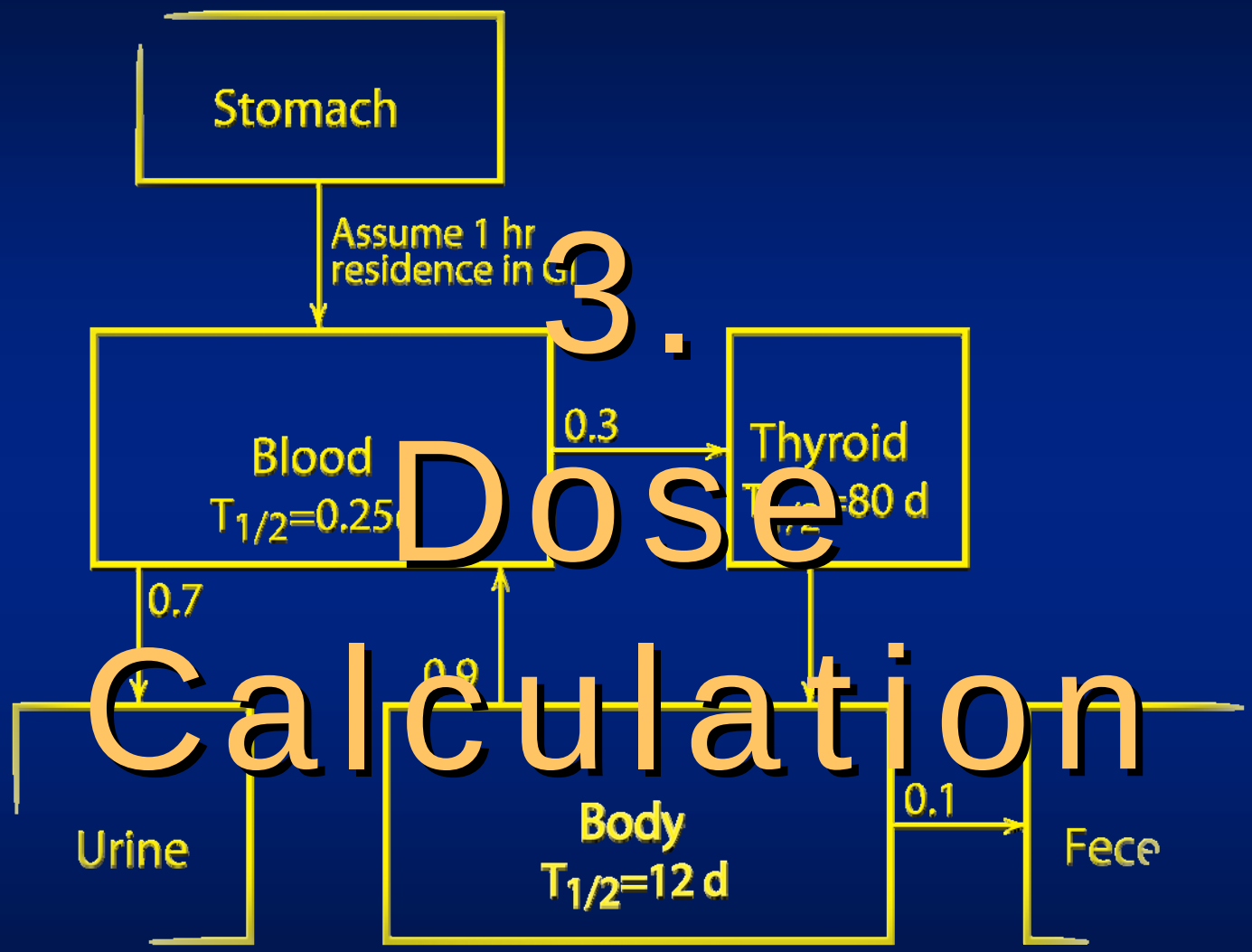
3. Dose Calculation



Radiation Fundamentals 101

(as used in assessments/PARs)

- **Radiation:** the process of emitting energy as electromagnetic waves or particles
- **Ionizing radiation:** electromagnetic waves or particles of sufficient energy to ionize an atom or molecule (e.g., as in tissue) which can lead to cellular effects
- **Alpha radiation:** a charged particle comprised of two neutrons and two protons (i.e., nucleus of a helium atom)
  - A concern only for inhalation or ingestion of alpha emitters
  - Typically not modeled by emergency dose assessments
- **Beta radiation:** an electron ejected from nucleus of an atom by conversion of a neutron to a proton.
  - Typically modeled as a contributor to skin dose if external
  - Contributes to doses from ingestion or inhalation
- **Photon radiation**: quanta that have both wave and particle properties. Also called **gamma** or x-ray radiation depending on source
  - Very penetrating—relaxation length of about 100 meters in air or 50 cm in water
  - Always modeled by emergency dose assessments

