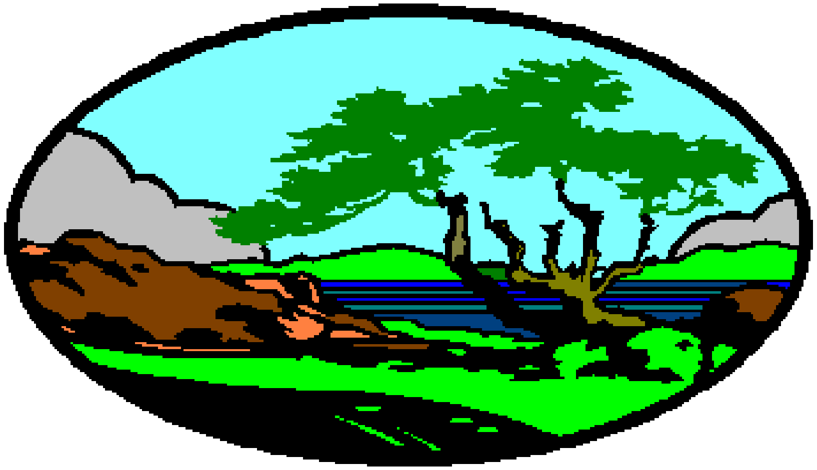
C-14 Environmental Pathways to Man



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Key Solutions

C-14 Background Levels

- Anyone Have Pre-Op Environmental Data for C-14?
- Good Start
  – Select control location upwind and outside of significant plant discharge influence.
  – Assume current C-14 background levels are representative of historical background.

Key Solutions

C-14 Background Levels

- Historical Data for C-14 Levels is Available!
  - Sample Old Growth Near Site
    - Ideally Plant Should Have Reached Maturity Near the Time of Plant Startup
    - Sample Plant Material Laid Down Prior to Initiation of Radiological Releases
    - Provides Historical Snapshot of C-14 Levels for a Know Time Interval

C-14 Background Levels

- Old Growth Sampling Can Provide the Following:
  – Environmental Pre-Op C-14 Levels
  – Reasonable Estimate of Environmental Levels During Operation of Plant
  – Potential for Good Time Resolution (year)

C-14 Background Levels

Tree Ring Sampling for ^{14}C is a Well Established Technique

C-14 Environmental Dilution

- Dilution Occurs During Physical Transport (χ/Q)
- Dilution Occurs at Each Trophic Level
- Dilution Can Occur in Each Environmental Compartment

Key Solutions

C-14 Pathway Considerations

- Only C-14 in CO_2 form is of dosimetric interest.
- Inhalation and Liquid Pathways are insignificant.
- Carbon is transported through the environment without significant biomagnification.
- Human Food Chain
  - Inhalation uptake by animals is negligible.
  - Only viable dose pathways:
    - Vegetation Ingestion OR
    - Products from Animals Feeding on Contaminated Vegetation

Reg Guide 1.109 Model

- Concentration of C-14 in Vegetation - [pCi/kg]

$$C_{14}^{V} = 3.17 \times 10^{7} \cdot p \cdot Q_{14} \cdot \chi/Q \cdot 0.11/0.16$$

Where:

3.17×10^{7}	units factor [pCi/Ci per sec/yr]
p	Fractional equilibrium
Q_{14}	Annual C-14 release rate [Ci/yr]
χ/Q	Atmospheric dispersion [sec/m^3]
0.11	Fraction of total plant mass that is assumed to be carbon
0.16	Natural C concentration in air [g/m^3]

[Eq C-8 from Reg Guide 1.109]

Reg Guide 1.109 Model Parameters

- Equilibrium Fraction
- C-14 Release Rate
- Atmospheric Dispersion
- Plant Carbon Fraction
- Atmospheric Carbon Concentration

Key Solutions

Equilibrium Fraction

- Used to account for intermittent releases.
- 1.109 defines as the ratio of the total annual release time (for C-14 release to the atmosphere) to the total annual time during which photosynthesis occurs.
  - 1.109 assumes annual photosynthesis time of ½ yr or 4400 hours.
  - For continuous C-14 releases this is assumed to be unity.

Equilibrium Fraction

- Actual Photosynthesis Time is Much Shorter
  - Restricted to daylight hours during growing season.
- Example
  - Typical growing season for corn ~ 120 days
    - 1440 hrs of daylight
  - Typical growing season for soy beans ~ 90 days.
    - 1080 hrs of daylight
  - Growing season for lettuce can be as short as 8-10 weeks.
    - 700 to 800 hrs of daylight.

