Ketterer air filtration measurements, April 2024

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Contents

This document augments Ketterer's air filtration measurements of April 2024 to include data on airborne radioactivity and radiation dose and compares with the natural outdoor alpha emitter radon and background radiation (terrestrial+cosmic rays). Note that links below to the website of the Rocky Flats Stewardship Council may disappear at any moment, but are available from DMW.

1 *Data*

location	samp	subsamp	wgt (mg)	pCi/g	fCi/m^3
east gate	01	1	25	1.19	0.059
"	01	25	15	0.69	0.034
SE gate	02	2	25	0.85	0.12
"	02	21	25	0.20	0.027
"	02	22	25	0.15	0.0203
"	02	22	25	0.18	0.024
CO 128 (Rock Creek)	03	3	25?	ND	–

Table 1: Ketterer air sampling data. ND = none detected. Weights in mg are for subsamples.

Ketterer's affidavit (dated 21 May 2024) is available from Rocky Mountain Peace and Justice. It provides key information about methods and samples. He used a 1590 cubic feet per minute air blower with two back-to-back very fine furnace filters attached to the inlet. Average sampling times were about 21 minutes, during which about 9.46×10^5 liters of air passed through the filters. The parent sample with highest pCi/g (subsample 1, 1.19 pCi/g) weighed 46.5 mg (the weight of dust after both filters were entirely burned away) and was taken from near the former east gate of the Rocky Flats plant.

We treat each cited pCi/g value as an independent measurement to be applied to the same parent sample (each collected at a particular location). Total masses: Sample 1: 46.5 mg; sample 2: 127.7 mg; sample 3: 63.9 mg. Thus each subsample will contribute a different estimate of the total Pu activity of dust filtered at that location.

By comparing the histogram of measured Pu soil values in pCi/g for the Ketterer samples with the corresponding histogram for Jefferson Parkway samples [Fig. 1] we see that what Ketterer measured was roughly consistent with what is expected on the eastern boundary of the Refuge. A value as high as 1.19 pCi/g is relatively unlikely according to the much more detailed Parkway sampling. Overall, the data reinforces the usual assumption, that the composition of airborne dust reflects what is present on the surface of the soil.

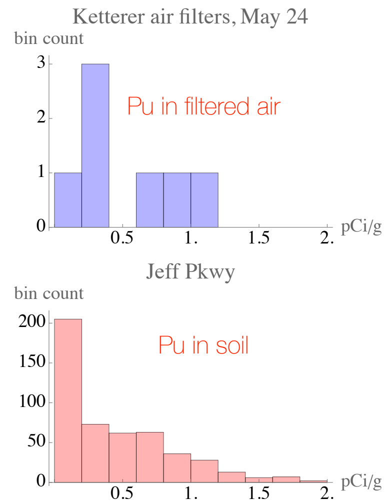

Figure 1: Histograms of Pu in soil from 7 Ketterer samples (1 with no Pu detected) compared with sampling on eastern Refuge boundary for the Jefferson Parkway.

Conversion to Pu activity per unit volume for comparisons

As an example: sample 01 had an activity of 1.19 pCi/g $\times$ 0.0465 g, or 0.0553 pCi. The average Pu concentration in the air for this sample was thus 0.0553 pCi/(9.46×10^5 liters) = 5.85×10^{-8} pCi per liter. In terms of Bq/m^3 [1 pCi/liter = 37 Bq/m^3] this is is 2.16×10^{-6}. (Values in fCi/m^3 are given in Table 1.) The graphic below was used because it is free of copyright restrictions, so we adopted its units in order to plot Ketterer's results. Ketterer's data is toward the high end of post-1970 measured air-sampling data in the figure, but roughly 100 times below maximum values measured during the operating lifetime of the Rocky Flats plant (which peaked during the 1969 plant fire). These data were accumulated via full-year continuous monitoring rather than on a single day.

