U.S. DEPARTMENT OF ENERGY

Overview of DOE's Regulatory Compliance Process and Performance Assessment

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Dose Limits in Context

100,000 mrem – Dose leading to ~5% chance of Fatal Cancer (UNSCEAR)

10,000 mrem/yr – IAEA mandatory intervention

5,000 mrem/yr – Worker dose standard (DOE)

1,000 mrem/yr – IAEA reference level for intervention for cleanup situations

620 mrem/yr – US Average dose all sources (NCRP)

100 mrem/yr – All sources limit (IAEA, DOE, NRC)

25 mrem/yr – NRC and DOE LLW

15 mrem/yr – EPA Radiation (40 CFR 191)

10 mrem/yr – Air (atmospheric) (40 CFR 61)

4 mrem/yr – Drinking Water (40 CFR 141)

1 mrem/yr – IAEA Exemption/Clearance

In 2009, NCRP updated US Annual Average Dose from 360 to 620 mrem/yr

EPA Recommended Radon Action Level of 4 pCi/L in Basements ~7 x 10^{-3} Risk of lung cancer for non-smoker

One Transcontinental round trip flight - 5 mRem

Note: Air crew average (300 mrem/yr) From UNSCEAR (2000)

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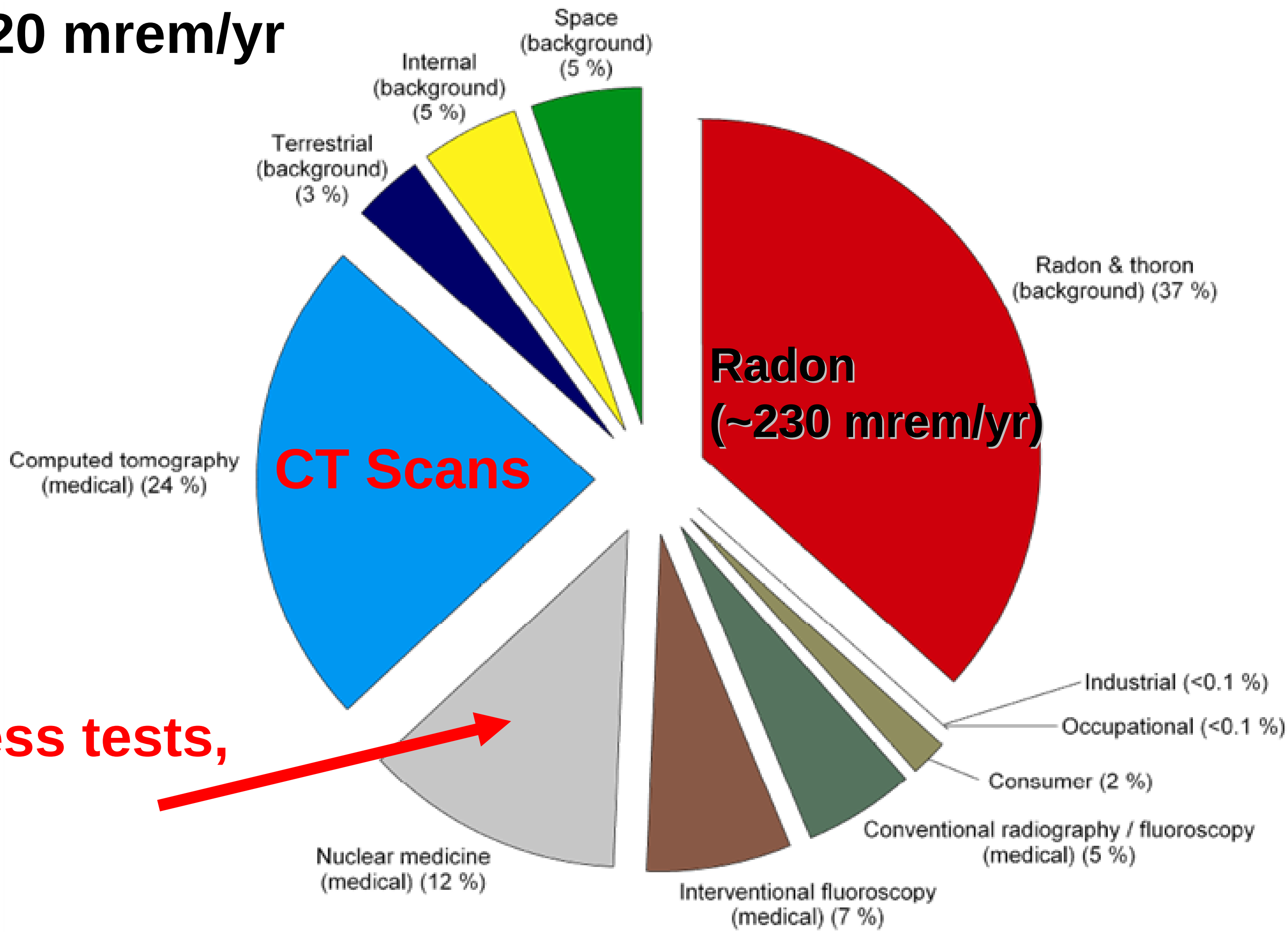
NCRP 2009 Report Annual Average Dose

620 mrem/yr



Stress tests, etc.

Performance Assessment Contents

- What is PA?
- How are PAs conducted?
- Key Concepts and Terminology
- DOE approach to reviewing PAs

Performance Assessment Applications

- **Development of Waste Acceptance Criteria for disposal facilities – waste forms, radionuclide content, etc.**
- **Estimate health effects associated with leaving different amounts of waste in tanks or different levels of contamination in facilities**
- **Evaluation of health effects associated with different options for remediation or D&D**
  - **PA provides capability to be able to distinguish benefits of specific features**

