RESRAD Family of Codes — A Suite of Tools for Environmental Radiological Dose Assessment

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Presentation Outline

- RESRAD Family of Codes Overview
- Brief Overview of the RESRAD Methodology
- RESRAD-BUILD Overview
- RESRAD-OFFSITE Overview
- RESRAD-BIOTA Overview
- Summary

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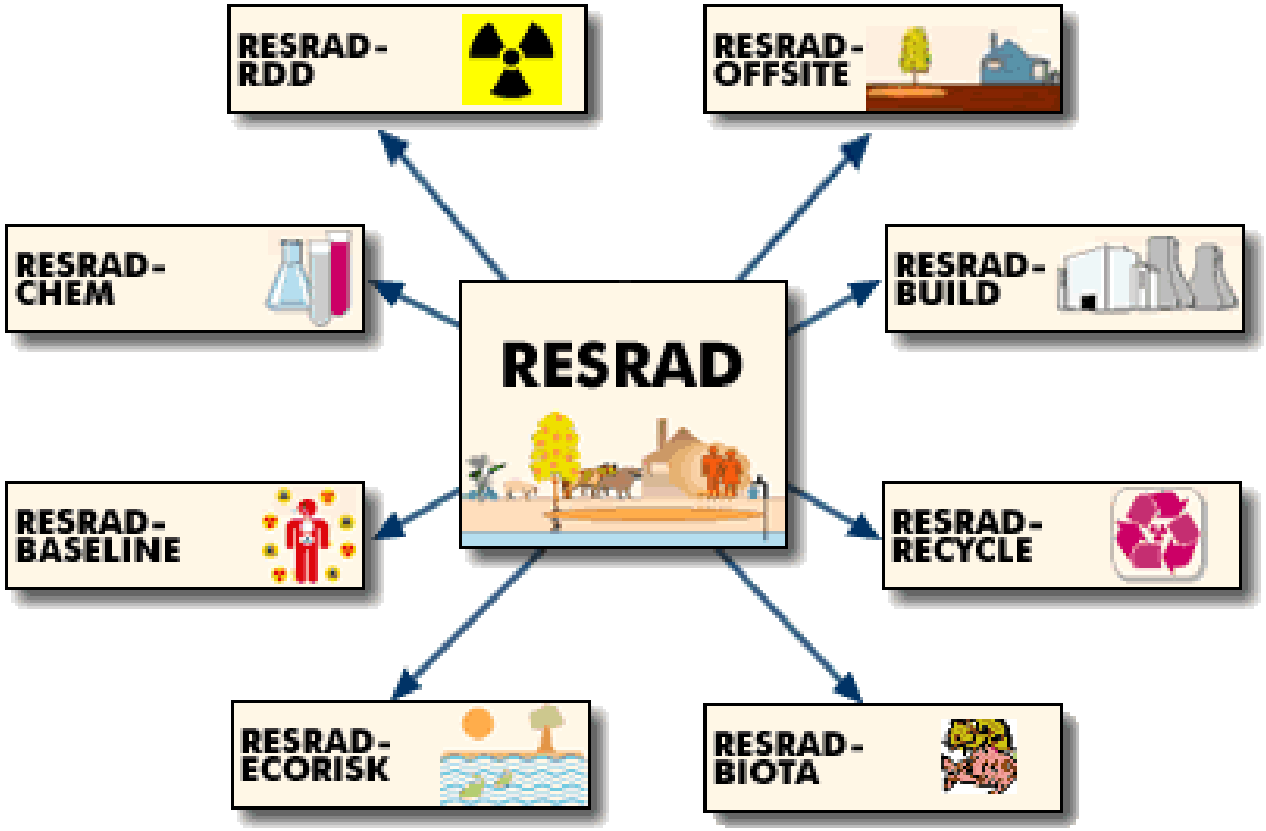
RESRAD Family of Codes Overview

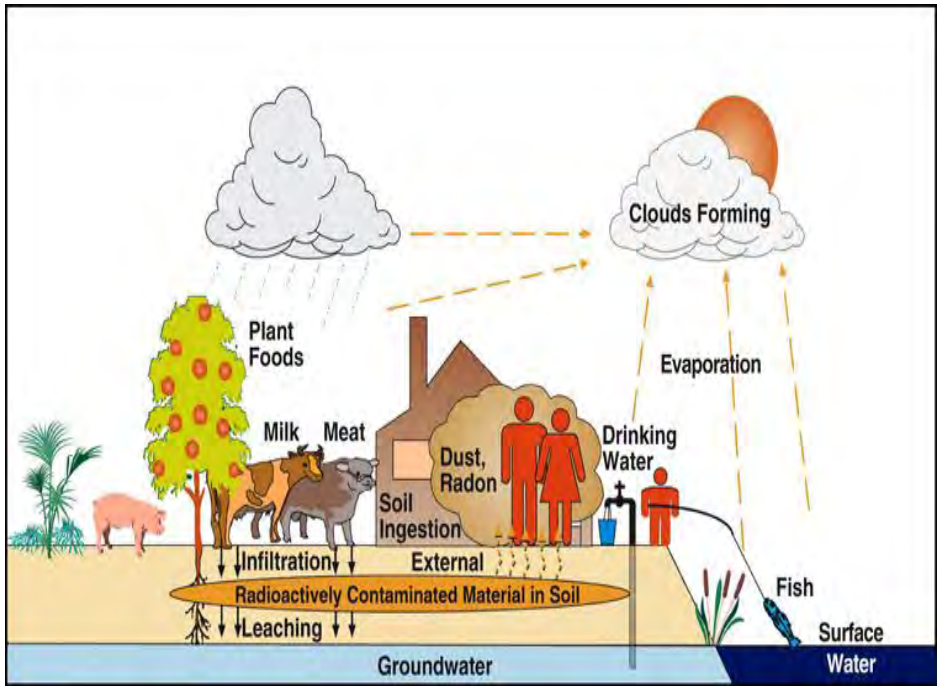
U.S. DEPARTMENT OF ENERGY

RESRAD Family of Codes



RESRAD (onsite) - 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?"



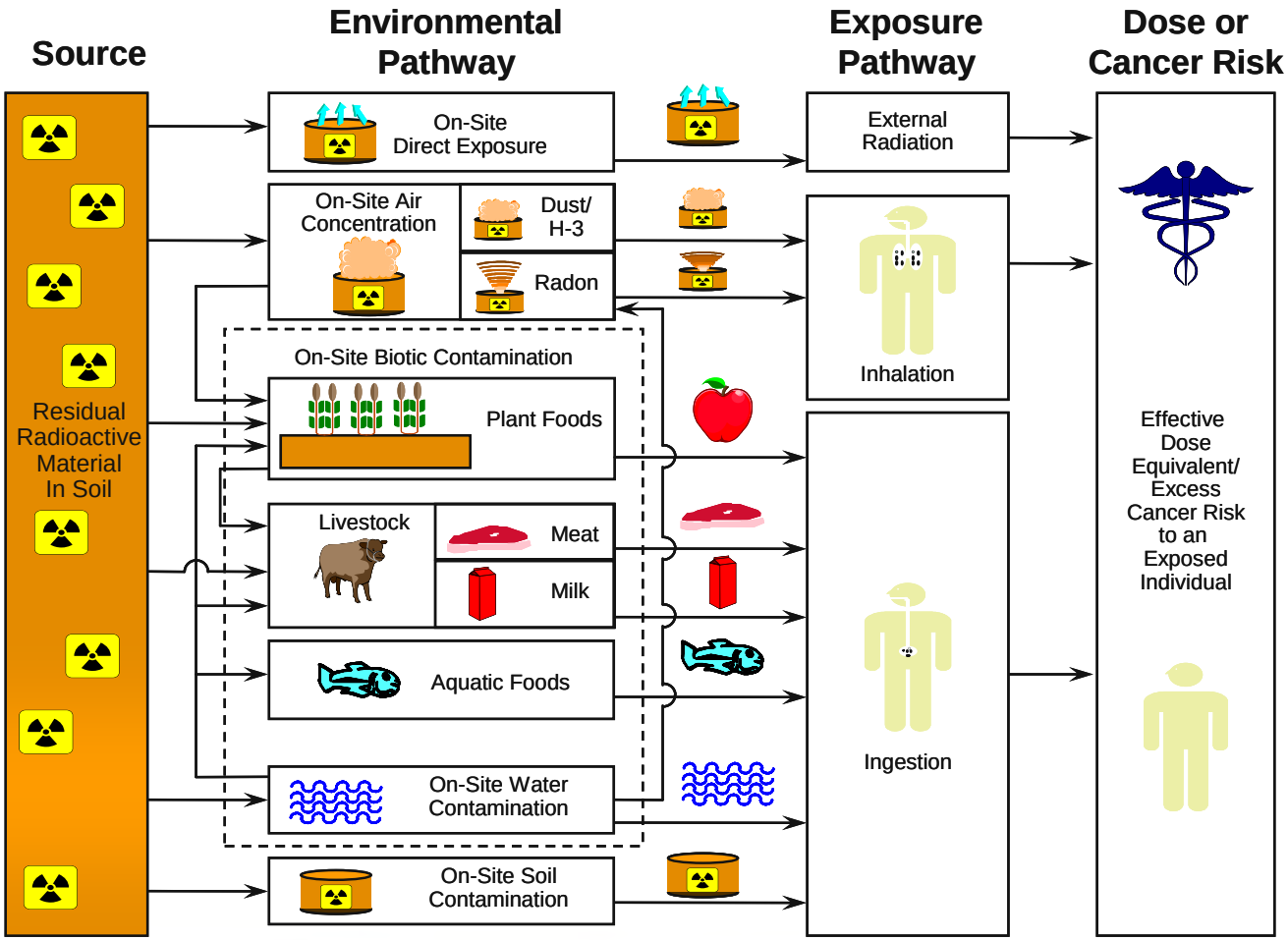
Accepted for use by government regulatory agencies

