Regulatory Guide 1.109 Exposure Pathways, Equations, and Input Requirements

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Presented at the 23rd Annual RETS-REMP Workshop Training Session
Westminster, CO / 24 Jun 2013

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Regulatory Guide 1.109

- Regulatory Guide 1.109, "*Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance With 10 CFR Part 50, Appendix I* "
- Intended primarily for calculating doses to demonstrate compliance with 10CFR50 Appendix I effluent ALARA objectives
- Also applicable to demonstrate compliance with 10CFR20 and 40CFR190 dose limits

History

- Regulatory Guide 1.109, Revision 0 first issued in March 1976
- Extensive revision reissued as Revision 1 in October 1977 to address consistent approach to demonstrating compliance with 10CFR50 Appendix I; ***Current Version Available***
- Based on modeling approaches developed in 1960s-1970s, use dose factors from ICRP-2, circa late 1950s
- Incorporated into NRC computer codes LADTAP and GASPAR
- Possible updates being considered to support new construction and transition to ICRP-103; likely several years off

Sections of RG-1.109

- Regulatory Position – first section of report containing major equations for calculation of all liquid and gaseous exposure pathway doses
- Appendix A – Liquid effluent pathways expanded equations, factors, and assumptions
- Appendix B – Noble gas pathways expanded equations, factors, and assumptions
- Appendix C – Gaseous effluent particulate, iodine, tritium, C-14 pathways expanded equations, factors, and assumptions
- Appendix D – Population dose assumptions (no longer required)
- Appendix E – important numerical constants, usage factors, dose conversion factors, etc.
- Appendix F – Methods for evaluating the noble gas I function

Digesting RG-1.109

- RG-1.109 contains a large number of equations and data tables
- Can appear to be a daunting task the first time one reads into the document... equations are SCARY!!!
- Question: *How do you eat an elephant?*
- Answer: *One bite at a time!*

General Approach

- Logical progression of steps
  1. Use effluent release to calculate nuclide concentrations in environmental media of interest, usually air, water and food products... pCi/m^3, pCi/L, pCi/kg
  2. Multiply media nuclide concentration by human intake and consumption rates to calculate radionuclide intake... pCi/kg * kg/yr = pCi/yr
  3. Multiply radionuclide intake by dose conversion factor to determine resulting dose...
     pCi/yr * mrem/pCi = mrem/yr
- Consumption rates and dose conversion factors are age-specific... infant, child, teen, adult

Understanding Equations

- Become accustomed to dimensional analysis; make sure units cancel each other out when multiplying and dividing; uncanceled units make up term of interest
- Pay special attention to time units, especially in half-lives, decay constants, delay times, buildup times, etc. – some equations use differing units

Equilibrium Buildup Equation

- Appears in many equations; has units of time = hours, days, years; larger value for long half-life –> I-131=small, Cs-137=BIG, due to less decay over duration of buildup
- ~95% equilibrium reached after ~4.3 half-lives

Assumed buildup period - hours, days, or years

$$\frac{[1 - \exp(-\lambda_i t_b)]}{\lambda_i}$$

Nuclide half-life - ln(2) ÷ T1/2, inverse units of hours, days, or years

Exposure Pathways - Liquid

- Liquid Effluent Pathways
  - Potable Water ingestion – internal radiation
  - Aquatic Food ingestion – internal radiation
  - Shoreline Deposits – external radiation
  - Irrigated Crop ingestion – internal radiation
  - Milk and meat ingestion – internal radiation
    - Animals derive radionuclide intake from drinking contaminated water and eating irrigated vegetation and forage

Exposure Pathways - Gaseous

- Gaseous Effluent Pathways
  - Noble gas exposure – external radiation
  - Ground deposition exposure – external radiation
  - Inhalation – internal radiation
  - Crop ingestion – internal radiation
  - Milk and meat ingestion – internal radiation
    - Animals derive radionuclide intake from eating vegetation and forage contaminated by deposition, direct on vegetation or uptake from soil by roots