Key Solutions

C-14 Release Rate

- 1.109 Model Assumes
  - Continuous Release
  - Steady State Meteorology
  - Equilibrium in All Environmental Transport Compartments
  - Continuous Uptake

Key Solutions

C-14 Release Rate

- Physical Transport of C-14 is Transient in Nature
  - There is no environmental reservoir that supplies a steady concentration of CO_2 for plant uptake.
  - No integrating compartments such as soil or ground plane.
- Only C-14 released during daylight growing season will be taken up by vegetation.
- CO_2 fixation in plants takes place very quickly.

C-14 Release Rate

- Rate of $^{14}CO_2$ uptake in vegetation will vary diurnally and seasonally.
- Rate of incorporation of CO_2 into vegetation will directly track short term atmospheric concentrations.

Atmospheric Dispersion

[Killough 1978]

- C-14 Inhalation Pathway Should Be Modeled Using Long Term Averaged Dispersion (Annual average χ/Q)
- C-14 Ingestion Pathways Should Be Modeled Using Meteorology During Daytime Growing Season

Growing Season Meteorology

[Killough 1978]

- Growing Season Meteorology Will Differ Significantly From Annual Average –
  - Pasquill Stability Class
    - Summer meteorology results in higher frequency of unstable atmospheric conditions (Pasquill categories A and B)
  - Wind Speed
  - Wind Direction
- Killough Suggests “Renormalization” of Met Data

Key Solutions

Growing Season Meteorology

[Killough 1978]

- Summer daytime meteorology results in higher frequency of unstable atmospheric conditions (Pasquill categories A and B).
- Can Result in *Higher* or *Lower* average ground level concentrations as compared to annual average data set.
- Results are dependant on receptor location as well as release point characteristics.

Growing Season Meteorology

[Killough 1978]

Pasquill Class	Percent Frequency Relative To: Entire Year 24 Hrs/Day	Percent Frequency Relative To: Growing Season (Apr. – Aug.) Daytime Only
Daytime		
A	1.2	4.5
B	8.8	26.9
C	11.0	27.0
D	20.9	41.6
Nighttime		
D, E, F, G	58.1	NA

Growing Season Meteorology

[Killough 1978]

- Killough's results based on data taken in Knoxville, TN exhibited a <u>3 × increase</u> in ground level daytime growing season χ/Q over annual average χ/Q.
- Results will vary at each site – But *there can be significant differences* between daytime growing season χ/Q and annual average.

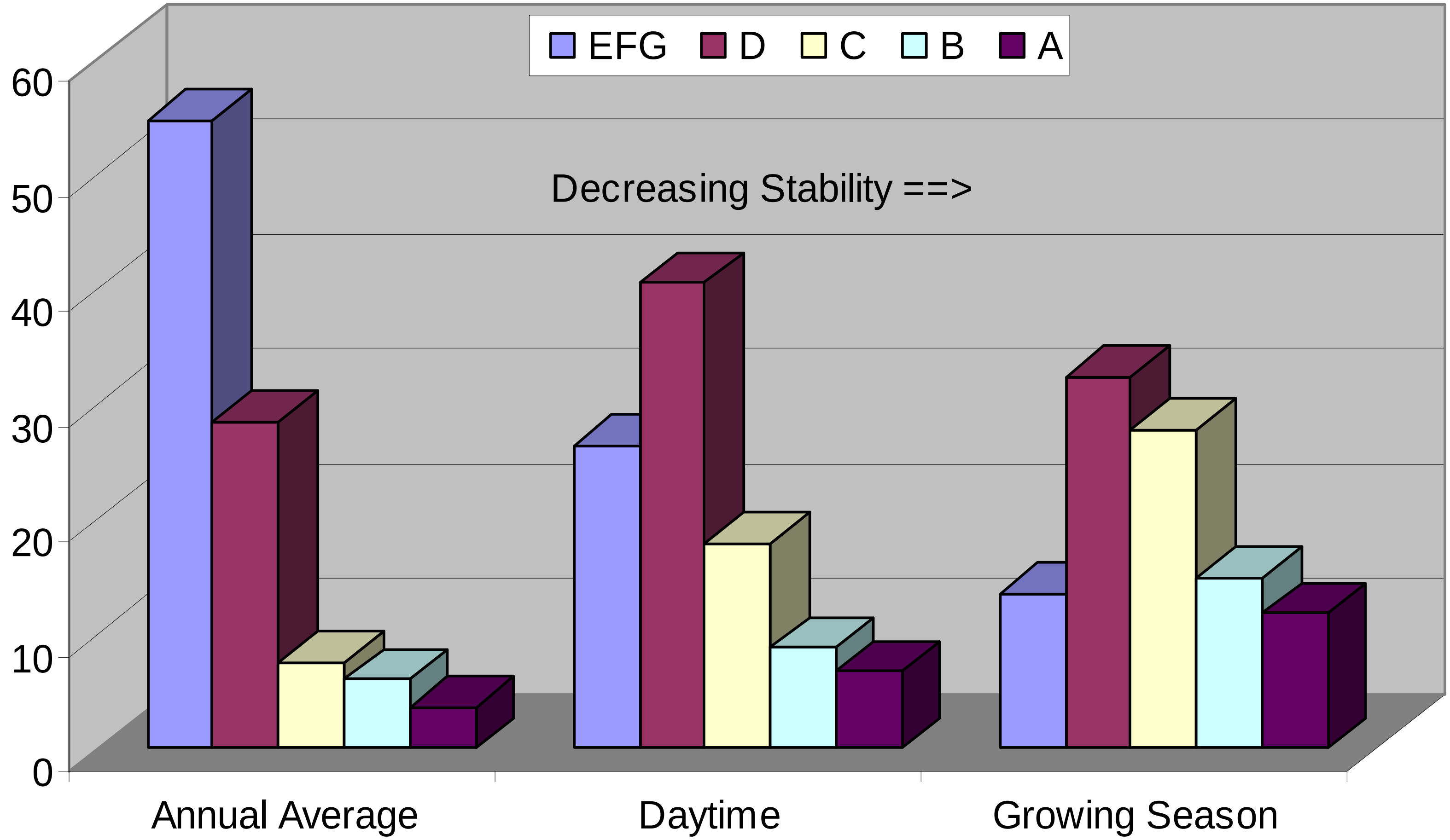
Growing Season Meteorology - Columbia Station

