Radon, Thoron and Their Progeny: DOE's Proposed Internal Dosimetry Standard

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Overview

- Introduction
- Issues peculiar to radon, thoron, and their progeny
- Air monitoring
- Air sampling for personnel dosimetry
- Current status in the DOE
- Future directions

Introduction

- DOE's Proposed Standard *Internal Dosimetry*
- December 1996
- www.doe.gov/html/techstds/tsdrafts/tsdrafts.html

Introduction

- Radon (^{222}Rn, 3.82 d) and thoron (^{220}Rn, 55.6 s) are the messengers
- Short-lived progeny (decay products) are the message
  - short-lived, alpha-emitting heavy metals
  - $^{238}U \rightarrow \ldots\ ^{226}Ra,\ ^{222}Rn,\ ^{218}Po,\ ^{214}Pb,\ ^{214}Bi,\ ^{214}Po$
  - $^{232}Th \rightarrow \ldots\ ^{220}Rn,\ ^{216}Po,\ ^{212}Pb,\ ^{212}Bi,\ ^{212}Po$

Issues peculiar to radon, thoron, and their progeny

- Is it Nature's radon or DOE's radon?
- History of being ignored (not a product!)
- No *practical* bioassay
- Weird quantities and units

Weird Quantities and Units

- funky equilibrium, equilibrium factor
- unattached fraction
- potential alpha energy concentration *(PAEC)*; working level (WL)
- potential alpha energy exposure *(PAEE)*; working level month (WLM)

Air Monitoring

- Workplace
  - characterize in real time the concentrations that workers might be exposed to while in an area
- Environment
  - not covered in Proposed *Internal Dosimetry Standard*
- Mature technology, many manufacturers
- Instruments measure alphas
- Usually don't have to discriminate against Pu!

Air Monitoring 2

- should be
  - real-time monitors that
  - continuously measure and display results
  - for periods of one hour or less
- should be placed to measure the highest concentrations to which workers in the area are likely to be exposed

Air Sampling for Personnel Dosimetry

- Personnel monitoring
  - establish the exposure of record for workers
  - a potential area for intercomparison, accreditation
- should be
  - continuous instruments
  - either time-averaged or real-time measurements
  - placed to measure the concentrations to which workers are exposed
  - individual personnel monitors needed for large gradients of concentration or equilibrium (e.g., outdoors)

Air Sampling for Personnel Dosimetry 2

- Active devices
  - pump with filter: measure progeny
  - Energy discriminating:
    - Si surface barrier
    - CR-39 with filters
  - Not energy discriminating: *PAEE* (WLM)
- Passive devices
  - measure radon gas
    - etched-track detectors
    - charcoal

Exposure Monitoring Thresholds for Radon and Thoron Progeny

- Two PAEE approaches
- DOE 10 CFR 835: *above* background
  - 0.08 WLM/year for radon progeny
  - 0.24 WLM/year for thoron progeny
- Exemption from 10 CFR 835: *including* background
  - 0.4 WLM/year for radon progeny
  - 1.2 WLM/year for thoron progeny

Why *PAEE*?

- relevant ionizing energy is delivered to the bronchial epithelium by alpha particles
  - ^{218}Po and ^{214}Po in the case of ^{222}Rn
  - ^{212}Bi and ^{212}Po in the case of ^{220}Rn (thoron)
- decay-product aerosol often contains an unknown mixture of the various radon and/or thoron progeny

Assessment of Intake, Exposure, and Dose

$$PAEC_{Rn}\ (\mathrm{WL}) = \frac{(0.105\ C_{Po\text{-}218} + 0.516\ C_{Pb\text{-}214} + 0.379\ C_{Bi\text{-}214})}{100\ \mathrm{pCi/L\ of\ radon\ per\ WL\ at\ equilibrium}}$$

$$= (0.00105\ C_{Po\text{-}218} + 0.00516\ C_{Pb\text{-}214} + 0.00379\ C_{Bi\text{-}214})$$

$$PAEC_{Tn}\ (\mathrm{WL}) = \frac{(0.913\ C_{Pb\text{-}212} + 0.087\ C_{Bi\text{-}212})}{7.43\ \mathrm{pCi/L\ of\ thoron\ per\ WL\ at\ equliibrium}}$$

$$= (0.12288\ C_{Pb\text{-}212} + 0.011709\ C_{Bi\text{-}212})$$

Background

- Highly variable
- Best to measure
- Default values:

Location	^{222}Rn Progeny	^{220}Rn Progeny
Indoors	0.006 WL	0.002 WL
Outdoors	0.002 WL	0.001 WL

Equilibrium Equivalent Concentration

$$EEC\ (\text{pCi/L}) = C\ (\text{pCi/L}) \cdot F$$

Equilibrium Factor, *F*

$$F_{Rn} = \frac{0.105\, C_{Po-218} + 0.516\, C_{Pb-214} + 0.379\, C_{Bi-214}}{C_{Rn-222}}$$

$$F_{Tn} = \frac{0.913\, C_{Pb-212} + 0.087\, C_{Bi-212}}{C_{Rn-220}}$$

Acceptable Default Equilibrium Factors for Radon (F_{Rn})

Location/Environment	Default F_{Rn}
Indoors, normal ventilation	0.4
Indoors, unusual ventilation	measure
Outdoors - no local radon sources	0.4
Outdoors with "local" radon sources	measure

Assigned Respiratory Protection Factors for Rn, Tn, and Their Progeny

- What good does a respirator do?
- Noble gas goes through

Option	Radon	Radon Progeny	Thoron	Thoron Progeny
Measure Gas and Progeny	1	ANSI Z88.2-1992	1	ANSI Z88.2-1992
Eq. Factor, Gas Measurement	$1 \leq APF \leq 100 \cdot F_{Rn}$		$1 \leq APF \leq 500 \cdot F_{Tn}$	
NIOSH/ICRP	1	10	1	10

Time-Integrated Concentration, N_V

$$1\,\frac{\text{pCi}\cdot\text{d}}{\text{L}} = \frac{37\ \text{Bq/m}^3}{\text{pCi/L}}\cdot\frac{86{,}400\ \text{s}}{\text{d}}\cdot\frac{1\ \text{transition}}{\text{Bq}\cdot\text{s}}$$

$$= 3{,}196{,}800 \text{ radioactive transitions per cubic meter}$$

$$= 3.1968 \text{ transitions per cubic millimeter,}$$

Equilibrium Equivalent Concentration, *EEC*

$$\bar{C}\ (\text{pCi/L}) = \frac{N_V\ (\text{pCi}\cdot\text{d/L})}{t_E\ (\text{d})} \text{ and}$$

$$EE\bar{C}\ (\text{pCi/L}) = F\cdot\bar{C} = \frac{F\cdot N_V\ (\text{pCi}\cdot\text{d/L})}{t_E\ (\text{d})}.$$

PAEE and transitions per unit volume

$$PAEE\,(\text{WLM}) = F \cdot N_V\,(\text{pCi}\cdot\text{d/L}) \cdot \left(\frac{1\ \text{WL}}{100\ \text{pCi/L}}\right)\left(\frac{24\ \text{h}}{\text{d}}\right)\left(\frac{1\ \text{Month}}{170\ \text{h}}\right)$$

$$= 1.4118 \times 10^{-3}\, F \cdot N_V\,(\text{pCi}\cdot\text{d/L});\ \text{and}$$

$$PAEE\,(\text{WLM}) = 5.6471 \times 10^{-4}\, N_V\,(\text{pCi}\cdot\text{d/L})\ \text{if}\ F = 0.4.$$