Liquid Discharge - General Equation

- RG-1.109 Equation A-1

Usage factor for age class a of exposure pathway p - kg/yr, L/yr, hr/yr

Dose to age class a from radionnuclide i in exposure pathway p to organ j - mrem/yr

$$R_{aipj} = C_{ip} \; U_{ap} \; D_{aipj}$$

Concentration of radionuclide i in exposure pathway p - pCi/kg, pCi/L, pCi/m^2

Dose factor for age class a from radionuclide i in exposure pathway p to organ j - mrem/pCi, mrem/hr

Liquid Discharge
Ingestion – Potable Water

- RG-1.109 Equations 1, A-2

Dose - mrem/yr for age group a, organ j

Usage factor - L/yr for age group a

Mixing ratio - dimensionless

Nuclide release - Ci/yr

$$R_{apj} = 1100 \frac{U_{ap} M_p}{F} \sum_i Q_i D_{aipj} \exp(-\lambda_i t_p)$$

Unit conversion factor, Ci/yr and ft^3/sec to pCi/L

Flow rate into water body - ft^3/sec

Dose Factor - mrem/pCi for age a, organ j

Decay term

Liquid Discharge
Ingestion – Fish, Invertebrates

- RG-1.109 Equations 2, A-3

$$R_{apj} = 1100 \frac{U_{ap} M_p}{F} \sum_i Q_i \boxed{B_{ip}} D_{aipj} \exp(-\lambda_i t_p)$$

Bioaccumulation factor for nuclide i in media p - pCi/kg per pCi/L; element-specific
freshwater vs. saltwater
fish vs. invertebrate

Liquid Discharge
Ingestion – Water, Fish, Invertebrates

- Examination of common factors
  - Values in red boxes determine the concentration of nuclide i in receiving body of water

$$R_{apj} = \boxed{1100} \frac{U_{ap} \boxed{M_p}}{\boxed{F}} \sum_i \boxed{Q_i} \; D_{aipj} \exp(-\lambda_i t_p)$$

  - Other values affect concentration in media, resulting dose

Liquid Discharge
Shoreline Recreation

- RG-1.109 Equations 3, A-7

Shoreline use factor - hr/yr

Shoreline width factor at exposure location; ranges from 0.1 for steep slope like canal bank, to 0.5 for ocean beach, to 1.0 for tidal basin

Equilibrium buildup term, assumed to be 15-yrs for midpoint of plant operating life; important only for long-lived nuclides

$$R_{apj} = 110{,}000 \frac{U_{ap} M_p W}{F} \sum_i Q_i T_i D_{aipj} [\exp(-\lambda_i t_p)][1 - \exp(-\lambda_i t_b)]$$

Proportionality constant to convert Ci/yr and ft^3/sec to pCi/L, with assumptions of transfer of nuclide activity from water to sediments

Nuclide half-life - days

External dose conversion factor - mrem/hr per pCi/m^2

Liquid Discharge
Sediment Concentration – pCi/kg

- RG-1.109 Equation A-4

Concentration of nuclide i in sediment - pCi/kg

Concentration of nuclide i in water pCi/L

$$C_{is} = K_c \, C_{iw} \, \frac{[1 - \exp(-\lambda_i t_b)]}{\lambda_i}$$

Transfer coefficient from water to sediment - L/kg-hr ≈ 0.072; one value for all nuclides, but likely depends on element and type of sediment

Buildup term based on 15-yr, midpoint of plant life

Liquid Discharge
Sediment Concentration – pCi/m^2

- RG-1.109 Equation A-5

Area sediment concentration - pCi/m^2; assumes 2.5 cm layer

Concentration in water - pCi/L

Shoreline width factor

$$S_i = 100\, T_i\, C_{iw}\, W\, [1 - \exp(-\lambda_i t_b)]$$

Proportionality constant - L/m^2-day; combines K transfer coefficient, soil density in 2.5cm layer, time conversion

