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Biosphere Dose Modeling

Ali Simpkins

Center for Nuclear Waste Regulatory Analyses

HP 403 Training

July 31, 2007

Outline

- Introduction/Definitions
- Postclosure atmospheric models
- Postclosure aqueous models
- Preclosure dose methods

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What is Performance Assessment (PA)

- PA 10 CFR Part 63 Definition: "an analysis that (1) Identifies the features, events, process (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the YM disposal system and their probabilities of occurring during 10,000 years after disposal; (2) Examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the YM disposal system; and (3) Estimates the dose incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence."

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What is Biosphere Dose Modeling?

- Supports Item 3 of 10 CFR Part 63 PA definition
- Biosphere – Part of the earth capable of sustaining life
- Dose – quantity of ionizing radiation absorbed by a unit mass of matter
- Typically the general word dose really means total effective dose equivalent (TEDE) – 10 CFR Part 63 definition: “means, …..For the purposes of assessing doses to members of the public (including RMEI), TEDE means the sum of the effective dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).”
- Biosphere Dose Modeling – includes radiation dose to man from various pathways

Reasonably Maximally Exposed Individual

- 10 CFR Part 63 definition: means the hypothetical person meeting the criteria specified at 63.312: "The reasonably maximally exposed individual is a hypothetical person who meets the following criteria (a) Lives in the accessible environment above the highest concentration of radionuclides in the plume of contamination; (b) Has a diet and living style representative of the people who now reside in the Town of Amargosa Valley, Nevada…. use the mean values…(c) Uses well water with average concentrations of radionuclides based on an annual water demand of 3000 acre-feet; (d) Drinks 2 liters of water per day from wells drilled into the ground water at the location specified in paragraph (a) of this section; and (e) Is an adult with metabolic and physiological considerations consistent with present knowledge of adults."

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Reasonably Maximally Exposed Individual

- Approximately 18 km south of potential repository
- Amargosa Valley resident
- Average consumption rates for the region

Postulated Release Mechanisms for YM PA modeling

- Igneous disruptive event (Atmospheric Release)
- Groundwater release

Igneous Atmospheric Releases

- Gaussian plume model used for air transport of suspended particulates from a point source release
  - Not appropriate for igneous with volcanic eruption column and large volcanic particle diameters
- Igneous model assumes volcanic eruption column is a line source of contaminants in upward direction and is appropriate for larger particle size distributions

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Igneous Atmospheric Releases

- Downwind ground surface concentrations are predicted (mass of ash per area)
- Incorporation ratio used to relate ash to waste
- After initial deposition from the plume, redistribution can occur by wind or surface water drainage from Fortymile Wash