PAEE to Dose Equivalent Conversions For ^{222}Rn Progeny

- DOE's 10 CFR 835 (with stochastic DAC):

$$\left(\frac{5\ \text{rems}}{2000\ \text{DAC-hours}}\right)\left(\frac{1\ \text{DAC}}{1/3\ \text{WL}}\right)\left(\frac{2000\ \text{hours}}{12\ \text{Months}}\right) = 1.25\ (\text{rems/WLM})$$

- 1994 ICRP (Pub. 65), 1996 IAEA SS 115 dose conversion convention: 5 mSv/WLM (= 0.5 rem/WLM)

Converting Measurements to *CEDE*

- Ignore refinements based on
  - particle size
  - equilibrium factor
  - unattached fraction
- Don’t know
  - effect of respiratory protection
  - worker’s breathing rate
  - nose or mouth breathing

Converting Measurements to *CEDE*

$$H_{E,50}\ (\text{rems}) = PAEE\,(\text{WLM}) \cdot 1.25\ (\text{rems/WLM})$$

$$= 1.7647 \times 10^{-3} \cdot F \cdot N_V\ (\text{pCi} \cdot \text{d/L});\ \text{or}$$

$$= 7.0588 \times 10^{-4}\, N_V\ (\text{pCi} \cdot \text{d/L})\ \text{if}\ F = 0.4.$$

Minimum Detectable Dose for a Nuclear Track Etch Radon Detector

- minimum detectable amount for time-integrated radon concentration: 30 pCi-d/L (9.59E7 transitions/m^3)

$$H_{E,50}\ (\text{rems}) = (7.0588 \times 10^{-4})\ (30\ \text{pCi} \cdot \text{d/L})$$

$$= 0.021\ \text{rems if } F = 0.4.$$

Committed Dose Equivalent to Lung and Intakes

- From CEDE to CDE: backwards!

$$H_{50,lung} = \frac{H_{E,50}\ (\text{due to Rn or Tn})}{0.12}$$

- Intake in joules (J); exposure in WLM
- What nuclides were taken in?

Rounding

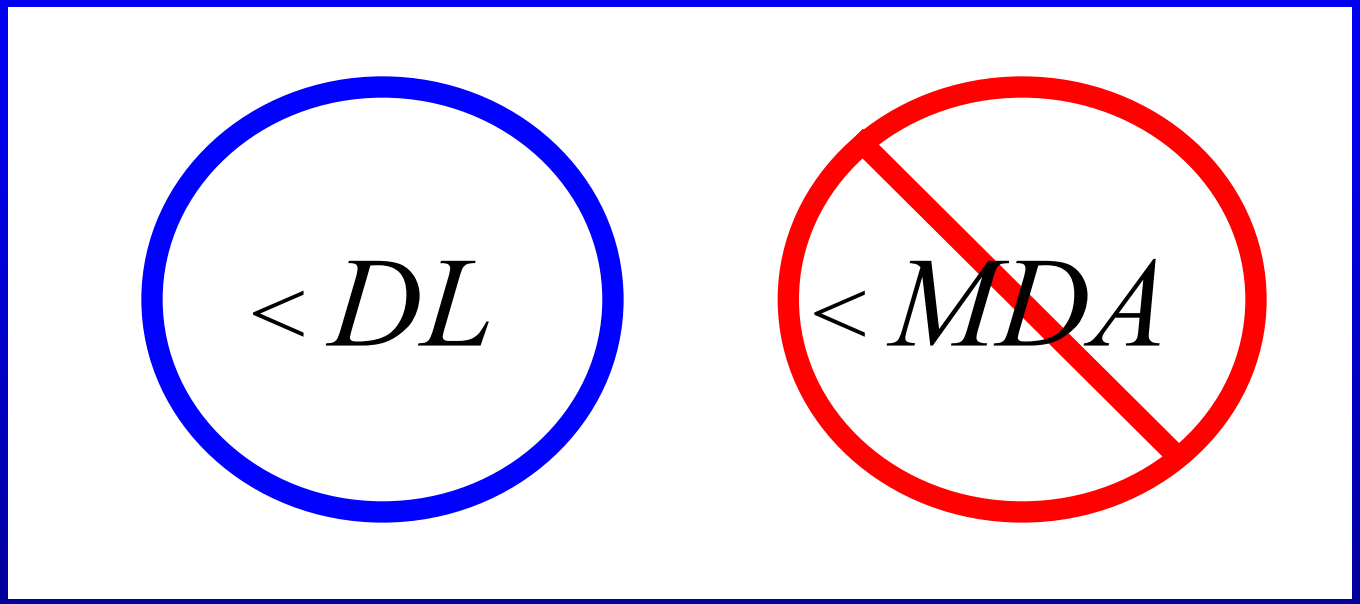
- Rounding is biasing
- Lack of knowledge never justifies biasing what you do know
- Standards are *exact* numbers
- 1/3 WL and 3E-8 $\mu Ci/cm^3$ EEC differ by 11.1%
- You're smart enough to know when to round