Nuclide half-life - days

Portion of buildup equation

Liquid Discharge
Irrigation Ingestion – All Pathways

- RG-1.109 Equations 4, A-13

For all radionuclides except tritium:

$$R_{apj} = U_{ap}^{veg} \sum_i d_i \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right]$$

$$+ U_{ap}^{animal} \sum_i F_{iA} D_{aipj} \left\{ Q_F d_i \exp(-\lambda_i t_h) \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_I} \right] + C_{iAw} Q_{Aw} \right\}$$

Dose from crop ingestion

Dose from meat ingestion

For tritium:

$$R_{apj} = U_{ap}^{veg} C_v D_{apj} + U_{ap}^{animal} D_{apj} F_A (C_v Q_F + C_{Aw} Q_{Aw})$$

Liquid Discharge
Ingestion – Vegetables and Crops

- RG-1.109 Equation A-8

Foliar contamination term - "external" contamination on surface of plants

Root uptake term - "internal" contamination of plants from uptake from soil by roots

Concentration in vegetation - pCi/kg

$$C_{iv} = d_i \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P \lambda_i} \right] \exp(-\lambda_i t_h)$$

Deposition rate - pCi/m^2-hr, product of water concentation in pCi/L and irrigation rate in L/hr

Decay between time of harvest and time of consumption

- For tritium, concentration in vegetation assumed to be same as that in irrigation water

Liquid Discharge
Ingestion – Vegetables and Crops -2

- RG-1.109 Equation A-8

Fraction of deposited activity that remains on plant

Fraction of year that crop is irrigated

Soil to plant transfer coefficient - pCi/kg in plant per pCi/kg in soil

$$C_{iv} = d_i \left[\frac{r\,[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v\,\lambda_{Ei}} + \frac{f_I\,B_{iv}\,[1 - \exp(-\lambda_i t_b)]}{P\,\lambda_i} \right] \exp(-\lambda_i t_h)$$

Vegetation yield - kg/m^2

Effective half-life of activty on surface as a function of weathering

Soil density - kg/m^2

Liquid Discharge
Ingestion – Animal Products

- RG-1.109 Equation A-11

Concentration of nuclide i in media milk - pCi/L, meat - pCi/kg

Concentration of nuclide i in animal forage pCi/kg

Concentration of nuclide i in water pCi/L; zero if animals don't drink affected water

$$C_{iA} = F_{iA} \left[C_{iF} Q_F + C_{iAw} Q_{Aw} \right]$$

Stable element transfer coefficient - pCi/L per pCi/day for milk; pCi/kg per pCi/day for meat

Forage ingestion rate - kg/day

Water ingestion rate - Liters/day

Liquid Discharge
Irrigation Ingestion – All Pathways

- RG-1.109 Equations 4, A-13

For all radionuclides except tritium:

$$R_{apj} = U_{ap}^{veg} \sum_i d_i \exp(-\lambda_i t_h) D_{aipj} \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_i} \right]$$

$$+ U_{ap}^{animal} \sum_i F_{iA} D_{aipj} \left\{ Q_F d_i \exp(-\lambda_i t_h) \left[\frac{r[1 - \exp(-\lambda_{Ei} t_e)]}{Y_v \lambda_{Ei}} + \frac{f_I B_{iv}[1 - \exp(-\lambda_i t_b)]}{P\lambda_I} \right] + C_{iAw} Q_{Aw} \right\}$$

Dose from crop ingestion

Dose from ingestion of animal products, milk & meat

For tritium:

$$R_{apj} = U_{ap}^{veg} C_v D_{apj} + U_{ap}^{animal} D_{apj} F_A (C_v Q_F + C_{Aw} Q_{Aw})$$

Gaseous Noble Gases

Gamma Air Dose from Stack >80 m high

- RG-1.109 Equations 6, B-1

Unit conversion factor to calculate mrad/yr
mrad-radians-m^3-disintegration/sec-MeV-Ci

Numeric integration constant as a function of release height, wind speed, stability class, vertical plume standard deviation, and photon energy; dimensionless
See Appendix F