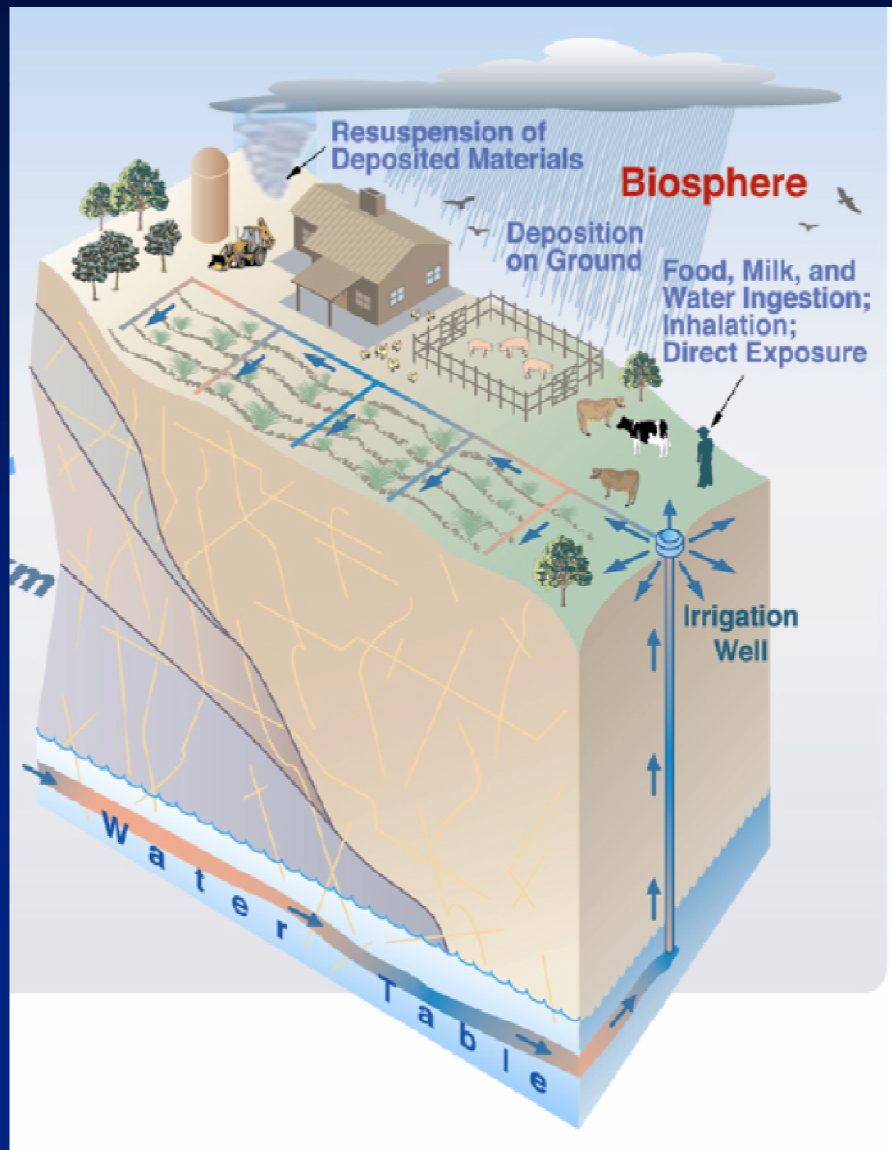
Biosphere Exposure Pathways Associated with Igneous Releases

- Inhalation
  - Using mass loading model
- Ground surface exposure
- Ingestion of local crops, animal products and soil
- Redistribution model only considers inhalation which is the most risk significant pathway
- Details of these to be discussed later

Ground Water Release

- Time-dependent groundwater concentrations at receptor location
  - Dispersion of annual saturated zone flux to accessible environment into annual water demand volume, a volume specified by 10 CFR 63.312(c)