[Madden - 2010]

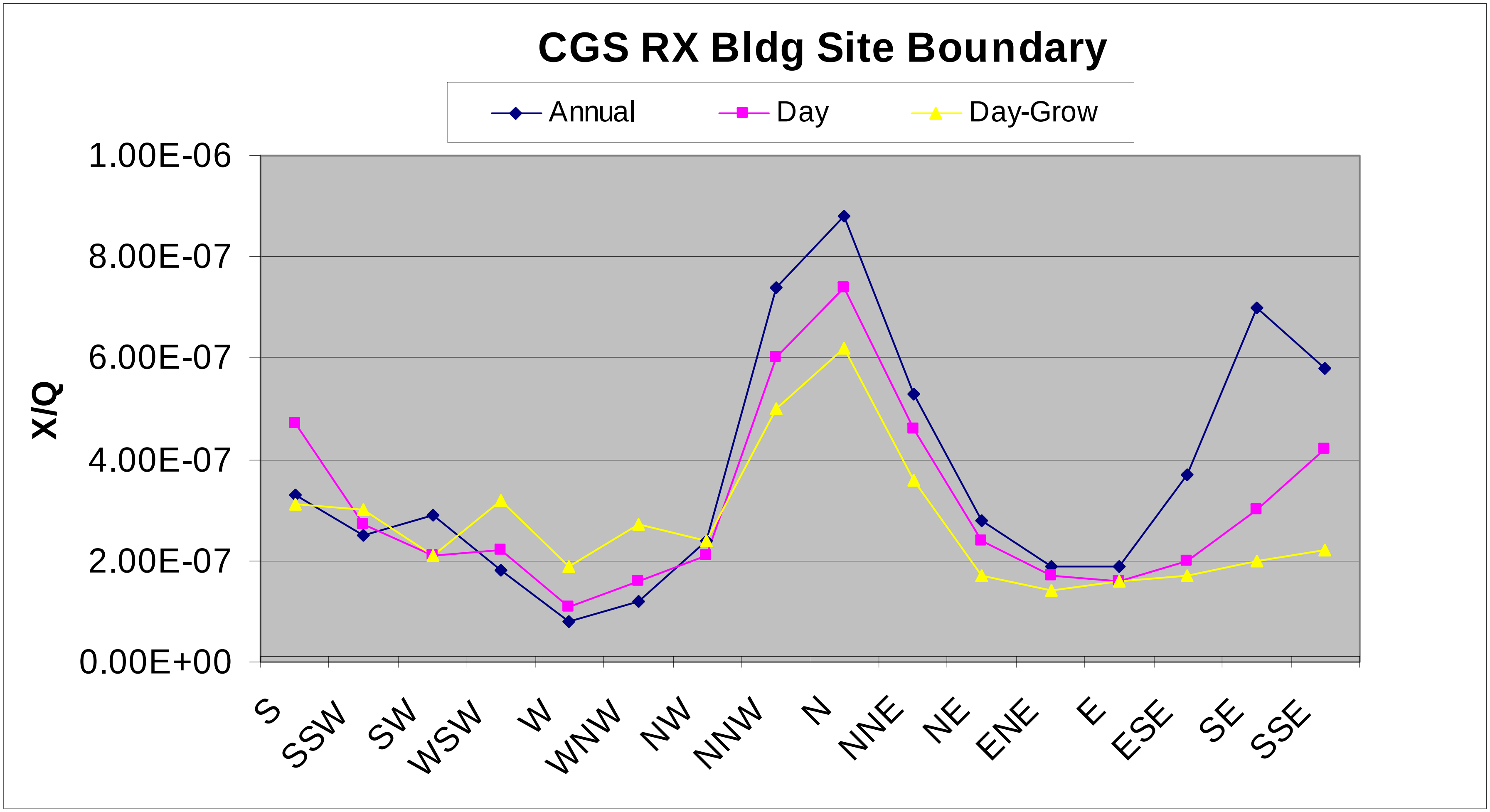
Pasquill Class	Percent Frequency Relative To: Entire Year 24 Hrs/Day	Daytime Only	Growing Season (Apr. – Aug.) Daytime Only
Daytime			
A	3.59	6.7	11.73
B	5.96	8.72	14.8
C	7.41	17.78	27.65
D	28.46	40.46	32.34
Nighttime			
D, E, F, G	54.59	26.33	13.49