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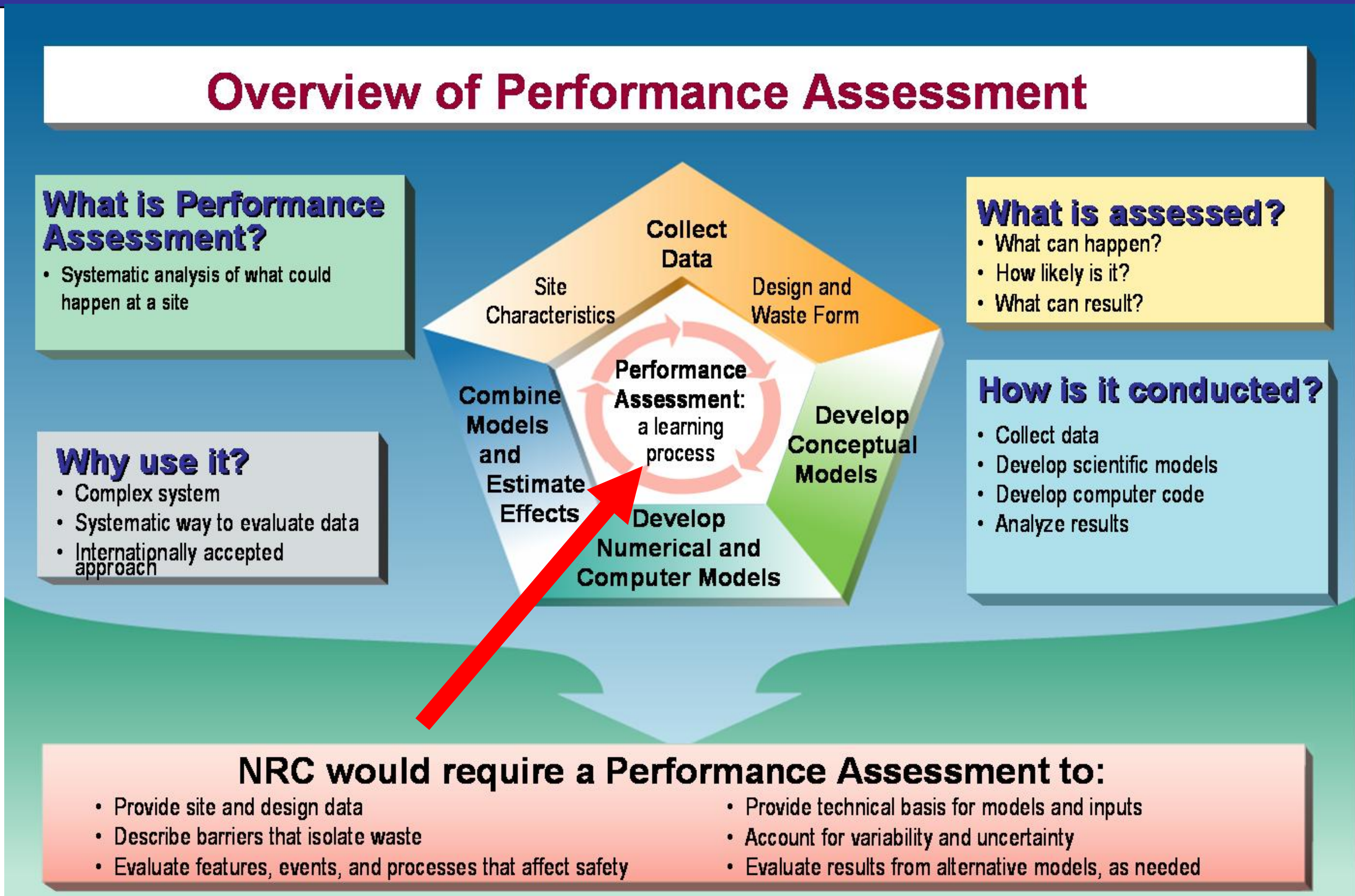
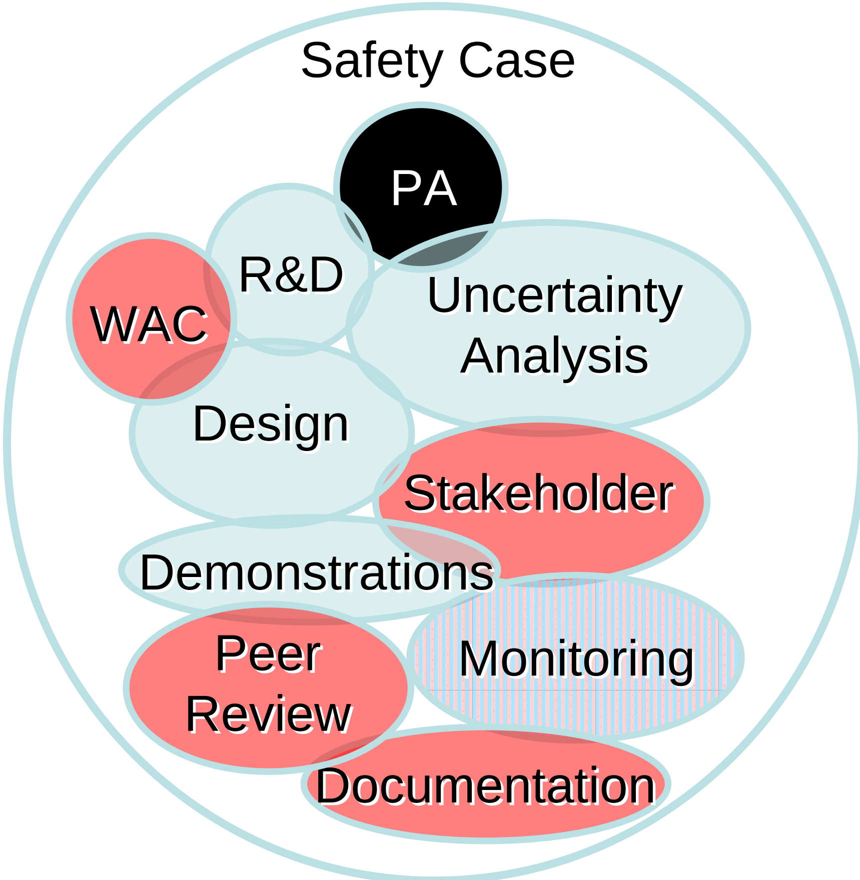
NRC Staff Perspective



Courtesy: David Esh, US NRC

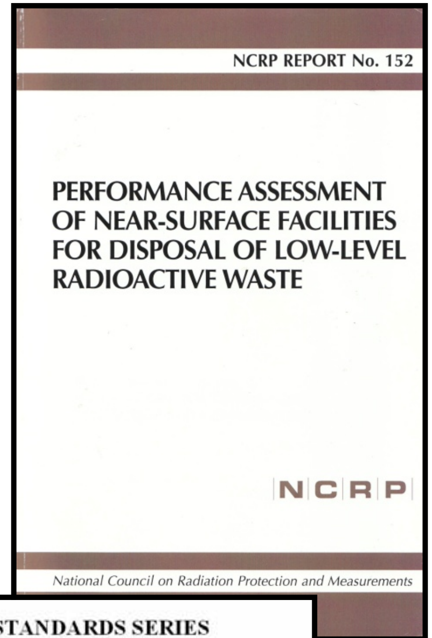
International Safety Case Concept

- **IAEA, Nuclear Energy Agency and others**
- **Reflects use of performance assessment as only one part of a package used to support decisions**
  - ***"The purpose of computing is insight, not numbers"* – Richard Hamming**
- **Similar concept to the Radioactive Waste Management Basis in the DOE System**



Other Perspectives on Performance Assessment

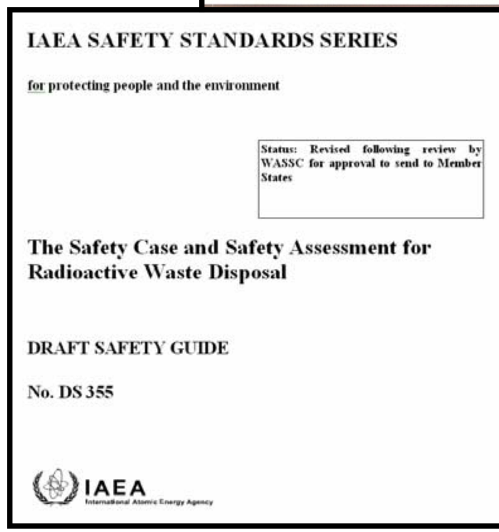
- National Council on Radiation Protection and Measurements (NCRP) Report No. 152
  - Merits of deterministic, probabilistic and combined approaches
  - “Importance Analysis”
- International Atomic Energy Agency
  - Decades of global experience on assessments
  - Develop Safety Standards for waste management activities
  - PRISM project looking at practical application of safety case concept


NCRP REPORT No. 152

PERFORMANCE ASSESSMENT OF NEAR-SURFACE FACILITIES FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

NCRP

National Council on Radiation Protection and Measurements


IAEA SAFETY STANDARDS SERIES

for protecting people and the environment

Status: Revised following review by WASSC for approval to send to Member States

The Safety Case and Safety Assessment for Radioactive Waste Disposal

DRAFT SAFETY GUIDE

No. DS 355

IAEA

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Performance Assessment …

IS…	IS NOT…
▪ A means to address post-closure protection of human health in a decision process ▪ A process to build confidence that projected doses are reasonably likely to be less than a given standard ▪ A means to provide perspective on the significance of different site, facility and waste features relative to protection of human health (demonstrate understanding of the system)	▪ A "prediction" of doses to real people, it is assumed that someone will live and use water at a specific location at some point in the future ▪ Safety analysis for worker and public protection during pre-closure operations ▪ An assessment of worst case scenarios