Radiation Fundamentals 101

(as used in assessments/PARs)

- **External Dose**
  - Radiation dose that occurs from exposure to radiation emitted by radioactive materials outside of the body
    - Largely from photon radiation; skin dose from beta radiation
    - Since range of beta in air is short, receptor must be submersed in the radioactive cloud, standing on contaminated ground, or have contamination on skin or clothing
    - One does not need to be submerged in the radioactive plume to be exposed to photon radiation; plume can be overhead
  - Since the radioactive material is outside the body, the exposure ceases when the source is removed, or the receptor is removed from the source
    - Protective actions are: sheltering, evacuation, decontamination

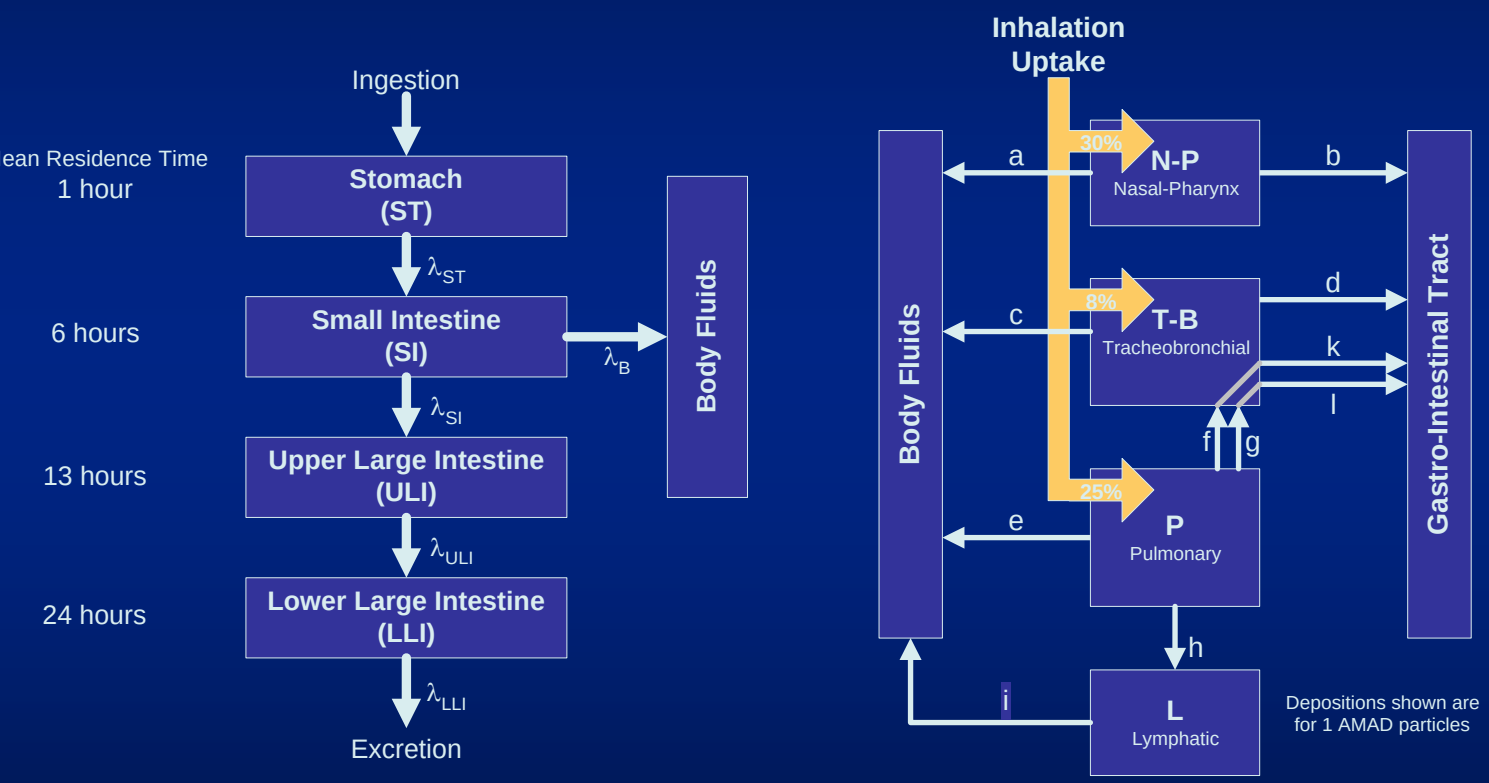
Radiation Fundamentals 101

(as used in assessments/PARs)