Biosphere Dose Pathways



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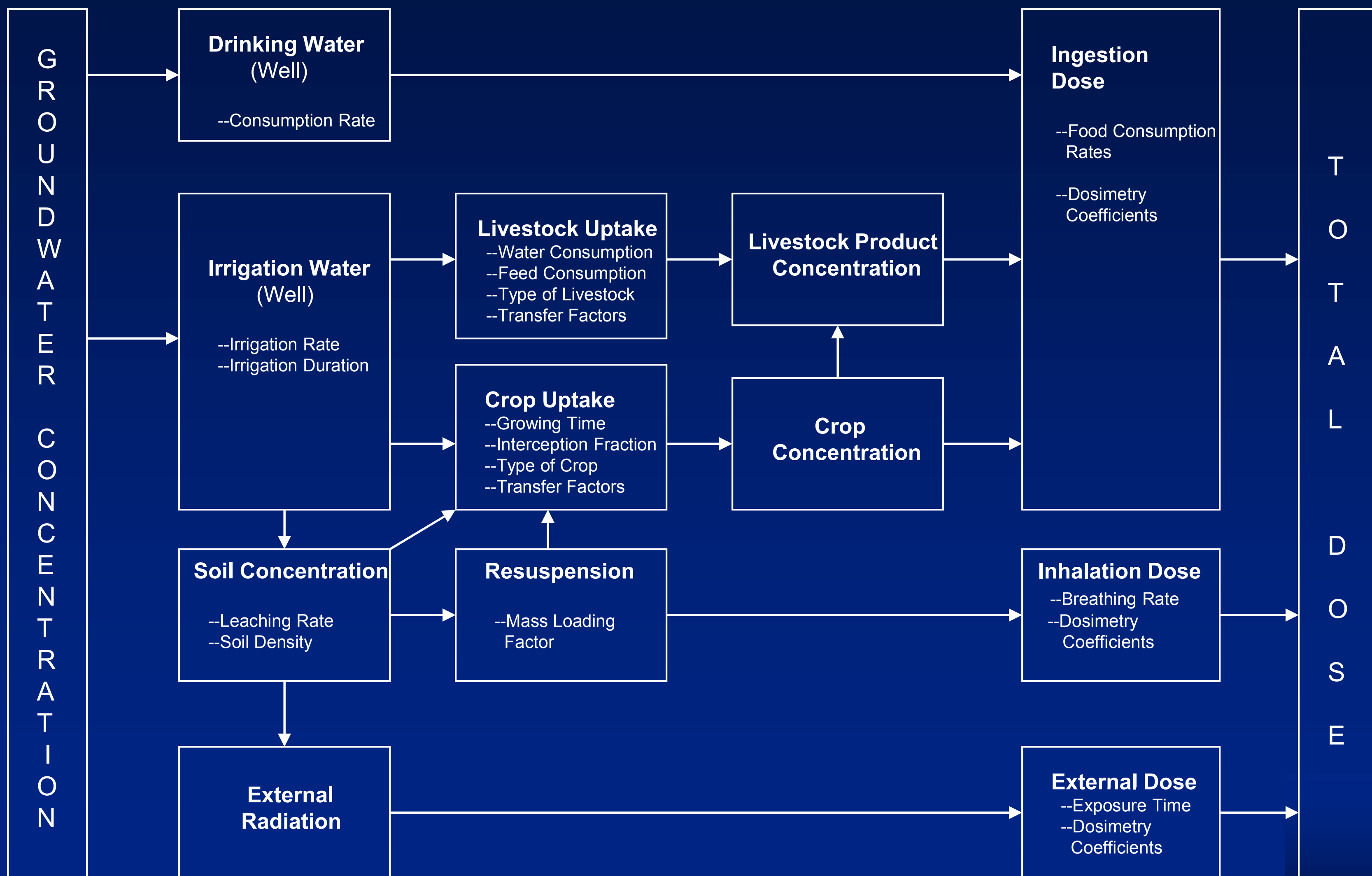
Ground Water Pathways



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GENTPA: TPA Biosphere Pathway Model

- Based on GENII V1.485
- GENII was developed by PNNL
- Environmental pathway model
- Input parameters are subset of total GENII inputs

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Inhalation Dose

$$D_{inh}(t) = C_a(t) I_a DC_{inh}$$

$D_{inh}(t)$	—	dose from inhalation for year t [Sv]
$C_a(t)$	—	concentration in air at year t [Bq/m^3]
I_a	—	inhalation rate [m^3/yr]
DC_{inh}	—	dose coefficient for inhalation [Sv/Bq]

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Ground Shine

$$D_g(t) = C_{soil}(t) \times DC_{gs}\, 1\, yr\, CF$$

$D_g(t)$	—	dose from ground shine for year t [Sv]
$C_{soil}(t)$	—	concentration in soil at time t (Bq/m2]
DC_{gs}	—	dose coefficient for exposure to contaminated ground surface [Sv m^2/Bq/s]
1 yr	=	exposure time
CF	—	seconds per year [3.15×10^7 s/yr]

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Ingestion Dose

$$D_f(t) = C_f(t) I_f DC_{ing}$$

f	—	ingestion pathway (e.g. vegetables, meat, milk)
$D_f(t)$	—	dose from pathway f [Sv] in year t
$C_f(t)$	—	concentration in food/water product [Bq/L or Bq/kg] in year t
I_f	—	ingestion rate [L/yr or kg/yr]
DC_{ing}	—	dose coefficient for ingestion [Sv/Bq]

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Example Calculation: Vegetable Ingestion Dose

Irrigation deposition rate = groundwater concentration × irrigation rate

Soil concentration = irrigation deposition rate × buildup over time

$$C_{soil,i}(t) = ID_i \left[\frac{1 - e^{-(\lambda_i + \lambda_{l,i} + \lambda_e)t}}{\lambda_i + \lambda_{l,i} + \lambda_e} \right]$$