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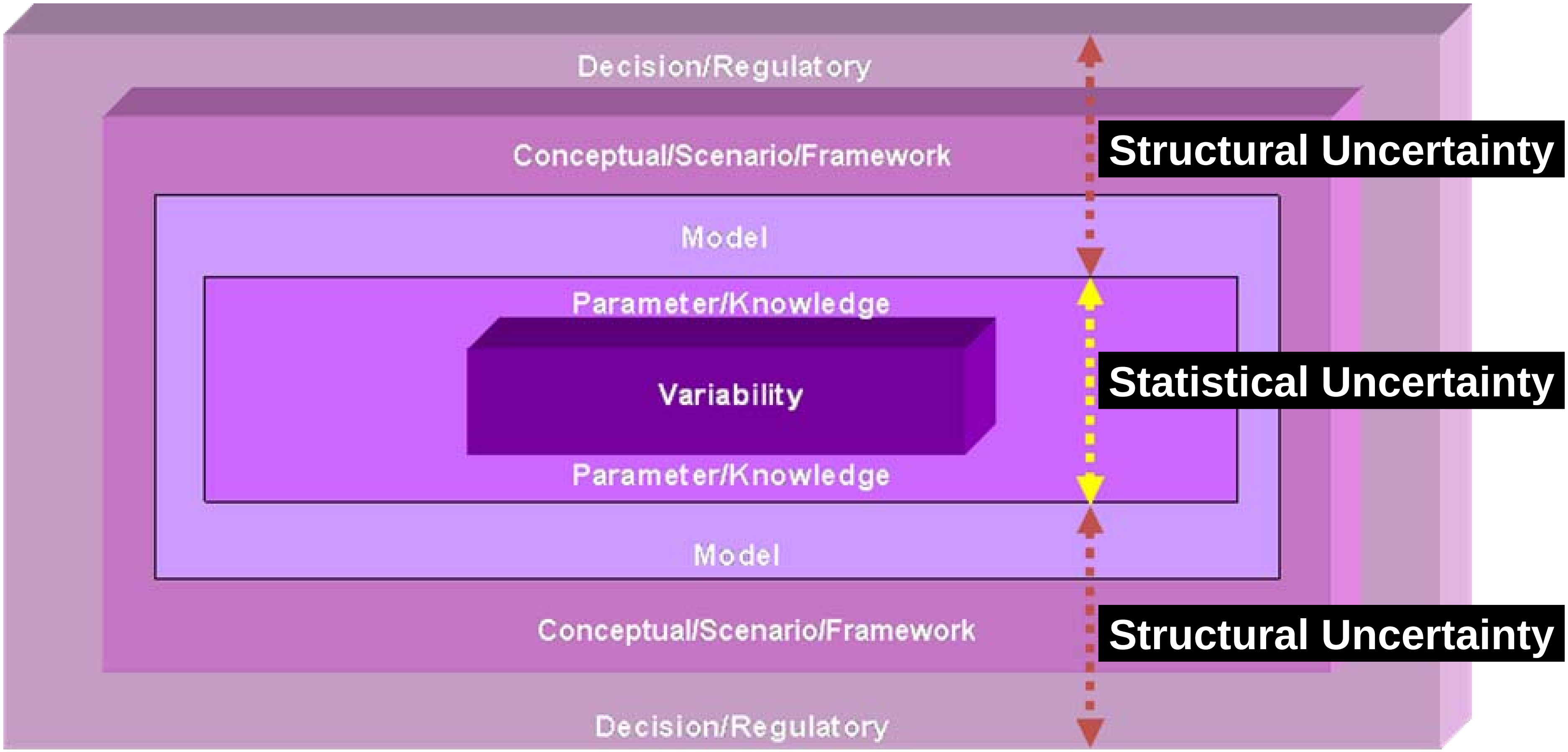
Uncertainties



Courtesy: Bruce Crowe

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Performance Assessment Reality

Dose Criteria?

Intruders?

NRC

State

Time of Compliance?

PA
- Requirements
- Modeling
- Results
- Interpretation

Justification for Barriers?

Cleanup/Closure or Disposal?

Point of Assessment?

Stakeholders

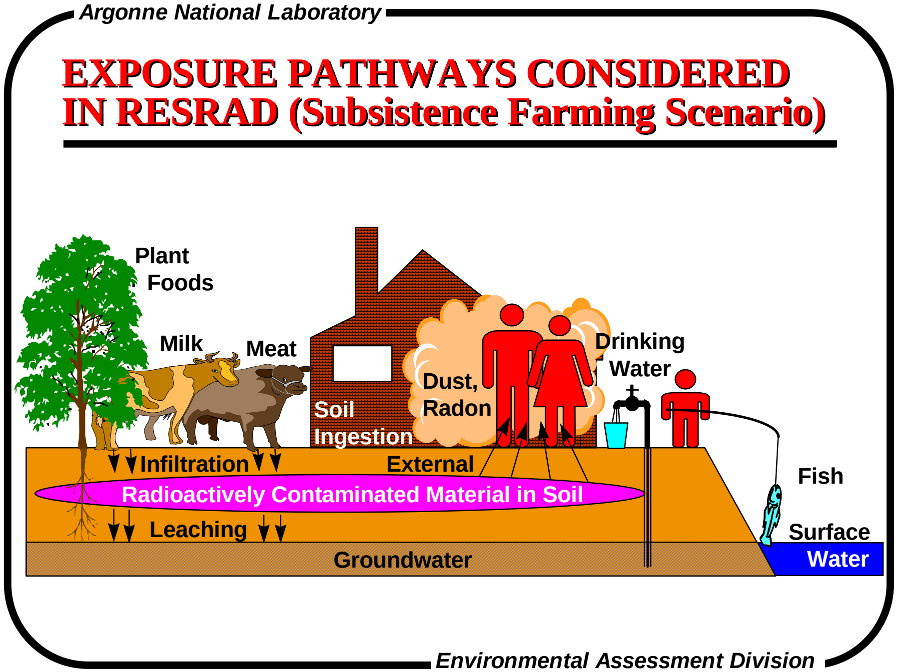
Exposure/Failure Scenarios?

EPA

HLW Tanks, LLW disposal, D&D?

Exposure Scenarios

- **Assume complete loss of institutional control of DOE Site**
- **Resident drills a well at point of peak concentration in aquifer (outside buffer zone)**
- **Resident farmer with beef and milk cows, garden for consumption**
- **Intruder digs basement and drills well immediately above the waste (hypothetical, not a performance objective)**
- **Focus on the important features, events, and processes (FEPs)**



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Receptor Location

- Dose is dependent on location and habits of the receptor
- Point of compliance is a critical consideration (increased distance is generally equivalent to increased dilution and time for decay)
- Exposures are more significant through different pathways for different radionuclides (e.g., I-129 in milk, Tc-99 in leafy vegetables, C-14 in fish, Cs-137 for external exposure)

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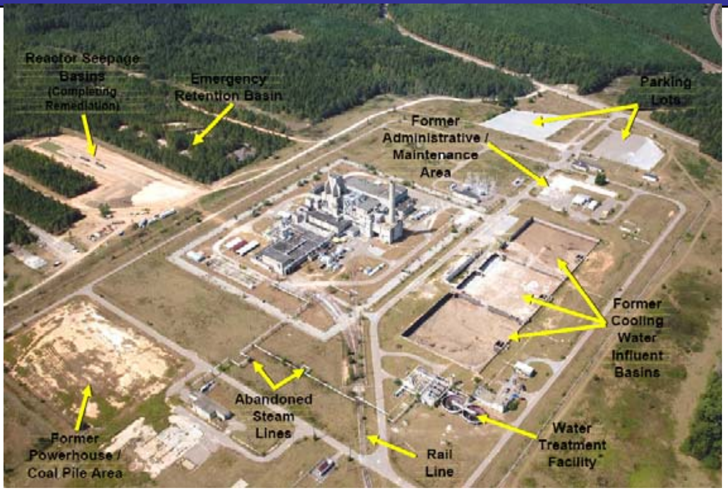
Source Term

- Drives the PA Process
- Facility Description
  - Dimensions
  - Barriers (concrete, metal)
  - Initial condition and degradation of barriers
- Contaminant Inventory
  - Chemical/physical form



