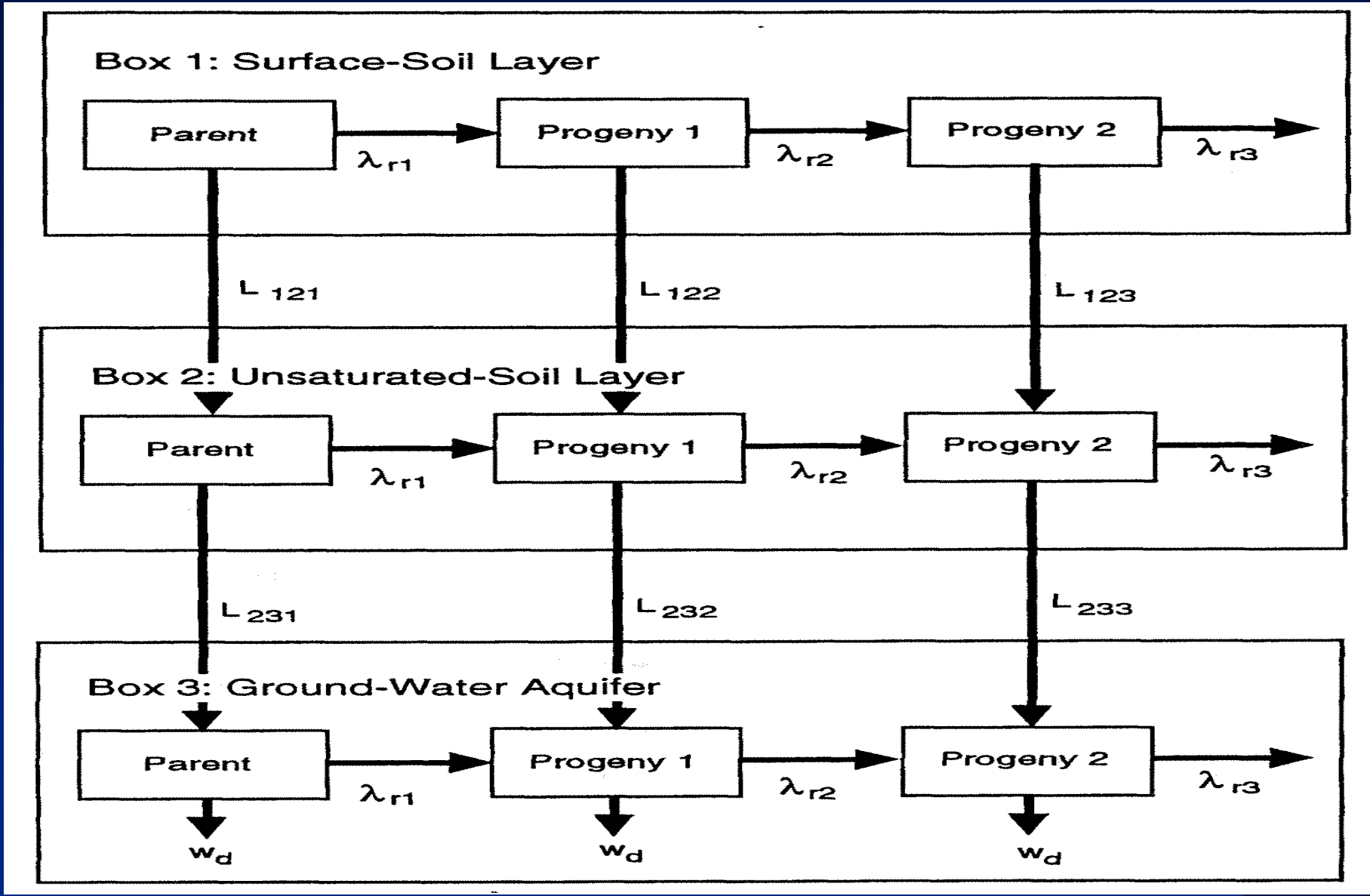
D&D Three-Box GW Leach Model



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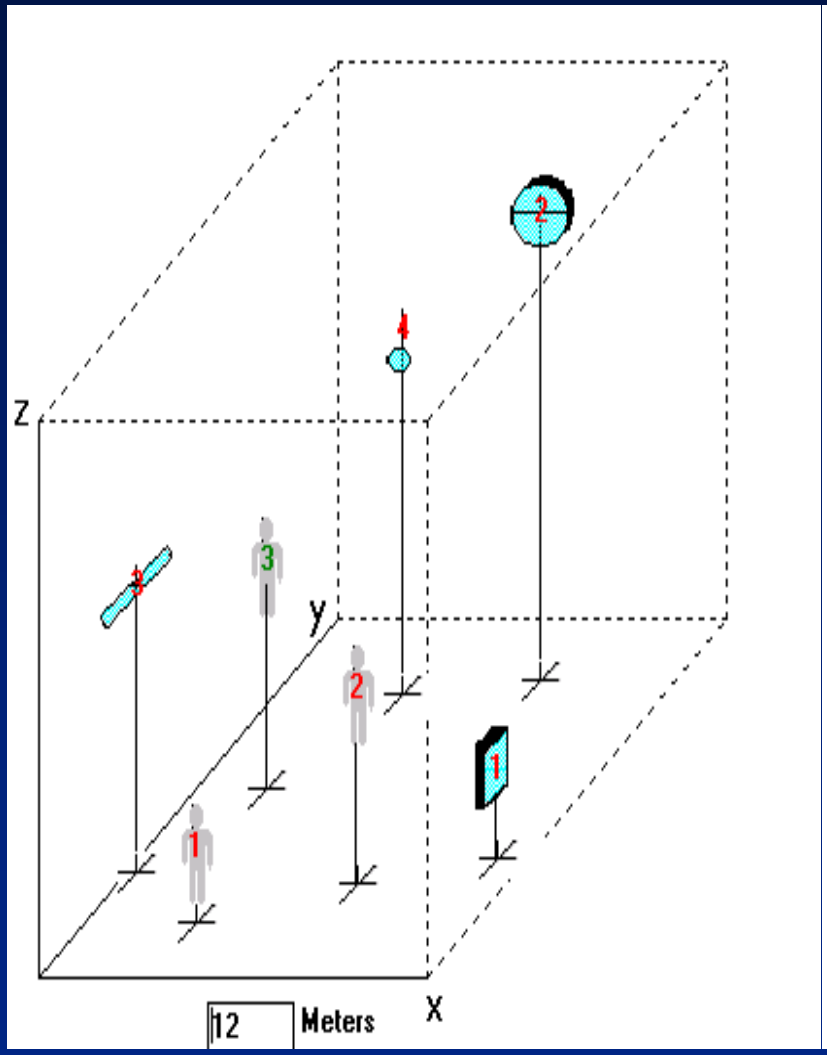
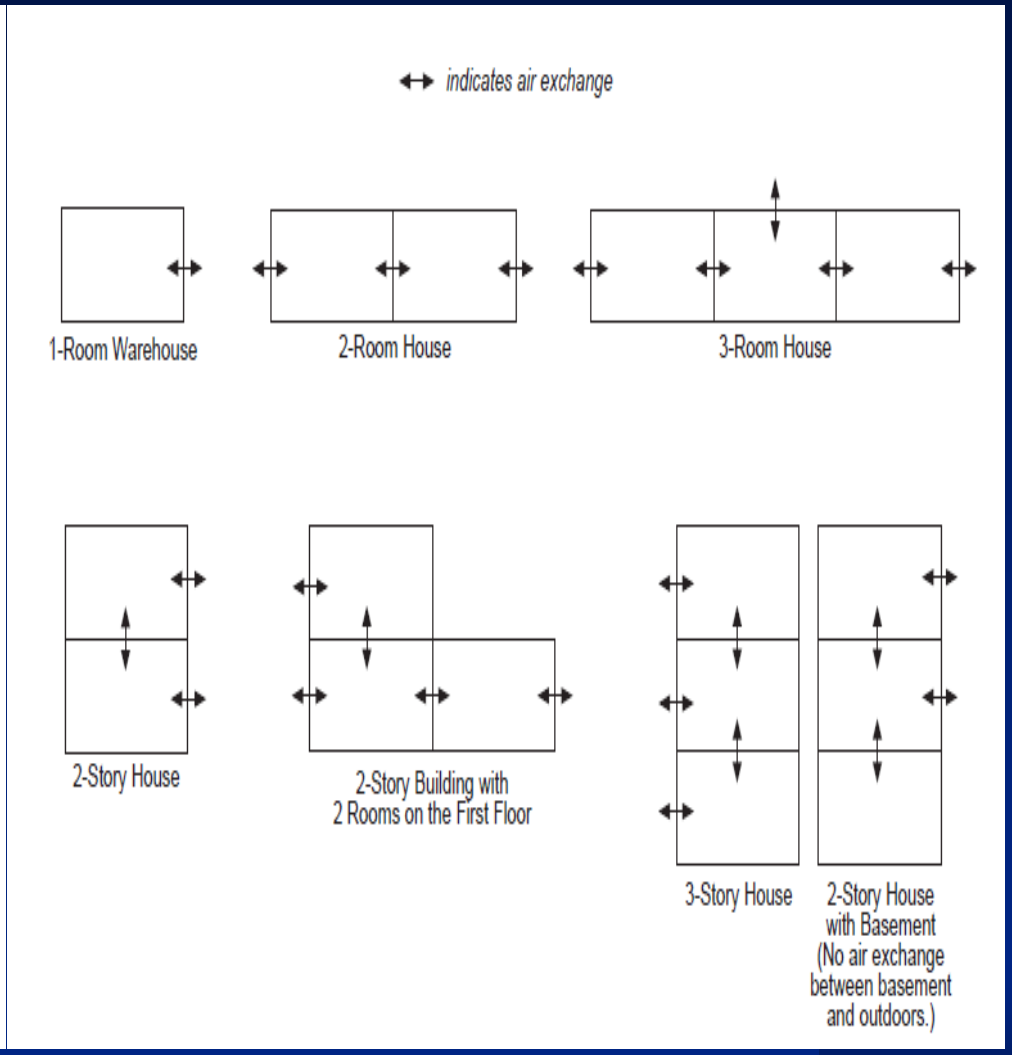
RESRAD-BUILD Model Assumption
Involves Contamination on Building Surfaces





