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CALCULATION OF RADON EMISSION, DISPERSION AND DOSIMETRY FROM K-65 STORAGE TANKS AT THE FEED MATERIALS PRODUCTION CENTER

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LETTER

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Calculation of Radon Emission, Dispersion and Dosimetry from K65 Storage Tanks at the Feed Materials Production Center

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Introduction

Two tanks containing residues principally resulting from the processing of pitchblend ore are located on the site of the Feed Materials Production Center near Fernald, Ohio. The residues contain high concentration of ^{226}Ra which produce copius amounts of the nobel gas ^{222}Rn. Release of this gas from the tanks is responsible for elevated concentration of ^{222}Rn in the atmosphere in the vicinity of the plant.

The objective of this study is to characterize the emission of radon from the tanks. This provides a source term which when coupled with meteorological data can be used to compute concentration of radon using an atmospheric dispersion model. The results of this model were used to assess population exposures and suggest ways for reducing concentration to values that are as low as reasonably achievable.

Materials and Methods

The emission of radon from tailings was computed using steady state diffusion equations. The effects of barometric pressure, wind speed and temperature were not included in the source term calculations.

The one dimensional steady state equations describing the diffusion of gases through porous media are (Co81)

$$\frac{D}{\varepsilon}\frac{d^2C}{dz^2} - \lambda C + \phi = 0$$

$$J = -D\frac{dC}{dz}$$

where;

C = Concentration of ^{222}Rn in pore system of the media

J = Current density (FLUX)

D = Effective diffusion coefficient in porous medium

ε = Porosity of medium = ratio of pore volume to bulk volume

λ = Decay constant of ^{222}Rn

ϕ = Production source term of ^{222}Rn in pores

$$= \frac{[Ra] * EF * \rho * \lambda}{\varepsilon} \qquad (pCi/cm^3)$$

[Ra] = Concentration of radium in medium (pCi/g) 10^{-12}

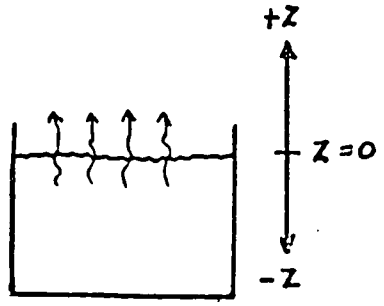
EF = Emanation fraction

ρ = Bulk density of medium

ℓ = Diffusion length = $\sqrt{D/\varepsilon\lambda}$

Solutions for these equations for special cases relating to the K65 tanks are as follows:

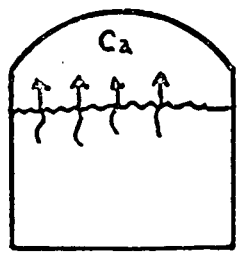
CASE I Open Tank



$$-C(z) = \frac{\phi}{\lambda}\left(1-e^{z/\ell}\right)$$

$$J = \frac{\phi}{\lambda\ell} = \phi\varepsilon\ell$$

CASE II Closed Tank



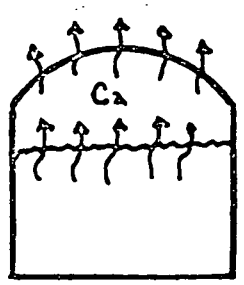
$$Ca = \frac{\phi}{\lambda}\left(\frac{\varepsilon\ell}{\varepsilon\ell+h}\right)$$

$\frac{\phi}{\lambda}$ = Radium Concentration in Pore Space

$\frac{\varepsilon\ell}{\varepsilon\ell+h}$ = Ratio of the value of air voids in the tailings to a depth of one diffusion length compared to the sum of this volume and the air space above tailings

h = Effective height of air volume above tailings

CASE III Diffusion from Tank Cover

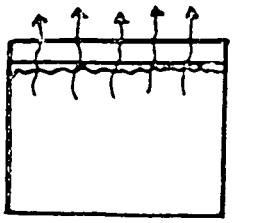


$$J = \varepsilon\lambda\ell\left\{\frac{Ca}{\sinh(L/\ell)}\right\}$$

Ca = Concentration of ^{222}Rn in Tank

L = Thickness of Concrete Cover

CASE IV Diffusion from Concrete Slab Directly Over Tailings



$$J_c = \phi \varepsilon_c \ell_c \left[\cosh\left(\frac{L}{\ell_c}\right) + \left(\frac{\varepsilon_t}{\varepsilon_c}\right)\left(\frac{\ell_t}{\ell_c}\right) \sinh\left(\frac{L}{\ell_c}\right)\right]^{-1}$$