SRS P Reactor Area

Material Composition

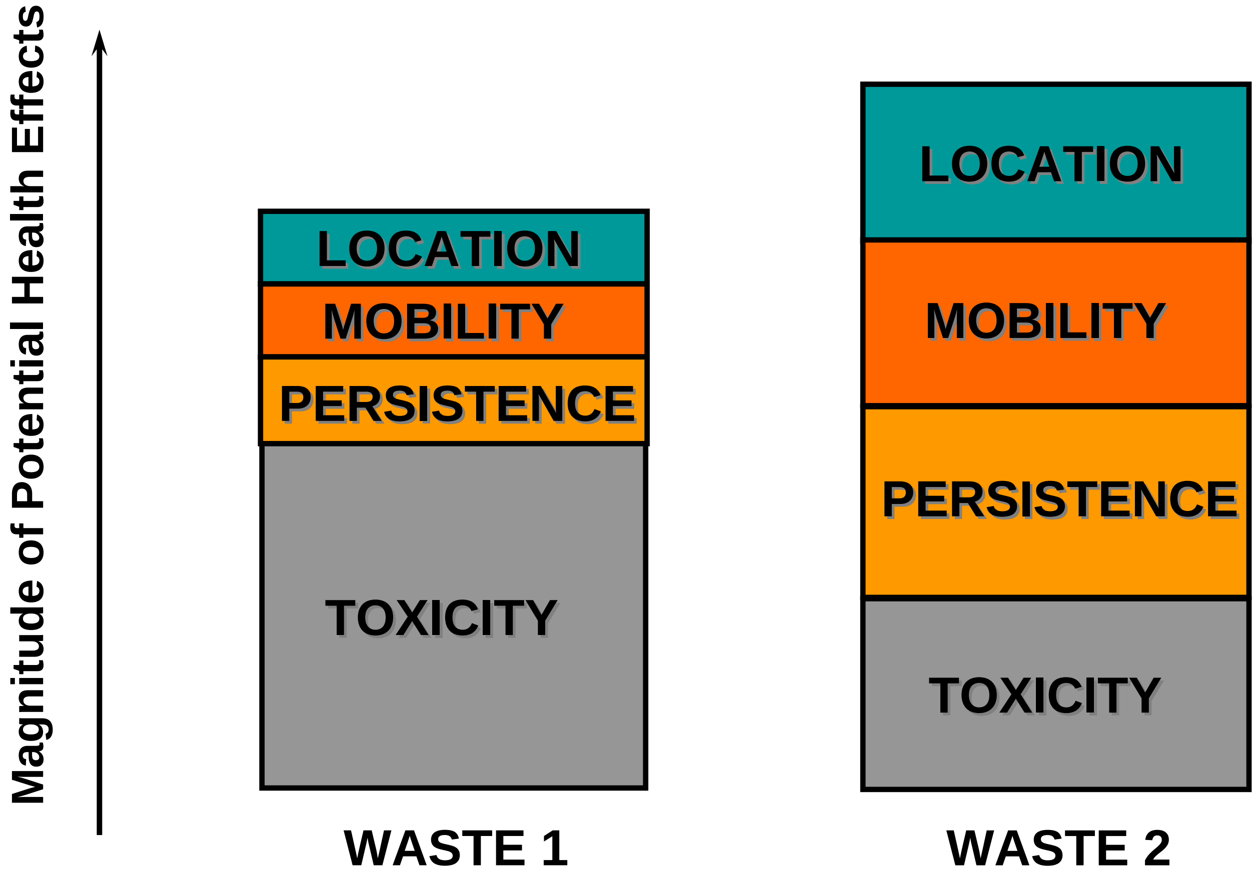
container lifetime? **resins?**

concrete? **enhanced mobility?**

activated metal? **solubility?**

gaseous release?

Factors Impacting Health Effects



Toxicity includes amount and inherent toxicity
Mobility includes site properties and barriers/waste form
Location includes pathways and distance to receptor

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“Toxicity”

- Represented by Dose Factors (e.g., mrem/Ci)
- More activity generally leads to greater toxicity
- Different radionuclides have different toxicity
- Toxicity also depends on the pathway of exposure (ingestion, inhalation, external exposure)

Persistence – Short-Lived Radionuclide

- **Cs-137 source removed from teletherapy device by junk dealer in Goiânia, Brazil**
- **Extensive contamination (3,500 m^3 of waste)**
- **Concrete vault provides hundreds of years of isolation to protect nearby community**

Initial Inventory	30 yr	100 yr	200 yr	300 yr	500 yr
~1400 Ci	700 Ci	139 Ci	14 Ci	1.4 Ci	0.01 Ci
0.4 Ci/m^3	0.2 Ci/m^3	0.04 Ci/m^3	0.004 Ci/m^3	0.0004 Ci/m^3	0.000004 Ci/m^3

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Persistence – Short- and Long-Lived

- **Mixture of contamination and activated metals**
- **Much of activity levels within metal matrix, grouted**
- **Chemical (grout) and physical barriers (vessel, metals)**
- **Total Inventory ~60,000 Ci**

	Half-Life	Initial Ci	100 yr	500 yr	1000 yr	10,000 yr
H-3	12.3 yr	32,900	118	0.00000002	-	-
C-14	5,730 yr	13.3	13.1	12.5	11.8	4
Co-60	5 yr	1,970	0.002	-	-	-
Ni-59	76,000 yr	132	131.9	131.4	130.8	120.5
Ni-63	100 yr	24,200	12,100	760	24	-
Cs-137	30 yr	2.7	0.3	0.00003	-	-

"-" < 1E-9 Ci

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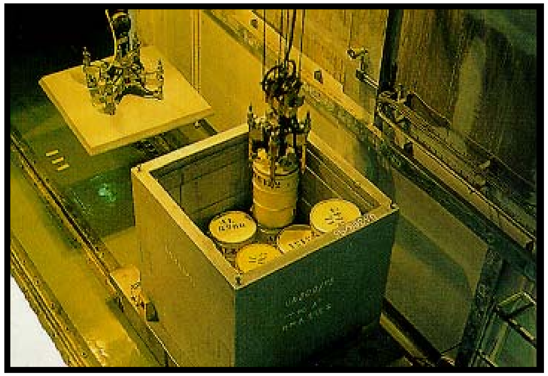
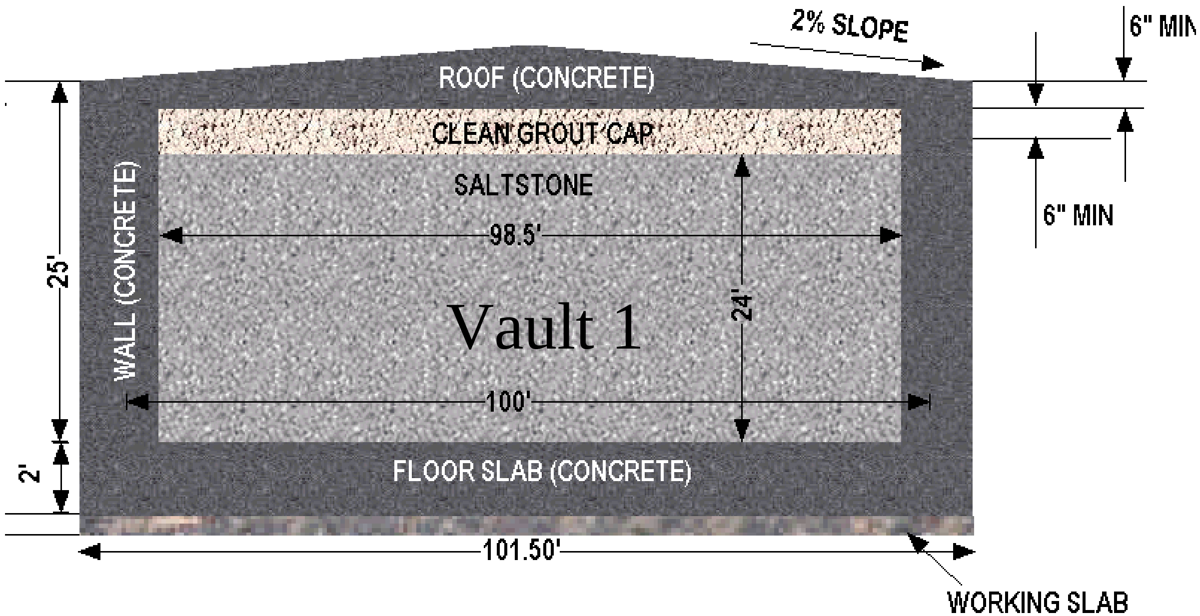
Factors Influencing Mobility