Pasquill Stability Category Distribution – CGS

[Madden - 2010]



Effect on X/Q at CGS



Plant Carbon Fraction

- C-14 incorporated into vegetation only in the form of CO_2.
- Essentially 100% of carbon in vegetation comes from the atmosphere.
- Occurs as a result of photosynthesis process.
- For C3 plants this occurs only during daylight hours.

Plant Carbon Fraction

- Rate of $^{14}CO_2$ uptake in vegetation will change dramatically due to meteorology
  - Local atmospheric CO_2 concentrations will vary widely due to micrometeorology.
  - Drought Conditions/Heat Stress
    - Leaf stomas will close in order to conserve plant water effectively shutting down CO_2 intake.
    - Note plants routinely "wilt" during the middle of a hot day to conserve moisture.

Key Solutions

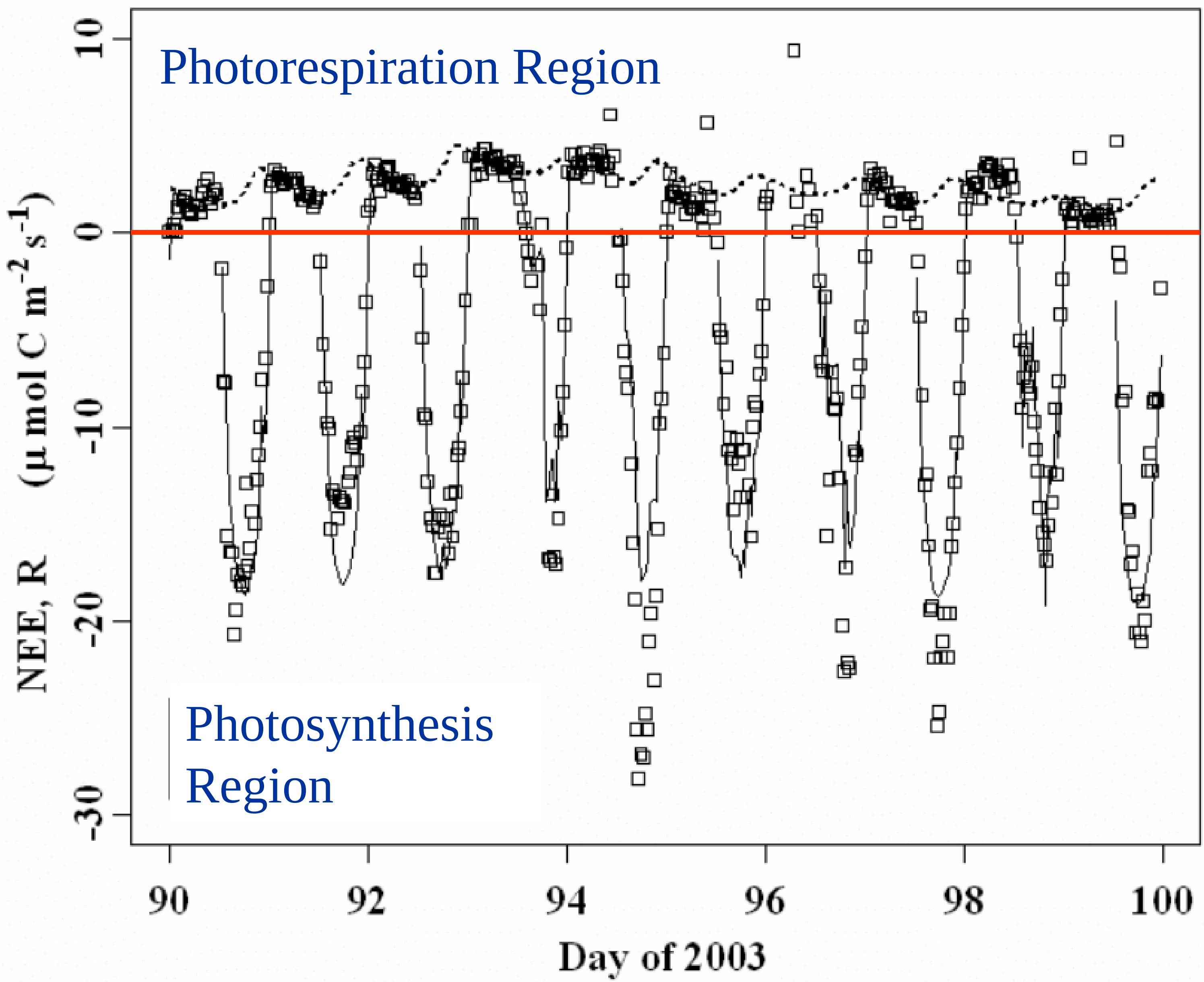
Plant Carbon Fraction

- Initial fixation takes place in chloroplast.
  - CO_2 chloroplast saturation can occur with the result the plant ceases to assimilate CO_2
  - Typically occurs during mid day and can last from minutes to an hour.
  - Chloroplast saturation can actually result in CO_2 being released from the plant
    - Photorespiration.

Key Solutions

Variation of CO_2 Exchange During Growing Season

(Winter Wheat)



[Fischer - 2007]

Plant Carbon Fraction

- Stem and root development can result in inhomogeneous deposition of C-14
  - Concentration of carbon in edible portion of vegetation will change during plant growth cycle.
  - C-14 transported to non-edible portions of plant.
- Biological Half-Life of carbon in crops of 50 days has been proposed. [Collins 2001]

Key Solutions

Vegetation Carbon Fractions

[NCRP – 1983]

g Carbon per Kg Produce	
Leafy Vegetables	
Lettuce, Cabbage, Celery, Spinach, Broccoli, Cauliflower, Brussels Sprouts, Summer Squash	20 - 65
Non-Leafy Vegetables	
Potatoes, Sweet Potatoes, Tomatoes Dried Peas, Sugar Cane, Peanuts, Pecans	395 - 659
Fruits	
Peaches, Apples, Grapes, Strawberries, Cantaloupe	25-83
Grains	
Corn	118
Wheat, Soybeans, Oats, Barley	391 - 465
Miscellaneous	
Eggs	156
Honey	365

Carbon Fractions for Animal Products

[NCRP – 1983]

	g Carbon per Kg Produce
Milk	
Cow	67
Goat	70
Sheep	107
Meat	
Beef	178