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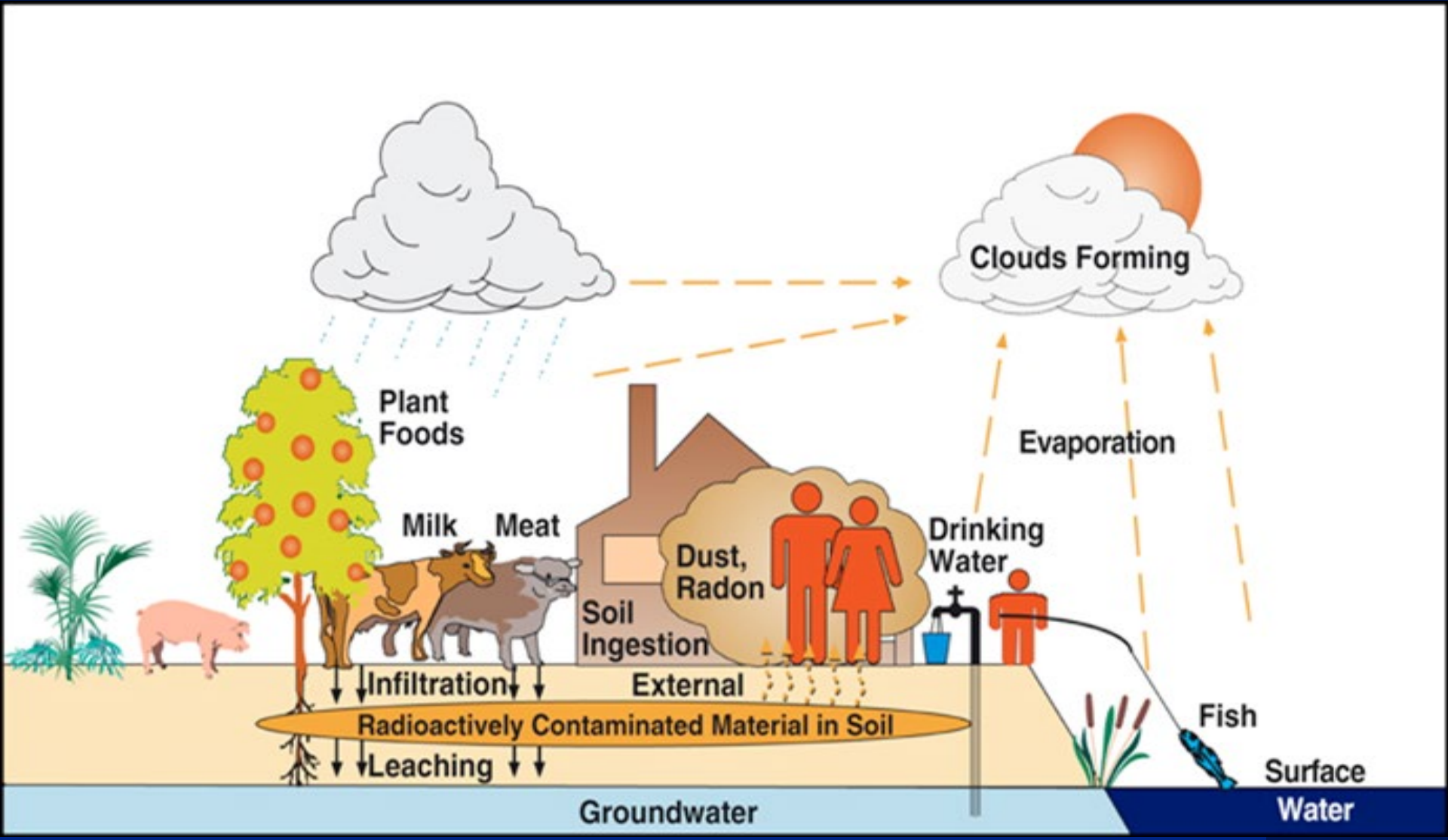
RESRAD ONSITE Schematic Exposure Pathways



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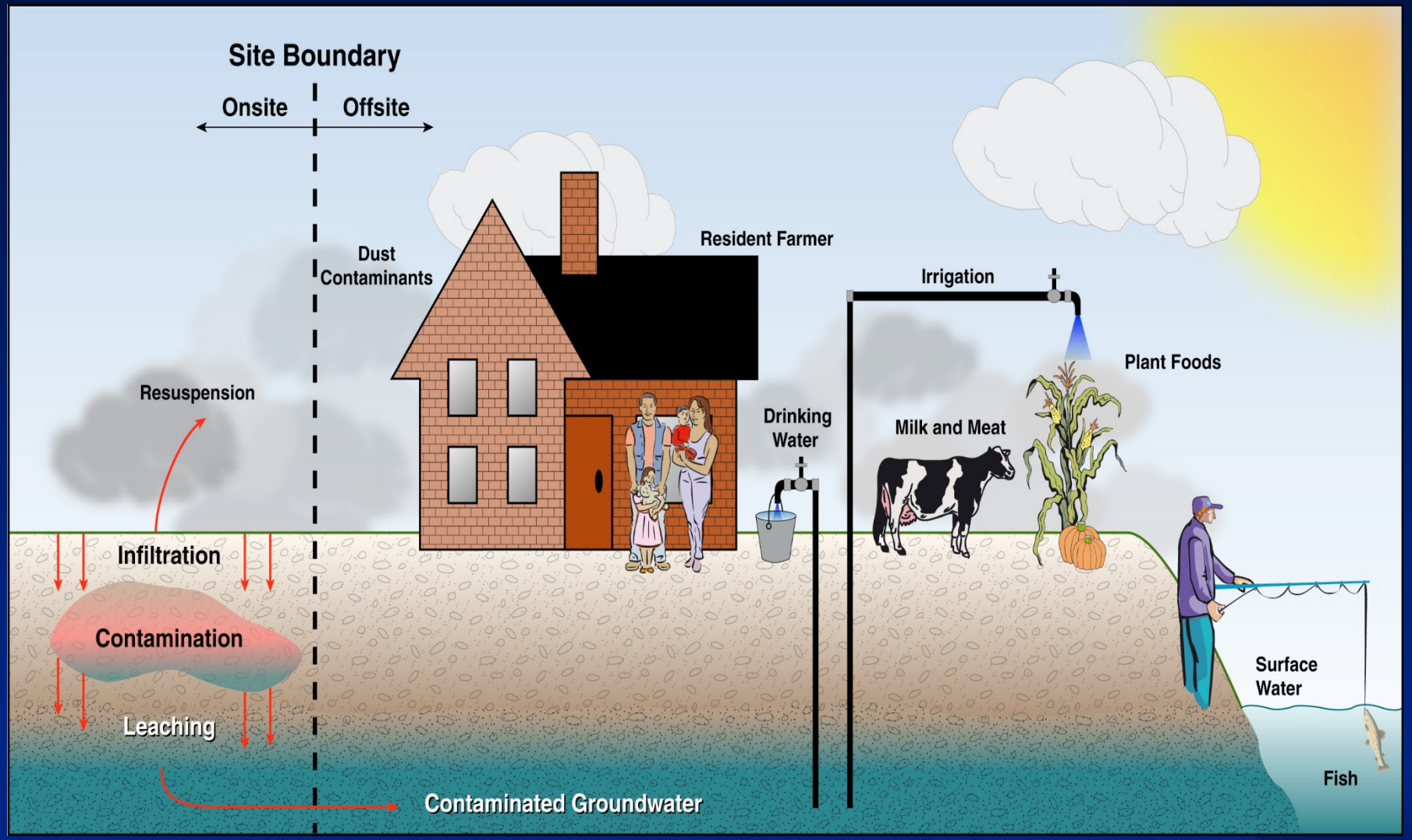
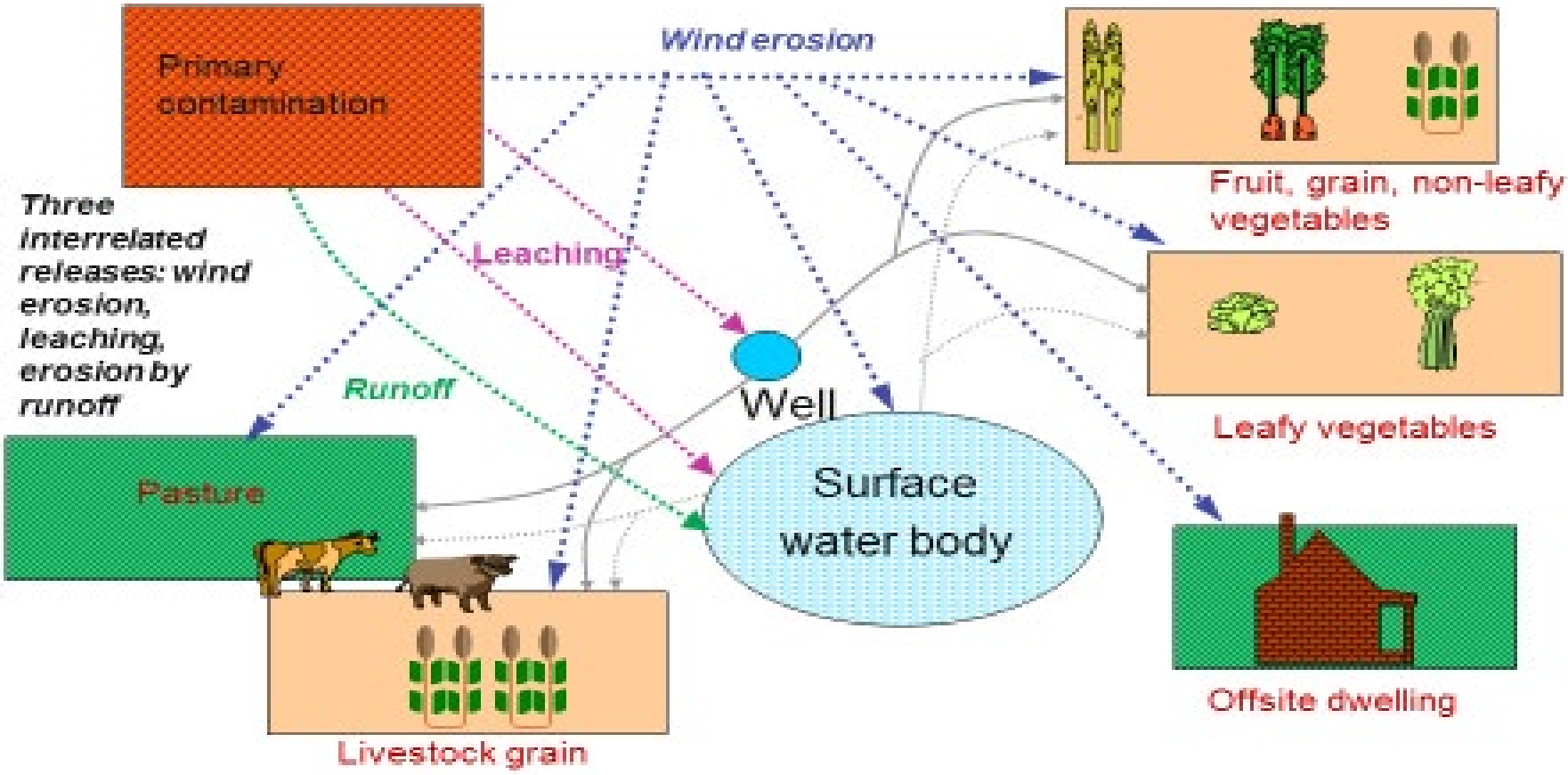
RESRAD-OFFSITE Conceptual Model