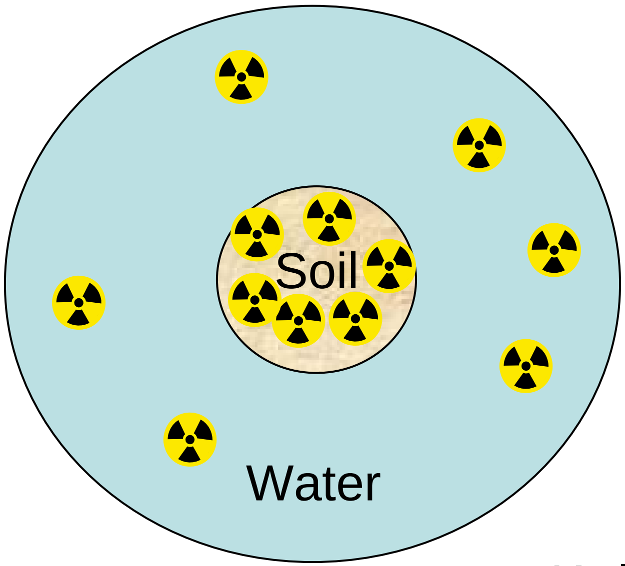
- Chemistry
  - Partitioning (K_d)
  - Solubility
- Waste Form
  - Grout
  - Activated metals
- Containers
- Barriers
  - Concrete
  - Steel





Mobility – Soil/Water Partitioning

$$K_d \text{ (ml/g)} = \frac{\text{mass of solute on the solid phase per unit mass of solid phase, g/g}}{\text{concentration of solute in solution, g/ml}}$$



K_d = 0, all activity in water

K_d large, most activity on solid

Persistence, Toxicity, and Mobility

	Half-Life (yr)	Dose Factors (mrem/pCi)		External Dose (mrem/yr)/(pCi/g)	K_d (mL/g)	
		Ingestion	Inhalation		Sandy	Clayey
H-3	12.3	6.4E-08	6.4E-08	0	0	0
C-14	5730	2.1E-06	2.1E-06	1.3E-05	10	400
Ni-59	76,000	2.1E-07	2.7E-06	0	7	30
Ni-63	100	5.8E-07	6.3E-06	0	7	30
Co-60	5	2.7E-05	2.2E-04	16	7	30
Tc-99	211,100	1.5E-06	8.3E-06	1.3E-04	0.6	1.8
Cs-137	30	5.0E-05	3.2E-05	3.6 (Ba-137m)	10	50
Np-237	2,140,000	4.4E-03	0.54	0.08	3	9
Pu-239	24,110	3.5E-03	0.43	2.9E-04	290	5,950

Most limiting Ingestion and Inhalation dose factors shown here,
External Dose Factor is for a source of infinite thickness
K_d = Distribution Coefficient (soil and water partitioning)

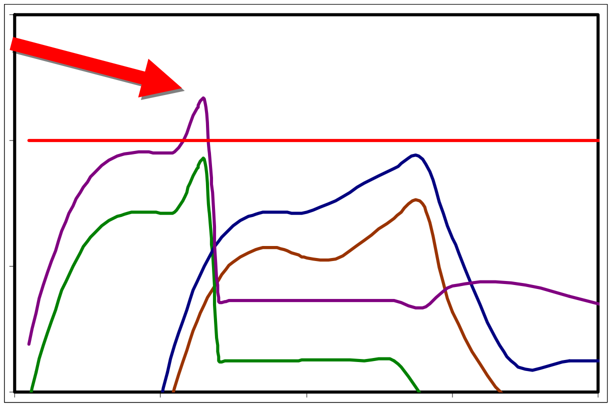
Technical Approaches - Deterministic Assessment

- **Traditional, deterministic standards (Idaho Tank PA, many existing PAs for LLW disposal)**
- **Demonstrate dose is less than standard**
- **Add sensitivity cases to address "what-if" type questions**
- **How do you interpret "what-if" cases that may exceed the standard?**

WHAT IF ….

Early tank failure?

Early cover failure?

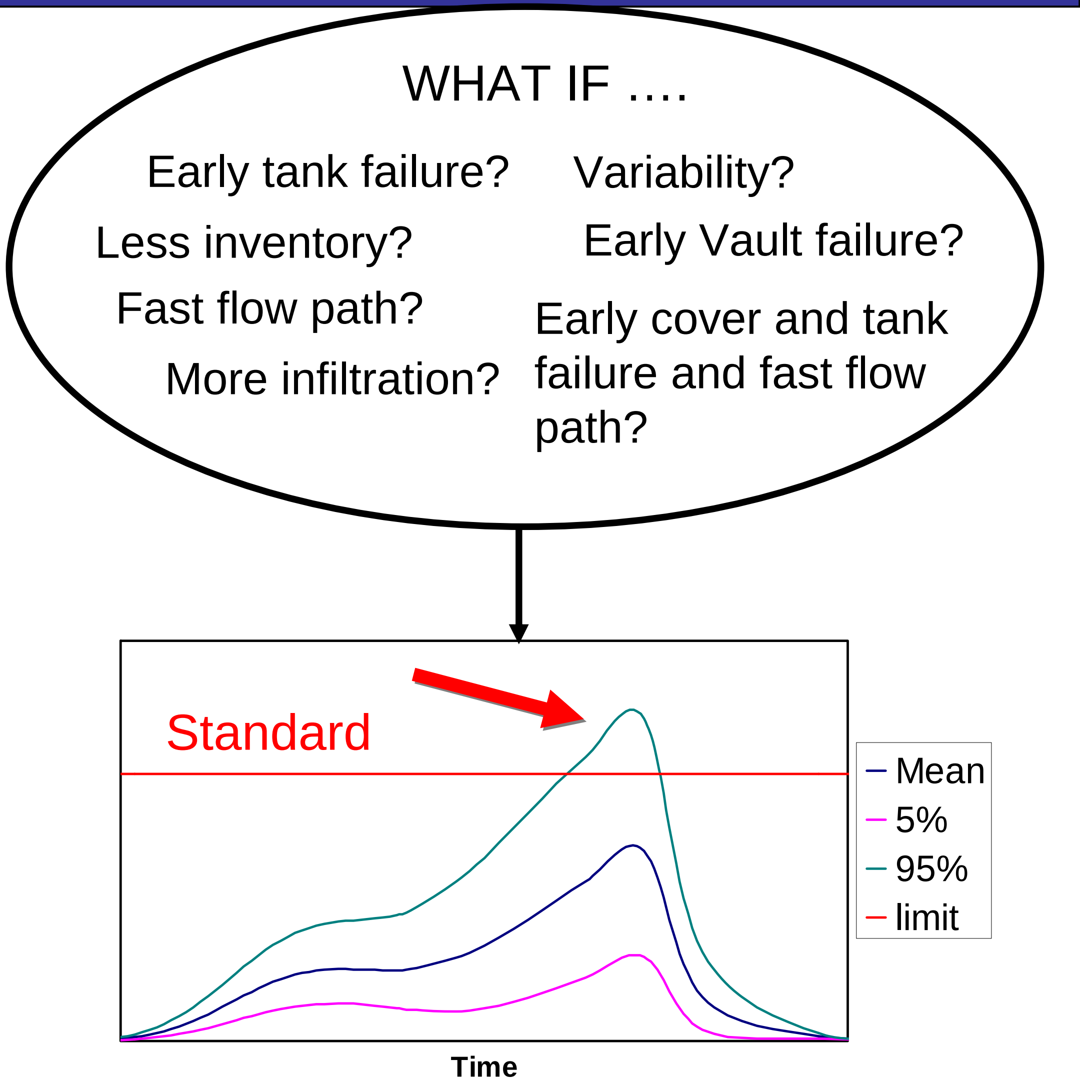


Less inventory?

Early cover and tank failure?

