Evaluation of Risk to a Groundskeeper, Student, and Resident on the Colorado School of Mines Site, Golden, Colorado

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December 11, 2009

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1 Introduction

The risks to a groundskeeper, student, and resident exposed to residual Ra-226 contamination at the Colorado School of Mines Site (CSMRI) was evaluated using the RESRAD Version 6.3 computer code (Yu *et al.* 2001) and MicroShield 7.0 computer code (Grove Software 2005). In addition, the risk to the groundskeeper from ingestion of arsenic in soil was also calculated using U.S. Environmental Protection Agency (EPA) methodology outlined in Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (EPA 2005).

2 Summary of Scenarios Evaluated

2.1 Groundskeeper

The following sections describe risk to a groundskeeper of arsenic exposure from soil ingestion and inhalation of Ra-226 and radon and exposure to Ra-226.

Arsenic exposure from soil ingestion

A groundskeeper who gardens during spring and summer months could be exposed to arsenic in soil via ingestion of soil. The risk (linear, low-dose cancer) from this exposure pathway was calculated using the formula from EPA (1989):

Risk = CDI X SF

where:

Risk = a unitless probability (e.g., 2×10^{-5}) of an individual developing cancer

CDI = chronic daily intake averaged over 70 years (mg/kg-day)

SF = slope factor, expressed in $(mg/kg\text{-}day)^{-1}$

The following assumptions were used to calculate the risk:

- The groundskeeper gardens 5 days/week, 26 weeks of year (May-October)
- He or she spends 5 years as a gardener (entry-level position)
- An adult gardener consumes soil at a rate of 2 kg/day (EPA 1997)
- Body weight is 70 kg (EPA 2005)
- Averaging time is 70 years (EPA 2005)
- From the above information, the chronic daily intake is 2.83×10^{-7} mg/kg/day
- The slope factor for inorganic arsenic is 1.5 $mg/kg/day^{-1}$ (EPA IRIS)

Inhalation of Ra-226 and radon and exposure to Ra-226

The groundskeeper who works outside could be exposed to Ra-226 and radon emitted from soil through the following pathways:

- Direct inhalation of radon vapors and particles of Ra-226 released from soil
- Exposure to Ra-226 in soil

The inhalation pathway dose was calculated using RESRAD 6.5. All data were default values with the exception of:

- Outdoor time fraction = 1; Indoor time fraction = 0

The concentration of Ra-226 in the soil was conservatively estimated to be 6.23 pCi/g (the average concentration measured in the flood plain east of the former settling pond) (Stoller 2009).

The external exposure dose was estimated using MicroShield 7.0 and assuming:

- The groundskeeper works in a small area at a time, best represented by a cylinder geometry, with a contaminated zone thickness of 1.2 m and radius of 1 m.

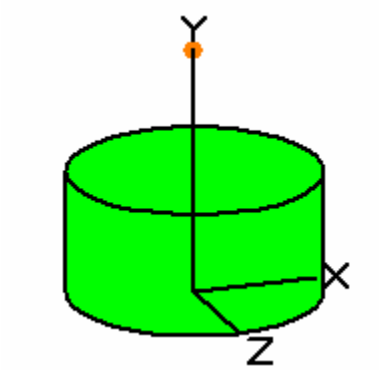

Figure 1. Geometry used in MicroShield Calculation (Grove 2005)

- There is no shielding.
- The maximum exposure occurs 1 m (3 ft) above the surface.
- The groundskeeper spends 2,000 hours/yr working outdoors: gardening in the spring and summer months, raking in the autumn months, and shoveling snow in the winter months.
- The groundskeeper works exclusively in the flood plain area, which has the highest concentrations of Ra-226.
- The Ra-226 concentration in the flood plain area, east of the former settling pond is 6.23 pCi/g (Stoller 2009).

2.2 Student

Students were hypothetically exposed to Ra-226 in soil through three scenarios: an ecology field study on the flood plain; a residence hall built on the upper terrace; and a dorm built adjacent to the upper terrace with windows that can be opened.

For the ecology field trip, it was assumed that the exposure pathways are:

- Direct inhalation of radon vapors released from soil
- Inhalation of Ra-226 in soil particles that are suspended in air
- Direct exposure to Ra-226 in soil

The ecology student was assumed to study soil and flora at the location of maximum Ra-226 concentration (28 pCi/g). RESRAD 6.5 was used for the inhalation pathways using default parameter values. MicroShield 7.0 was used to estimate the dose from external exposure to Ra-226 in soil using the same geometry shown in Figure 1.