Multiply	In Units Of	By	To Obtain	In Units Of
Concentration, *C*	pCi/L	1E-9	Concentration, *C*	µCi/mL
Ambient ^{222}Rn or ^{220}Rn concentration, *C*	pCi/L	*F**	Equilibrium equivalent ^{222}Rn or ^{220}Rn concentration, *EEC*	pCi/L
^{222}Rn *EEC*	pCi/L	1/100 = 0.01	Potential alpha energy concentration, *PAEC*	WL
^{220}Rn *EEC*	pCi/L	1/(7.43) = 0.13459	*PAEC*	WL
^{222}Rn or ^{220}Rn progeny *PAEC*	WL	Exposure time, *t* (hours) ÷170	Potential alpha energy exposure, *PAEE*	WLM

Multiply	In Units Of	By	To Obtain	In Units Of
Integrated ^{222}Rn concentration, N_V (ambient)	pCi·d/L	$F \times 1.4118E-3$	*PAEE*	WLM
Integrated ^{222}Rn concentration, N_V (ambient)	pCi·d/L	5.6471E−4 assuming $F = 0.4$	*PAEE*	WLM

Multiply	In Units Of	By	To Obtain	In Units Of
^{222}Rn *PAEE*	WLM	5/4 = 1.25	$H_{E,50}$	rems
^{222}Rn *PAEE*	WLM	2000/4 = 500	*E* (exposure)	*DAC*·h
^{220}Rn *PAEE*	WLM	$5/12 = 0.433\overline{33}$	$H_{E,50}$	rems
^{220}Rn *PAEE*	WLM	$2000/12 = 166.6\overline{6}$	*E* (exposure)	*DAC*·h
$H_{E,50}$ for ^{222}Rn or ^{220}Rn	rems	$1/0.12 = 8.333\overline{3}$	$H_{50,lung}$	rems
PAEC	WLM	4.2490E−3	Potential alpha energy intake, *I*, of ^{222}Rn or ^{220}Rn progeny	J
*for ^{222}Rn, $F_{default}$ = 0.4; for ^{220}Rn, $F_{default}$ = 0.04				

DL and *MDA*



- Never compare data with minimum detectable amount ($MDA = L_D$)
- Compare data with decision level ($DL = L_C$)

Current Status in the DOE

- Personnel monitoring for radon/radon progeny not done at any DOE site
- Exemptions from 10 CFR 835 at 9 sites
- Active pump samplers with crude or refined alpha spectroscopy preferred to track etch
- Active samplers are expensive, not made in USA
- Will be needed at Fernald for some operations
- By current standards, likely were needed in past

Future Directions

- DOE may adopt ICRP/IAEA standard
- Progeny aerosol inside respirator
  - poor understanding
  - unattached fraction very high
  - equilibrium factor very low
- Mining and milling not in DOE mission

Conclusions

- Radon, thoron, and progeny are unique
  - known human carcinogen (radon progeny)
  - complex measurements
  - complex dosimetry
  - no *practical* bioassay
  - ownership question: Nature or DOE
- Changing mission and exemptions have taken care of problem