- DOE (Designated by Order 5400.5 and 458.1)
- NRC (NUREG-1757)
- EPA
- State agencies

In use for more than 25 years

- Evaluation of more than 300 cleanup sites
- More than 100 training workshops
- International recognition (IAEA multilingual version and training)

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



Strong Track Record

- Only code designated in DOE Order 5400.5 (and O 458.1) for the evaluation of radioactively contaminated sites
- NRC has approved the use of RESRAD for dose evaluation by licensees involved in decommissioning, NRC staff evaluation of waste disposal requests, and dose evaluation of sites being reviewed by NRC staff
- EPA used RESRAD in the analysis of radiation site cleanup regulations, and the EPA Science Advisory Board reviewed the RESRAD model
- NRC supported the development of the probabilistic modules for demonstrating compliance with the license termination rule
- EPA sponsored a benchmarking study
- NRC supported the development of a source term model for waste disposal facility performance assessment
- IAEA sponsored several RESRAD training courses and interested in developing multilingual version of RESRAD codes
- Many universities used RESRAD as a teaching and research tool
- About 1,000 journal articles and reports used/referenced RESRAD
- More than 80 countries downloaded RESRAD codes

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Brief Overview of the RESRAD Methodology

U.S. DEPARTMENT OF ENERGY

Demonstrating Compliance Using Derived Concentration Guideline Levels

- RESRAD derives single radionuclide soil guidelines at the time of maximum total dose, and at the time of maximum dose for each individual radionuclide, as well as for each user specified time

- $$G_i \left(\frac{\text{pCi}}{\text{g}}\right) = \frac{H_{EL} \left(\frac{\text{mrem}}{\text{yr}}\right)}{DSR_i \left(\frac{\frac{\text{mrem}}{\text{yr}}}{\frac{\text{pCi}}{\text{g}}}\right)}$$

- $DSR_i(t)$ is the dose to source ratio (mrem/yr per pCi/g)
- H_{EL}= basic dose limit

  = 25 mrem/year for single source

  or = 100 mrem/year for all sources

Calculation of the Dose to Source Ratio

- $DSR_{ip}(t) = \sum_{j} DCF_{j,p} \times BRF_{i,j} \times \sum_{q} \int_{t}^{t+t_{int}} ETF_{ij,pq}(\tau) \times SF(\tau)\, d\tau$
- DCF_{jp} = dose conversion factor (mrem/yr per pCi/g or mrem/pCi)
- BRF = branching factor (dimensionless)
- $ETF_{jp}(t)$ = environmental transport factor (dimensionless or g/yr)
- $SF_{ij}(t)$ = source factor for ingrowth, decay and leaching (dimensionless)

Dose Conversion Factors

- External exposure pathway:
  - infinite depth volume factors (mrem/yr per pCi/g)
- Inhalation pathway:
  - inhalation factors (mrem/pCi)
- Ingestion pathways:
  - ingestion factors (mrem/pCi)

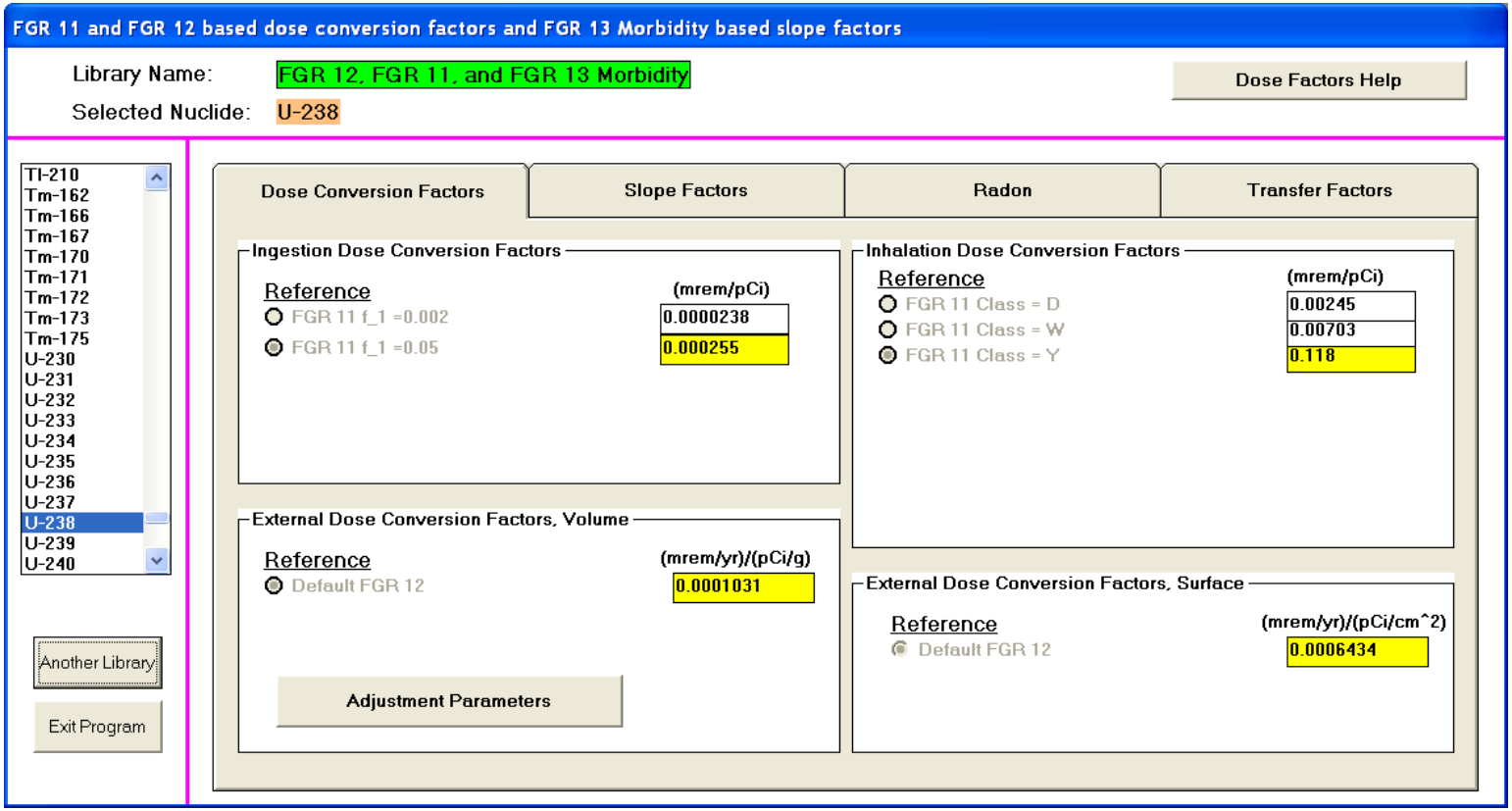
References:

External DCFs - Federal Guidance Report (FGR) No.12 (1993)
- ICRP 60 (1990)
- DCAL

Inhalation/Ingestion DCFs - FGR No.11 (1988),
- ICRP 72 (1996) - Age-dependent DCFs
- ICRP 68 (1994) - Workers DCFs

Dose Conversion Factor/Risk Factor Libraries

- Using the Dose Conversion Factor Editor
  - Users can modify Dose Conversion Factors
    - Select a more appropriate DCF from the standard library
    - Create a new DCF library with values that are appropriate to the site