When comparing data in Table 1 with other tabulations several different sets of units have been commonly used, for which conversion factors are

$$\begin{aligned} 1\ \text{fCi/m}^3 &= 10^{-6}\ \text{pCi/L} = 37\ \mu\text{Bq/m}^3 \\ 1\ \text{Bq/m}^3 &= \frac{1}{37}\ \text{pCi/L} = \frac{1}{37}\ \text{nCi/m}^3 \end{aligned}$$

We have given conversions to pCi/liter (pCi/L) since these are the units in which household (or outdoor) radon levels are often cited in the U.S. CSU reports that average indoor (we assume *unmitigated*) radon levels in Colorado are about 6.3 pCi/liter, and outside, about 0.4 pCi/liter according to the EPA. Using the largest value (0.12 fCi/m^3) measured by Ketterer, radon *radioactivity* levels per unit volume outdoors are about 3.3 million times larger than what is contributed by airborne plutonium.

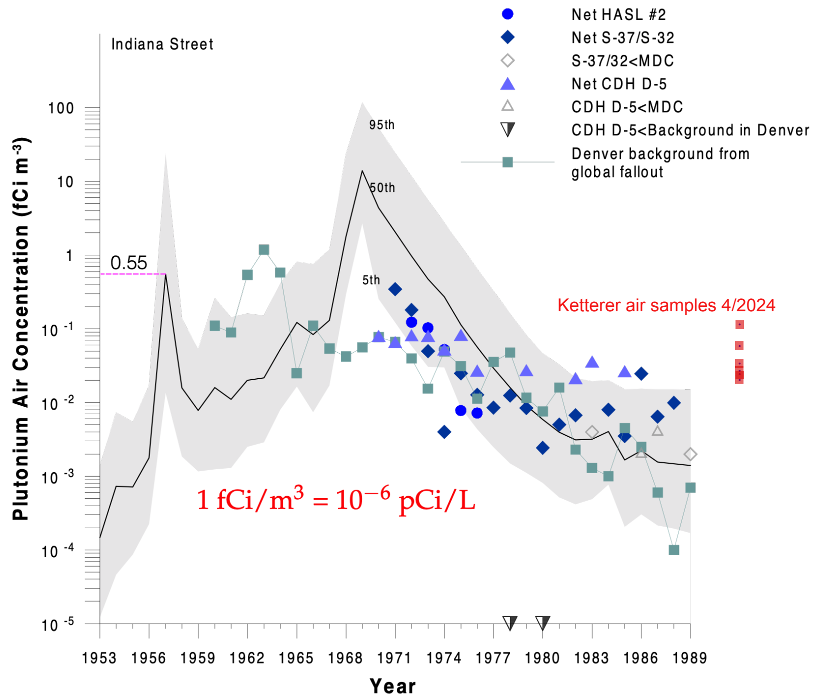

Figure 2: 6 Ketterer data points (right edge) displayed with historical plutonium air concentration data. Original figure [1] here, Figure 16.

2 *Health impacts*

source	*dose advice*	*dose* (12 h)	*dose* (1 y)
PuO_2	DOE	1.55×10^{-3}	0.0793
radon	DOE granular	1.67	1,220
background	direct measurement	1.68	1,230

Table 2: 12-hour and 1-year radiation effective doses in μSv from inhalation of PuO_2 [Ketterer data] or radon, and background radiation (gamma rays from soil radionuclides + cosmic rays).

It is important to calculate *doses* not only for plutonium but also for radon, a ubiquitous outdoor *natural* alpha emitter which provides a benchmark against which to compare. Details are given in the Appendix, where distinct methods for computing dose are considered. Table 2 above summarizes the most robust dose estimates for PuO_2 and radon; background was directly measured (0.140 μSv/h, spring 2019). The 12-hour data is relevant while the Pu measurements were being made, that is (i) on an extremely windy day, (ii) physically close to where surface soil Pu contamination is fairly high. On the other hand, the 1-year dose reflects the wind speed statistics by (over)estimating that 7% of the year has very windy conditions. Under ordinary circumstances it is quite likely that the Pu dose drops almost to zero, since no soil suspension occurs below a threshold wind speed of about 10 mph.