Note: $\frac{J_c}{\phi \varepsilon \ell} = \frac{J_c}{J_o}$ = Ratio of Flux through Concrete Slab to Flux from Bare Tailings

The steady state emission rate can be obtained by multiplying the flux, J, by the surface area of the tanks. Since each tank is surrounded by an earthen beam, the radon was assumed to emerge from two flat surfaces having a diameter of 80′.

The dispersion of radon from the tanks was determined using the computer code UDAD (MO79). This code was developed at Argonne National Laboratory for the Generic Environmental Impact Statement on Uranium Milling. It is particularly well suited for the dispersion of radon originating from mill tailings.

UDAD requires meteorological data including a stability wind rose which describes the relative frequency of occurrence for each wind direction, wind speed class and stability category. Unfortunately, this information does not exist specifically for the FMPC site near Fernald. However, data from the greater Cincinnati airport in Covington KY was available. Seasonal and annual wind distributions by Pasquill stability classes for the period 1/70 - 12/74 were obtained from the U. S. Department of Commerce, National Climatic Center (USDC81). This is the same meteorological data set that was used for the preparation of the Environmental Impact Statement for the FMPC.

The UDAD code provides the annual average concentration of radon gas (PCi/ℓ) and potential alpha energy from radon daughters (Working Level, WL). The principle risk from radon gas comes from the ingrowth and inhalation of radon daughters inside buildings. Thus, the dose conversion factor for population exposures was obtained using the following assumptions:

a) Outdoor radon eventually migrates indoors

b) Radon daughters reach an equilibrium ratio of 50%

c) People are resident in buildings for an average of 16 hours per day

d) The weighted dose equivalent conversion factor for inhalation of radon daughters in houses is 0.55 rem/WLM (OECD83)

This combination of assumptions yields a conversion factor of

$$0.1 \frac{\text{mrem/yr}}{\text{pCi/m}^3}$$

Population densities as a function of distance and direction from the site were obtained from the staff at FMPC.

Results

Source Term

The following parameters were used for modeling the K-65 tanks:

$[Ra] = 200\ mCi/tonne = 2 * 10^{5}\ pCi/g$

$EF = 0.2$

$\rho = 1.94 * 10^{6}\ lbs\ /\ 1.95 * 10^{5}\ f^{3} = 1.6\ g/cm^{3}$

$\lambda = 2.1 * 10^{6}\ s^{-1}$

ε tailings = 0.3

ε concrete = 0.3

ℓ concrete = 12 cm

ℓ tailings = 150 cm

Area of Tanks = $934 m^{2}$

NLO Case 1: Radon Flux from open tank

$$J_o = \phi \varepsilon \ell$$

$$= 20 \ (pCi/cm^2 \cdot s)$$ 0.1 $\frac{\text{mrem/yr}}{200{,}000 \ pCi/m^3}$

$$J_o = 2 * 10^5 \ (pCi/m^2 \cdot s)$$ 200,000

NLO Case II: Concentration of radon above the tailings in a closed tank

The dome is simulated by a right circular cone of height 8' and diameter of 40'. The volume of a cone is $1/3\pi b^2 h$. Thus, the effective height of the dome is 8'/3 = 2.6'. The total effective height above the tailings is thus 10' = 300 cm.