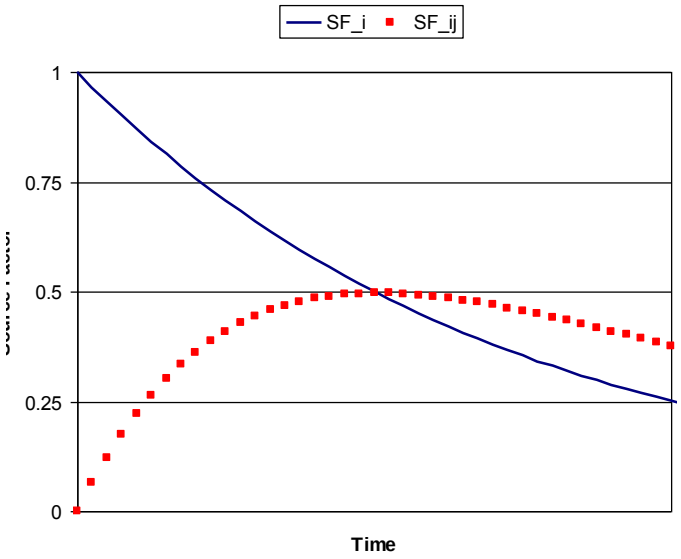


Source Factors

- Ingrowth of principal radionuclide j from principal radionuclide i, assuming associate radionuclides are in secular equilibrium with their principal radionuclides
- Accounts for radioactive decay and leaching

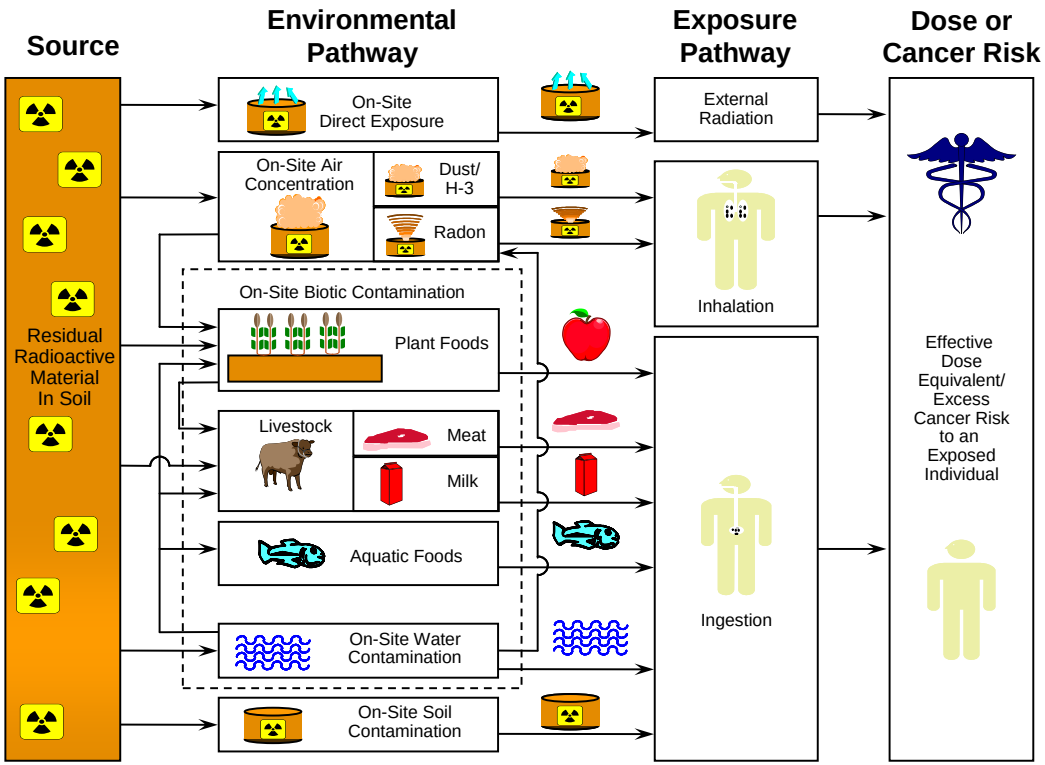
$$SF_{ij}(t) = \frac{S_{ij}(t)}{S_i(0)}$$

See Appendix G for more details



Environmental Transport Factors

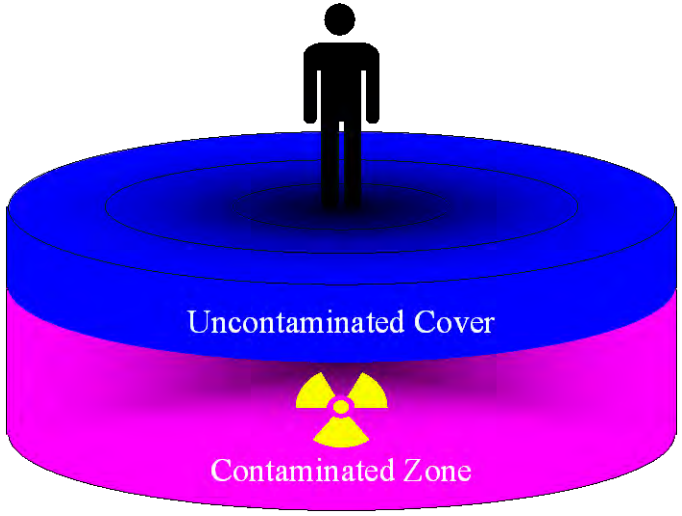
- Mathematical representation of the environmental pathways
- ETFs for
  - External
  - Inhalation
  - Ingestion
    - Water
    - Soil
    - Plant
    - Meat
    - Milk
    - Aquatic Organisms



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} = nuclide specific shape factor
  - $FA_{i1}(t)$ = nuclide specific area factor
  - $FCD_{i1}(t)$ = nuclide specific depth and cover factor

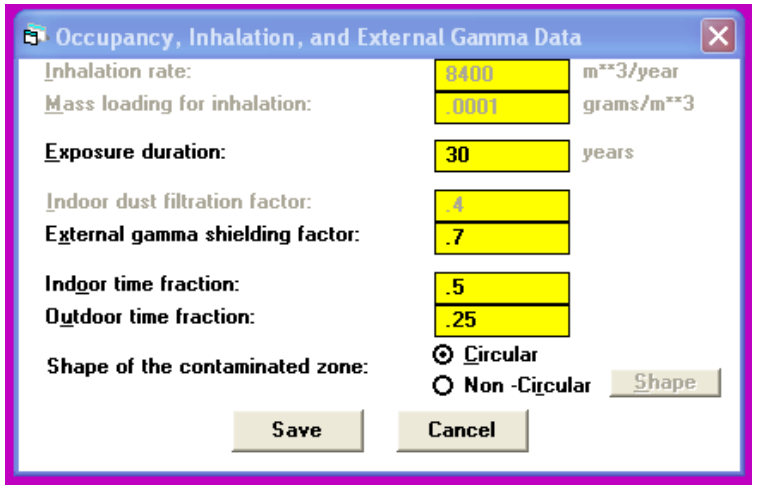
Occupancy and Shielding Factor

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

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

- Default Case

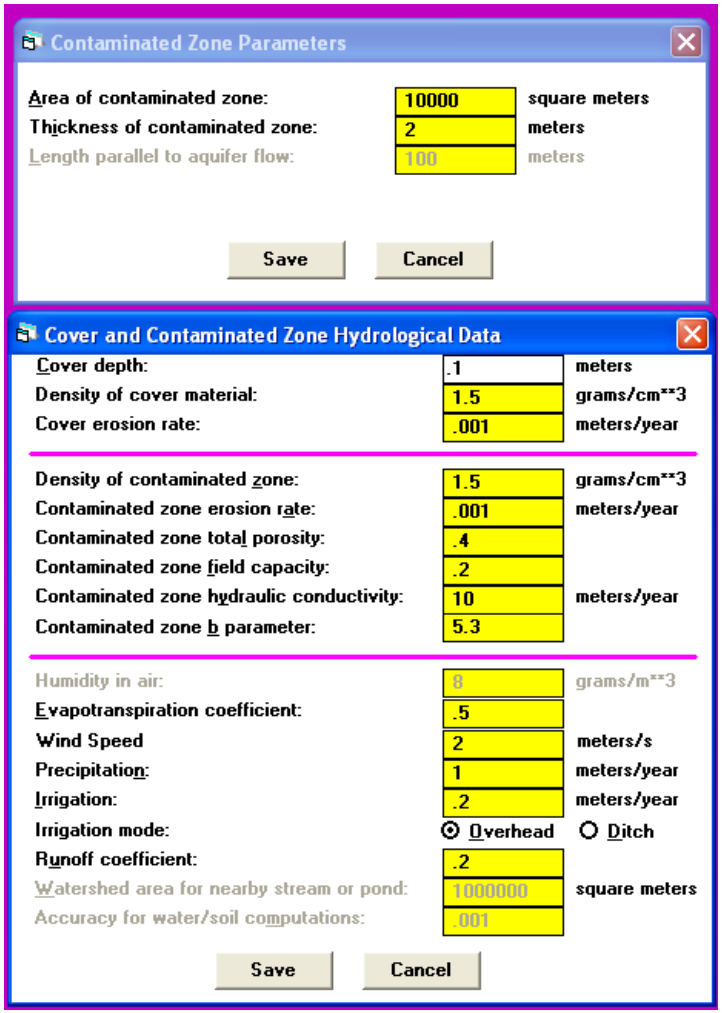
$$FO_1 = 0.25 + (0.5 \times 0.7) = 0.6$$