Photon yield for photons in energy group k from decay of noble gas i
photons/disintegration

Gamma air dose at distance r in sector θ
mrad/yr

Joint frequency of stability class s in wind speed class n at sector θ

$$D^{\gamma}(r,\theta) = \frac{260}{r\,(\Delta\theta)} \sum_n \frac{1}{u_n} \sum_s f_{ns} \sum_k \mu_a(E_k)\, E_k\, I(H,u,s,\sigma_z,E_k) \sum_i Q^D_{ni}\, A_{ki}$$

Distance to receptor meters

Sector width for averaging at receptor radians

Mean wind speed in wind speed class n
m/sec

Air energy apsorption coefficient for k-th photon energy group
1/meters

Energy of the k-th photon energy group
MeV

Release rate of noble gas i decayed for transit to distance r under wind speed class n
Ci/yr

Gaseous Noble Gases

Transit Decay Correction for Noble Gas

- RG-1.109 Equation B-3

Release rate of noble gas i corrected for decay at distance r under wind speed un Ci/yr

Decay constant for noble gas i 1/ sec

Note that decay constant is based on nuclide half-life in seconds

$$Q^D_{ni} = Q_i \exp(-\lambda_i \, r / u_n)$$

Initial release rate of noble gas i Ci/yr

Distance to receptor meters

Mean wind speed meters/sec

Gaseous Noble Gases

Gamma/Beta Air Dose from all Releases <80 m high

- RG-1.109 Equations 7, B-5
  - Receptor assumed to be immersed within plume

Gamma air dose or Beta air dose at distance r in sector mrad/yr

Annual release rate of noble gas i Ci/yr

Atmospheric dispersion coefficient X/Q at distance r in sector sec/m^3 decayed for transit to receptor location

$$D^{\gamma}(r,\theta) \text{ or } D^{\beta}(r,\theta) = 3.17 \times 10^{4} \sum_{i} Q_i \, [\chi/Q]^{D}(r,\theta) \, (DF_i^{\gamma} \text{ or } DF_i^{\beta})$$

Unit conversion factor pCi/Ci ÷ sec/yr

Dose conversion factor for noble gas i for Gamma air dose or Beta air dose mrad-m^3/pCi-yr

Gaseous Noble Gases

Noble Gas Ground Concentration

- RG-1.109 Equation B-4

Airborne concentration of noble gas i at distance r in sector θ pCi/m^3

Release rate of noble gas i Ci/yr

$$\boxed{\chi_i(r,\theta)} = \boxed{3.17 \times 10^4} \; \boxed{Q_i} \; \boxed{[\chi/Q]^D(r,\theta)}$$

Unit conversion pCi/Ci ÷ sec/yr

Atmospheric dispersion coefficient X/Q at distance r in sector θ sec/m^3 decayed for time of transit to distance r

Gaseous Noble Gases

Total Body Dose from Stack >80 m high

- RG-1.109 Equations 8, B-6

Total body dose at location(r,θ) mrem/yr

Gamma air dose at location(r,θ) mrad/yr

Tissue energy absorption coefficient cm^2/gram

$$D^T(r,\theta) = 1.11 \; S_F \sum_k D_k^\gamma(r,\theta) \exp\left[-\mu_a^T(E_k)\, t_d\right]$$

Average ratio of tissue to air energy absorption coefficients

Shielding factor for residential structures
Outdoor = 1
Indoor = 0.7

Product of tissue density and depth used to calculate total body dose grams/cm^2

Gaseous Noble Gases

Skin Dose from Stack >80 m high

- RG-1.109 Equations 9, B-7

Annual skin dose at location (r,θ) mrem/yr

Gamma skin dose component at location (r,θ) calculated from gamma air dose at location (r,θ) adjusted for shielding and energy absorption mrem/yr