- **Internal Dose**
  - Radiation dose that occurs from exposure to radiation emitted by radioactive materials which enter the body by ingestion or inhalation
    - Since material is in contact with internal body tissues, alpha, beta, and photon emitters are a concern
    - Once in the body (i.e. uptake), the radioactive material behaves physiologically as would the stable element
    - Materials are eliminated from the body by normal physiological functions and by radioactive decay (e.g., Cs137 has a radiological half life of 11000 days, a biological removal from lungs of about 140 days)
  - Since the radioactive material is inside the body, the exposure continues until the material is eliminated from the body
    - Protective actions are: sheltering, evacuation, interdiction of contaminated foodstuffs
    - Because of this retention, internal dose from inhaled radioiodine will generally exceed the external dose from standing in a cloud of radioiodine

Radiation Fundamentals 101

(as used in assessments/PARs)



Radiation Fundamentals 101

(as used in assessments/PARs)

- **Special case—submergence in radiogas**
  - Although noble gases can be inhaled, and cause internal exposure, their uptake by the body is minimal
  - Since the volume of the nobles gases that could be contained within the lungs is small in comparison to the volume of plume that the individual is submerged in, noble gases are treated as external exposure

Radiation Quantities 101

(as used in assessments/PARs)

Absorbed Dose: **energy absorbed in tissue** **(rad)**

Dose Equivalent (DE): **absorbed dose adjusted for biological insult** **(rem)**

- Not all absorbed energy has the same effect

Effective Dose Equivalent (EDE): **sum of the products of DE to each organ (external exposure) and a weighting factor** **(rem)**

Deep-Dose Equivalent (DDE): **the DE at a tissue depth of 1 cm** **(rem)**

- Corresponds to the EDE when the dose is distributed evenly over the whole body
- A reasonable assumption for external exposures during an emergency

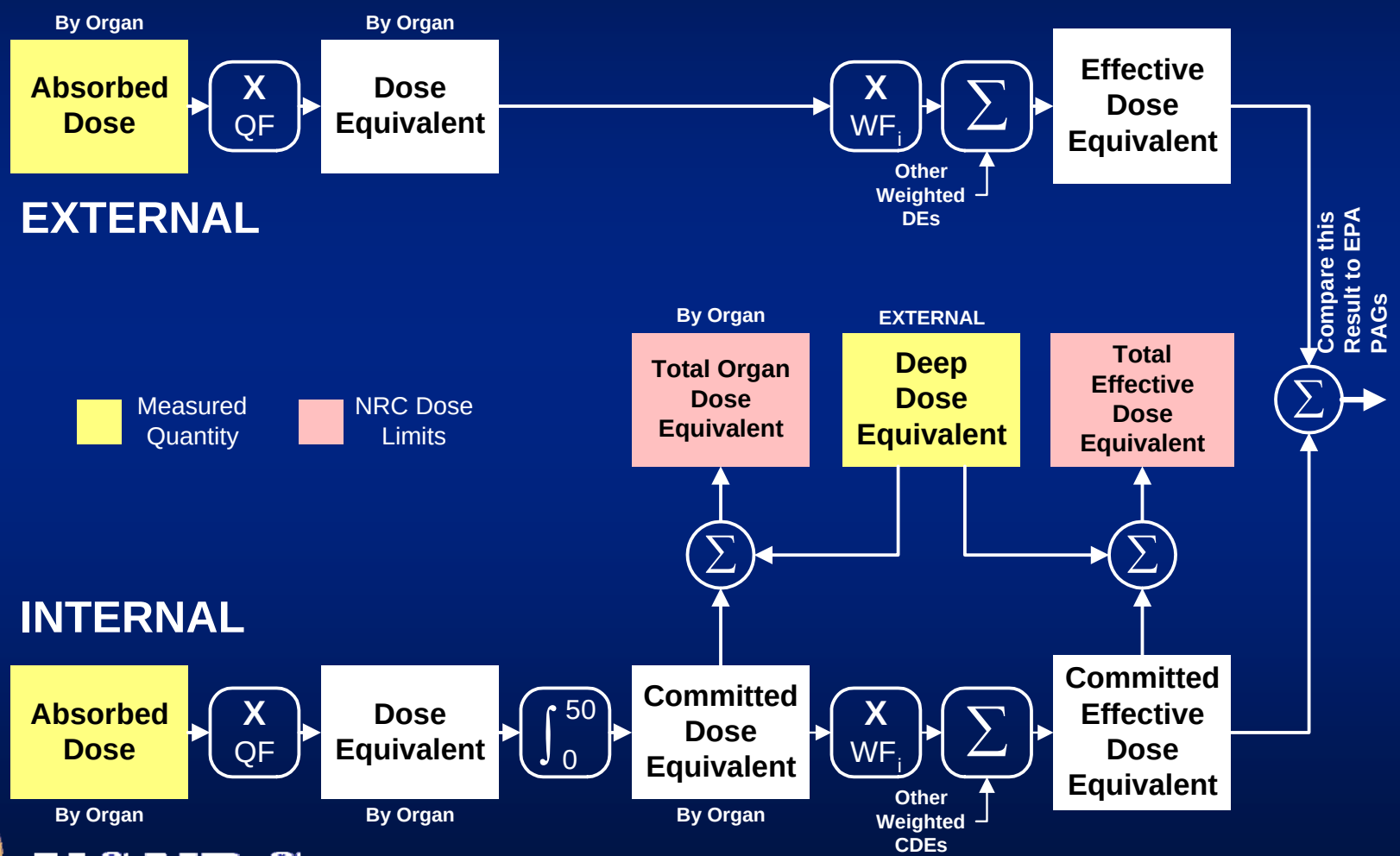
Committed Dose Equivalent (CDE): **DE to an organ due to an intake of radioactive material (internal exposure) integrated over 50 years** **(rem)**