Transport to Areas of Secondary Contamination



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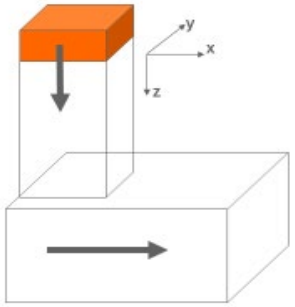
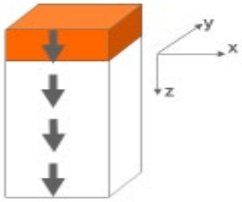
Groundwater Transport Model in RESRAD-OFFSITES – An Overview

Processes Modeled for Groundwater Transport



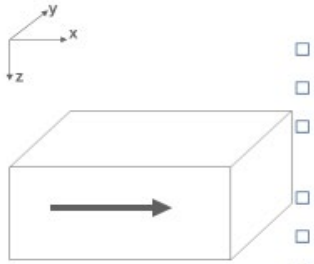
- Advective and Dispersive transport
  - Within the primary contamination
  - Through the layers below
  - Transformations during transport
- Nuclide specific solute-soil interaction
  - Transport rate
  - Concentration in water
- Concentration in Well water
- Areally integrated flux to Surface water body

Processes Modeled for Vertical Transport in the Unsaturated Zones



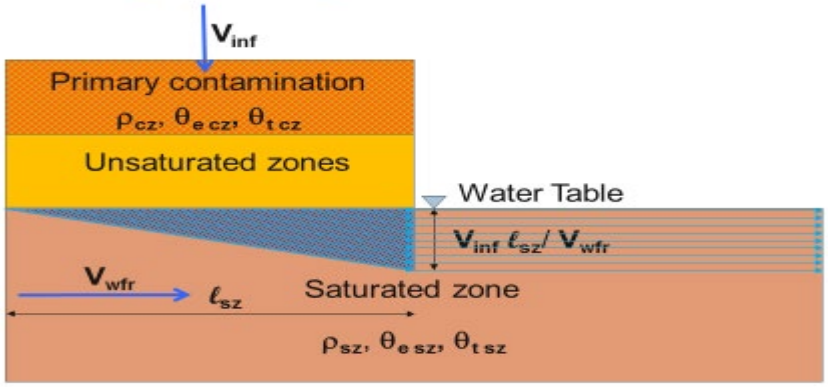
- Vertical transport
  - Longitudinal (z) advection
  - Longitudinal (z) dispersion
  - Transformations during transport
  - Nuclide specific solute-soil interaction
    - Transport rate
    - Concentration in water
- Areally integrated flux to water table
- Uniformly spaced computation time points require smaller execution time

Processes Modeled Saturated Zone Transport



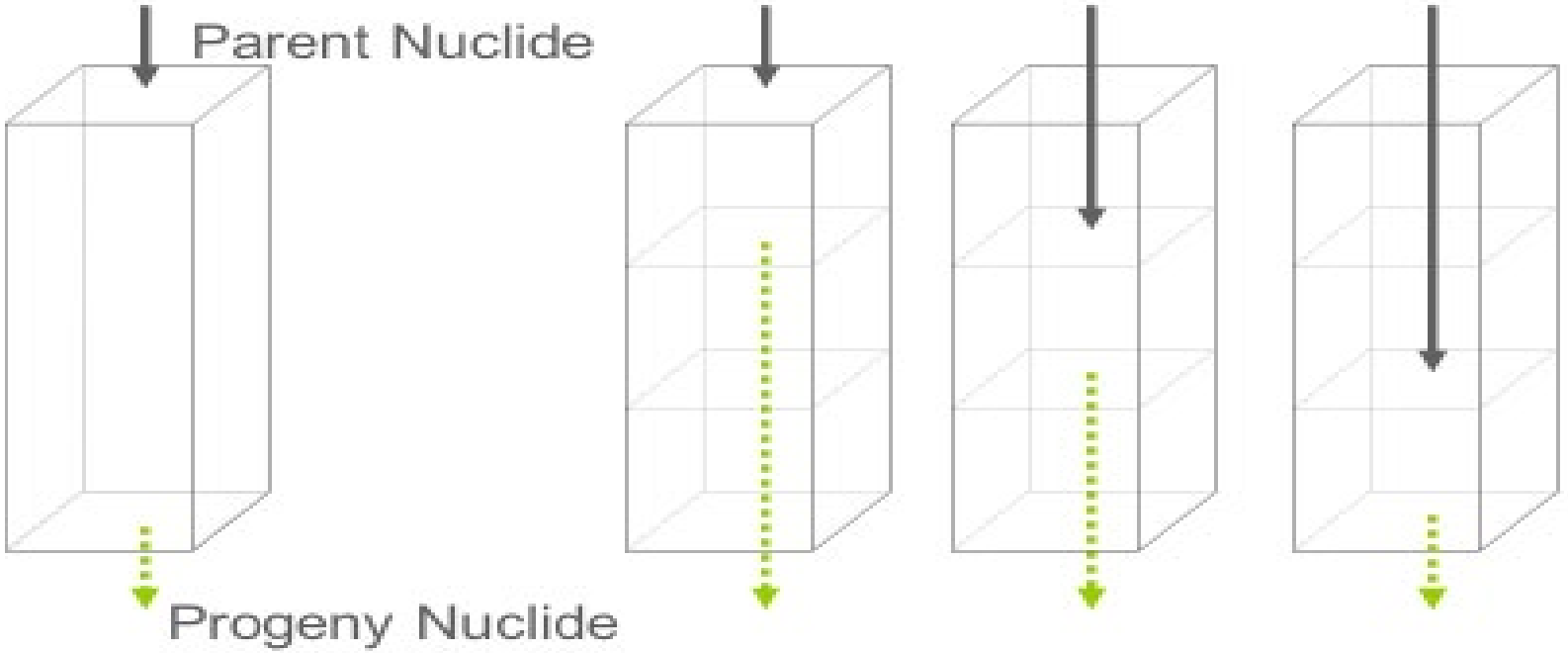
- Longitudinal (x) advection
- Longitudinal (x) dispersion
- Nuclide specific solute-soil interaction
- Transverse (y, z) dispersion
- Concentration in well water
- Areally integrated flux to surface water body
- Uniformly spaced computation time points require smaller execution time

Conceptualization for Groundwater Transport Unsubmerged Primary Contamination



Groundwater Transport Model in RESRAD-OFFSITES – An Overview

Subdivision of Transport Zone



- One of the processes (longitudinal dispersion or nuclide specific water soil interaction) is ignored over a shorter travel distance
  - More subdivisions there are, shorter this distance is