Beta skin dose component at location (r,θ) from immersion within a semi-infinite plume of noble gas mrem/yr

$$D^S(r,\theta) = 1.11\ S_F\ D\gamma(r,\theta) + 3.17 \times 10^4 \sum_i Q_i\ [\chi/Q]^D(r,\theta)\ DFS_i$$

Annual release rate of noble gas i Ci/yr

Atmospheric dispersion coefficient X/Q at location (r,θ) sec/m^3

Beta skin dose conversion factor assuming immersion within a semi-infinite cloud of noble gas i mrem/yr per pCi/m^3

Gaseous Noble Gases

Total Body Dose for all Releases <80 m high

- RG-1.109 Equations 10, B-8
  - Receptor assumed to be immersed within plume

Annual total body dose at location mrem/yr

Ground-level airborne concentration of noble gas i at location pCi/m^3

$$D_{\infty}^{T}(r,\theta) = S_F \sum_i \chi_i(r,\theta)\, DFB_i$$

Residential shielding/attenuation Factor

Total body dose conversion factor assuming immersion within a semi-infinite cloud of noble gas i mrem/yr per pCi/m^3

Gaseous Noble Gases

Skin Dose for all Releases <80 m high

- RG-1.109 Equations 11, B-9
  - Receptor assumed to be immersed within semi-infinite plume

Annual skin dose at location mrem/yr

Gamma skin dose component at location calculated from ground-level immersion gamma air dose at location adjusted for shielding and energy absorption mrem/yr

Beta skin dose component at location from immersion within a semi-infinite clooud of noble gas mrem/yr

$$D_{\infty}^{S}(r,\theta) = 1.11\, S_F \sum_i \chi_i(r,\theta) DF_i^{\gamma} + \sum_i \chi_i(r,\theta)\, DFS_i$$

Ground-level concentration in semi-infinite cloud of noble gas i at location pCi/m^3

Beta skin dose conversion factor assuming immersion within a semi-infinite cloud of noble gas i mrem/yr per pCi/m^3

Gaseous Effluent Ground Deposition

- RG-1.109 Equations 12, C-2

Dose to organ j mrem/yr at location(r,Θ)

Shielding Factor - Indoor 0.7 Outdoor 1

Dose factor for organ j when standing on contaminated ground - mrem/hr per pCi/m^2

$$D_j^G(r,\Theta) = 8760\, S_F \sum_i C_i^G(r,\Theta)\, DFG_{ij}$$

Hours/yr

Ground plane concentration of nuclide i at location(r,Θ) in pCi/m^2

Gaseous Effluent
Ground Deposition Concentration

- RG-1.109 Equation C-1

Ground plane concentration of nuclide i at location (r,θ) in pCi/m^2

pCi/Ci

Atmospheric Ground deposition coefficient D/Q at location (r,θ) in 1/m^2

$$C_i^G(r,\theta) = \frac{[1.0 \times 10^{12}]\,[\delta_i(r,\theta)\,Q_i]}{-\lambda_i}\,[1 - \exp(-\lambda_i t_b)]$$

Buildup term

Gaseous Effluent
Inhalation of Radionuclides in Air

- RG-1.109 Equations 13, C-4

Dose to organ j of age class a at location (r,Θ) mrem/yr

Airborne concentration of nuclide i at location (r,Θ) pCi/m^3

$$D^{A}_{ja}(r,\Theta) = R_a \sum_i x_i(r,\Theta)\, DFA_{ija}$$

Inhalation rate of age class a - m^3/yr

Dose factor for organ j in age class a from nuclide i - mrem/pCi inhaled

Gaseous Effluent

Concentration of Radionuclides in Air

- RG-1.109 Equation C-3

Airborne concentration of nuclide i at location (r,Θ) pCi/m^3

Airborne dispersion coefficient X/Q at location (r,Θ) in sec/m^3

$$\boxed{\chi_i(r,\theta)} = \boxed{3.17 \times 10^4}\ \boxed{Q_i}\ \boxed{[\chi/Q]^D(r,\theta)}$$