Committed Effective Dose Equivalent (CEDE): **sum of the product of CDE to each organ and a weighting factor** **(rem)**

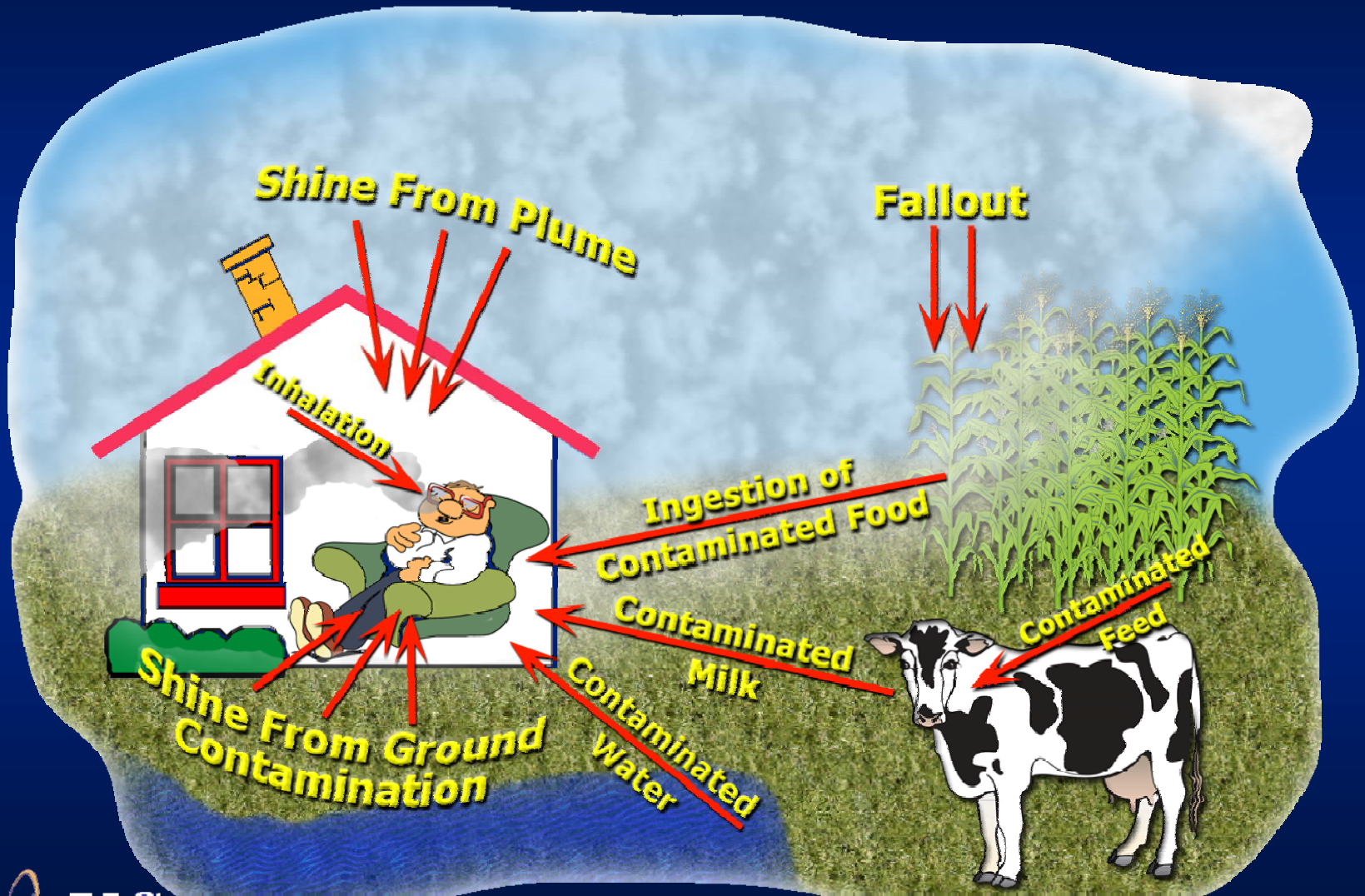
Total Effective Dose Equivalent (TEDE): **sum of DDE and CEDE** **(rem)**