Lamb	176
Pork	258
Chicken	155

Carbon Consumption Rate

- 1.109 Model Assumes Ingestion Vegetation Carbon Fraction of 0.11 (110gC / Kg ingested)

1.109 Model Annual Carbon Consumption via Vegetation Pathway (Kg-C / year)

Pathway	Child	Teen	Adult
Fruits, Vegetables and Grain	57	69	57
Leafy Vegetation	3	5	7

- Highest Dietary Carbon Not From Leafy Vegetation
  - Obviously Leafy Vegetation Not Necessarily the Most Important Pathway

Key Solutions

Atmospheric Carbon Concentration

- Seuss Effect
  - Increase in airborne CO_2 results in a decrease in the specific activity of C-14 in the carbon cycle.
  - Effect is to reduce the long-term environmental dose impact from C-14.
  - Urban areas can have elevated CO_2 levels (CO_2 bubble) resulting in lower C-14 specific activity.

Key Solutions

Atmospheric Carbon Concentration
The Seuss Effect

- Concentration of Natural Carbon in Atmosphere in gm-C/m^3
  - The 0.16 gm/m^3 value used in Reg Guide 1.109 value was based on a historical assessment of 326 ppm.
  - Current Global Average is 0.19 gm/m^3 based on 383 ppm.

Isotopic Fractionalization

- Reg Guide 1.109 model assumes the ratio of C-14 to natural C in vegetation is same as ratio of C-14 to natural C in air:
  - i.e. environmental equilibrium
  - and no isotopic effects.
- In fact isotopic effects do occur.
  - $C^{14}O_2$ being a heavier molecule and C^{14} forming slightly stronger bonds undergoes chemical reactions more slowly than $C^{12}O_2$.
  - NCRP Report 76 lists an air to biota isotopic fractionalization value of 0.9. [NCRP - 1985]

Key Solutions

C-14 in Harvested Products

- Once C-14 is fixed and produce harvested there is no removal mechanism.
- Although incorporation of C-14 into vegetation takes place only during the growing season animals and humans can continue to ingest contaminated food stuffs year round.

Key Solutions

C-14 Releases from PWRs

- From PWR Studies (Ginna)
  – Highest C-14 releases occurred during containment venting during outages.
    - Does this occur during growing season?
  – 75% of C-14 was released from Aux Building Ventilation.
    - χ/Q for Aux Building releases – is it significantly different than for other release points?