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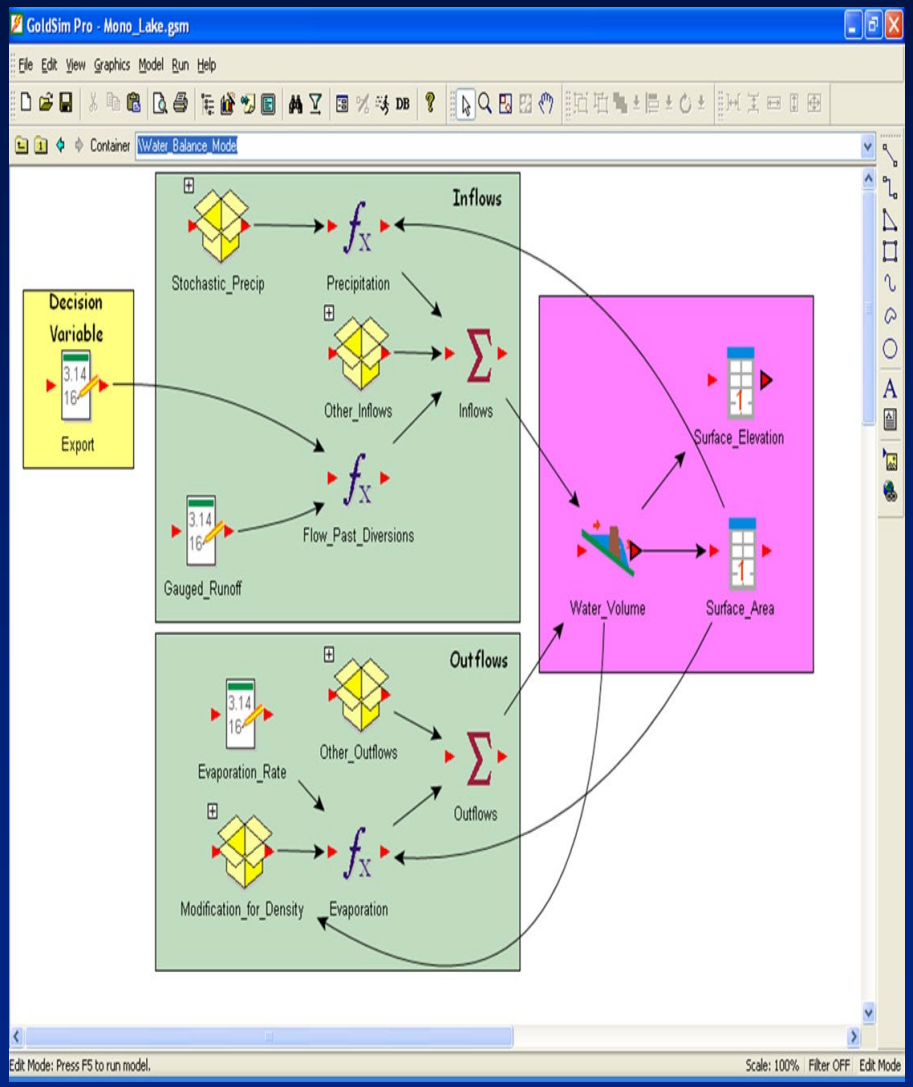
GoldSim Code



- GoldSim is a highly graphical, Windows-based program for carrying out dynamic, probabilistic simulations of complex systems to support management and decision-making in engineering, science and business.
- GoldSim was designed to facilitate the incorporation of additional modules (program extensions) to address specialized applications.
  - The Contaminant Transport Module provides the ability to simulate the transport and fate of radionuclides and other contaminants through the environment (performance assessment).

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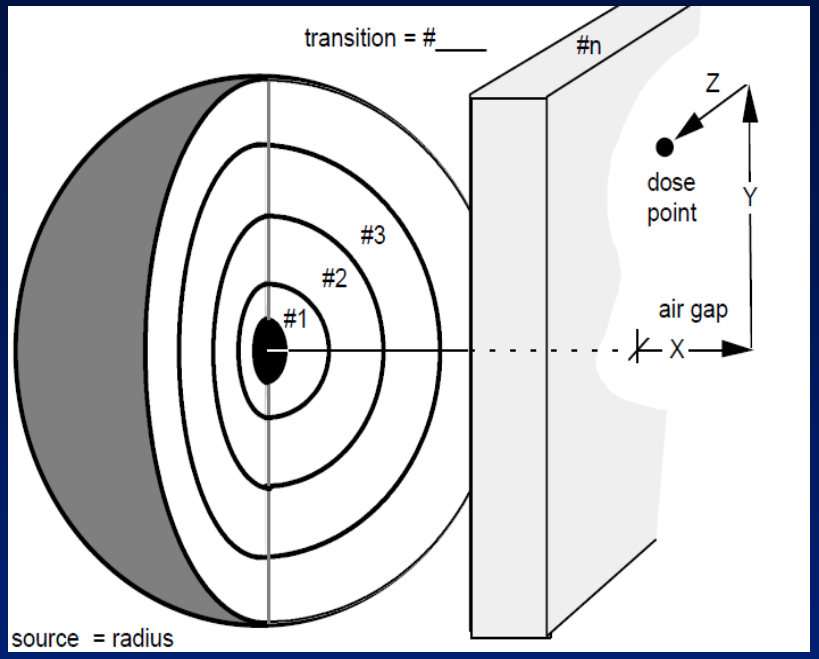
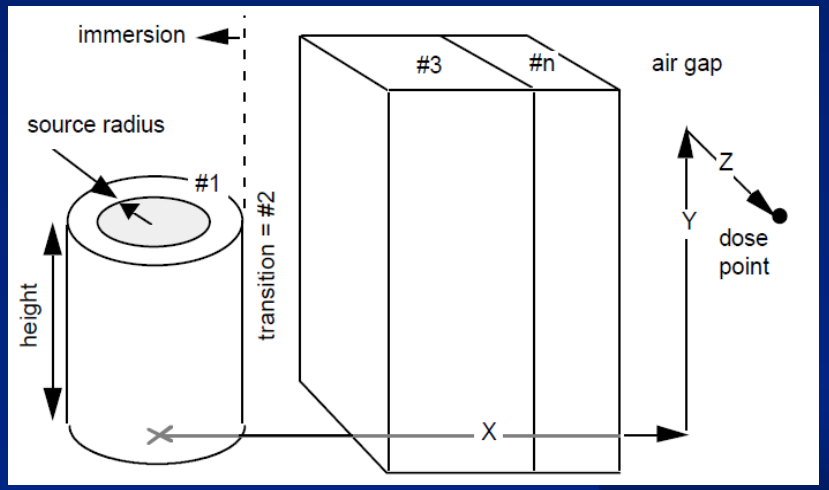
MicroShield Code

- As many as 10 "standard" shields are possible for each geometry. They are specified by their thickness in the X direction (Y for cylinder source with end shields) which is an orthogonal projection away from the source. Any shield can be designated as zero thickness in which case it will not affect results, unless it is the transition shield (see below).
- In the case of the cylinder with end shields, the thicknesses are in the Y direction.
- For sources that are volumetric, the source material can be specified separately from the shields.
- For the annular cylinder source, the source is in the second cylindrical shield outside of the core. The cylindrical core is also a shield as is the first cylindrical shield outside the core. For the external dose point, the "outer“ shields may be cylindrical or slabs.





Models Used by NRC PA Staff

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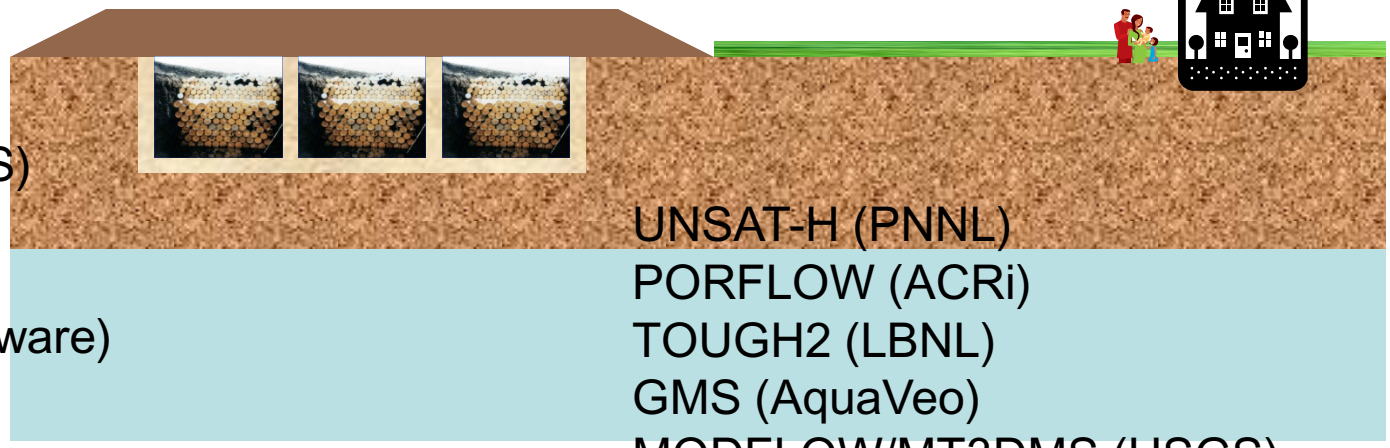
GoldSim (GTG), RESRAD (ANL), D&D (ANL)

HELP (US COE)
Siberia (Telluric Research)

GENII (PNNL)
BDOSE (CNWRA)



4SIGHT (NIST)
BLT (BNL)
PHREEQC (USGS)
DUST-MS (BNL)
Geochemist's Workbench (Rockware)

UNSAT-H (PNNL)
PORFLOW (ACRi)
TOUGH2 (LBNL)
GMS (AquaVeo)
MODFLOW/MT3DMS (USGS)

Others – Microshield (Grove Software)
Mathematica (Wolfram)
Neuralworks Predict (NeuralWare)
ArcGIS (ESRI)
MVS (Ctech)
Earthvision (Dynamic Graphics)
MCNP (LANL)
SADA (U of Tenn)