$$Ca = 3 * 10^4 \ pCi/cm^3$$

$$= 3 * 10^7 \ pCi/\ell$$

NLO Case III: Radon Flux from Tank Covered with 4" (10 cm) of Concrete

$$J = 0.24 \ pCi/cm^2 \cdot s$$

$$= 2400 \ pCi/m^3 \cdot s$$ 2,400

NLO Case IV: Radon Flux From 4" Concrete Slab Directly Above Tailings

$$J_c = J_o * 0.105$$

$$= 2 * 10^4 \text{ pCi/m}^2\cdot\text{s}$$ 20,000

The flux calculated from the model assuming a 4" concrete cover over the tanks is 2400 $pCi/m^2 \cdot s$. Measurements made by Monsanto Research Corporation ranged from 13 to $1.4 * 10^7$ $pCi/m^2 \cdot s$ (Ha85). The extremely large values were reported to be from cracks in the concrete dome. Using an average estimate of 2000 $pCi/m^2 \cdot s$ the annual emission rate is 60 Ci/yr. This source term was used as input for the dispersion code UDAD. Figure 1 shows the computed annual average contribution to the atmospheric radon from the K65 tanks. The data is presented as isopleths of 100, 10, 1 pCi/m^2.

The annual average background level near Cincinnati, Ohio has been estimated to be about 250 pCi/m^3 (Ge83). Measurements made by Monsanto Resesarch Corporation yield values similar to this at the fence line.

Conclusions

The dispersion model predicts that radon concentrations due to emissions from the K65 tanks fall to below background levels at distances less than 500 meters. The 100 pCi/m^2 isopleth lies entirely within the boundry of the FMPC facility. Fence line values are generally less than 5% of natural background.

The closest residence in the NNW direction (22.5°) is about 1.3 Km from the tanks. This corresponds to an excess radon concentration of 6 pCi/m^3 which yields an annual weighted dose equivalent of 0.6 mrem/year. The

closest residences at 90° and 180° would receive an annual weighted dose equivalent of 0.2 mrem/y and 0.3 mrem/y respectively.

An estimation of the population commitment is meaningless since the values predicted by the model are less than normal variation due to fluctuations in natural background and individual lifestyles.

The shape of the isopleths in this study do not conform to those presented in the Monsanto study (Ha85). This should not be surprising since the code cannot model the turbulence and shadowing due to structures very close to the source term and measurements were made only during a few months spanning late autumn and winter. This illustrates the considerable uncertainty in such modeling exercises.

In order to validate the conclusions of this study a comprehensive monitoring program should continue for at least one calendar year. A continuous radon monitor based on a flow through scintillation flask would provide information at daily intervals which could be integrated to yield an annual average. The daily variations could be compared to wind speed and direction to improve the predictive capabilities of the model.

Outdoor measurements of working levels are difficult because of the plate-out characteristics of radon daughters. Since the risk is related to ingrowth and inhalation of daughters indoors it is suggested to make continuous measurements in a small building or trailer. Commercial continuous working level monitors adequately measure radon daughters under these conditions.

A monitoring station containing a continuous radon and working level monitor should be located in a northeast direction about 500 meters from the tank and at the fence line. Background measurements in a general upwind

direction could be made with integrating devices if another set of continuous monitor is not available.