Kunz - 1982

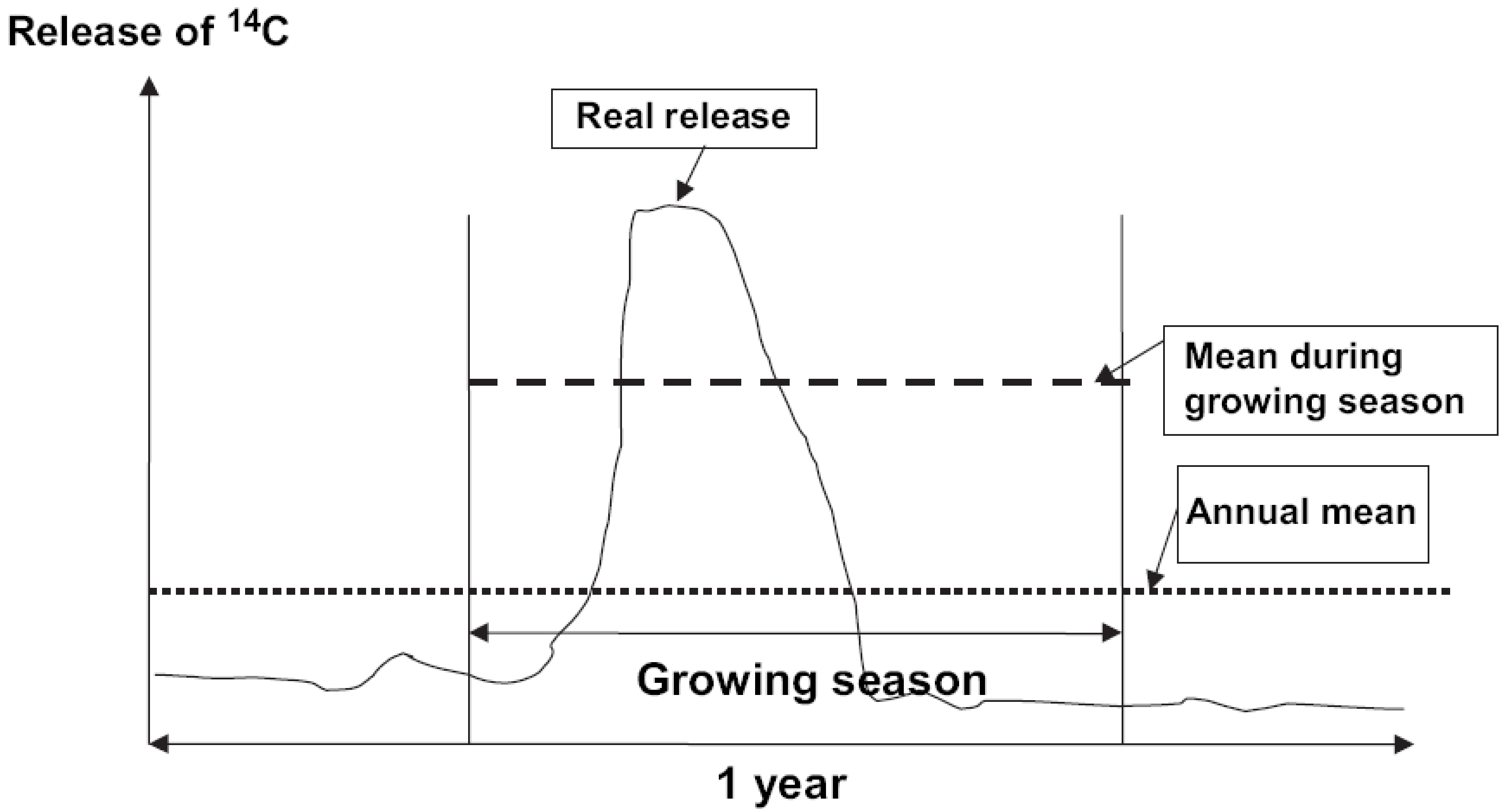
C-14 Releases from PWRs

- Ginna
  - Chemical composition of C-14 gaseous discharges
    - $^{14}CH_4$ (methane) – 69%
    - $^{14}C_2H_6$ (ethane) – 16%
    - $^{14}C_3H_8$ (propane) and $^{14}C_4H_{10}$ (butane) – 5%
    - $^{14}CO_2$ – 10%
  - Organics will be transported out of the local area before oxidizing to CO_2
    - Oxidation of Methane can take 1-10 yrs [NCRP - 1985]

Kunz - 1982

PWR Releases

[Aquilonius – 2005]



Key Solutions

C-14 Releases from BWRs

- From BWR Studies (FitzPatrick)
  - C-14 discharges dropped to essentially zero (< 0.1%) during shutdown.
    - Does this occur during growing season?
  - Release Point Distribution
    - Turbine Bldg – 13%
    - Rx Bldg – 5%
    - RadWaste Bldg – 16%
    - Refuel Floor – 66%