Unit conversion for pCi/Ci divided by sec/yr - pCi-yr/Ci-sec

Release rate of nuclide i - Ci/yr

Gaseous Effluent

Concentration of Radionuclides in Vegetation

- RG-1.109 Equation C-5
  - Similar to liquid equation A-8, except for atmospheric deposition

Concentration in vegetation at location (r,θ) in units of pCi/kg

$$C_i^v(r,\theta) = d_i(r,\theta)\left\{\frac{r[1-\exp(-\lambda_{Ei}t_e)]}{Y_v\,\lambda_{Ei}} + \frac{B_{iv}\,[1-\exp(-\lambda_i t_b)]}{P\,\lambda_i}\right\}\exp(-\lambda_i t_h)$$

Deposition rate of nuclide i at location (r,θ) in units of pCi/m^2-hr

Decay between time of harvest and time of consumption

Gaseous Effluent

Deposition of Particulate Radionuclides on Vegetation

- RG-1.109 Equation C-6

Deposition rate of nuclide i at location (r,θ) in units of pCi/m^2-hr

Ground deposition coefficient D/Q at location (r,θ) in 1/m^2

$$d_i(r,\theta) = 1.1 \times 10^8 \; \delta_i(r,\theta) \; Q_i$$

Unit conversion of pCi/Ci divided by hours/year - pCi-yr/Ci-hr

Release rate of nuclide i - Ci/yr

Gaseous Effluent

Deposition of Radioiodines on Vegetation

- RG-1.109 Equation C-7

Deposition rate of nuclide i at location (r,θ) in units of pCi/m^2-hr

Ground deposition coefficient D/Q at location (r,θ) in 1/m^2

$$d_i(r,\theta) = 5.5 \times 10^7 \; \delta_i(r,\theta) \; Q_i$$

Unit conversion of pCi/Ci divided by hours/year - pCi-yr/Ci-hr assumes 50% of iodine is elemental and subject to deposition; non-elemental assumed to remain airborne

Release rate of nuclide i - Ci/yr

Gaseous Effluent

Concentration of Carbon-14 in Vegetation

- RG-1.109 Equation C-8

Concentration of C-14 in vegetation at location (r,θ) pCi/kg

Fraction of plant mass assumed to be carbon

Carbon content of atmosphere, g/m^3

pCi/Ci * g/kg ÷ sec/yr

$$C^{v}_{14}(r,\theta) = 3.17 \times 10^{7}\ p\ Q_{14}\ [\chi/Q](r,\theta)\ 0.11\ /\ 0.16$$

$$= 2.2 \times 10^{7}\ p\ Q_{14}\ [\chi/Q](r,\theta)$$

Product of numeric constants

Fractional equilibrium ratio, hours of release per yr divide by hours of photosynthesis/yr

Atmospheric dispersion coefficient X/Q at location (r,θ)

Gaseous Effluent

Concentration of Tritium in Vegetation

- RG-1.109 Equation C-9

Concentration of tritium in vegetation at location (r,θ) pCi/kg

Fraction of plant mass assumed to be water

Ratio of tritium concentration in plant water to tritium concentration in atmospheric water

pCi/Ci *g/kg ÷ sec/yr

$$C_T^V(r,\theta) = 3.17 \times 10^7 \; Q_T \; [X/Q](r,\theta) \; (0.75) \; (0.5/H)$$

$$= 1.2 \times 10^7 \; Q_T \; [X/Q](r,\theta) \; / \; H$$

Product of numeric constants

Atmospheric dispersion coefficient X/Q at location (r,θ) sec/m^3

Absolute humidity in atmosphere at location (r,θ) g/m^3

Gaseous Effluent

Concentration in Milk

- RG-1.109 Equation C-10

Concentration of nuclide i in milk at location (r,θ) pCi/L

Concentration of nuclide i in animal feed at location (r,θ) pCi/kg

Decay during transit of milk to receptor

$$C_i^m(r,\theta) = F_m \, C_i^v(r,\theta) \, Q_F \, \exp(-\lambda_i t_f)$$

Stable element transfer coefficient from forage to milk; cow vs. goat days/Liter

Daily forage consumption rate - kg/d; cow vs. goat

Gaseous Effluent

Concentration in Animal Feed

- RG-1.109 Equation C-11

Concentration in animal feed at location (r,θ) pCi/kg

Concentration in pasture grass at location (r,θ) pCi/kg

Concentration in stored feed at location (r,θ) pCi/kg can be at different location than pasture