Depth and Cover Factor

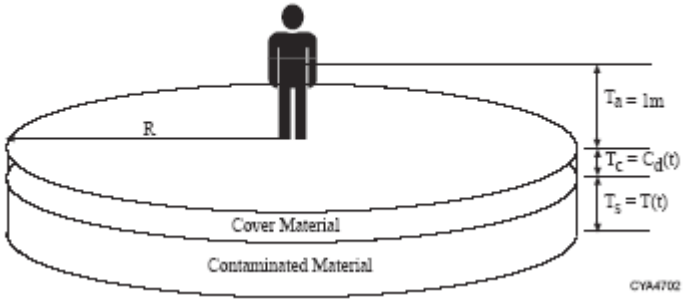
- Allows users to enter
  - Any contaminated zone thickness, and density
  - Any one cover thickness and density
- Based on a regression analysis of FGR 12 DCFs
- FCD's are radionuclide dependent

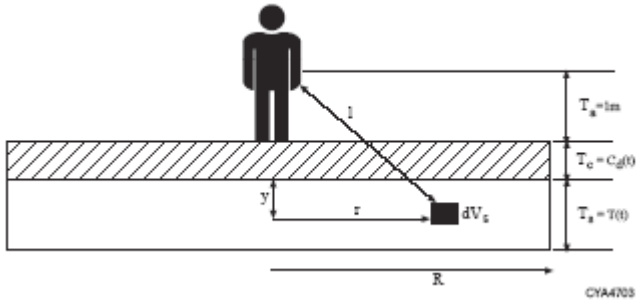
$$FCD_{i1} = \frac{DCF_i^{FGR}\left[t_c = C_d, T_s = T(t)\right]}{DCF_i^{FGR}\left[t_c = 0, T_s = \infty\right]}$$



Area Factor

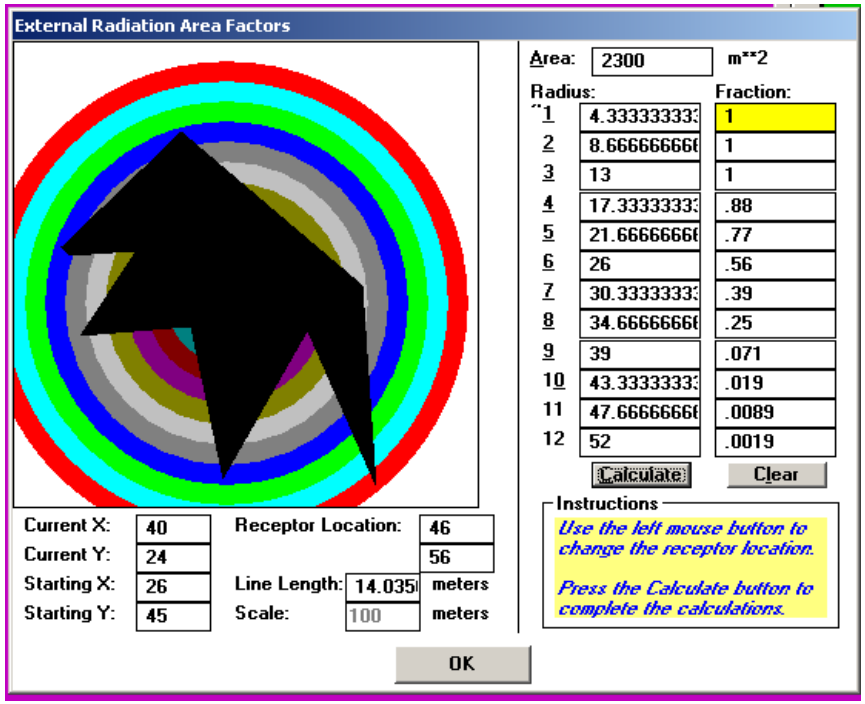
- Radionuclide specific factor to correct an infinite geometry (FGR 12) to finite geometry (site-specific)
- Performs point-kernel integration on the dose
- Uses ICRP-38 photon spectra
- Benchmarked against MCNP