Kunz - 1984

Key Solutions

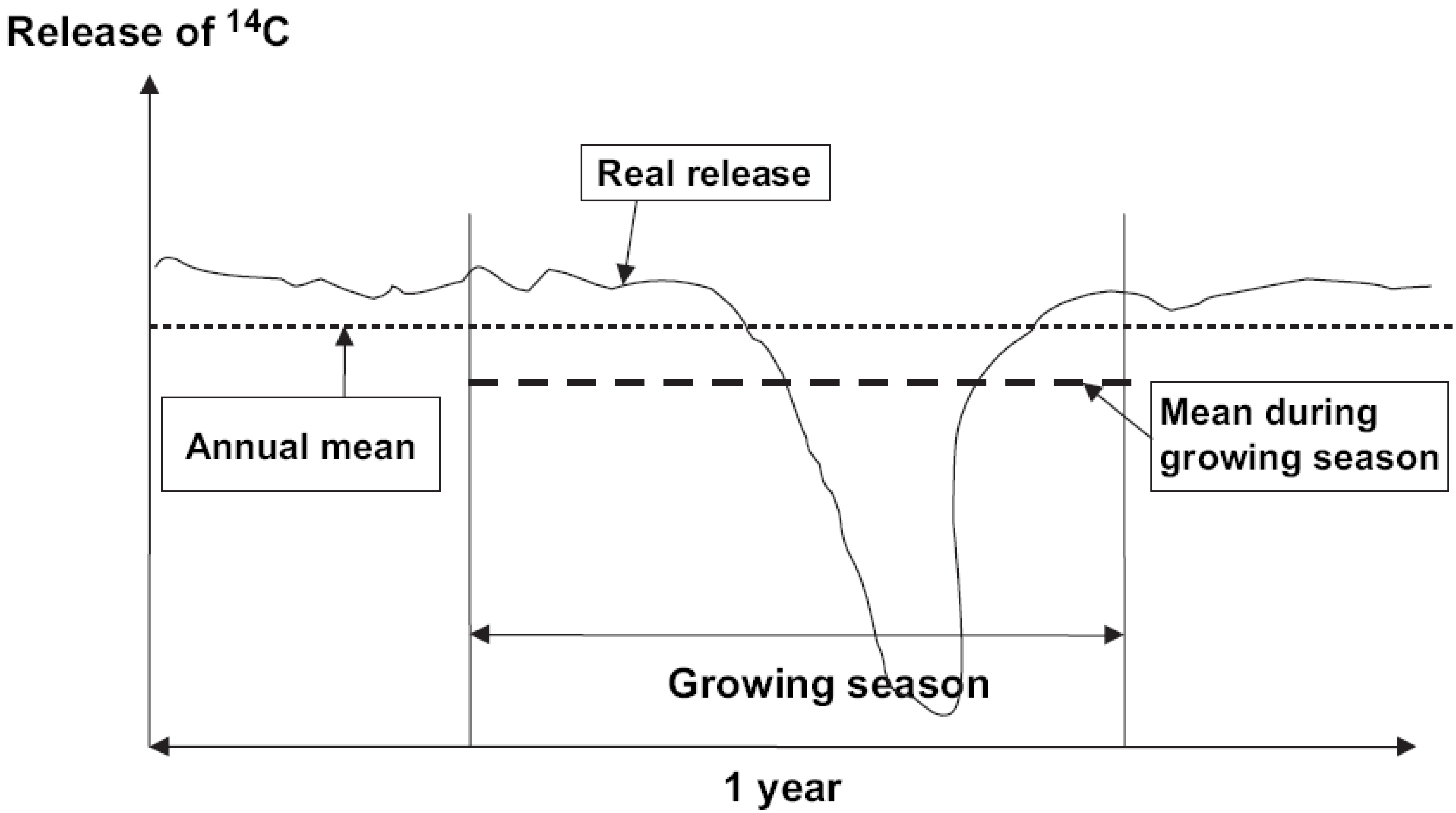
C-14 Releases from BWRs

- From BWR Studies (FitzPatrick)
  - Chemical composition of C-14 gaseous discharges
    - $^{14}CO_2$ – 95%
    - Misc Hydrocarbon Gases – 5%
      - $^{14}CH_4$ $^{14}C_2H_6$ $^{14}C_3H_8$ and $^{14}C_4H_{10}$

Kunz - 1984

BWR Releases

[Aquilonius – 2005]



Operational Considerations

[Davis - 1977]

- Tall Discharge Stack (up to 300 m).
- Increase Gaseous Effluent Plume Buoyancy (and therefore plume rise) by Heating Discharge Gas
- Use of Nocturnal Rather Than Continuous Emissions to Minimize C^{14} Vegetation Uptake
- Schedule Significant Atmospheric C^{14} Releases Outside of Growing Season