- EPA PAGs use “EDE and CEDE”

Radiation Quantities



Exposure Pathways



EPA PAG Manual Pathways

- The EPA protective action guides assume the following exposure pathways:
  - External exposure to photon radiation from the plume
  - Inhalation of radioactive material in plume
  - External dose from deposited radioactive materials
- Exposure to plume shine and the inhalation of material from the plume continues as long as the plume is transiting the EPZ
- The EPA assumes that exposure to deposited materials continues for four days
  - This is NOT four days of deposition—deposition is limited to the plume transit time
  - The EPA sought to ensure that significant exposure to deposited materials would be considered in making the initial, early phase protective action recommendations
  - Four days was selected as a likely transition point from early phase to intermediate phase
- Most commercial dose assessment programs include this protocol

Semi-infinite Submersion Dose Model

- **Assumptions:**
  - Semi-spherical cloud surrounding the receptor standing on the ground plane having a radius:
    - Larger than the range of the highest energy beta (a few meters)
    - Much larger than the relaxation length for the highest energy photon (100's meters)
  - All radiation emissions within the cloud are absorbed by the receptor

$${}_{\beta}D'_{\infty} = 0.23 \cdot \overline{E}_{\beta} \cdot \chi \qquad {}_{\lambda}D'_{\infty} = 0.25 \cdot \overline{E}_{\lambda} \cdot \chi$$