The student may be exposed to Ra-226 and radon for 12 hours a day for five years via the inhalation and external exposure pathways while living in a hypothetical dorm. For the dorm built on the upper terrace, it was assumed that radon can diffuse through the foundation into the first floor room. For the dorm built adjacent to the upper terrace, it was assumed that radon gas emanates from the soil and drifts into the open window. For both cases, the concentration of Ra-226 used is 4.1 pCi/g (the action level). Again, RESRAD 6.5 was used for inhalation pathways, using parameter values discussed in the resident scenario. MicroShield 7.0 was used for the external exposure pathway.

2.3 Resident

For this scenario, it was assumed that a house would be built on two possible locations: the flood plain (east of the former settling pond) and the upper terrace. The flood plain house is a highly unlikely and conservative scenario. It is doubtful that anyone would be permitted to build in a wetlands area. Moreover, the high moisture in the soil would minimize radon flux and suspension of contaminated soil particles. However, it was addressed, as the highest Ra-226 concentrations were measured there.

For the flood plain scenario, the hypothetical 2,000 ft^2 house is situated over the highest measured concentration (28 pCi/g) of Ra-226 (Figure 2). The house foundation encompasses sample locations shown in Table 1. The average Ra-226 concentration within the house perimeter is 10 pCi/g.

Table 1
Sample results for residential scenario

Sample #	Ra-226 (pCi/g)
1211	5.70
1212	2.29
CSM158	4.70
CSM159	9.30
CSM160	28.00
Minimum	2.29
Maximum	28.00
Median	5.70
Mean	10.00

RESRAD 6.5 was used to calculate the dose to the hypothetical resident through the following pathways:

- Direct inhalation of radon vapors released from soil, which diffuse through the foundation and into the house
- Exposure to Ra-226 in soil when outdoors