$$C_i^v(r,\theta) = f_p \, f_s \, C_i^p(r,\theta) + (1 - f_p) \, C_i^s(r,\theta) + f_p \, (1 - f_s) \, C_i^s(r,\theta)$$

Fraction of year animals feed on pasture

Fraction of daily intake that is pasture grass when animal is on pasture

Fraction of year that animal is not on pasture

Fraction of daily intake that is not pasture grass

Gaseous Effluent

Concentration in Meat

- RG-1.109 Equation C-12

Concentration of nuclide i in meat at location (r,θ) pCi/kg

Concentration of nuclide i in forage at location (r,θ) pCi/kg

Decay during transit of meat to receptor

$$C_i^F(r,\theta) = F_f \, C_i^V(r,\theta) \, Q_F \, \exp(-\lambda_i t_s)$$

Stable element transfer coefficient from forage to meat days/kg

Forage consumption rate kg/day

Gaseous Effluent

Dose from Atmospherically-Released Nuclides in Food

- RG-1.109 Equations 14, C-13

Dose to organ j of age class a from ingestion of all gaseous pathways mrem/yr

Intake of nuclide i from ingestion of non-leafy vegetables, fruits, & grain

Intake of nuclide i from ingestion of milk

Intake of nuclide i from ingestion of meat

Intake of nuclide i from ingestion of leafy vegetables

$$D_{ja}^{D}(r,\theta) = \sum_i DFI_{ija} \left[U_a^v f_g C_i^v(r,\theta) + U_a^m C_i^m(r,\theta) + U_a^F C_i^F(r,\theta) + U_a^L f_\ell C_i^L(r,\theta) \right]$$

Ingestion dose conversion factor for nuclide i to organ j in age class a mrem/yr per pCi ingested

Dose Conversion Factors

- RG-1.109 Internal Dose Conversion Factors
  - Four age classes: adult, teen, child, infant
  - Seven critical organs: Bone, Liver, Total Body, Thyroid, Kidney, Lung, GI-LLI
  - Inhalation: Tables E-7 through E-10
  - Ingestion: Tables E-11 through E-14
- Derived from ICRP-2, late 1950s
- Original RG-1.109 tables only addressed 72 radionuclides; expanded tables in LADTAP/GASPAR addressed 169 radionuclides

Dose Conversion Factors, Part 2

- If nuclide is not included in expanded list, NRC suggests using ICRP-30 dose factors; 855 nuclides
- 10CFR20 revised in 1991 based on ICRP-30 dose models and conversion factors
  - In implementing ICRP-30, NRC abandoned critical organ approach for Committed Effective Dose Equivalent (CEDE), or effective whole body dose based on risk-weighted organ doses
  - ICRP-30 is intended for occupational worker, single age class of Adult; doesn't include other age classes in RG-1.109
- ICRP-72 used internationally; contains age-specific dose factors for six age classes; 761 nuclides

Summary

- RG-1.109 equations are fairly easy to understand if you take the time, and remember to:
  - Step through dimensional analysis – make sure units cancel out, carry remaining units
  - Recognize importance of buildup equations
  - Pay close attention to time units, especially in half-lives, decay equations, and buildup equations

Summary

- RG-1.109 equations generally calculate doses from effluent releases by calculating concentrations in environmental media that result in human exposure
  - Several equations lend themselves to calculating dose from REMP samples; substitute REMP concentrations in place of effluent-derived concentrations, multiply by age-specific usage factors and age-specific dose conversion factors

Questions?