Dose to Critical Receptor

The dose to the critical receptor (designated CR Dose) from radioiodines, tritium, and particulates with half-lives greater than 8 days in gaseous effluents release to the unrestricted area is determined as follows:

$$\boldsymbol{CR\ Dose_{api}(mrem) = 3.17 \times 10^{-8} W \sum_{i} R_{aipj} \tilde{Q}_i}$$

Where:

***CR Dose**$_{apj}$* = Is the critical receptor dose for age group **a**, pathway **p**, and organ **j**.

NUREG-0133 Style Dose Calculation for C^{14}

$$D_{apj}^{C-14}(\text{mrem}) = 3.17\times10^{-8}\left[\overline{\chi/Q}\right]\cdot R_{apj}^{C-14}\cdot \tilde{Q}_{C-14}$$

Where:

D_{apj}^{C-14} = Critical Receptor Dose due to C-14 in mrem for age group **a**, pathway **p** and organ **j**.

3.17×10^{-8} = yrs/sec.

$\left[\overline{\chi/Q}\right]$ = Atmospheric Dispersion in sec/m^3.

R_{aj}^{C-14} = C-14 Site Specific Dose Factor in mrem/yr per $\mu Ci/m^3$ for age group **a** and organ **j**.

$\tilde{Q}_{C-14}$ = Total Release of C-14 in μCi.

C^{14} Site Specific Vegetation Dose Factor

$$R_{aj}^{C-14} = 10^{12} \cdot U_a^{VC} \cdot DFL_{aj}^{C-14} \cdot \frac{1}{0.19}$$

Where:

R_{aj}^{C-14} = Site Specific Dose Factor of age group **a**, organ **j**.

10^{12} = pCi/uCi × gm/Kg.

U_a^{VC} = Annual Carbon Ingestion via Vegetation Pathway in Kg-Carbon per yr for age group **a**.

DFL_{aj}^{C-14} = C-14 Ingestion Dose Factor in mrem/pCi for age group **a** and organ **j**.

0.19 = Atmospheric Concentration of Natural Carbon in gm/m^3 based on 383 ppm.

C^{14} Site Specific Carbon Ingestion

$$U_a^{VC} = \sum_G U_{aG}^{V} f_G F_G$$

Where:

U_a^{VC} = Annual Carbon Ingestion via Vegetation Pathway in Kg-Carbon per yr for age group **a**.

U_{aG}^{V} = Annual consumption of vegetation group **G** for age group **a** in Kg/yr.

f_G = Fraction of annual intake of vegetation group **G** grown locally.

F_G = Natural carbon fraction for vegetation group G in Kg-Carbon per Kg-Vegetation.

Key Solutions

REMP Considerations

- Vegetation sampling should be limited to edible portions of food crops.
  - Leafy vegetation not necessarily the most sensitive environmental indicator for C-14.
  - In lieu of sampling food crops - vegetation with similar characteristics of locally grown crops can be sampled. [Reg Guide 4.8]
    - Similar Growing Season
    - Similar Carbon Fractions

REMP Considerations

- Avoid Old-Growth Sampling
  - Not indicative of what is in the actual food chain.
  - Could be used as an indicator of general environmental levels over a longer period of time than represented by growing season sampling.

C-14 Changes Some Things

- For Atmospheric Particulate and H-3
  - Direct deposition and integrating compartments make leafy vegetation highest potential dose pathway.
- For Atmospheric C-14
  - Highest dose driven by local dietary carbon.
  - Food stuffs other than leafy vegetation can become significant.

Guidance Requirements for Pathways Newly Identified by Land Use Census

- NUREGs 0472, 0473, 1301, 1302
  - If new pathway generates dose commitments greater than current locations (airborne releases) –
    - Identify in next annual REMP report.
  - Dose commitments 20% or greater (via current pathways) than current locations –
    - Add to REMP within 30 days.
    - Details in REMP report.
- Reg Guide 1.109
  - If new pathway adds a dose increment of 10% it is considered a significant dose pathway and therefore ODCM dose calculations should address it.

Key Solutions

Summary

- Establish Local Background Levels
- Renormalize Local Meteorology to Address Daylight Growing Season
  - Dose May Go Up or Down
- Calculate Doses for Plant Releases Occurring Only During Daylight Growing Season
- Determine Site Specific Annual Carbon Consumption for Critical Receptor (CR)
  - Carbon Fractions of Ingested Food stuffs
  - Fraction of Produce Consumed by CR Grown Locally

Summary

- Address Seuss Effect
  - Model C-12 value is 0.19 g/m^3 (vs 0.16 g/m^3 in Reg Guide 1.109).
  - Lowers Dose by Approximately 16%
- Be Alert to Impact of Operations on C-14 Releases
- "… may take account of any real phenomenon or factors actually affecting the estimate of radiation exposure…"
  (10 CFR 50 App I Sec III.A.2)

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