Naturally-occurring Carbon-14 and Implications to Power Plant Dose Assessment

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Presented at the 20th Annual RETS-REMP Workshop
San Jose, CA / 28-30 June 2010

Characteristics of Carbon-14

- Half-life = 5730 years
- Specific Activity = 4.46 Ci/g of C-14
  = 165 GBq/g of C-14
- Natural abundance of ~1.55 ppt of Carbon
- Carbon Spec.Act = 6.9 pCi C-14/g-Carbon
  = 0.26 Bq C-14/g-Carbon
- Weak Beta: 156 keV max., 49.5 keV avg.
- Typical analysis via liquid scintillation

Naturally-Occurring C-14

- Produced primarily by cosmic ray interactions with nitrogen in upper atmosphere
- Natural global inventory of C-14 is ~300 million Curies in the biosphere, mostly in ocean
- Nuclear weapons testing added ~9.6 million Ci, or about 3% of natural inventory
- Total global inventory had been used in the past to argue that power plant emissions would be “insignificant”... primary reason why we haven’t monitored C-14 in effluent

Natural C-14 in Atmosphere

- CRC Handbook: Constituents of Air
  CO_2 Volume Fraction = 3.3E-4
  CO_2 Mass Fraction = 5.0E-4
- CO_2 in air = 0.65 g CO_2/m^3 air
  = 0.18 g C/m^3 air
- C-14 in air = 1.2 pCi C-14/m^3 air
  = 0.044 Bq C-14/m^3 air
- C-14 in air becomes incorporated into vegetation through the process of photosynthesis... implications to ingestion pathways

Natural C-14 in Vegetation

- Regulatory Guide 1.109, Equation C-8
  Carbon Mass Fraction in Vegetation = 0.11
  - Assuming vegetation is comprised of $C_xH_{2x}O_x$ molecules, organic portion of vegetation is ~40% Carbon by weight. Assuming water content of ~75% in edible vegetation, edible vegetation is ~10% carbon by weight
- C-14 in vegetation = 760 pCi C-14/kg veg.
  = 28 Bq C-14/kg veg.
- If you sampled for C-14 in REMP, you'd expect to see such concentrations in your sample media

Power Plant Produced C-14

- Produced primarily by neutron activation of N, O, and C in coolant and other materials in vessel
- Most C-14 remains within the vessel, with primary release mechanism to environment as gaseous effluent
- Normal chemical forms of CO, CO_2, CH_4

Power Plant Produced C-14

- Nominal gaseous release rate is 8 to 12 Ci per Gigawatt (electric)-year
- For BWRs, 90-95% released as CO_2
- For PWRs, 15-20% released as CO_2
- For purposes of dose assessment, only the CO_2 form becomes incorporated into the food chain and is of interest to human dose

Natural C-14 Inventory in Atmosphere in Vicinity of Power Plant

- Assume area of interest is within 5 km radius of plant, 300 meters deep
- Total volume of air within area = 2.4E+10 m^3
- Assuming C-14 content of 1.2 pCi C-14/m^3 air, atmospheric inventory in area = 0.029 Ci
- ***While an annual release of 10 Ci/yr may be insignificant when compared to global inventory, it is <u>NOT</u> insignificant in comparison to the local atmospheric inventory of 0.029 Ci***

Natural C-14 Inventory in Vegetation in Vicinity of Power Plant

- Assume area of interest is within 5 km radius of plant, total land area = 7.9E+7 m^2
- Primary productivity (fixation of carbon in organic material) in temperate areas is 950 g-veg/m^2/yr = 380 g-C/m^2/yr = 3.0E+10 g/yr of carbon "fixed" in vegetation
- Assuming C-14 content of 6.9 pCi C-14/g carbon, vegetation inventory in area = 0.21 Ci/yr... actually less, as this assumes 100% vegetation coverage in area
- ***While an annual release of 10 Ci/yr may be insignificant when compared to global inventory, it is <u>NOT</u> insignificant in comparison to the local vegetation inventory of 0.21 Ci/yr***