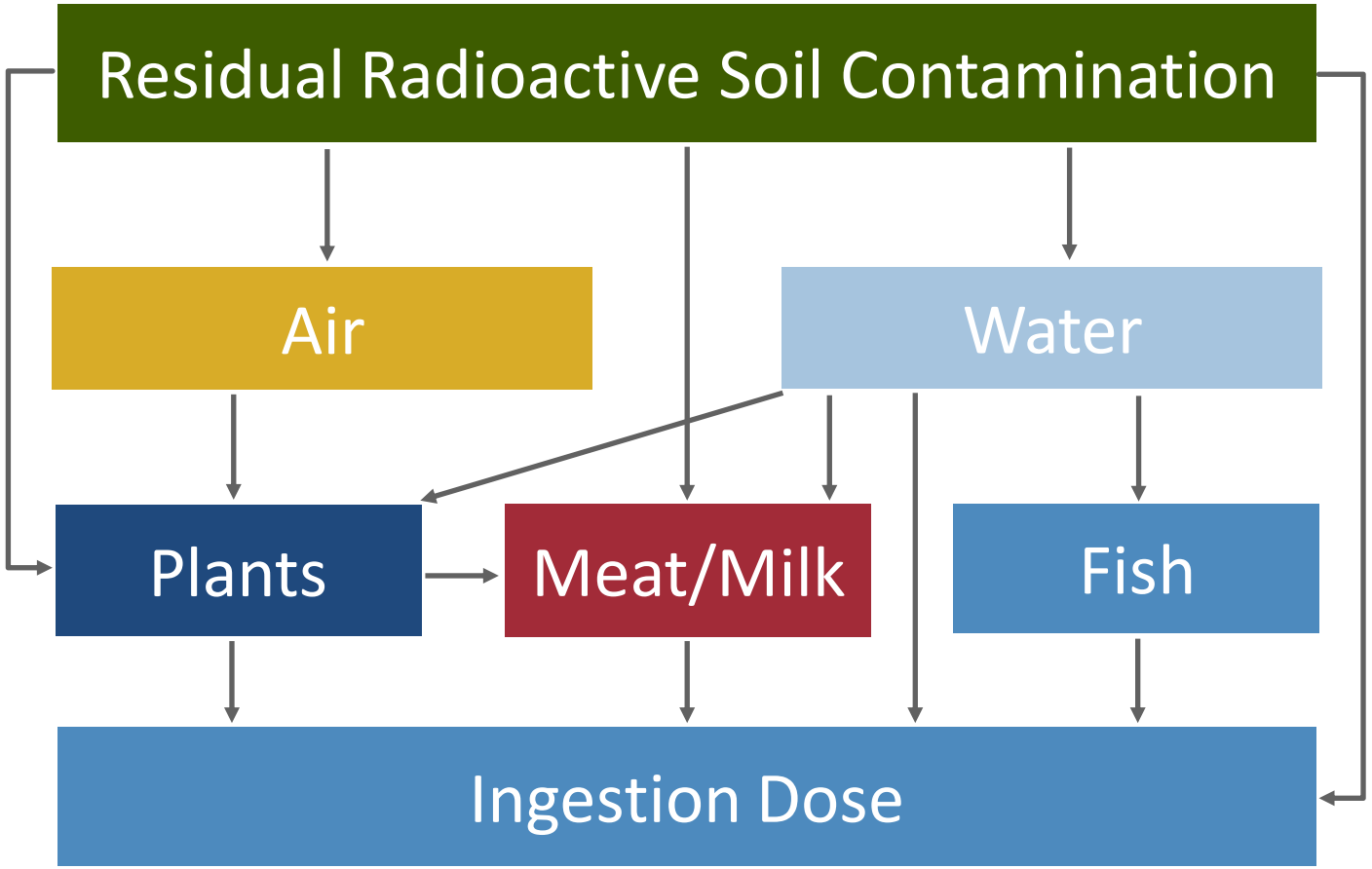


Shape Factor: Non-Circular Shapes

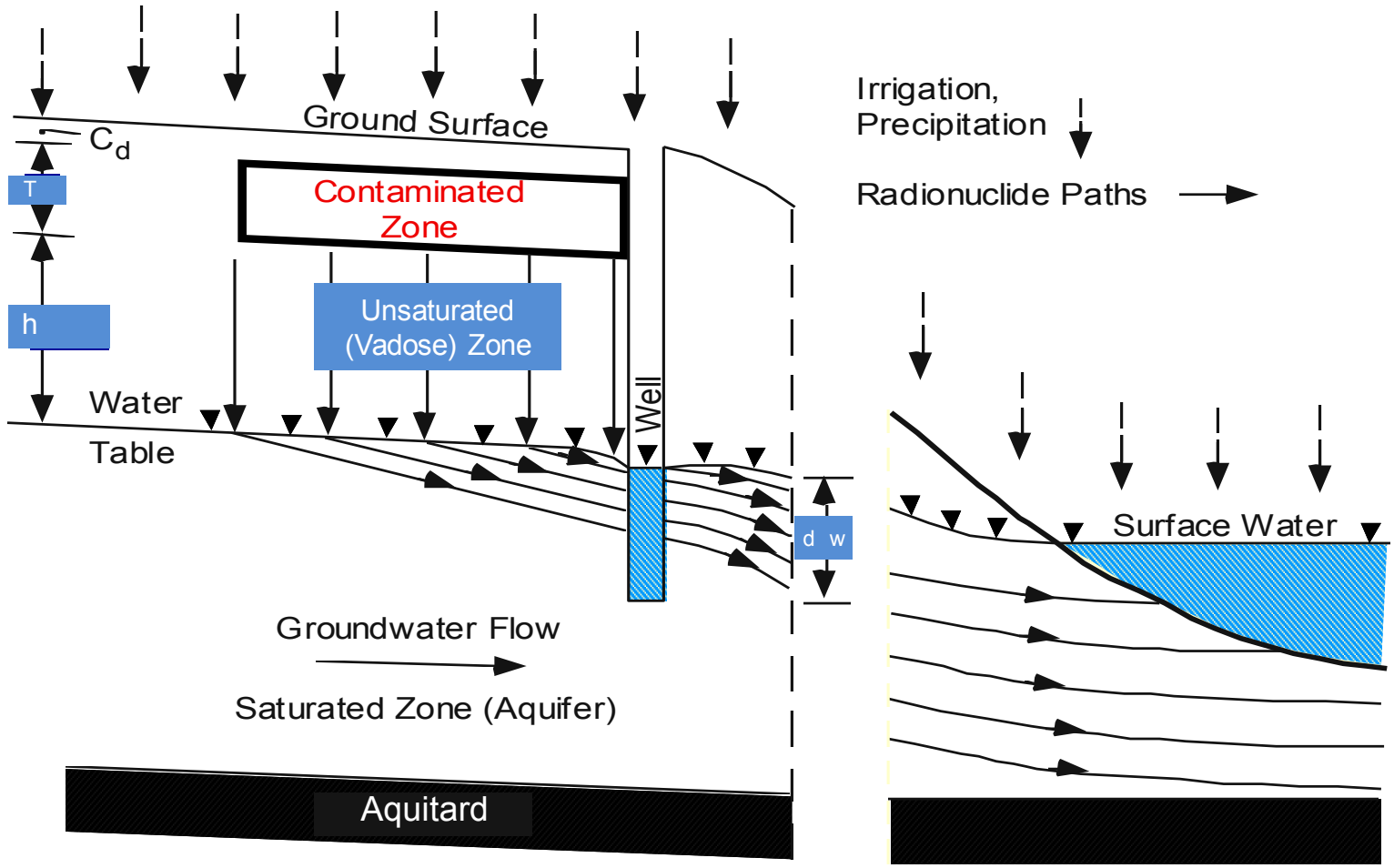
- RESRAD allows users to construct non circular shaped sources
- Allows users to place receptors anywhere on the source
- Biggest Impact on long rectangular sources
  - Roads
  - Railroad right of way
- Primarily affects the External Pathway
- Still Need to Specify the “Length Parallel to Aquifer Flow”



Ingestion Pathways



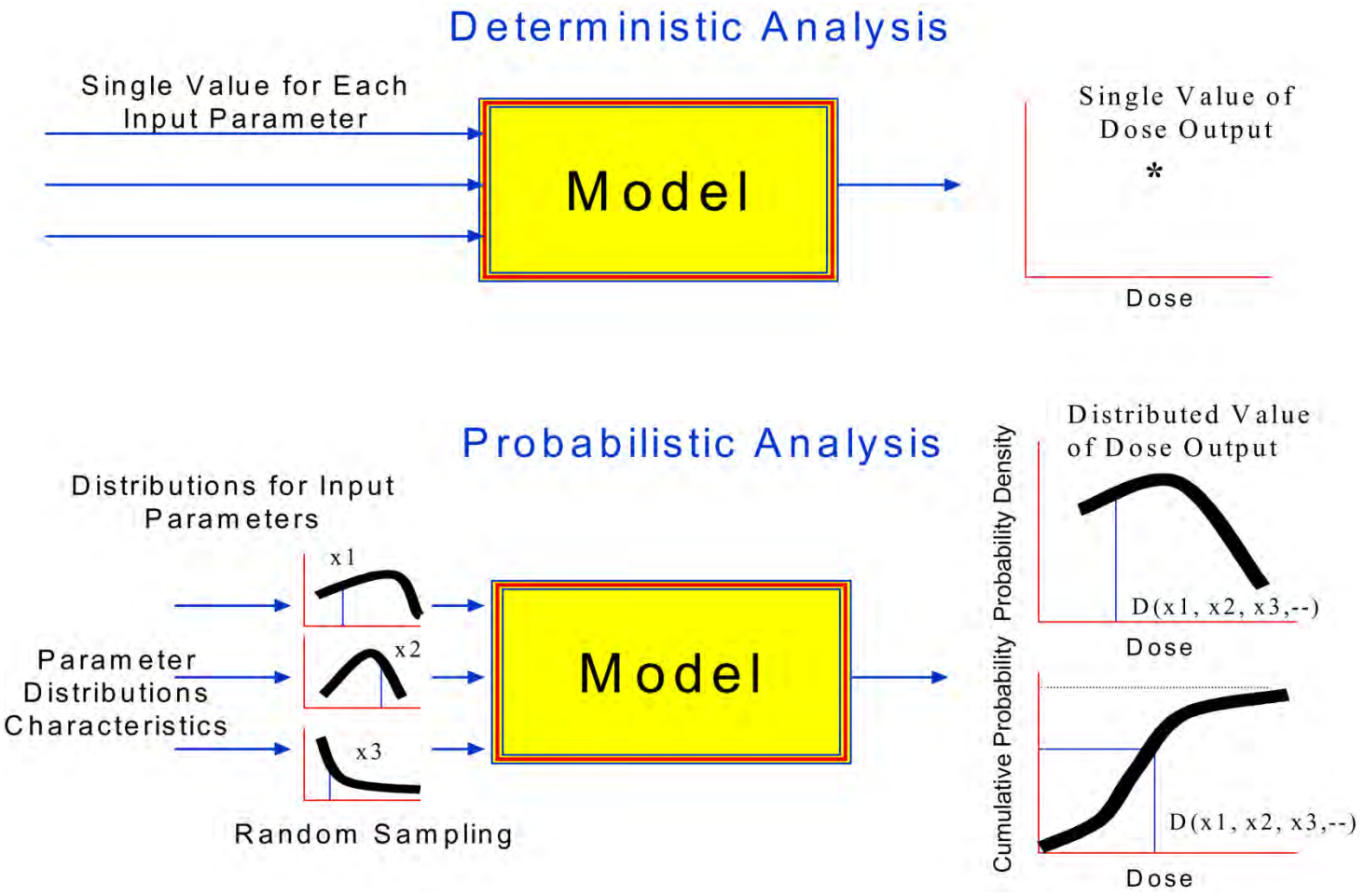
Schematic Representation of the Water Pathway Segments



RESRAD Parameter Database

- Decay and ingrowth data (ICRP-38 and ICRP-107)
- Dose conversion factors (FGR-11 and -12, ICRP -72)
- Cancer slope factors (FGR-13)
- Food transfer factors (plant/soil, meat/feed, milk/feed, fish/water) (IAEA-TRS/364 and TRS/472 and others)
- All 838 radionuclides contained in ICRP-38 are in RESRAD database
- In the process of incorporating ICRP-107 (1252 radionuclides)

Probabilistic vs. Deterministic Analysis



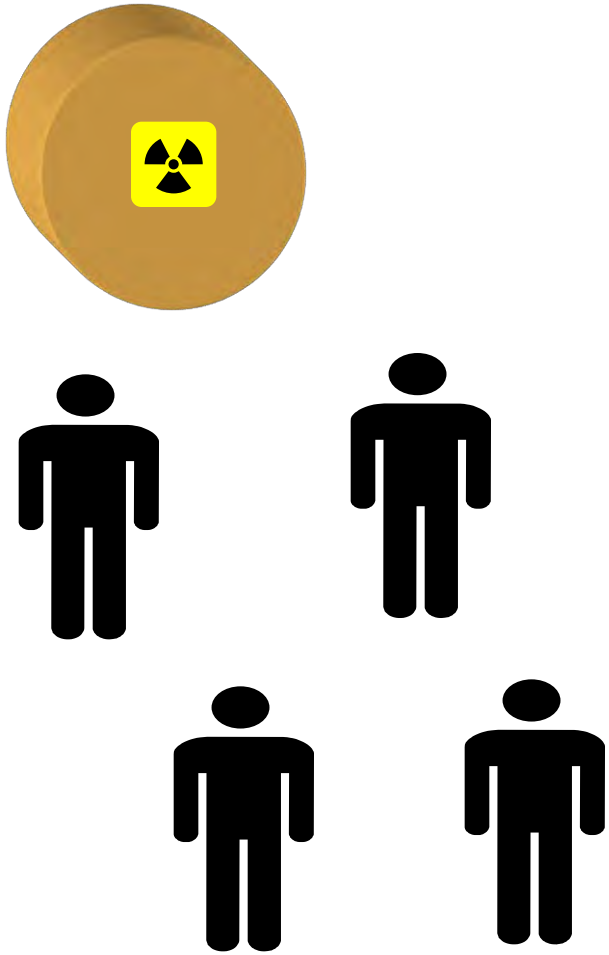
Verification and Validation

- RESRAD calculational results are verified by hand calculations
- Internal verification has been documented since 1989
- Halliburton NUS performed independent verification of RESRAD 5.03 (1994)
- Participating in international code-comparison and validation meetings – IAEA VAMP, BIOMOVS II, BIOMASS, EMRAS, etc. -- in some cases using Chernobyl data
- Many benchmarking exercises had been done in the past 20 years; most codes benchmark against RESRAD now (e.g., IAEA EMRASII NORM WG)