Risk-Informing Reviews
Barrier Analysis Example

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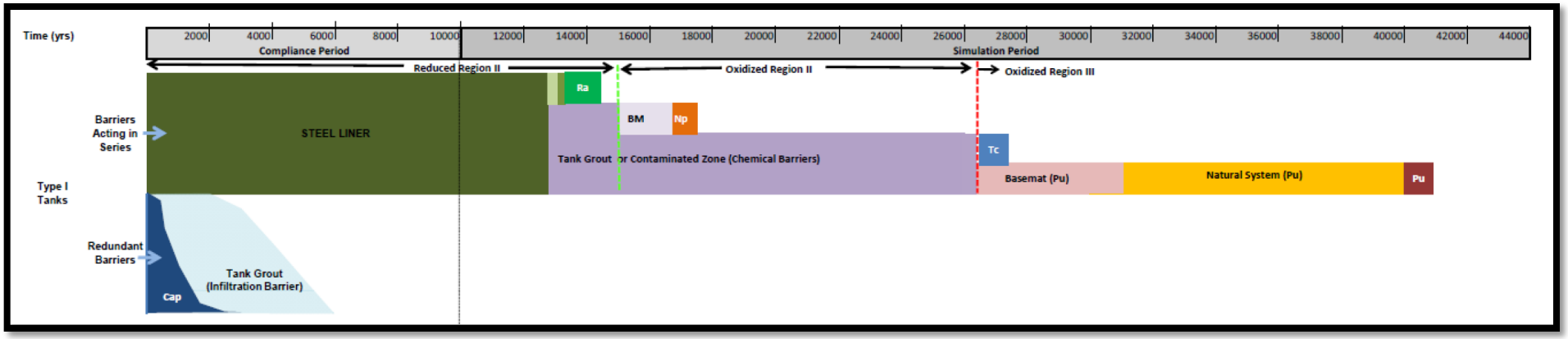
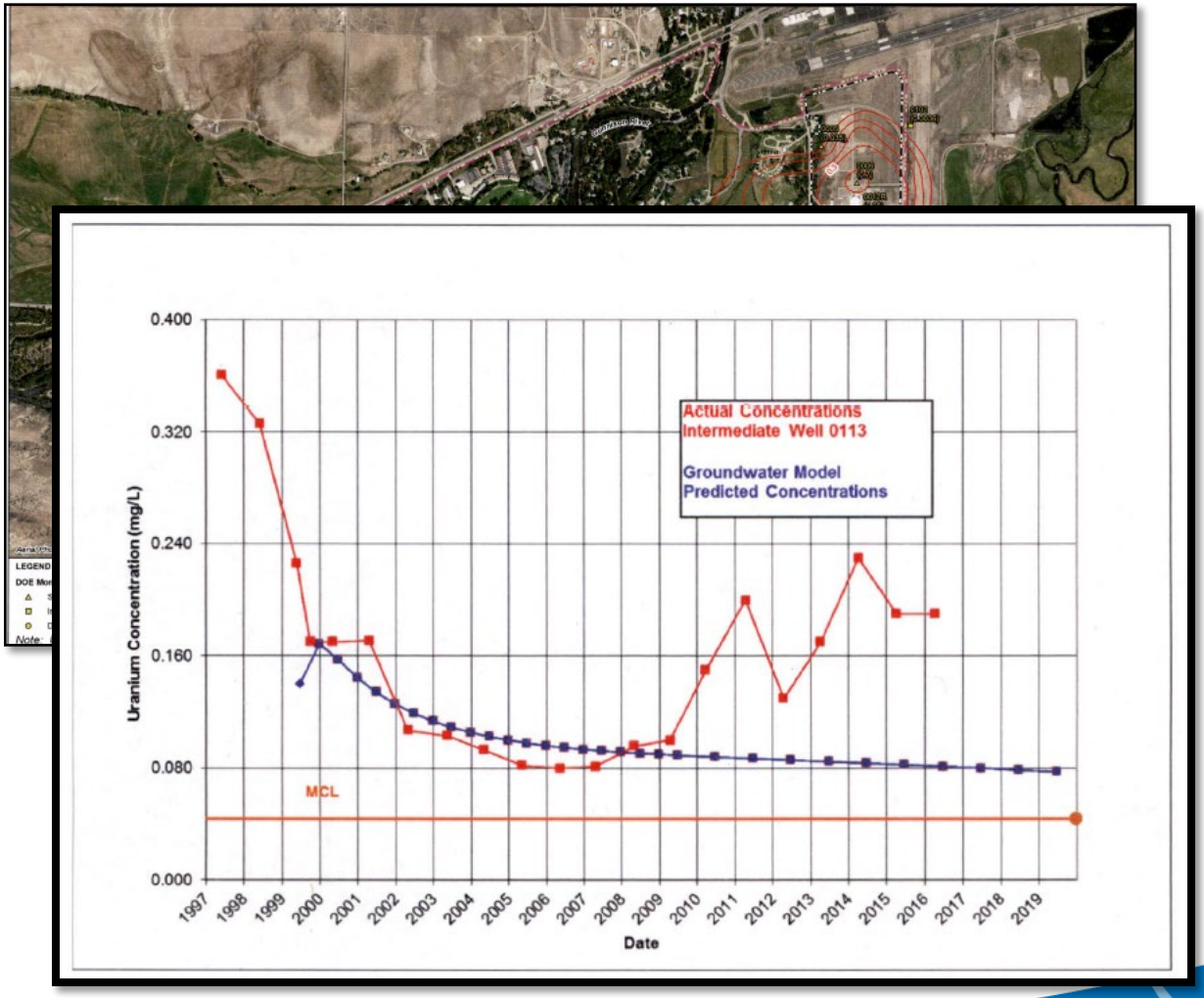
Savannah River Site: F-Area Tank Farm Performance Assessment Review



- Key (assumed) barriers to the magnitude and timing of peak dose
- Focus review on the most risk-significant barriers
- Support should be commensurate with the assumed level of credit for each barrier

Conceptual Site Model Gunnison, CO



- Natural flushing compliance strategy (2010)
- Uranium concentrations not declining as anticipated
- Residual uranium source below tailings pile
- Revised compliance strategy (2017)

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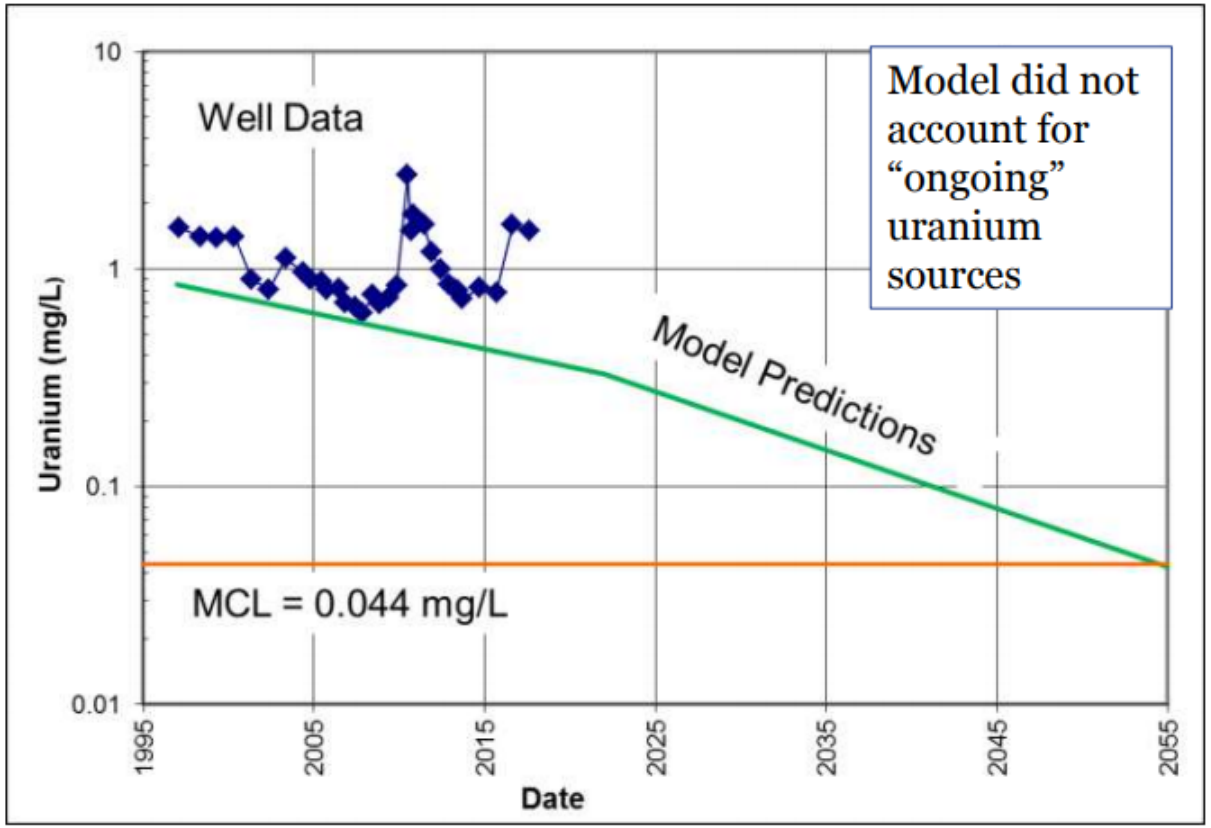
Adapted from DOE Draft Groundwater Compliance Action Plan for the Gunnison, Colorado, Processing Site, ML17124A592

Conceptual Site Model Riverton, WY



- Natural flushing compliance strategy
- Flooding of the Little Wind River in 2010
- Larger-than-expected uranium source in the unsaturated zone

Adapted from DOE at: https://www.energy.gov/sites/prod/files/2018/10/f56/Shafer-Learning-from-Nature.pdf

Challenges and Lessons Learned

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- Uncertainty + Bias
- Conceptual Site Model
- Model Complexity & Model Verification
- Model Support/Confidence Building Activities
- Training
- Feedback between modelers and field observations

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Summary & Conclusion

- In review of licensees' submittals, NRC staff uses different codes/models for screening or site-specific depending on site conditions (e.g.; simple/complex);
- The models/codes used by NRC staff have been tested, QA/QC'd and benchmarked;
- NRC adopted a risk-informed performance-based approach considering uncertainties;
- Licensees may use deterministic or probabilistic approaches; however RAIs would be different; .
- Deterministic Models/Codes with fixed scenarios and input parameters tend to be conservative and may be inappropriate for complex sites.