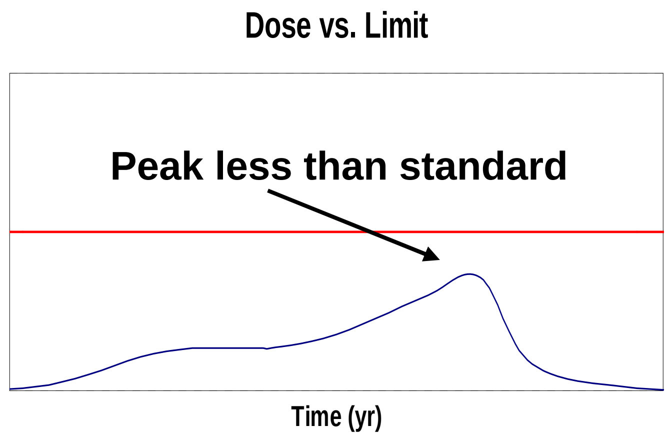
Technical Approaches - Probabilistic/Stochastic Assessment

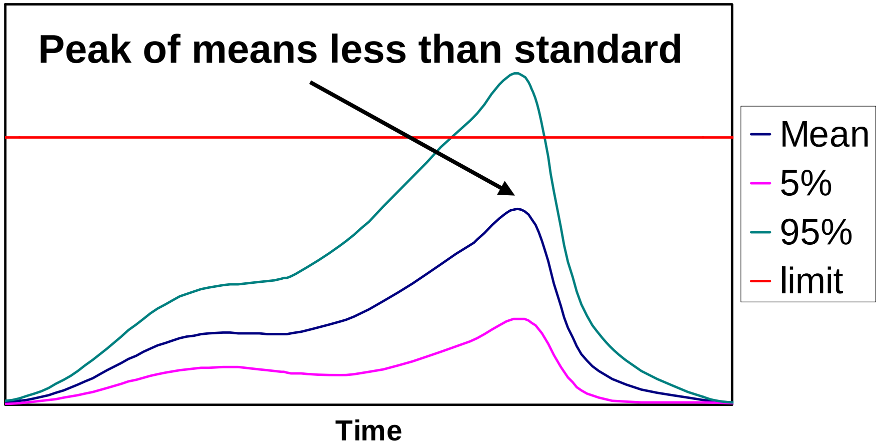
- **Becoming expected, risk-informed**
- **Demonstrate peak of means or median is less than deterministic standard**
- **"What-if" and uncertainty analysis implicitly included**
- **Relative likelihood of extreme cases is specifically represented**
- **How do we interpret results at extremes?**



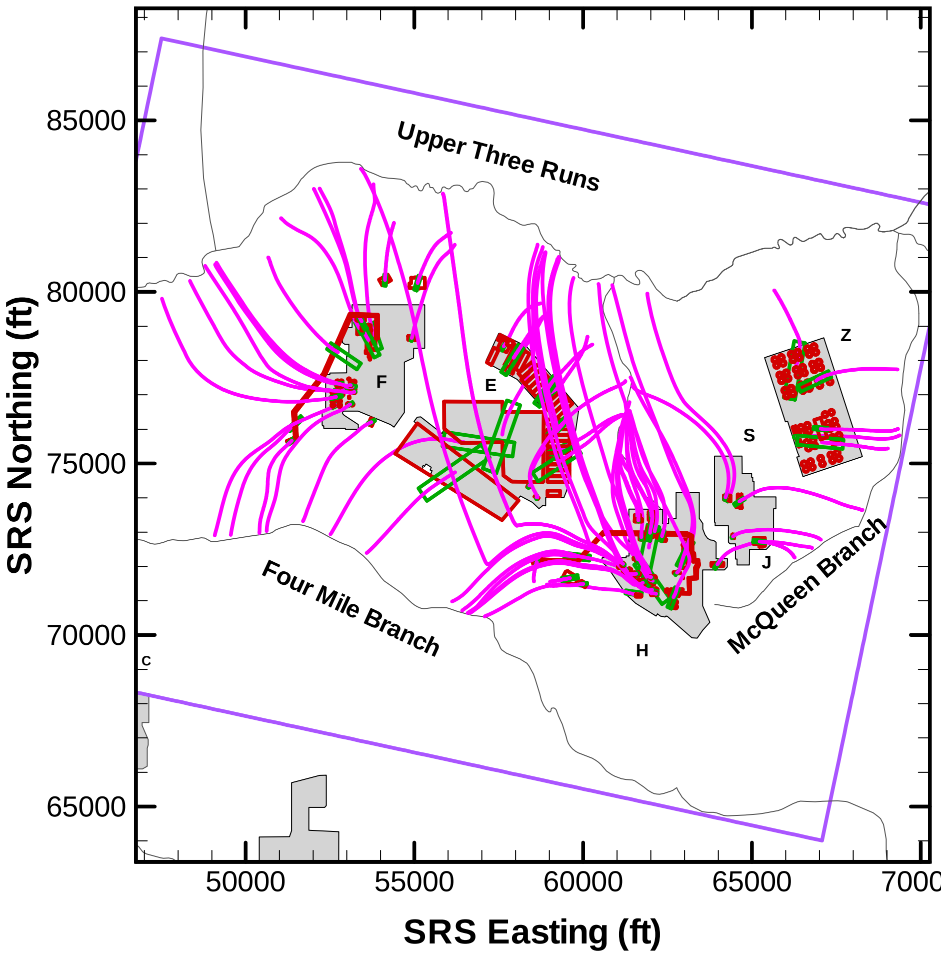
Technical Approaches -"Hybrid" Approach

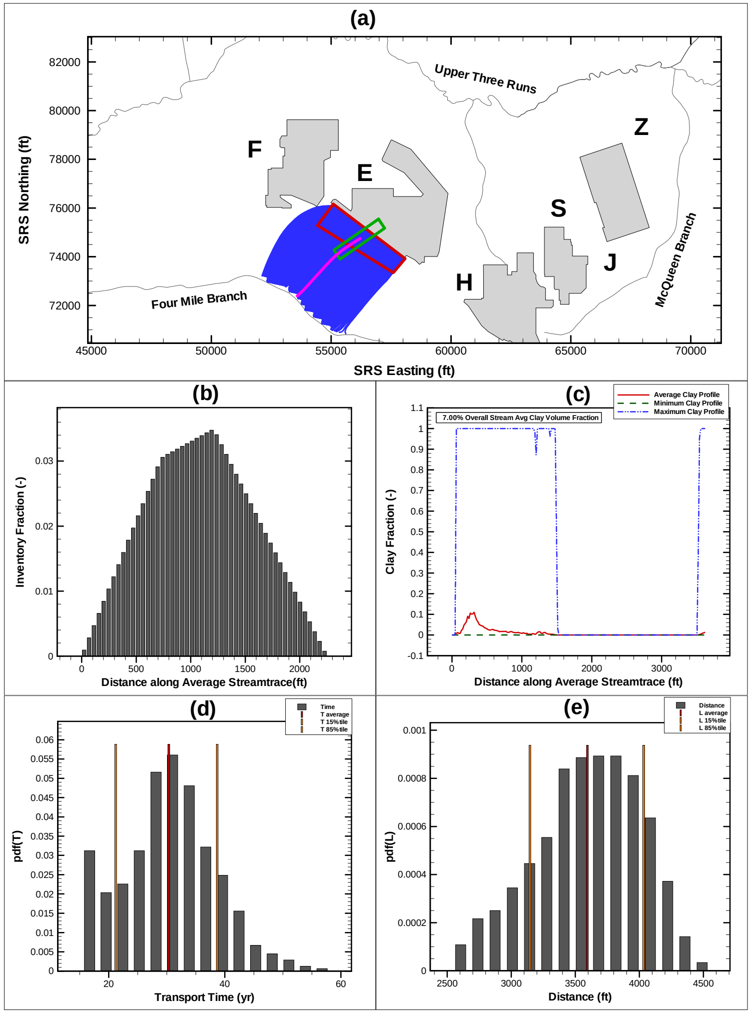
- Agree on deterministic baseline case(s) to compare with deterministic standard (add sensitivity "what-if" cases)
- Use probabilistic approach to capture "what-if" questions and uncertainty analysis
  - Multiple lines of reasoning
  - Models check each other





Technical Approaches - Abstraction

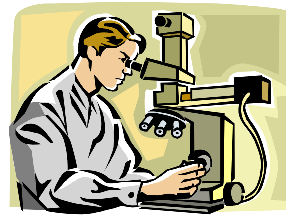


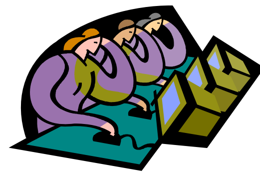


Detailed Modeling used to develop average pathlines for migration

Multi-Disciplinary Team Approach

PA





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Graded and Iterative Approach

- **Start simple**, more complex as necessary
- Models **commensurate** with quantity and quality of data
- Each successive iteration should be **focused on critical aspects**
- Contaminant-specific, focus on those **contaminants of concern**, or **features of concern**
- Take credit for specific barriers or processes as necessary, **defend** assumptions as necessary

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Graded, Barrier Analysis

Enhanced screening?