- *Where*: ${}_{\beta}D'_{\infty},\ {}_{\lambda}D'_{\infty} =$ Dose rate

  $\overline{E}_{\beta}, \overline{E}_{\lambda} =$ Energy per disintegration

  $\chi =$ Concentration in cloud

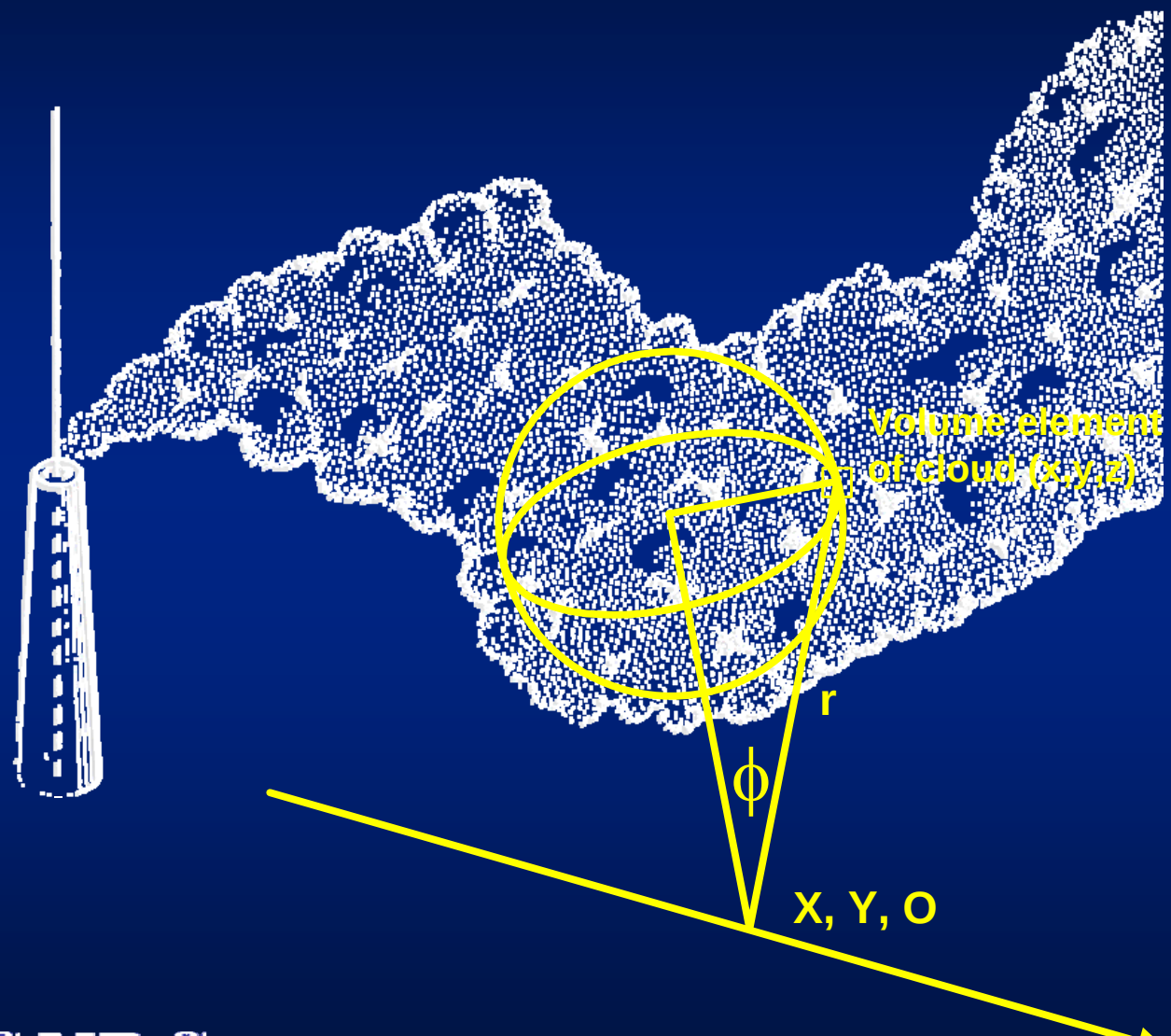
Finite Plume Dose Model

- At close-in distances to the release point, a semi-infinite model can fail to provide adequate estimates because of two situations:
  - The plume may not have reached a size that satisfies the submergence model assumption that the plume is much larger than the relaxation length of the photon emissions in the plume
    - Potential over-estimation of ground level dose
  - The plume may be overhead such that there is no ground level concentration is negligible (no submergence), but the radiation shine from the plume may be significant
    - Potential for significant under-estimation of the ground level dose
    - A particular concern for elevated releases, which are more prevalent at boiling water reactors

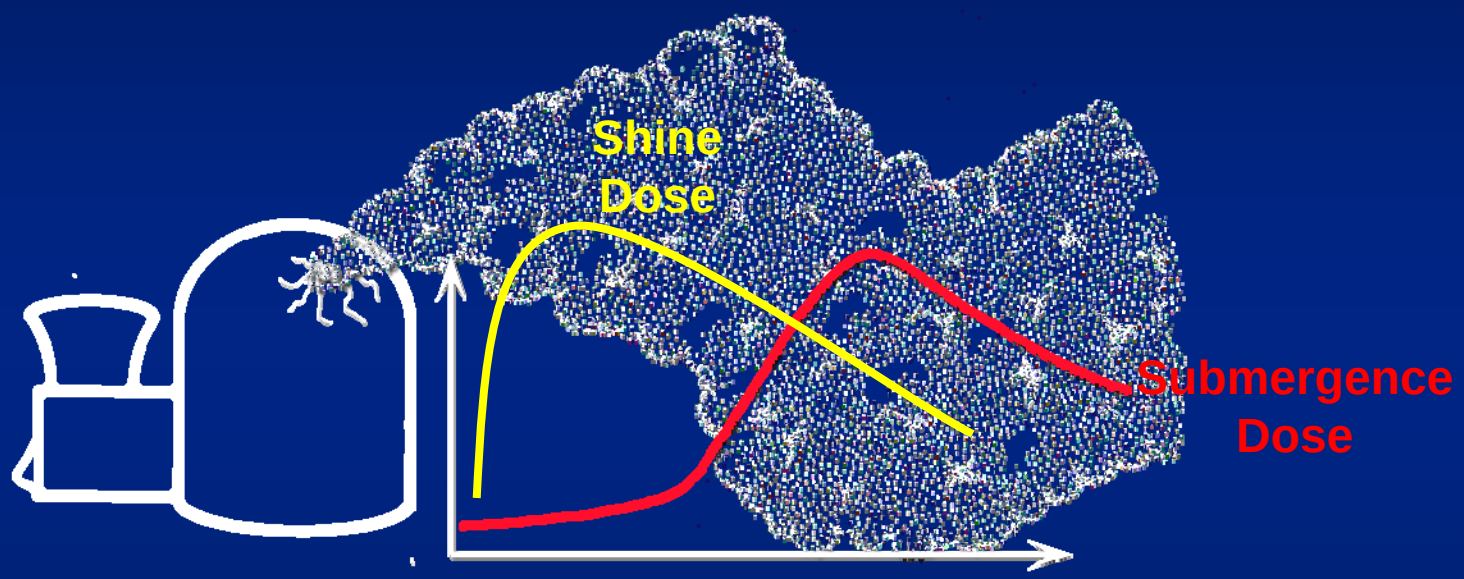
Finite Plume Dose Model

- With current computer processors, the computation burden in calculating the double integrals involved with the finite plume is no longer a limiting condition and this option should probably always be enabled

Finite Plume Dose Model



Finite Plume Dose Model



Curves are conceptual and serve only to illustrate potential underestimation of dose at close-in distances