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More Information

- **Decommissioning Web Page - http://www.nrc.gov/what-we-do/regulatory/decommissioning.html**
  - **Sites; regulations and guidance; process; public involvement; key program documents; International aspects; FAQs; Lessons Learned**
- **NRC's Regulations - http://www.nrc.gov/reading-rm/doc-collections/cfr/**

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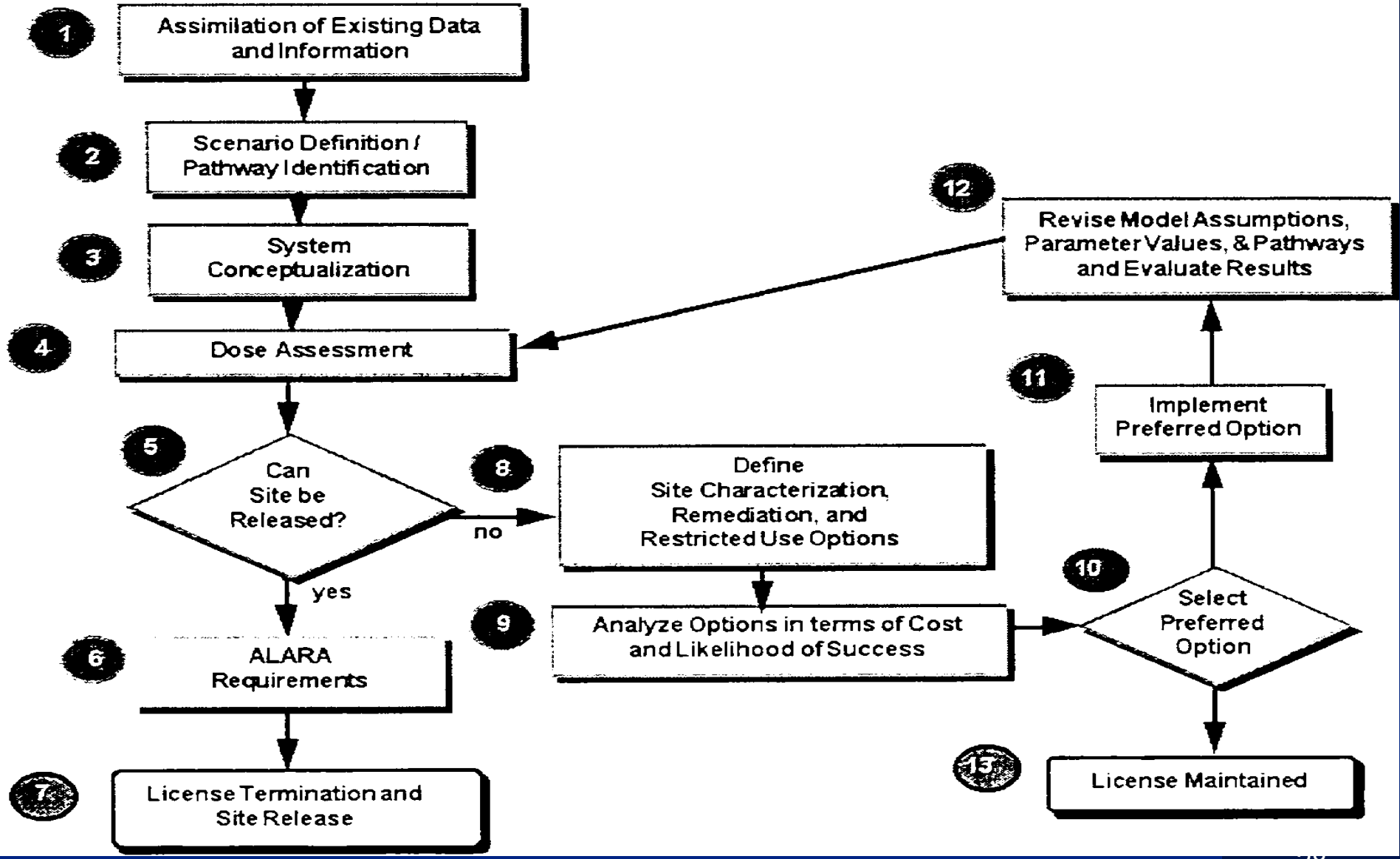
BACKUP SLIDES

NRC's Decommissioning Framework



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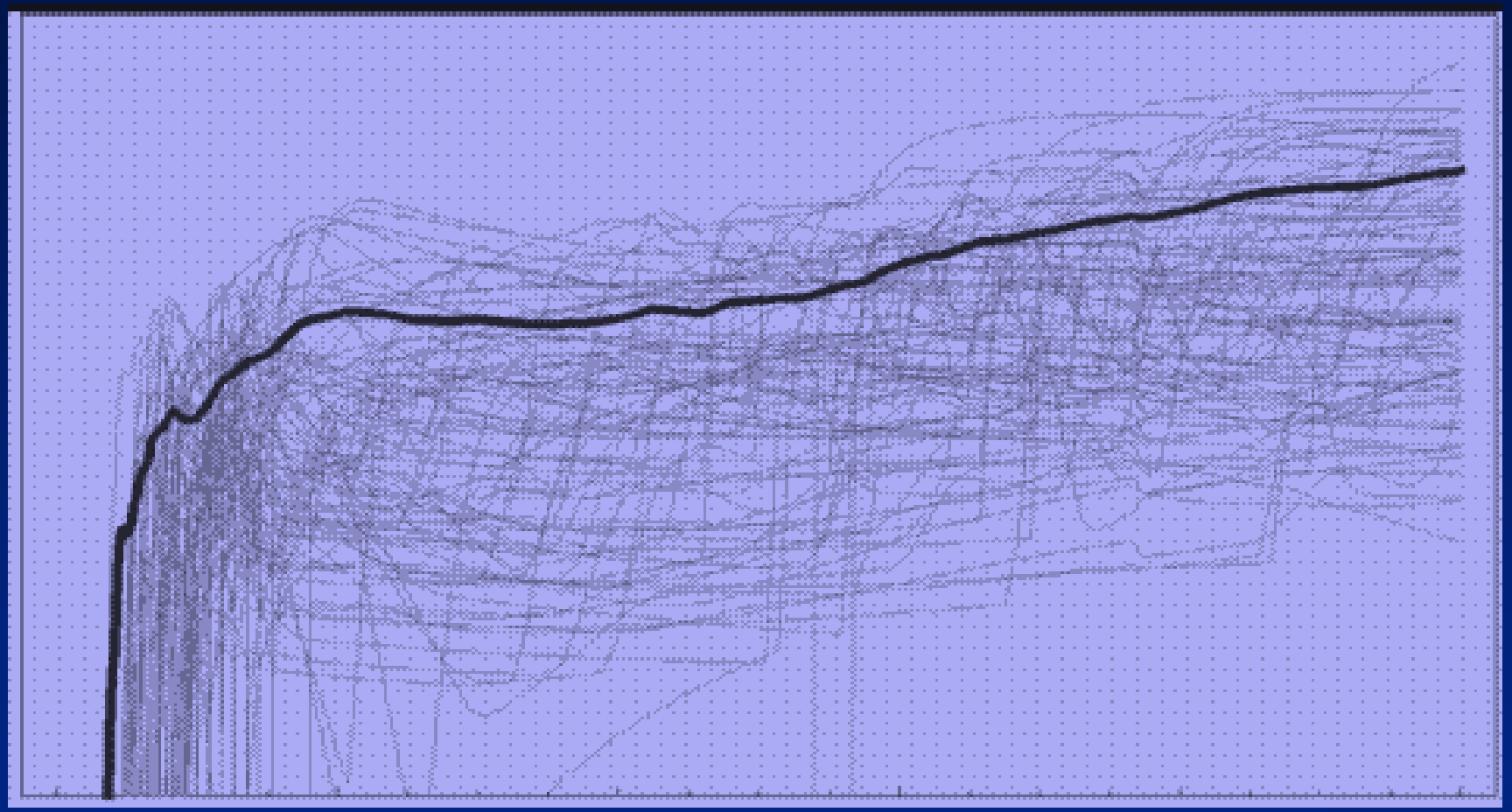
Dose - Time PA Outputs



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Groundwater Model Assumption in RESRAD-OFFSITE

- The material that contains the radionuclides is conceptualized to be in two forms:
  - a form that is susceptible to release radionuclides
  - a form that is release immune;
- The release can be delayed and can be distributed over time;
- First order rate controlled:
  - Use leach rate;
- Equilibrium:
  - Adsorption – desorption equilibrium of the radionuclides between solid and aqueous phases of the contaminated medium within the primary contamination:
    - Use distribution coefficient;
  - Solubility Equilibrium:
    - Use soluble concentration;
- Diffusive transport out of contaminated medium (above, straddling, or just below the water table)