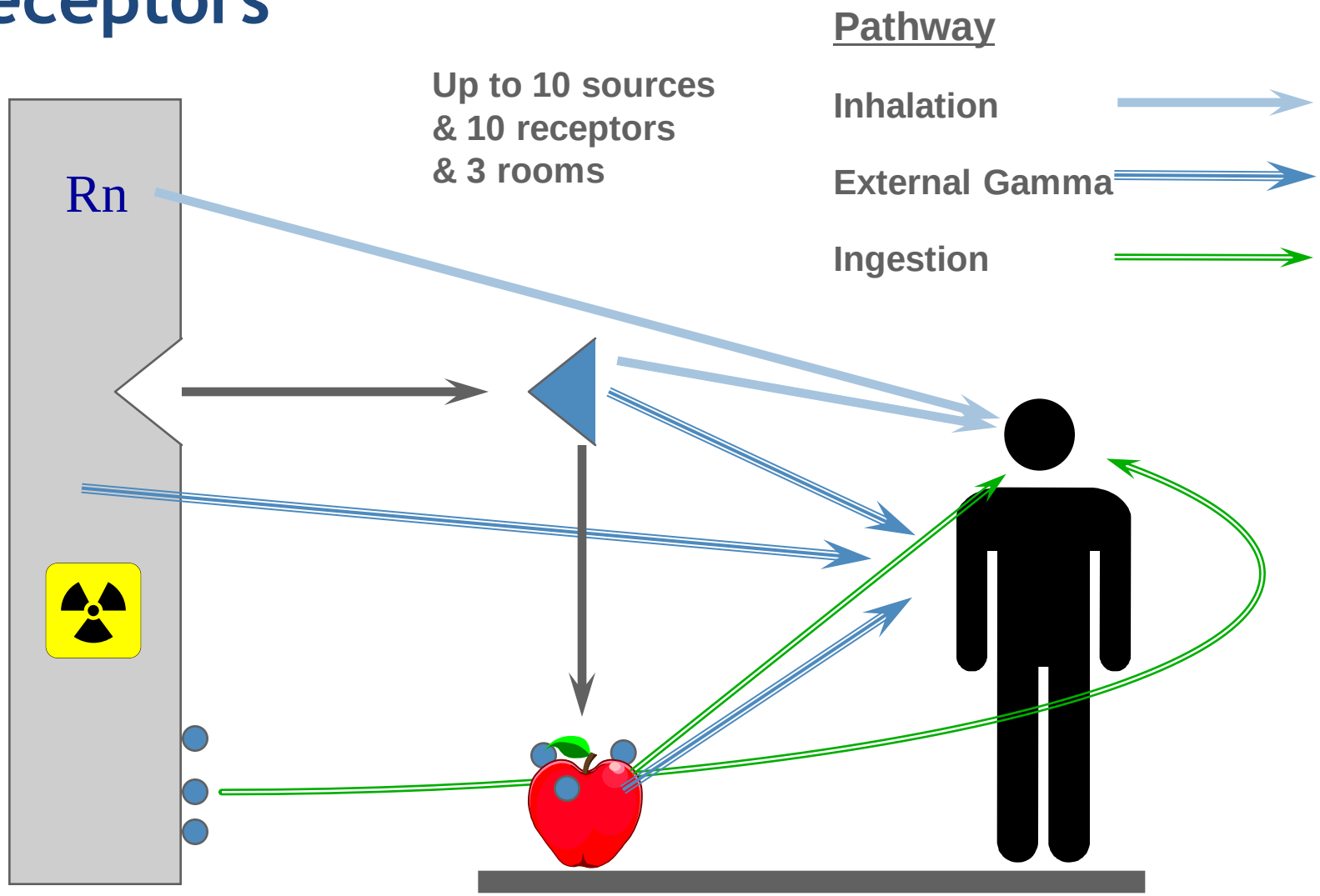
RESRAD-BUILD Overview

Sources and Receptors Considered

- Four distinct source types
  - Point
  - Line
  - Area
    - Circular
    - Rectangular
  - Volume
    - Circular
    - Rectangular
- Ability to co-locate sources
  - Area source above a volume source
  - Hot-spot in an area source
- Up to 10 sources in a single run
- Up to 10 receptors in a single run