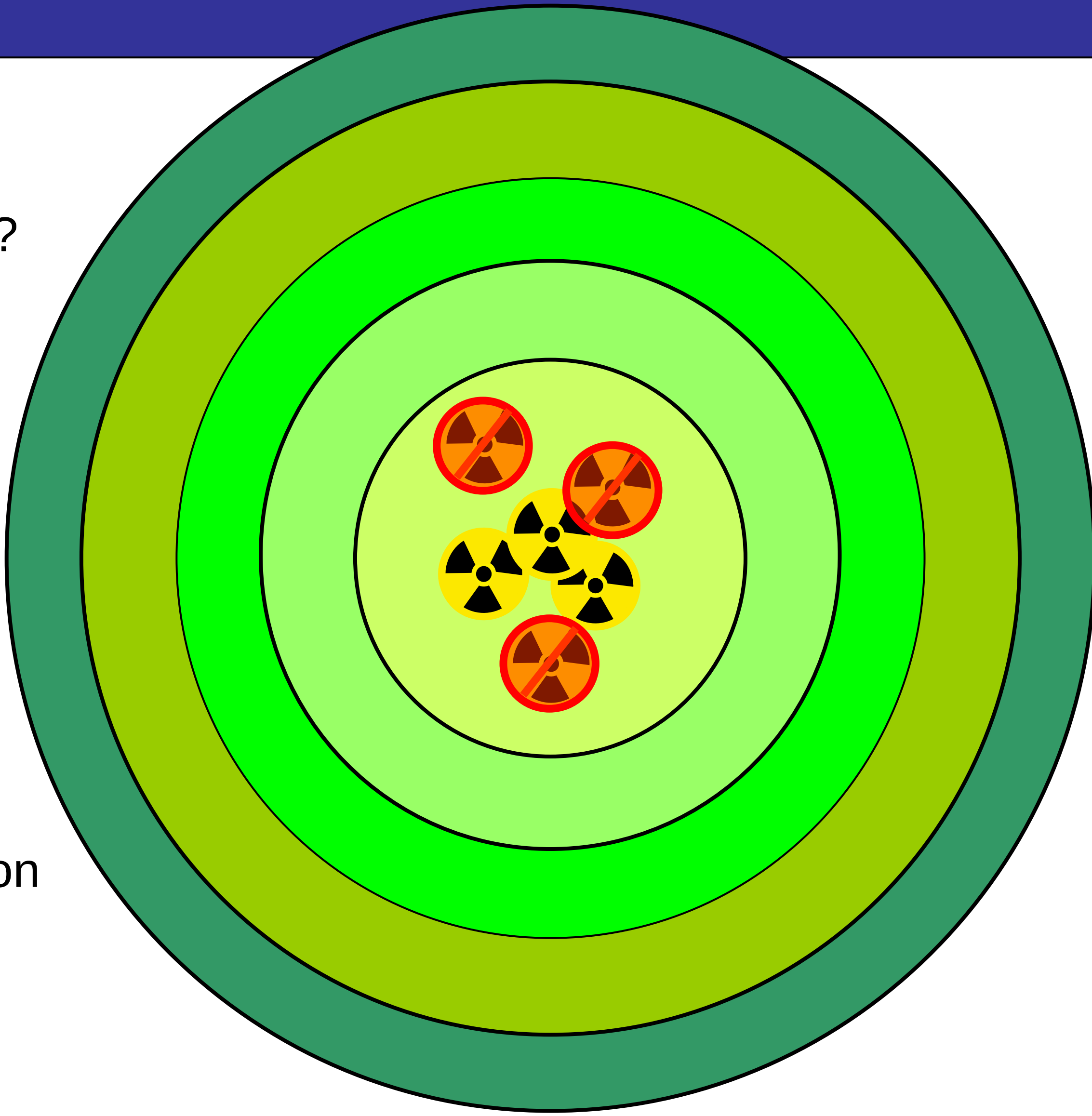
Improved cover representation?

Account for waste form (physical/chemical)?

Account for container (physical/chemical)?

Account for barriers (physical/chemical)?

More detailed site representation (physical/chemical)?



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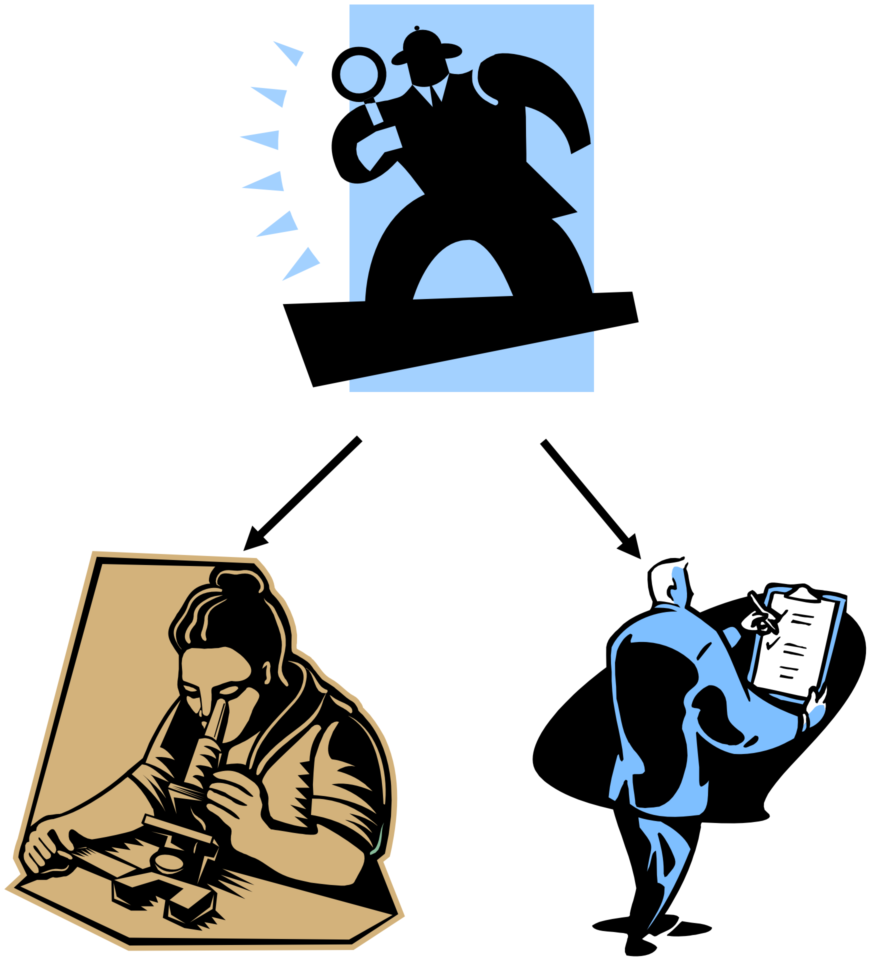
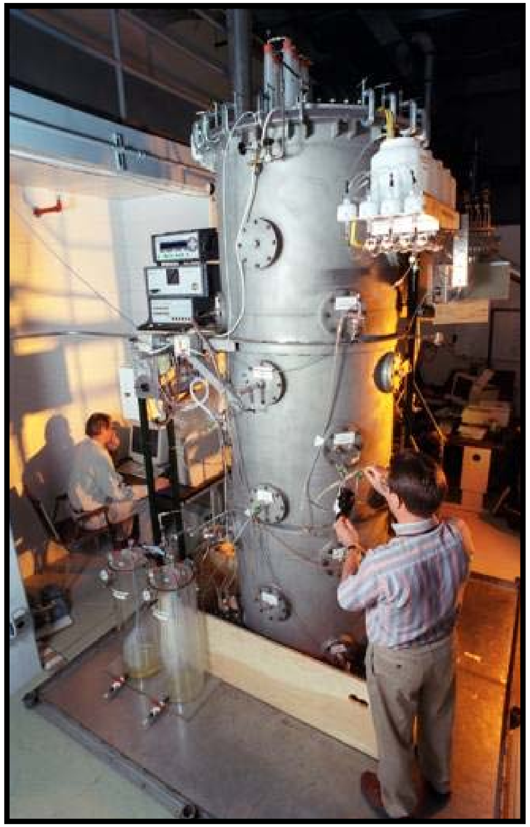
Sensitivity (Importance) Analysis

- **Focus attention on parameters of greatest interest for conclusions (not just model)**
- **NCRP Committee adopted the term “Importance Analysis”**
- **Guide reviewers and also identify areas where continued work can build confidence in conclusions**



PA Maintenance

- DOE approach to longer-term iterative process
- Importance analyses and results of reviews used to prioritize work
- Special analyses
- Laboratory/field studies, model development or model refinement to reduce conservatism, address key assumptions
  - C-14 column experiment at Idaho
  - SRNL waste-form specific K_d studies for I-129



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Integrate and Interpret Results

- Demonstrate understanding of the system?
- What are the critical assumptions, design features and barriers, radionuclides, etc.?
- Which options/barriers are effective and ineffective?
- "Robustness" test
- Do the results provide reasonable assurance that all radionuclides can be disposed of safely in given quantities?