- Leaching and erosion rates are computed values and assumed to be time invariant
- Several different soil models are available to enhance flexibility

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Concentration in Vegetation

Concentration in vegetation = deposition on plant surface + root uptake

$$C_{p,i}(t) = \left[ID_i \frac{12}{M_p} r_{i,p} + C_{soil,i}(t) RF v_{d,i} r_{d,p} CF\right] \frac{TV_p}{B_p} \left[\frac{1 - e^{-(\lambda_w + \lambda_i) T_{g,p}}}{\lambda_w + \lambda_i}\right] + \frac{C_{soil,i}(t) f_{rz,p} BV_{p,i} f_p}{P}$$

$ID_i(t)$	—	irrigation deposition rate of radionuclide i for year t [$Bq/m^2/y$]
M_p	—	months per year irrigation occurs for plant type p [months]
$r_{i,p}$	—	irrigation interception fraction for plant type p [unitless]
$C_{soil,i}(t)$	—	concentration in surface soil of radionuclide i at time t [Bq/m^2]
$v_{d,i}$	—	deposition velocity (radionuclide dependent) [m/s]
$r_{d,p}$	—	deposition interception fraction for plant type p [unitless]
RF	—	resuspension factor [1/m]
$r_{d,p}$	—	deposition interception fraction for plant type p [unitless]
CF	—	seconds per year [3.15×10^7 s/yr]

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Concentration in Vegetation – cont.

Concentration in vegetation = deposition on plant surface + root uptake

$$C_{p,i}(t) = [ID_i \frac{12}{M_p} r_{i,p} + C_{soil,i}(t) RF v_{d,i} r_{d,p} CF] \frac{TV_p}{B_p} \left[\frac{1 - e^{-(\lambda_w + \lambda_i) T_{g,p}}}{\lambda_w + \lambda_i} \right] + \frac{C_{soil,i}(t) f_{rz,p} BV_{p,i} f_p}{P}$$

TV_p	—	translocation factor for plant type p [unitless]
B_p	—	biomass for plant type p [kg/m^2]
λ_w	—	weathering constant [1/yr]
λ_i	—	radionuclide decay constant for radionuclide i [1/yr]
$T_{g,p}$	—	growing period for plant type p
$f_{rz,p}$	—	fraction of roots in surface soil for plant type p [unitless]
$BV_{p,i}$	—	soil-to-plant transfer factor for plant type p and radionuclide i (element) [unitless]
f_p	—	dry-to-wet ratio for plant type p [unitless]
P	—	surface soil density [kg/m^2]

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Vegetable Ingestion Dose

- Concentrations in various types of vegetation are calculated
  - Leafy vegetables
  - Other vegetables
  - Fruit
  - Grain

Dose from Animal Product Ingestion

- Concentration in forage and stored feed (hay or silage) is estimated using the same equation as vegetables, but different values
- Concentration in animal product is estimated using transfer/uptake factors
- Human food consumption rates used to estimate radionuclide intake
- Dose is estimated from radionuclide intake

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Dose from Animal Products

Includes intake from water, forage, and stored feed

$$C_{beef,i}(t) = F_b \left[\left[C_{w,i}(t) f_{w,b} U_{w,b} \right] + \left[\sum_{p=1}^{M} C_{p,i}(t) f_{p,b} U_{p,b} \right] \right]$$

Different parameters used for beef, milk cows, poultry, and egg production

Dose Coefficients

- ICRP 30 – International Commission on Radiological Protection – Internal and External
- ICRP 72 – Internal Only

Output

- TPA provides a variety of outputs
  - Mean dose calculated for each time step following release
  - Highest mean dose for all time steps is ‘peak of means’
- Other intermediate output files show dose by pathway and radionuclide for each realization

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Risk Insights Baseline Report: Redistribution of Radionuclides in Soil

- Low significance to waste isolation
- Inhalation pathway dominates
- 10,000-yr peak expected dose using multiple realizations
  - Np-237, 21%
  - I-129, 26%
  - Tc-99, 53%