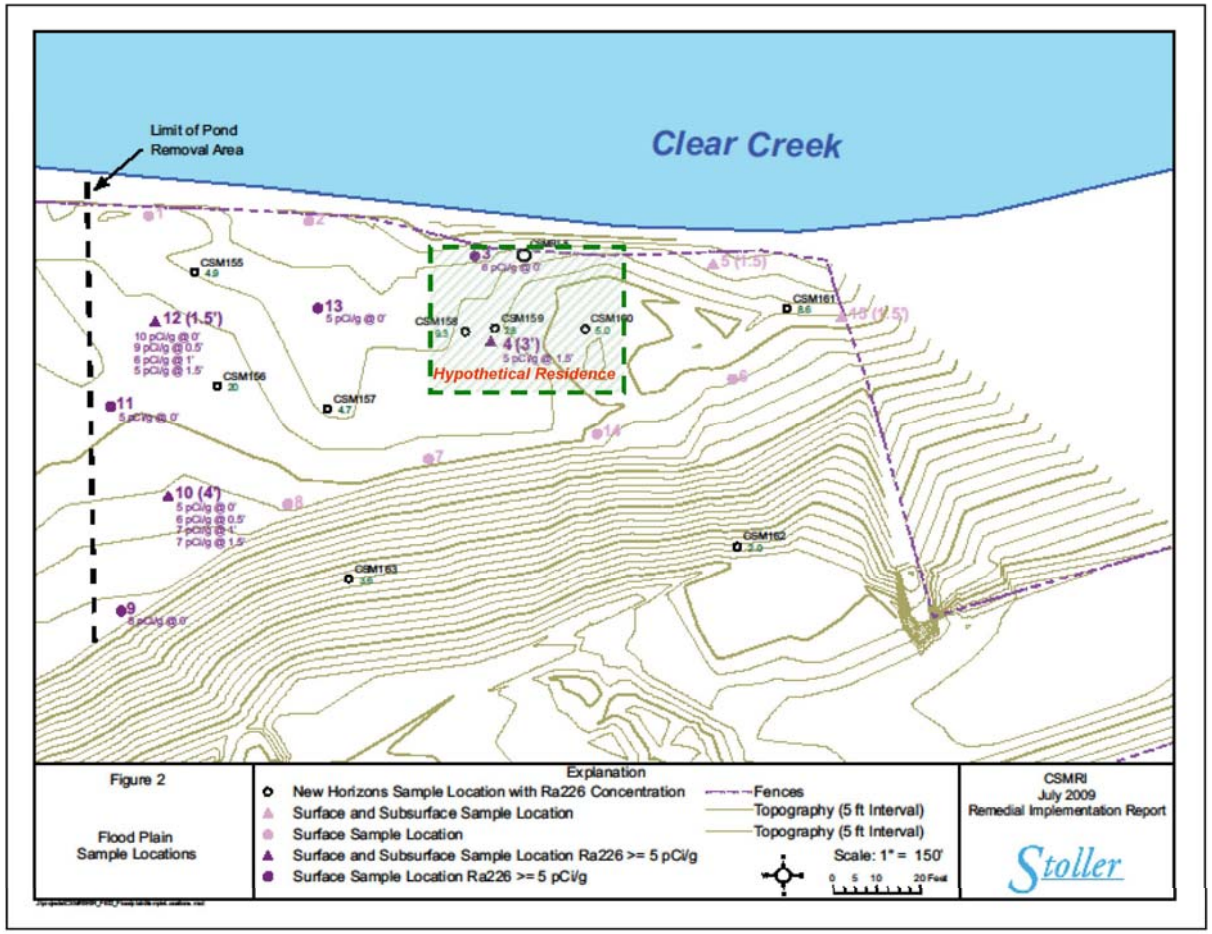

Figure 2. Location of hypothetical residence on flood plain

All data were default values with the exception of:

- Building foundation thickness of 0.2032 m (8 inches)
- Building foundation 0.2032 m (8 inches) below surface
- Building foundation radon diffusion coefficient of 3.4 E-08 m^{-2}/s and porosite of 0.11 as shown in Table 2

Table 2
Effective Diffusion Coefficient (D_e) for Radon in Concrete
(from Table 7.1 of Yu *et al.* 1993)

	D_e (m^2s^{-1})			Total porosity (p_t)			Reference
	1.10E-07	to	4.00E-07	0.11	to	0.13	Poffijn *et al.* (1988)
		1.20E-08			0.25		Culot *et al.* (1976)
		3.40E-08			0.05		Culot *et al.* (1976)
		3.40E-08			0.068		Zapalac (1983)
	8.00E-09	to	8.40E-08				Stranden (1988)
Median		3.40E-08			0.11		

The same parameters were used for the upper terrace scenario, except that the Ra-226 concentration used is 4.1 pCi/g, which is the site action level.

The external exposure to Ra-226, while the resident is outdoors, was estimated using MicroShield 7.0 and the same assumptions described previously for the groundskeeper scenario.

2.4 Commercial

The commercial scenario involves an adult who operates a refreshment booth on the upper terrace during sporting events for four hours per week for six months. The dose to the adult concession operator was calculated through the following pathways:

- Direct inhalation of radon vapors released from soil
- Inhalation of Ra-226 in soil particles that are suspended in air
- Direct exposure to Ra-226 in soil

RESRAD 6.5 was used to estimate the dose for inhalation pathways. All parameter values were default. MicroShield 7.0 was used to estimate the dose from external exposure to Ra-226 in soil using the geometry illustrated in Figure 1. The Ra-226 concentration in soil was assumed to be 4.1 pCi/g, which is the action level.

3 Background

Doses due to background concentrations of Ra-226 were estimated for each scenario using the same methodologies associated with each scenario. The background concentration of Ra-226 was estimated to be 1.9 pCi/g. This is the mean of the data reported in the URS 2000 and URS 2002 reports. The estimated background dose can be subtracted from the scenario dose to determine dose minus background contribution.

4 Results

Details of the calculation methodologies used may be found in the Excel worksheet named Ra_226_Doses.xls. The results are summarized in Table 3.

Table3
Results of calculations of doses due to exposure to Ra-226

Scenario/location	Ra-226 Concentration (pCi/g)	Dose with background (mrem/yr)	Dose above background (mrem/yr)
Groundskeeper			
Flood Plain	6.23	1.04E-01	5.03E-02
Background	1.9	5.39E-02	
Commercial			
Upper Terrace	4.1	5.87E-02	3.15E-02
Background	1.9	2.72E-02	
Residence			
Upper Terrace	4.1	2.37E+01	1.27E+01
Flood Plain	10	5.78E+01	4.68E+01
Background	1.9	1.10E+01	
Student			
Ecology field	28	4.00E-01	3.72E-01
Background	1.9	2.71E-02	
Dorm on upper terrace	4.1	2.37E+01	1.27E+01
Background	1.9	1.10E+01	
Dorm adjacent to upper terrace	4.1	5.95E-02	3.19E-02
Background	1.9	2.76E-02	

In addition to the dose calculations, the risk to ingestion of arsenic by the groundskeeper was estimated to be 4.25×10^{-7}.

5 References

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