Age Dependency

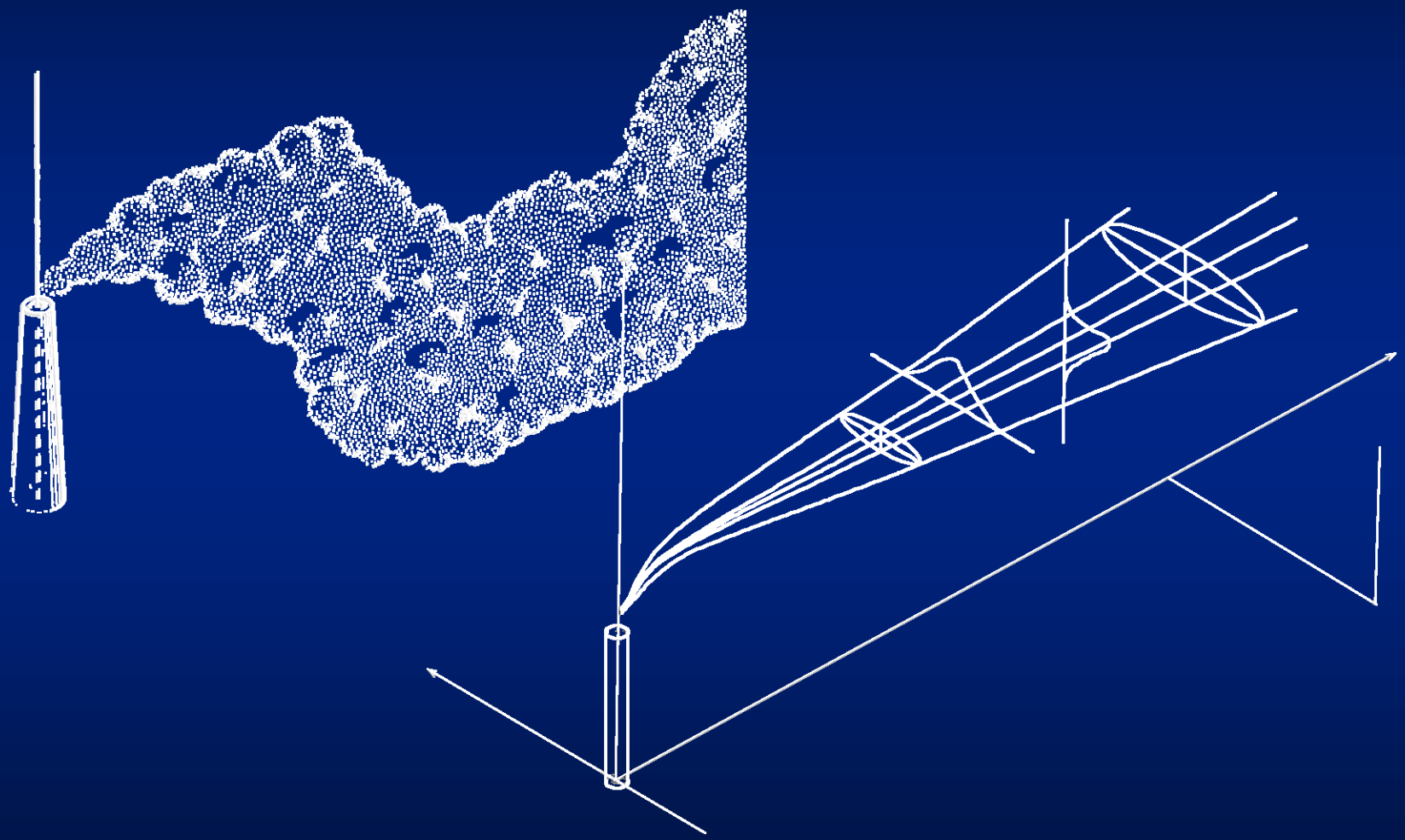
- Dose conversion factors used in dose assessment have traditionally been based on adult populations, with one exception, child thyroid dose was generally calculated
  - Since radiation dose is assessed in terms of energy deposition per unit mass of tissue, the relative sizes of organs in infants, children, teens, and adults can affect the dose.
  - Also, age dependent differences in ingestion or inhalation rates can change the amount of uptake of radioactive materials
- In the 1992 EPA PAG Manual, the EPA suggested basing dose assessment on the adult population
  - PAGs established at levels that will provide adequate protection for the general population
  - EPA rationalized that the family unit would move together and that age dependent dose calculations would unnecessarily increase complexity
- There is work ongoing on age dependent dose conversion factors
  - For the most part, these factors have not been implemented in commercial dose assessment packages (exc. child thyroid)

Tabulated Dose Conversion Factors

- Numerous tabulations of dose conversion factors are available in the open literature, e.g.:
  - Federal Guidance Report No. 11, *"Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion"*
  - Federal Guidance Report No. 12, *"External Exposure to Radionuclides in Air, Water, and Soil"*
- A caution:
  - User needs to understand the technical basis for the tabulated values when selecting values to affirm that the user's intended use is consistent with the author's assumptions in developing the values, e.g.:
    - Dose the table entry for Cs-137 include the contribution from Ba-137m?
    - Does the *"hour"* term in the denominator refer to *"per hour of deposition"* or *"per hour of standing on the deposited contamination*"?
    - Does the integration assume an *acute exposure* or a *chronic exposure*? *50 year* or *70 year* effective dose?