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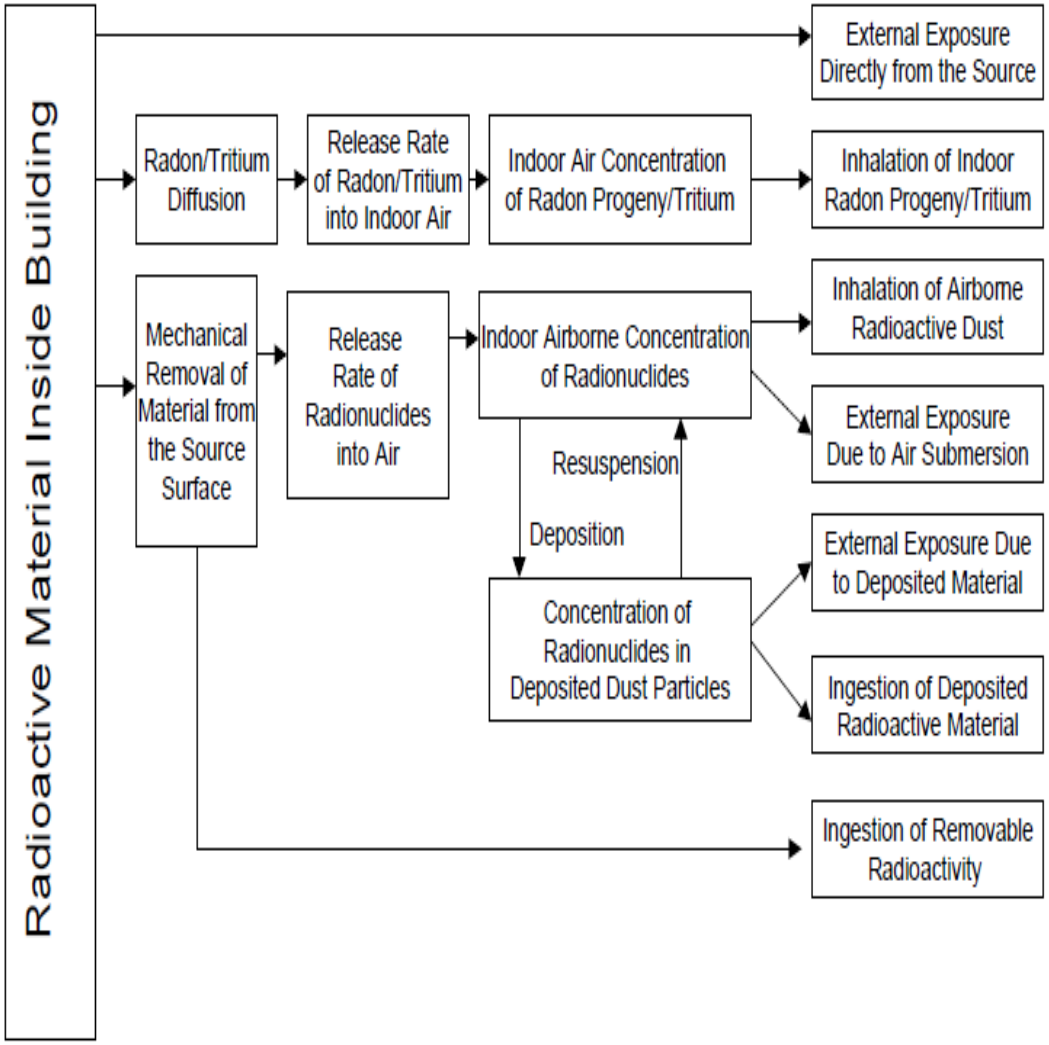
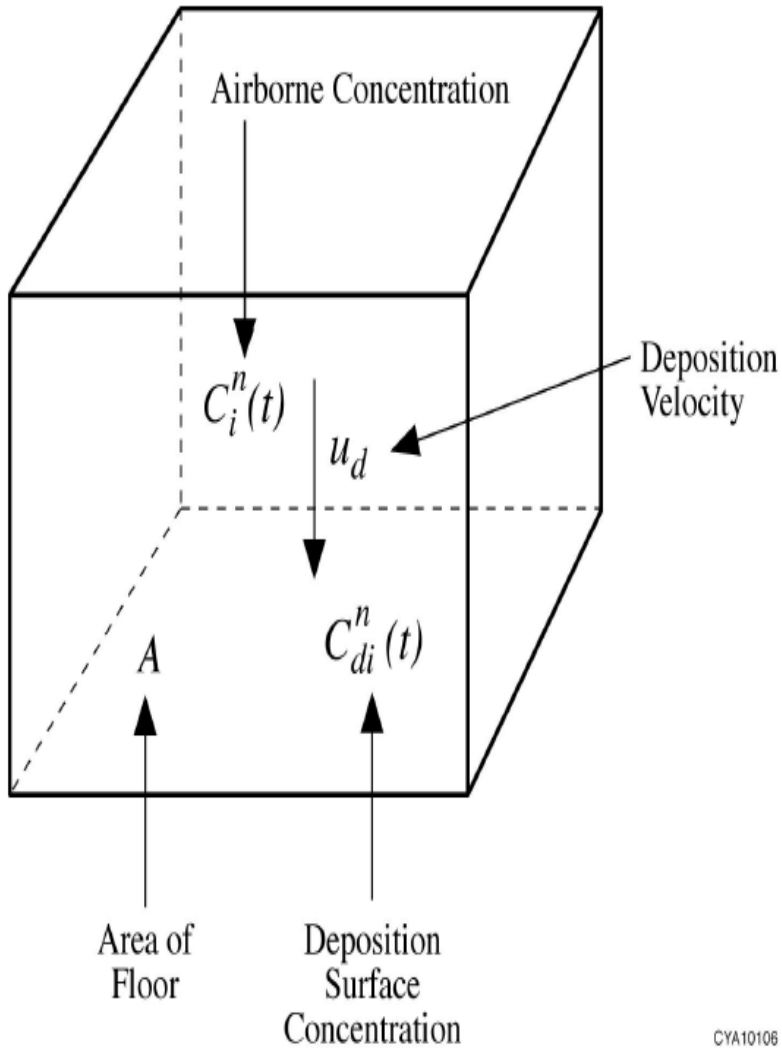
RESRAD-BUILD Exposure Pathways





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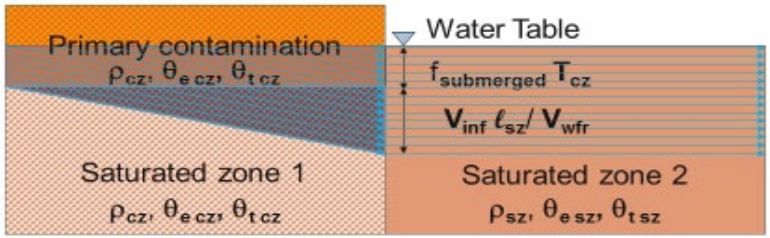
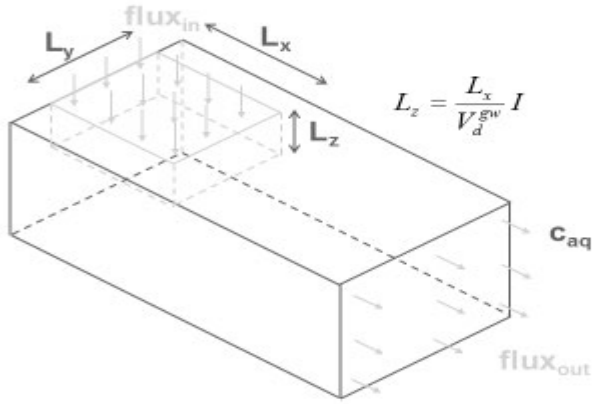
Groundwater Transport Model in RESRAD-OFFSITES – An Overview

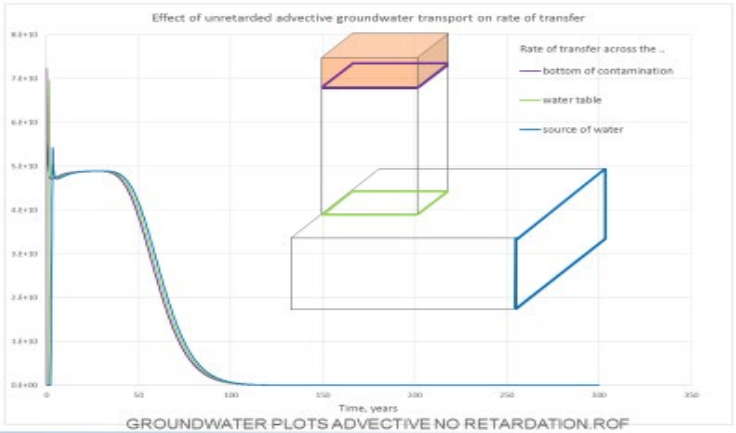
Conceptualization for Groundwater Transport Partially Submerged Primary Contamination



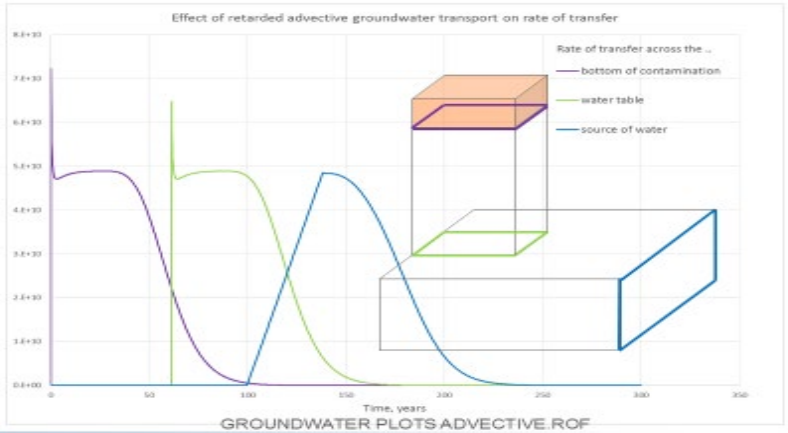
Idealization of Saturated Zone Transport



Un-retarded Advective Transport in Groundwater



Retarded Advective Transport in Groundwater



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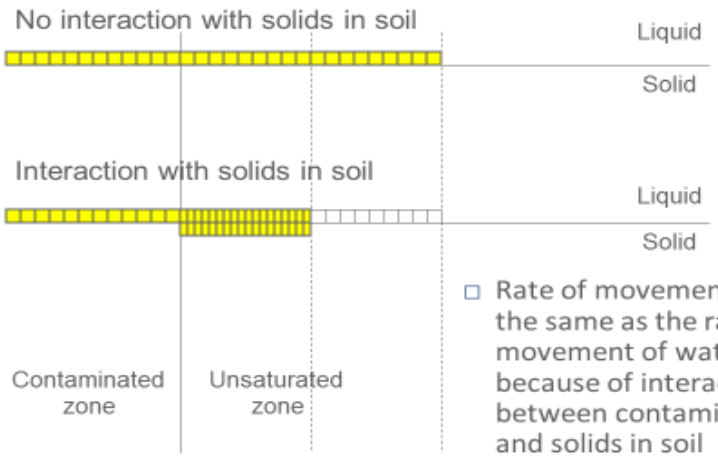
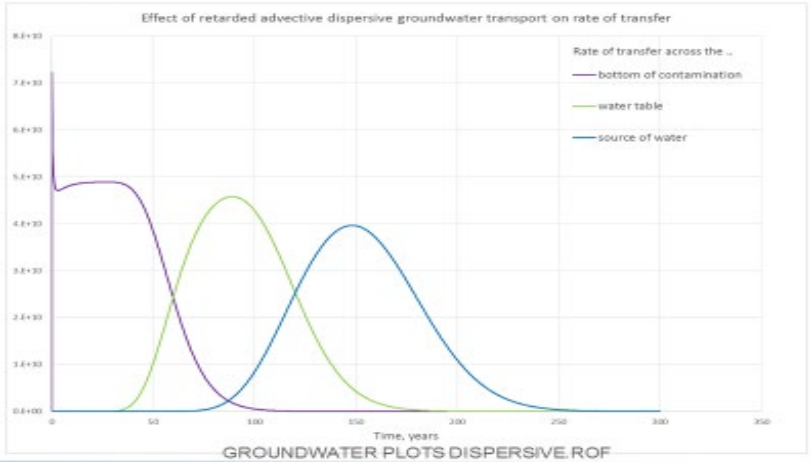
Groundwater Transport Model in RESRAD-OFFSITES – An Overview