Natural C-14 Intake Calculations

- Assume air contains 1.2 pCi C-14/m^3 air
- Using RG-1.109 Equation C-8, vegetation material (fruits, vegetable, grains) contains 840 pCi C-14/kg
- Using RG-1.109 meat transfer coefficients, meat contains 1300 pCi C-14/kg
- Using RG-1.109 milk transfer coefficients, milk contains 500 pCi C-14/Liter

Natural C-14 Intake Calculations

- Assumed RG-1.109 age-specific usage factors
- Child age class yielded highest dose
- Inhalation intake = 4500 pCi/yr
- Fruit+veg intake = 436,000 pCi/yr
- Leafy Vegetable intake = 21,800 pCi/yr
- Meat intake = 53,300 pCi/yr
- Milk intake = 166,000 pCi/yr

Natural C-14 Dose Consequence

Child dose by pathway – mrem/yr

Pathway	RG-1.109		ICRP-72
	Bone	Other	EDE
Inhalation	4.4E-02	8.2E-03	1.8E-04
Fruit+Veg	5.3E+00	1.1E+00	1.6E+00
Leafy Veg	2.6E-01	5.3E-02	8.0E-02
Meat	6.4E-01	1.3E-01	2.0E-01
Milk	2.0E+00	4.0E-01	6.1E-01
Total	**8.2E+00**	**1.6E+00**	**2.5E+00**

- ***Such doses from natural C-14 are much higher than gaseous effluent doses from most power plants!***

Natural C-14 Dose Consequence

Child dose fraction by pathway

Pathway	RG-1.109		ICRP-72
	Bone	Other	EDE
Inhalation	0.5%	0.5%	0.0%
Fruit+Veg	***64.1%***	***64.1%***	***64.4%***
Leafy Veg	3.2%	3.2%	3.2%
Meat	7.8%	7.8%	7.9%
Milk	24.4%	24.4%	24.5%
Total	100.0%	100.0%	100.0%

- ***Most dose results from ingestion of fruits and vegetables; inhalation dose essentially negligible***

Power Plant C-14 Dose Consequence

- Very site specific; highly dependent on X/Q dispersion factor
- Dose is dominated by fruit and vegetable pathway, followed by milk; negligible dose from inhalation
- Use caution in selecting receptor locations; make sure you use realistic assumptions for which ingestion pathways ***really*** exist, and proper X/Q values that apply
- Some facilities initially estimated doses in excess of 30 mrem/yr when assuming all pathways at a “fenceline” receptor location; when re-evaluated using realistic distance, X/Q values, and actual ingestion pathways, doses were reduced significantly

Considerations Regarding Photosynthesis

- C-14 becomes incorporated into the food chain only during daylight hours during the growing season
- This raises questions about applicability of long-term annual average X/Q values for calculating dose impact
- Should C-14 doses be assessed using a “tailored” X/Q derived using meteorological data from daytime hours during the growing season, as opposed to a 24-hr, 365-day meteorology?
- Jim Key will discuss this aspect in greater detail in his presentation

Summary

- Carbon-14 occurs naturally in the air and vegetation around nuclear power plants
- A significant inventory of C-14 exists in the atmosphere and vegetation around nuclear plants; however, annual gaseous releases would far exceed the natural inventory -- difficult to argue that nuclear plant releases are “insignificant”
- Calculated doses from naturally-occurring C-14 are in the range of 3 to 8 mrem/yr, and outweigh typical doses from particulate+iodine+tritium effluent releases

Summary

- Only the CO_2 form of C-14 is important to dose calculation due to incorporation into food pathways; ensure proper characterization of chemical form of C-14 in gaseous effluents -- especially important to PWRs
- Most dose results from ingestion of fruits and vegetables, followed by milk; inhalation doses are very small for gaseous forms of C-14
- Caution must be exercised in selection of critical receptor locations, X/Q values, and realistic ingestion pathways when calculating dose impact from power plant effluents; otherwise, dose impact may be grossly overestimated
- Consider application of daytime/growing season X/Q

Questions?