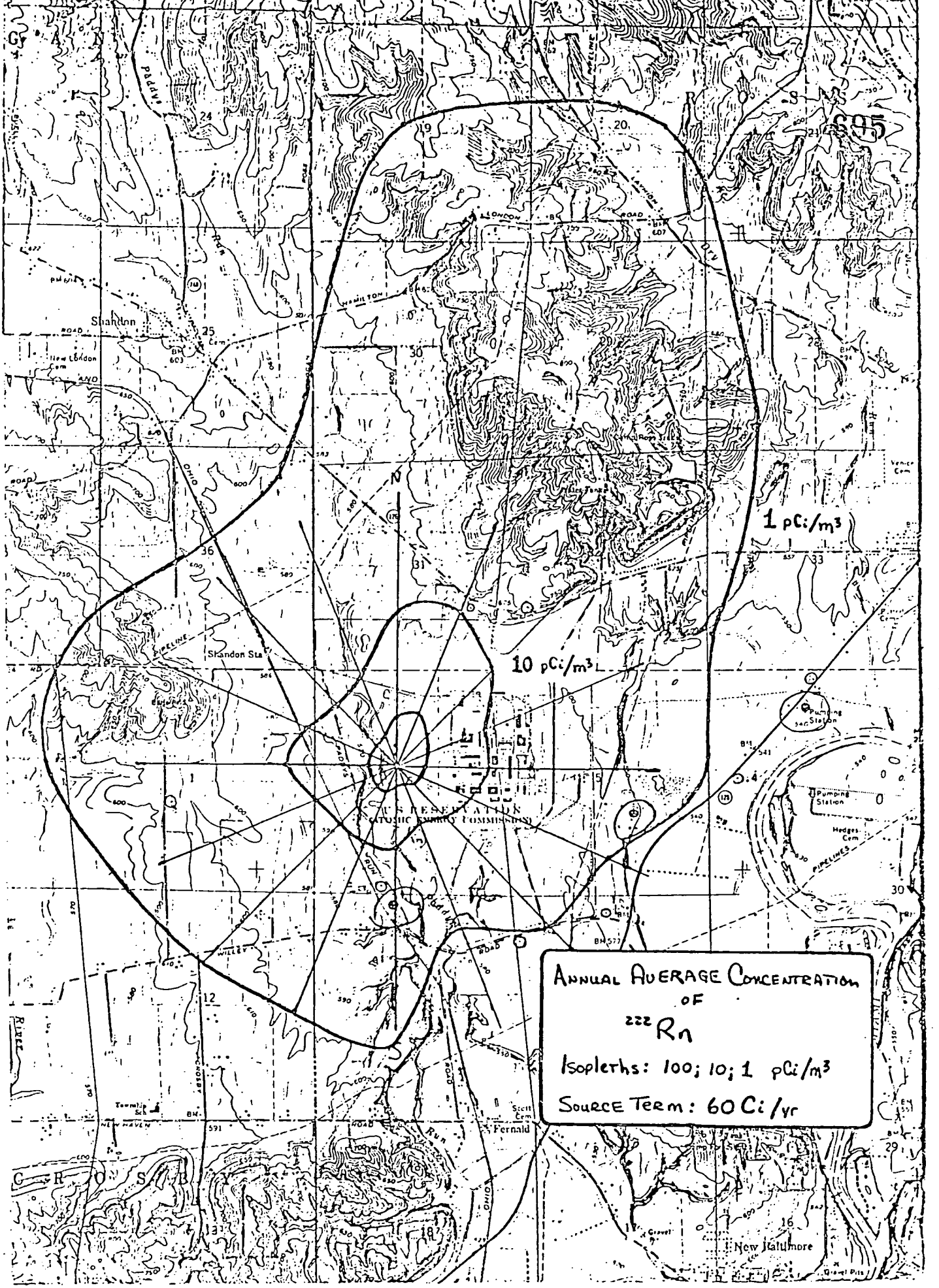
Several continuous monitors are available at Argonne National Laboratory. Since FMPC is a DOE facility a loan arrangement could be negotiated for the duration of the experiment.

If measurements indicate radon concentrations larger than predicted by the model several steps could be taken to reduce emissions from the tank. These are as follows:

a) Seal the apparent cracks in the dome. This is useful but could turn out to be a never ending exercise.

b) Increase the thickness of the concrete cover. This would certainly help but an additional 4" of concrete would only reduce the average flux by 60%.

c) Keep the tailings covered with water. This is an extremely efficient barrier since 2 cm of water is equivalent to 12 cm of concrete. However, caution should be exercised to prevent leaching and migration of Ra into underground aquafers.


695
1 pCi/m³
10 pCi/m³
Shandon
Shandon Sta
Pumping Station
Fernald
New Baltimore
Annual Average Concentration of
222Rn
Isopleths: 100; 10; 1 pCi/m³
Source Term: 60 Ci/yr

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