By chance, around Rocky Flats annual doses from background radiation and from outdoor radon are comparable. The doses are for

Ketterer selected a very windy day with “particularly strong steady winds and violent gusts occurring at Rocky Flats on the afternoon of that date.” [April 6, 2024]. It is estimated [2] that dust resuspension begins at wind speeds of 5-7 meters/sec (14 or 15 mph), with maximum dust emissions at about 27 mph. Section 5 (Air Monitoring Program) of a Rocky Flats Environmental Test Site document [3] notes that “The average wind speed is approximately 9.7 mph. . . Wind speeds greater than 20 mph occur between 500 and 600 hours per year.” This amounts to 6-7% of the time. Fort Collins, for example, suspends earthmoving and demolition work when wind speeds exceed 30 mph to avoid dust. Thus conditions permitting large soil resuspension are fairly rare over Rocky Flats.

100% outdoor occupation. In fact, significant time spent indoors will *lower* background exposure (from shielding by building materials) and *raise* radon exposure (which can be 10-20 times higher in unmitigated buildings). Thus it is fair to say that the yearly radiation dose due to radon is distinctly higher than from background.

Generally speaking background radiation doses worldwide (annual doses of about 2,400 μSv = 2.4 mSv) per year (apart from a handful of 'high natural background areas' where annual doses are 260 mSv) are believed to have no health impacts, and outdoor levels of radon about 0.4 pCi/L are regarded as safe. According to Ketterer's data, maximum doses from airborne Pu **during the very high winds** are 1000-3500 times *smaller* than from either or background radiation along the Front Range. This drops to 15000-50000 times smaller for yearly doses because of the statistics on high winds.

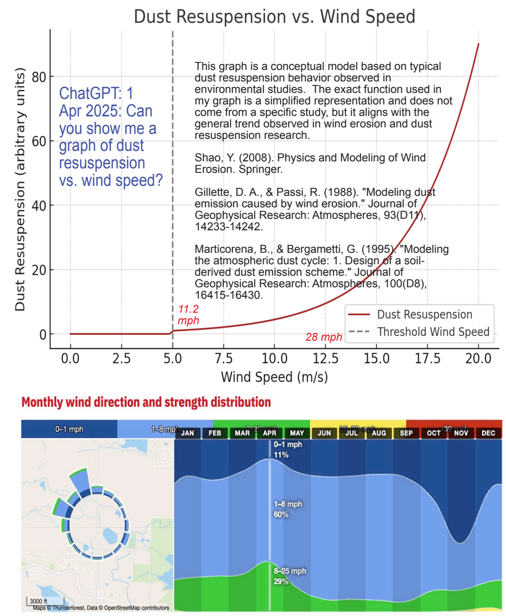

Figure 3: Top: ChatGPT generated graphic showing semi-quantitative dependence of dust resuspension on wind speed. Bottom: wind statistics for Standley Lake/Rocky Flats.

Takeaways: significance

- The Ketterer measurements are the most recent for PuO_2 suspended in air downwind of Rocky Flats. They are presumably much more relevant to establishing radiation doses than are estimates based on average yearly inhaled or swallowed dirt, as is done, for example, in radiation compliance software such as RESRAD.
- Ketterer's values of dust pCi/g are consistent with what was expected for the eastern boundary of the Refuge, but his highest value is probably not typical (based on much larger data sets).
- Airborne plutonium measured was far above what would be *normally* present, because of extremely windy conditions and the fact that a minimum wind speed is required to resuspend dust.
- Airborne Pu, measured right on the eastern Refuge boundary, would be far above what would be measured in areas where 'downwinders' live.

Takeaways: data and doses

- Translated into pCi/L of air, the maximum value among all subsamples was 0.12 fCi/m^3 or 1.2×10^{-7} pCi/L. Since outdoor levels of radon and its decay progeny in air are about 1.8 pCi/L, the suspended Pu contributes about 3.5 million times less than radon to airborne *radioactivity*.
- The (alpha) radiation dose from plutonium during the extremely windy conditions measured by Ketterer was between 1000-3500

smaller than from **either** outdoor radon and radon progeny (mostly alpha radiation) **or** from background radiation around Rocky Flats.