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Risk Insights Baseline Report: Redistribution of Radionuclides in Soil

- 100,000-yr peak expected dose using multiple realizations
  - Np-237, 74%
  - I-129, 10%
  - Tc-99, 16%

Risk Insights Baseline Report: Characterization of Biosphere

- 10 CFR Part 63 specifies using mean values for many important biosphere parameters
  - Reduces range of variation in ground water release biosphere calculations
- Low significance

Sensitivity Analysis

- LaPlante and Poor performed sensitivity analysis in 1997
- Radionuclide-specific results indicate sensitive parameters
  - Soil/Plant transfer factors
  - Crop interception fractions
  - Grain consumption rate
  - Animal uptake factor

DOE's ERMYN Model

- ERMYN- environmental radiation model for Yucca Mountain, Nevada
- Used to compute Biosphere Dose Conversion Factors (BDCFs) to calculate dose in TSPA model
  - BDCF distributions are computed and sampled
- BDCFs are precalculated doses for a unit release of a given radionuclide
- Implementation in TSPA is less flexible approach than in TPA

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PRECLOSURE

Preclosure Dose Compliance

- 10CFR63.111(a) (2) “During normal operations and for Category 1 event sequences, the annual TEDE (hereafter referred to as “dose”) to any real member of the public located beyond the boundary of the site may not exceed the preclosure standard specified in § 63.204.”

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Preclosure Dose Compliance

- 10CFR63.204 “DOE must ensure that no member of the public in the general environment receives more than an annual dose of 0.15 mSv (15 mrem) from the combination of (a) Management and storage (as defined in 40 CFR 191.2) of radioactive material that: (1) Is subject to 40 CFR 191.3(a); and (2) Occurs outside of the YM repository but within the YM site; and (b) Storage (as defined in § 63.202) of radioactive material inside the YM repository.”

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Category 1 and Category 2 Events

- Category 1 Event Sequences
  - Those event sequences expected to occur 1 or more times before permanent closure
- Category 2 Event Sequence
  - Those event sequences expected to have at least a 10^{-4} chance of occurrence before permanent closure

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Preclosure Safety Analysis

- 10 CFR Part 63 Definition of Preclosure Safety Analysis: "means a systematic examination of the site; the design; and the potential hazards, initiating events and event sequences and their consequences (e.g. radiological exposures to workers and the public). The analysis identifies structures, systems and components important to safety."

Preclosure Safety Analysis Tool

- PCSA developed to enable NRC and CNWRA staff to conduct independent analysis and review
- Windows based software package that features a graphical user interface
- Not all models are biosphere models but covered for completeness

PCSA Model Analysis

- SAPHIRE
  - Conducts fault tree and event tree analysis
- RSAC
  - Dose calculations from atmospheric releases of radiological material
- MELCOR
  - Used to estimate building discharge fraction

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PCSA Worker Dose Options

- Normal operations dose
- Accident dose outside
- Accident dose inside

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PCSA Worker Dose Options – Normal Operations Dose

- Dose to facility workers
- Underwater-handling events with workers present above the pool

PCSA Worker Dose Options – Accident dose outside

- Contaminated plume of air released from ventilation system of building
- HEPA filtration system may be assumed to operate properly or fail
- Wind flow around buildings is considered
  - Position of worker considered
    - Cavity zone
    - Wake zone
    - Displacement zone

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PCSA Worker Dose Options- Accident Dose inside

- Dry Conditions
  - Leakage of contaminated air from a hot cell into an adjoining room
  - Source may be damaged PWR SNF, BWR SNF or user-specified source
- Wet Conditions
  - Release of gases from SNF pool directly into room worker is located in
  - Underwater-handling events with workers above pool

PCSA Public Dose for Accidents uses RSAC

- Gaussian plume model
- Pathways considered
  - Inhalation dose
  - Shine
  - Ingestion

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Summary

- Biosphere dose modeling is widely used and has accepted methods
- Tools have been developed to help understand the methods
- Many parameters are used in the modeling
- Sensitivity analysis has identified the key parameters for post closure