Rate of Longitudinal Advection (Animation)

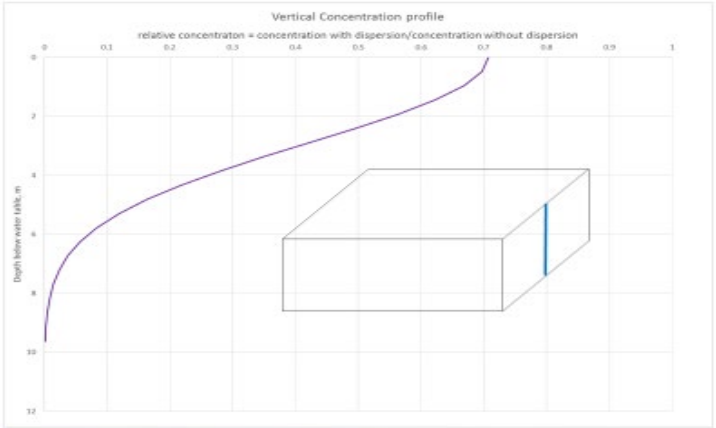


- Rate of movement not the same as the rate of movement of water because of interaction between contaminant and solids in soil

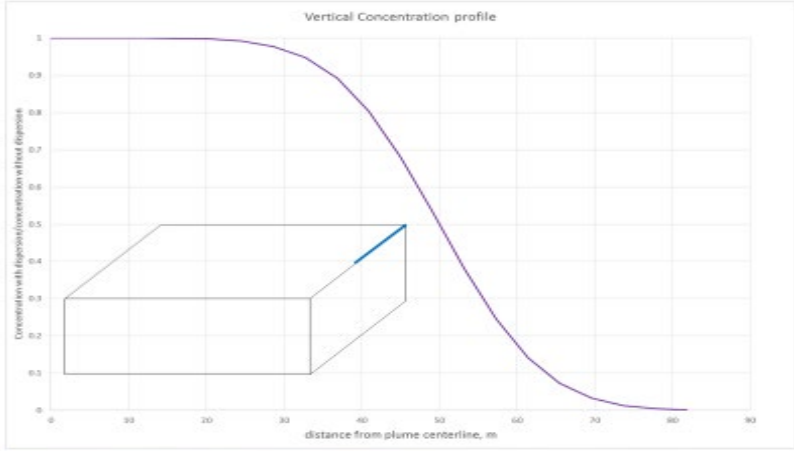
Retarded Advective Dispersive Transport in Groundwater



Vertical Concentration Profile in Aquifer



Horizontal Concentration Profile in Aquifer



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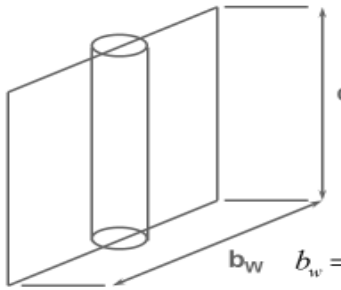
Groundwater Transport Model in RESRAD-OFFSITES – An Overview

Concentration in Well Water

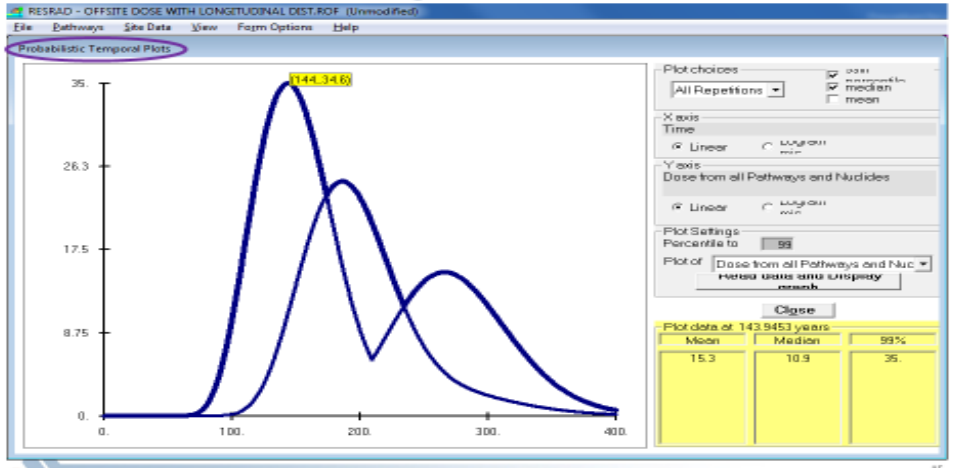
- Average of concentration over the area of the aquifer contributing to the well



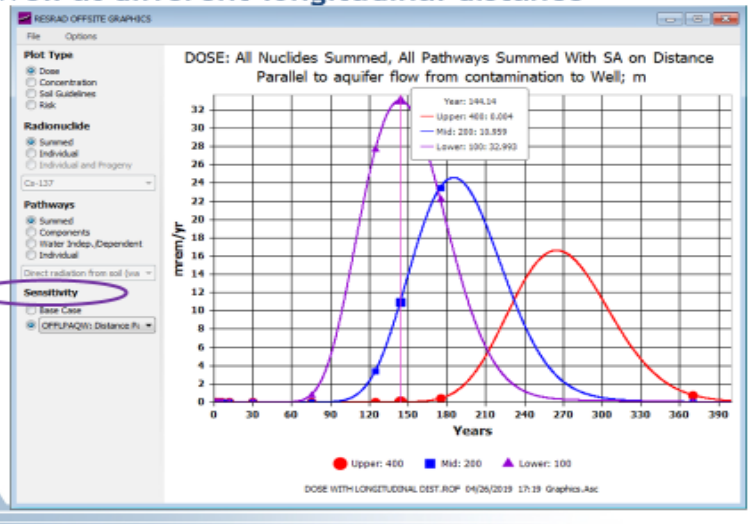
$$c_w(t) = \frac{\int_0^{d_w}\int_{-r_w}^{r_w} c_{aq}(x,y,z,t)\,dy\,dz}{2 d_w r_w}$$

$$b_w = \frac{U_w}{V_d d_w} \qquad r_w = \frac{b_w}{2}$$

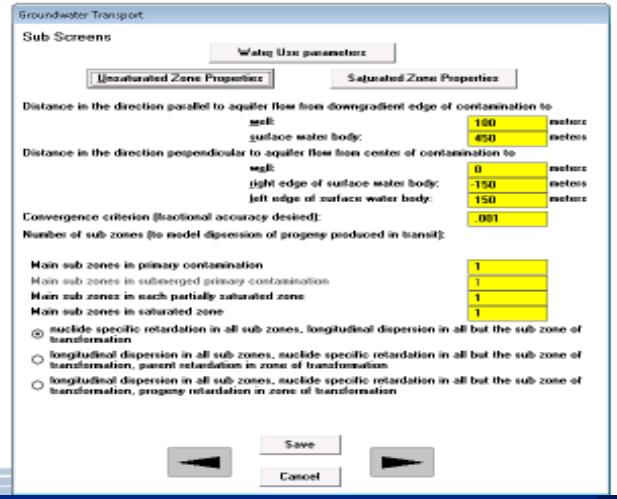
Well at different longitudinal distances



Well at different longitudinal distance



Modeling progeny produced during transport: longitudinal dispersion or nuclide specific distribution coefficient



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Decommissioning Plan Key Contents

- Site radiological data (site history and characterization)
- Planned decommissioning activities
- Plan to ensure protection of workers, the public, and the environment
- Dose analysis approaches to establish acceptable DCGLs corresponding to the dose criteria
- Planned radiological survey
- Decommissioning cost estimates and funding mechanism
- Decommissioning schedule
- Public inputs/institutional control for restricted site release

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Formal Opportunities for Public Involvement & Public Outreach Activities

- Public notification and participation in decommissioning (10 CFR 20.1403, 20.1405, and 50.82)
- Hearings (10 CFR Part 2, Subpart L)
- 2.206 Petition (10 CFR Part 2, Subpart B)
- Freedom of Information Act requests

Activities

- Public Meetings & Publicly-noticed meetings with the licensee
- Workshops & Informal contacts with NRC staff
- Press Releases
- Federal Register Notices
- Licensee-initiated community outreach
- NRC Web Site

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NRC Decommissioning Issues & Challenges

- Prevention of Legacy Sites
  - **Legacy sites – complex sites difficult to decommission for a variety of financial, technical, or programmatic reasons**
  - **Draft rulemaking to revise financial assurance requirements and 10 CFR 20.1406**
    - **Requirements to detect and minimize contamination**
    - **Requirements for prompt remedial action to limit migration**
- Decommissioning Lessons Learned Applicable to design and operation stages:
  - Adequate characterization of the subsurface;
  - Plant designs should minimize use of embedded pipes
  - Keeping records of:
    - Spills, contamination
    - As-built drawings and modifications of structures and equipment
    - Decommissioning cost estimate
    - Records of originally licensed area, acquisition of property, partial site release.