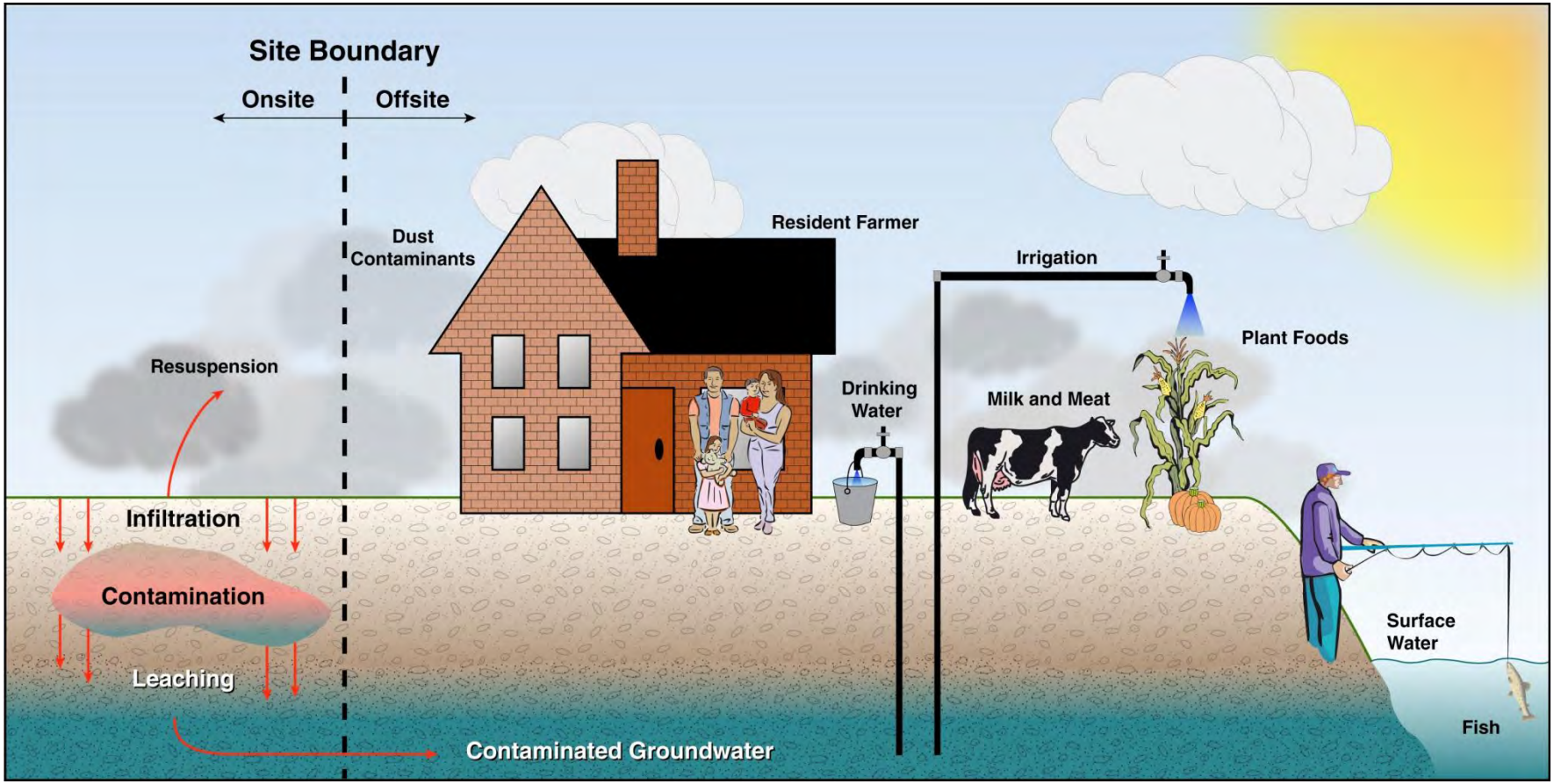


RESRAD-BUILD Sources, Pathways, and Receptors

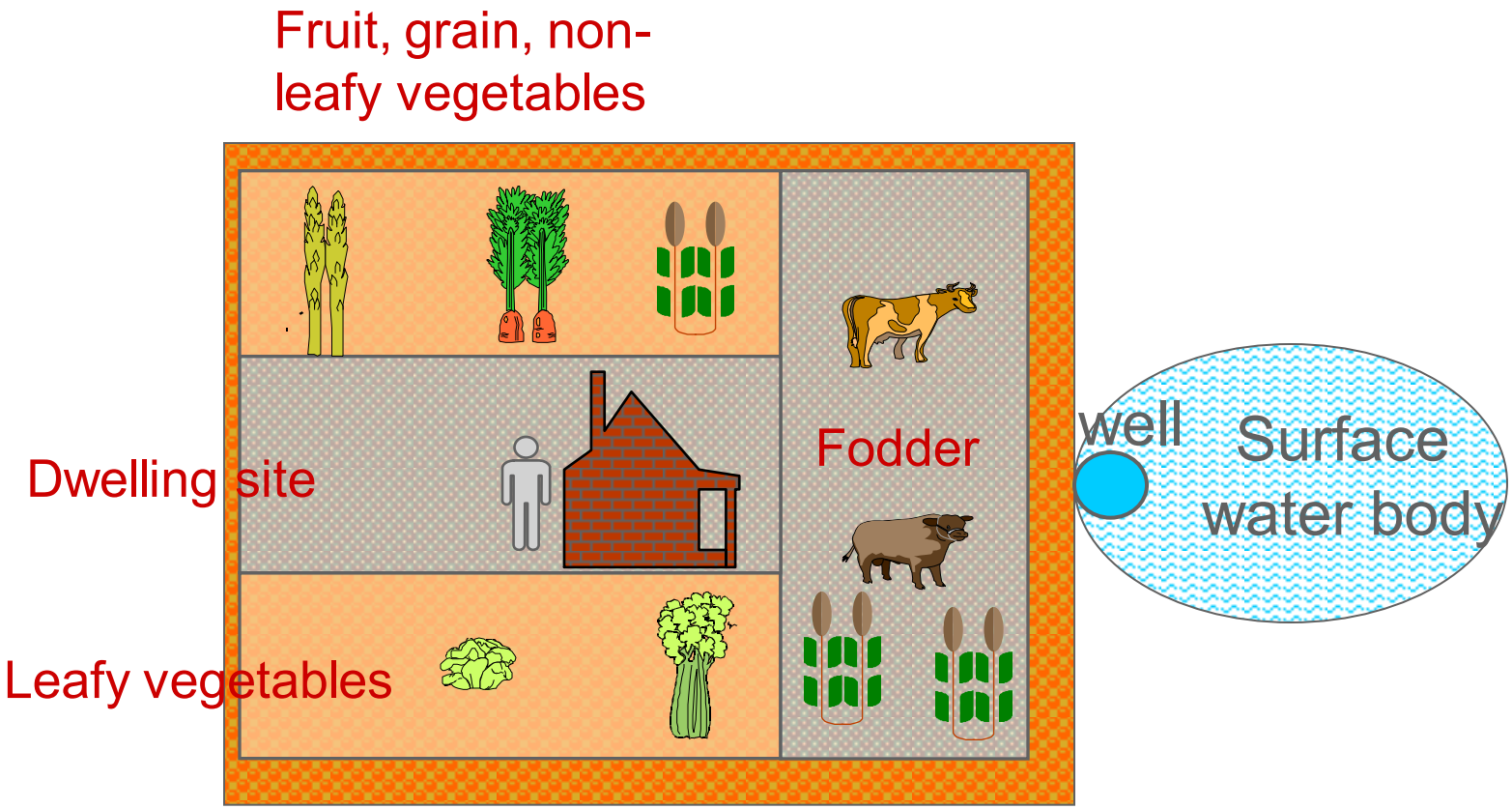


RESRAD-OFFSITE Overview

RESRAD-OFFSITE – Extending the Analysis Beyond the Contaminated Sites



Area of Primary Contamination

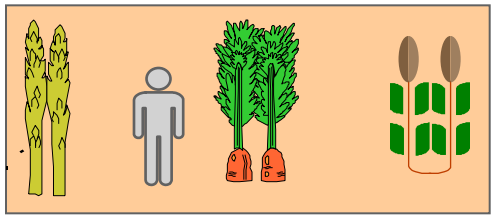


Primary contamination

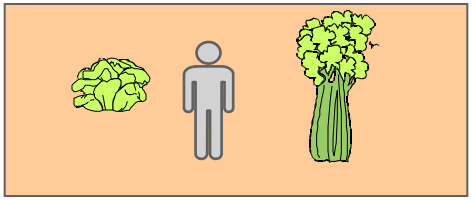
Areas of Secondary Contamination

Primary contamination

Fruit, grain, non-leafy vegetables



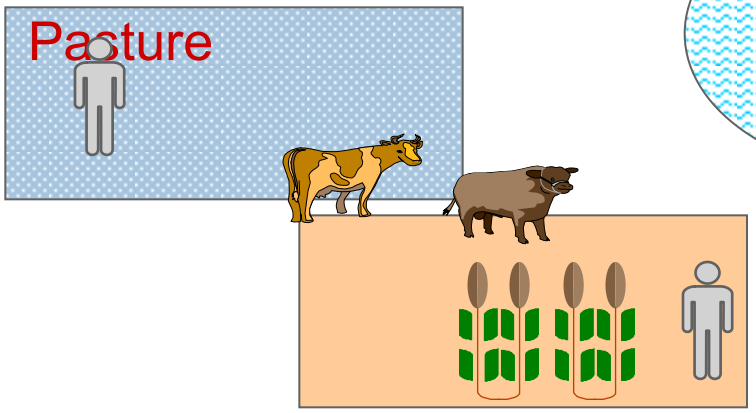
Well



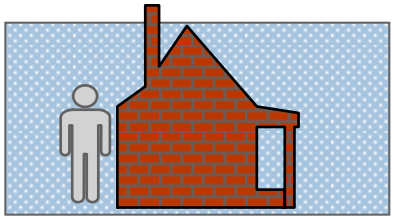
Leafy vegetables

Surface water body

Pasture

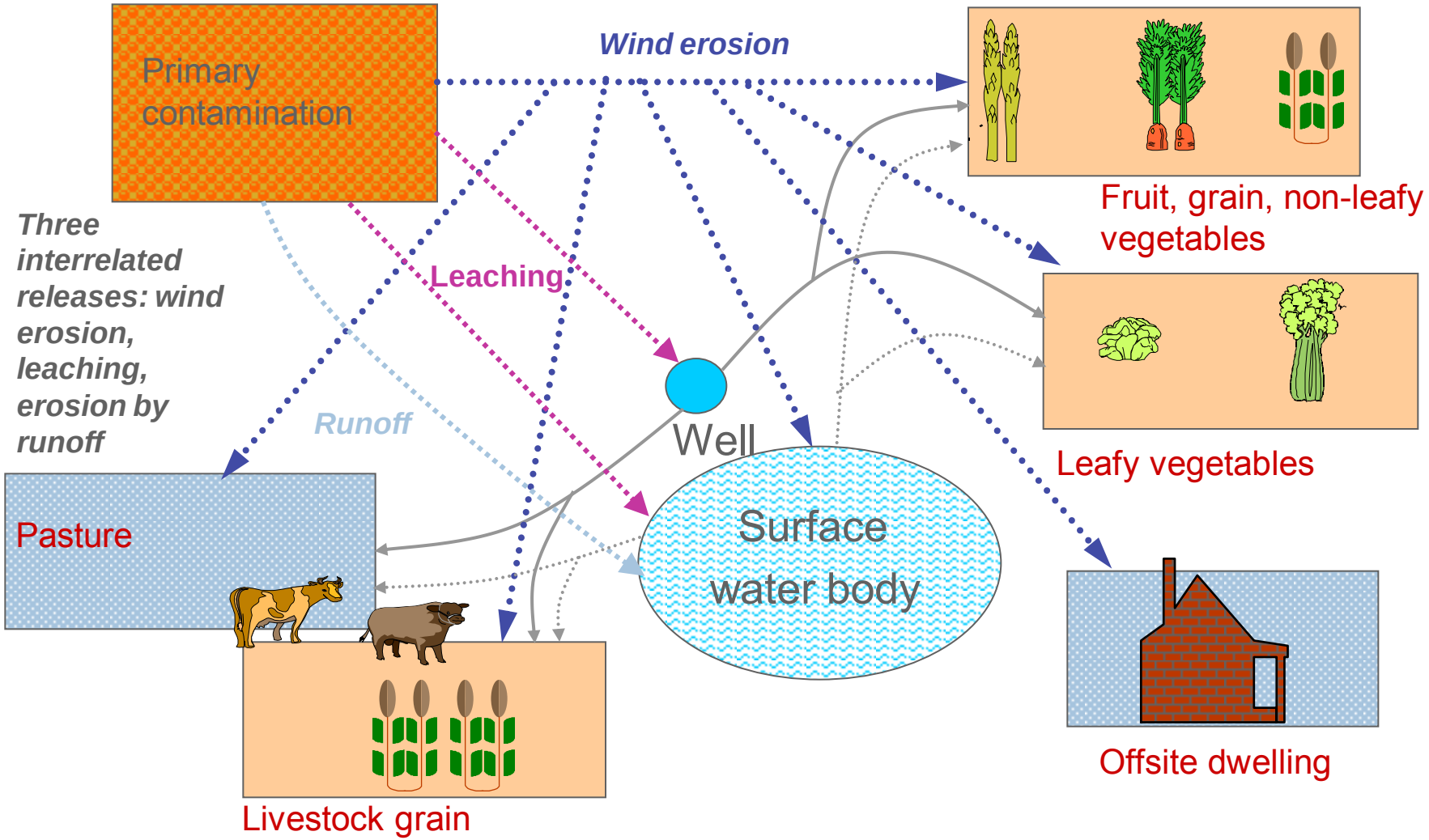


Livestock grain



Offsite dwelling

Transport to Areas of Secondary Contamination



Major 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 2 dwelling locations (onsite, offsite)
  - 4 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 ground water
    - → 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, or
  - Discharges from wastewater pipelines

RESRAD-BIOTA Overview

Evolution of Dose Limits for Biota

- Historical setting:
  - Human limits are dose-based
  - Protection established by examining all exposure pathways
- 1990's DOE considered parallel protection for biota
  - DOE Standard (DOE Order 5400.5):
    - 1 rad/d (10 mGy/d) for aquatic organisms
- Based on NCRP and IAEA findings, other standards proposed in 10 CFR 834, Subpart F and DOE evaluation and workshop:
    - 1 rad/d for terrestrial plants
    - 0.1 rad/d for terrestrial animals

Note: These dose criteria are for protection of the biota population rather than individuals. ICRP does not have dose limits for biota, but has published Reference Animals and Plants (RAPs) and Dose Conversion Coefficients.

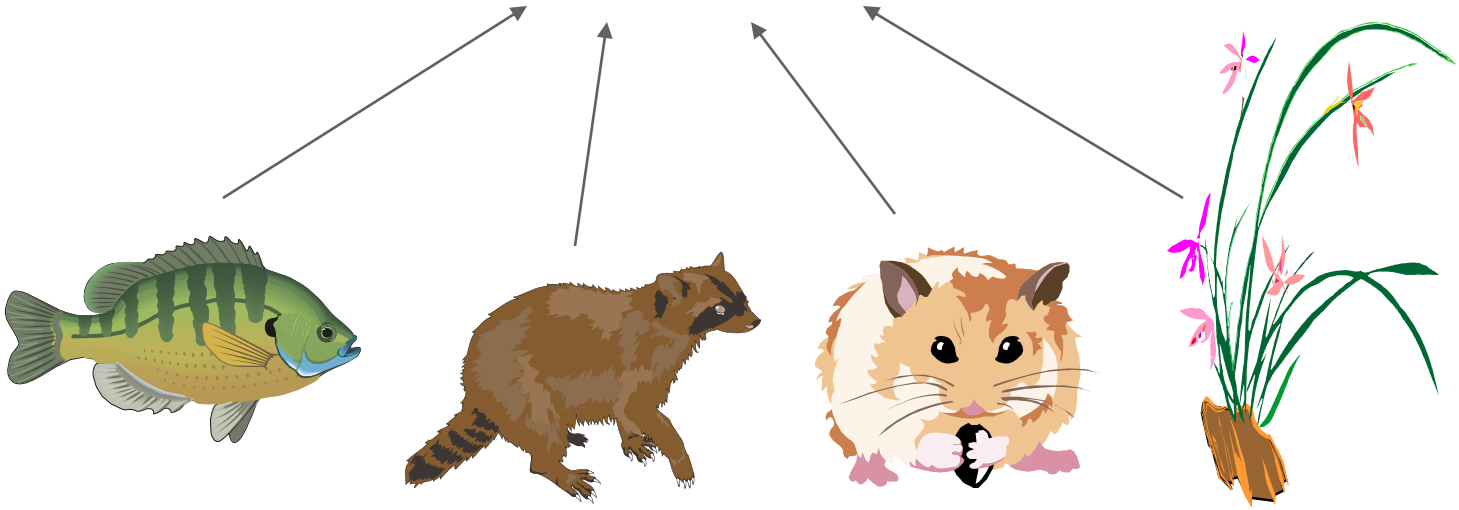