- Including the statistics conditions needed to resuspend soil dust on Rocky Flats, annual dsoes from plutonium are from 15,000 to 50,000 times smaller than doses from outdoor radon (and progeny)
- Arthur Rood noted that Ketterer compared the "Pu mass concentrations in dust [his maximum value was 1.19 pCi/g] to the State of Colorado soil concentration for construction of 0.9 pCi/g is inaccurate. The soil standard is for Pu concentrations in **bulk soil** and not suspendible dust collected on a filter." [Arthur Rood, personal communication]
- The usual conclusion: Just because a quantity is measurable does not mean if represents a health hazard.
- It is always helpful to understand doses from *naturally* occurring radionuclides before becoming anxious over human contributions.

Acknowledgement: I gratefully acknowledge many helpful suggestions from Arthur S. Rood, one of the authors of several publications about historical plutonium air concentrations. He caught an error, flagged the importance of including radon dose rather than simply its airborne radioactivity, included a sample spreadsheet, and noted the incorrect statement by Ketterer above about state of Colorado permissible soil concentrations.

3 *Appendix: Radiation doses from airborne PuO_2, radon, and background*

Both radon (^{222}Rn) and plutonium (^{239}Pu) are alpha particle emitters; these are probably the best understood of all radionuclides. The various fates of short-lived 'decay progeny' (almost entirely responsible for the radiation dose from the radon parent) *require* computing radiation doses for radon.

Plutonium

We established in the text that the largest Pu concentration in air during Ketterer's measurements was 1.15×10^{-7} pCi/L. Doses obviously depend on the amount of contaminated air that is breathed in during a reference period, which we take to be 12 hours (during the high-wind conditions) and 1 year (for long-term exposure and to acknowledge wind statistics around Rocky Flats). This yields the radioactivity (in pCi or Bq) inhaled during this time. The 'dose coefficient' for an inhaled radionuclide is designed to convert the radioactivity inhaled to the effective radiation dose. Thus it has units of, for example, μSv per Bq; this can be thought of as the whole-body radiation dose per second from the radionuclide (since 1 Bq = 1 decay per second).

The 'effective dose' includes the full biochemistry and biokinetics of the nuclide as it is dispersed around the body and is the best single measure of total health consequences, including cancer.

ICRP dose coefficients come from ICRP Publication 119 [4] for insoluble ('type S') inhaled PuO_2 (for particles in the range of 1μ equivalent aerodynamic diameter). They have been slightly revised in the DCFPAK version 3.02 dose libraries, currently used by RESRAD, for example, and are accepted as recently as 2022 [5], Analogous DOE dose coefficients are in the December 2022 DOE Standard (Derived Concentration Technical Standard) [6], p. 201 for inhaled low-solubility PuO_2.

"In the Standard, a "per capita" dose coefficient for a radionuclide and exposure mode is a weighted sum of age-specific effective dose coefficients, where the weight takes account of the fraction of each subgroup in the U.S. population, represented by an age-specific effective dose coefficient and the level of exposure to the radionuclide for that age group. The per capita dose coefficients may be useful in calculations supporting demonstrations of compliance with public dose limits without having to assess doses to individual age-specific categories".

These are typically based on the latest ICRP data (Publication 119 above) but DOE standards differ in several respects from data from the ICRP. See For example, DOE breathing rates reflect assumed time budgets. DOE standards are strongly oriented toward compliance among DOE labs and contractors.

The result is that there can be moderate differences between DOE and direct ICRP predictions of radiation dose directly computed from inhaled radioactivity. We have noted above that for airborne Pu it is important to acknowledge the importance of wind speeds, and that speeds above 20 mph (approximately the speed at which dust resuspension begins) occur only about 7% of the time on Rocky Flats. Thus we show in the table the 12-hour reference dose (during which the wind was fully blowing) a 1-year dose assuming conditions such as Ketterer experienced 7% of the time.