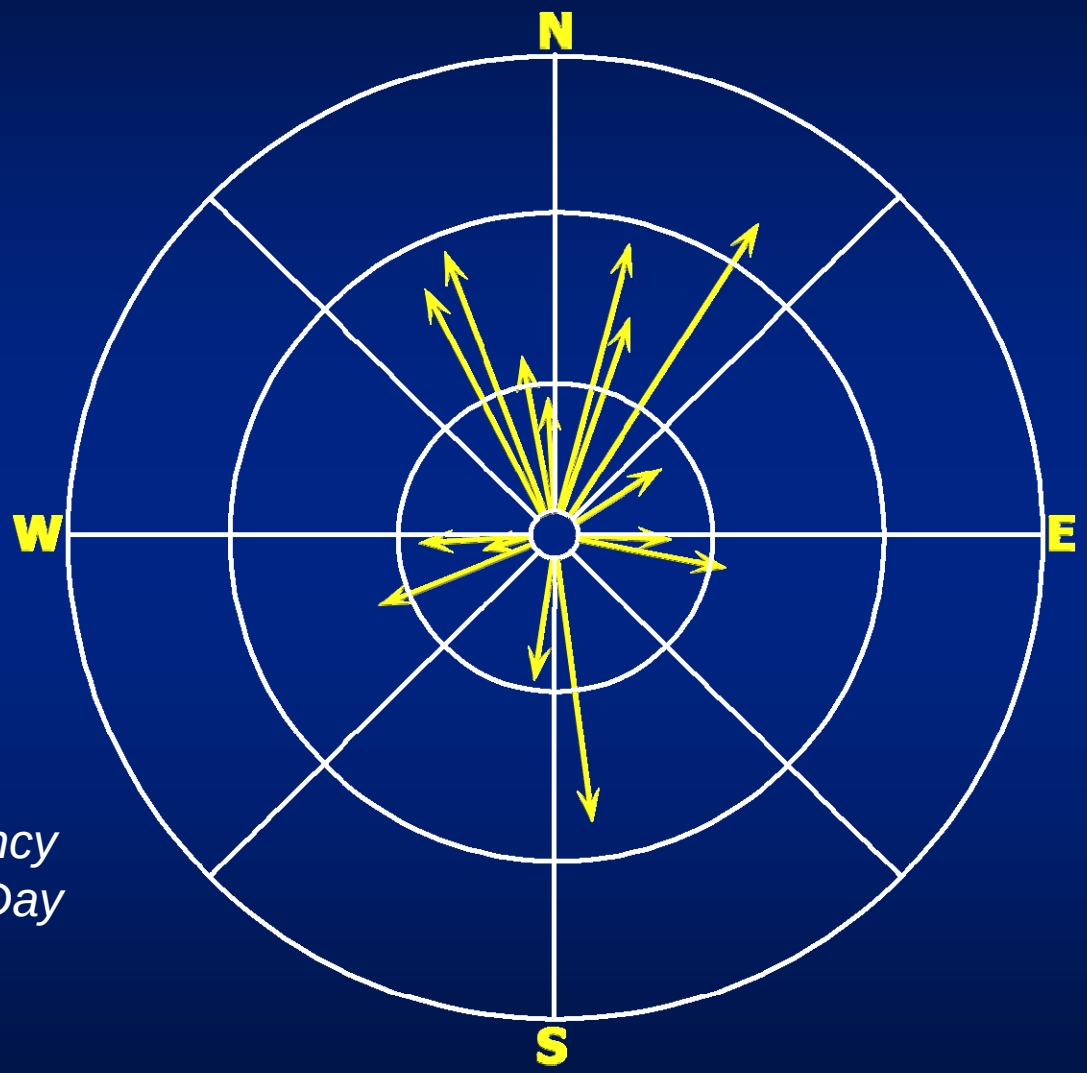
Dose Assessment Uncertainty

Dose Assessment Uncertainty



Dose Assessment Uncertainty

Wind Rose During TMI Accident



Vectors represent frequency of wind directions during Day 1 of the TMI accident.

Uncertainties in Dose Assessment Models

(between projected and actual dose for core melt)

Element	Uncertainty Factor		
	Best	Likely	Worst
OURCE TERM (event and sequence)	5	10^2 - 10^3	10^5
ISPERSION			
iffusion	2	5	10
ransport (direction)	22º	45º	180º
ransport (rate)	1	2	10
OSIMETRY	3	4	5
VERALL			
ose	10	10^2 – 10^4	10^5
irection	22º	45º	180º

REG-1210 v2

Questions?

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