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DOE Order 435.1, Radioactive Waste Management

- Effective implementation date July 9, 1999
- Establishes DOE HQ/Site responsibilities
  - Low-Level Waste Disposal Facility Federal Review Group (LFRG)
- Establishes Performance Objective and Requirements governing disposal actions:
  - 25 mrem all pathways dose
  - 10 mrem air pathway
  - 20 pCi/m^2/second radon flux
  - Intruder Scenario

LFRG Framework and Processes

- LFRG Manual
- LFRG Program Management Plan
- Format and Content Guide for Performance Assessments and Composite Analyses
- Closure Guide
- Maintenance Guide
- Monitoring Guidance

Authorization Requirements

Approved Disposal Authorization Statement (DAS)

- **Approved Performance Assessment (PA)**
- **Approved Composite Analysis (CA)**
- **Approved Preliminary Closure Plan**
- **Approved Monitoring Plan**
- **Approved PA/CA Maintenance Plan**
- **Approved Radioactive Waste Management Basis**
  - **Annual Summaries (Ongoing)**

Three Key LFRG Review Criteria

- **Are the information and analyses presented *complete*?**

- **Are the information and analyses *thorough and technically supported*?**

- **Are the conclusions *valid and acceptable*, based on the information and analyses presented?**

LFRG Review Topics and Review Criteria for PAs & CAs

- Site and Facility Characteristics -- **7 criteria**
- Radioactive Sources and Release Mechanisms -- **6 criteria**
- Performance Objectives and Measures -- **8 criteria**
- Point of Assessment -- **6 criteria**
- Conceptual Model -- **5 criteria**
- Mathematical Models -- **13 criteria**
- Assumptions -- **2 criteria**
- Exposure Pathways and Dose Analysis -- **14 criteria**
- Sensitivity and Uncertainty -- **7 criteria**
- ALARA and Options Analysis -- **3 criteria**
- Results Integration -- **11 criteria**
- Quality Assurance -- **2 criteria**

-- 84 Individual Criteria

Path Forward for DOE Order 435.1

- Complex-Wide Review initiated late 2008
  - More than 10 years since first Complex-Wide Review (1996)
  - 10 years experience implementing DOE Order 435.1
  - Opportunity to re-assess and evaluate DOE’s progress
  - Consistent with feedback and continuous improvement step of Integrated Safety Management System
  - Good first step for evaluating DOE Order 435.1 update needs
- Final Complex-Wide Review Report has been published
- DOE Order 435.1 Update underway and anticipated to complete late 2012
  - Will include a public review and comment period

Summary

- **LLW is regulated to a strict standard relative to everyday radiation exposures**
- **PA is used to help make decisions (demonstrate understanding) – many supporting activities in addition to modeling**
- **Persistence (time), Mobility, Toxicity and Location are key to determining what is important and what is not**
- **Deterministic and Probabilistic approaches are used**
- **Several decades of continually evolving experience on PAs (US and International) – extensive reviews are important**
- **Key Concepts**
  - **Multi-disciplinary**
  - **Iterative and graded process, barrier analysis**
  - **Source term**
  - **Sensitivity and Uncertainty**
  - **Integration and interpretation**
  - **PA Maintenance**

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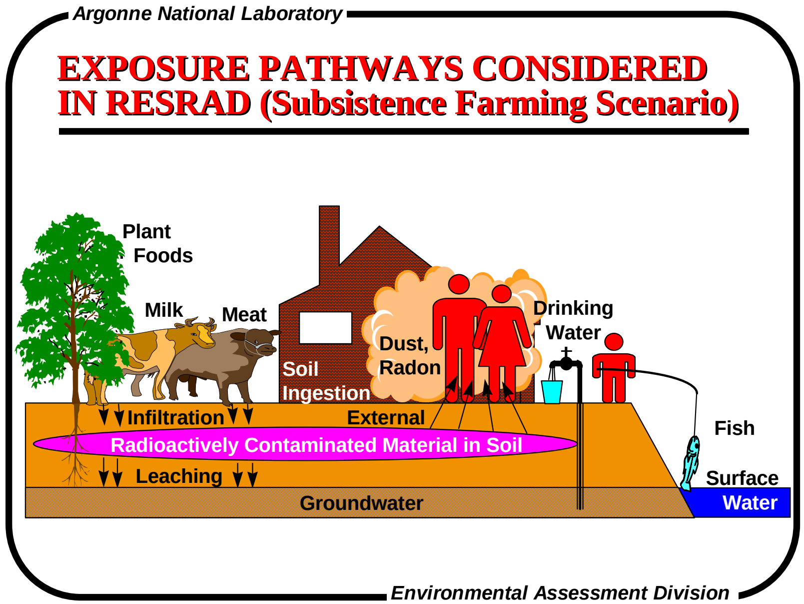
BACK UP SLIDES

Regulations and Performance Standards

- Regulations include specific criteria that must be met (performance objectives)
- DOE Order 435.1 and 10 CFR Part 61 include all pathways dose standards (25 mrem/yr)
- DOE Order 435.1 also includes composite analysis, groundwater protection and radon release standards
- NRC and DOE have performance measures for inadvertent intruder protection



Exercise 1 – Rank Each Category

- On the following slide, rank the different values in each column from smallest to largest
- Identify radionuclides with long half-lives (circle 3)
- Identify radionuclides with highest dose factors for each pathway (circle 3)
- Identify radionuclides that are most mobile in each soil type (low value) (circle 4 for sandy, 3 for clayey)
- Identify radionuclides that have a significant difference in mobility in sandy and clayey soil

Persistence, Toxicity, and Mobility

	Half-Life (yr)	Dose Factors (mrem/pCi)		External Dose (mrem/yr)/(pCi/g)	K_d (mL/g)	
		Ingestion	Inhalation		Sandy	Clayey
H-3	12.3	6.4E-08	6.4E-08	0	0	0
C-14	5730	2.1E-06	2.1E-06	1.3E-05	10	400
Ni-59	76,000	2.1E-07	2.7E-06	0	7	30
Ni-63	100	5.8E-07	6.3E-06	0	7	30
Co-60	5	2.7E-05	2.2E-04	16	7	30
Tc-99	211,100	1.5E-06	8.3E-06	1.3E-04	0.6	1.8
Cs-137	30	5.0E-05	3.2E-05	3.6 (Ba-137m)	10	50
Np-237	2,140,000	4.4E-03	0.54	0.08	3	9
Pu-239	24,110	3.5E-03	0.43	2.9E-04	290	5,950

Exercise 2 - Persistence, Toxicity, and Mobility

- **Identify long-lived radionuclides (>30 yr)**
  Use exercise 1 slide to help with these questions
- **Discuss which dose factors are most significant for those nuclides (Is external dose important?) – use slide for exercise 1**
- **How mobile are the “key” radionuclides? – use exercise 1**
- **Would a different type of soil reduce mobility for any nuclides?**
- **Discuss management considerations for the different radionuclides**

Note that this is a simplified example for illustration, a more detailed evaluation would be conducted in practice.

Persistence – Long-and Short-lived Isotopes

	Half-Life	Initial Ci	100 yr	500 yr	1000 yr	10,000 yr
H-3	12.3 yr	32,900	118	0.00000002	-	-
C-14	5,730 yr	13.3	13.1	12.5	11.8	4
Co-60	5 yr	1,970	0.002	-	-	-
Ni-59	76,000 yr	132	131.9	131.4	130.8	120.5
Ni-63	100 yr	24,200	12,100	760	24	-
Cs-137	30 yr	2.7	0.3	0.00003	-	-

"-" < 1E-9 Ci

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