Development and Features of RESRAD-BIOTA

- RESRAD-BIOTA was developed to support implementation of DOE-standard-1153-2002, “A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota” used for demonstrating compliance with DOE Order 458.1 requirements
- Purpose is to ensure the ecosystem is protected from effects of radiation and radioactive material from DOE Activities
- RESRAD-BIOTA has a user-friendly input interface with Help files and shows screening results (pass or fail) along with text reports and bar charts
- Users can do both sensitivity analysis and probabilistic analysis on input parameters

Receptors Used in Deriving the Screening Methodology

Biota Concentration Guides

BCGs



Aquatic Animal

Riparian Animal

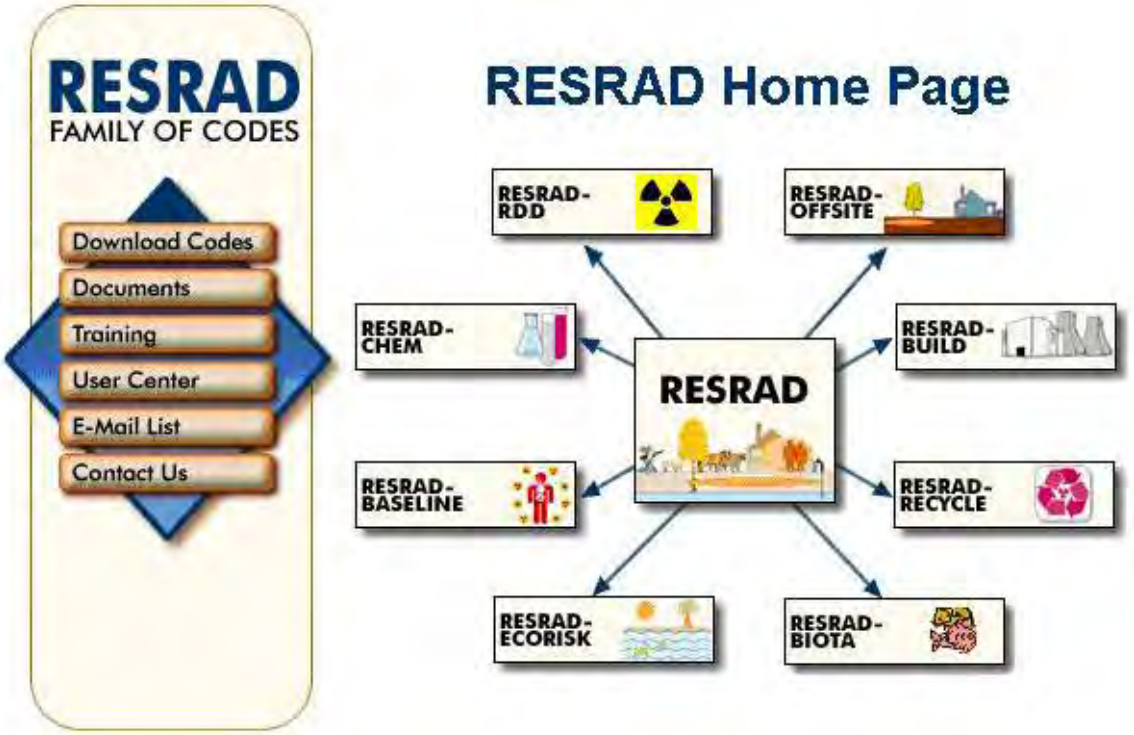
Terrestrial Animal

Terrestrial Plant

Summary

- RESRAD has been in existence for more than 25 years
- RESRAD is the most extensively tested, benchmarked, verified, and validated code in the environmental risk assessment and site cleanup field
- RESRAD has been widely used by federal and state agencies and their contractors
- Over 100 training workshops have been sponsored by DOE, NRC, EPA, DOD, state agencies, and IAEA
- Many universities have used RESRAD as a teaching and research tool
- Many papers (~ 1000) and theses have been published based on or referenced RESRAD Family of Codes (some in foreign languages)
- RESRAD has been widely used and more than 80 countries have downloaded RESRAD Family of Codes
- Comprehensive supporting documents are available for the application of RESRAD
- RESRAD is continuously maintained and improved
- RESRAD Family of Codes can be downloaded free of charge

Thank you!



More Info at RESRAD Web Site:

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

Email: resrad@anl.gov