Using the highest pCi/L measured by Ketterer (1.148×10^{-7}), and alternate sources for breathing rates and dose coefficients, we show in Table 3 12-hour and 1-year radiation effective doses in μSv from PuO_2. Dose coefficients are in μSv/Bq. 'avg' is average of common estimate 6 L/m and DOE value, 22.2 m^3 per day. The 1-year dose acknowledges that only about 7% of the time are wind speeds on Rocky Flats high enough to resuspend dirt; the rest of the time NO dirt is assumed suspended. This means that the 12-hour dose should be multiplied by $0.07 \times 365 \times 2 = 51.1$ to find the yearly dose. Table 3 contrasts the two approaches.

origin	L/m BR	dose coef	dose (12 h)	dose (1 y)
ICRP	10.7 (avg)	16.0	5.24×10^{-4}	0.0268
DOE	15.42	32.9	1.55×10^{-3}	0.0793

Table 3: 12-hour and 1-year radiation effective doses in μSv due to inhaled PuO_2. BR indicates breathing rate; dose coef in μSv/Bq.

Radon

The EPA nominal value for outdoor radon radioactivity is 0.4 pCi/L; in Europe it is taken as 10 Bq/m^3 (0.27 pCi/L). Radon is probably the best-studied of all radiation sources since it is universal and indoor radon is almost always the largest single radiation exposure to humans; the International Committee on Radiological Protection (ICRP) has multiple publications discussing radon doses.

In the context of radon protection, limits in pCi/L (or Bq/m^3) are generally used. If required, radiation *doses* may be computed using International Committee on Radiological Protection 'dose coefficients' which relate radioactivity to "effective radiation dose" in Sieverts (Sv). The dose coefficient for an inhaled radionuclide is the effective dose per decay if the exposure time is in seconds

The 'effective dose' includes the full biochemistry and biokinetics of the nuclide as it is dispersed around the body and is the best single measure of total health consequences, including cancer.

As a gas, radon (^{222}Rn) requires more careful treatment than many solid radionuclides. Only 2-5% of the radiation dose comes from radon itself [7], the rest from decay progeny ('daughters'): "Progeny...regardless of...location, ...are never totally in radioactive equilibrium with radon." Since the half-life of ^{222}Rn is much longer than for the others, all four can be in approximate radioactive 'equilibrium' provided they are not separated from one another via ventilation or the 'plating out' of charged progeny on tiny dust particles, which often end up on surfaces.

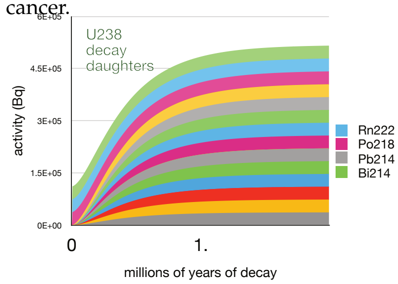

Figure 4: Radon and three main progeny are part of the ^{238}U decay chain. In 'equilibrium' the radioactivity of each is identical (equal 'layer' thicknesses.)

This is universally described by an "equilibrium factor" f_{eq} (the weighted sum of the main progeny concentrations divided by the radon concentration [7]), usually taken to be 0.4 indoors (range: 0.1-0.8) [8]. Multiplied by this factor, the radon concentration is referred to as the 'equilibrium equivalent concentration' (EEC) which could then be used in the dose calculation. *Outdoor* radon is described by a somewhat larger equilibrium factor (0.6) [8], which we will use below.

nuclide	half life	emits	dose coef
^{222}Rn	3.82 d	α	4.27×10^{-10}
^{218}Po	3.10 m	α	2.00×10^{-9}
^{214}Pb	26.80 m	α	1.20×10^{-8}
^{214}Bi	19.90 m	β	9.70×10^{-9}

Table 4: Half-lives and dose coefficients (Sv/Bq) for radon and three principal progeny. The very small dose coefficient of radon means that it barely contributes to dose.

There are a couple of approaches that would give reasonable radon dose estimates given the (i) radon concentration and (ii) assumed concentrations of the three main radon progeny, the breathing rate, and the duration of exposure. Given an assumed breathing rate BR in liters per minute (L/min) we can write for the total dose D per year in μSv as

$$
\begin{aligned}
D &\simeq 37,000 \text{ BR} \times [60 \times 24 \times 365] \sum_{i=1}^{4} A_i C_i \\
&= \text{BR } Q_0 \sum_{i=1}^{4} A_i C_i \qquad (1)
\end{aligned}
$$

where $Q_0 = 1.945 \times 10^{10}$ and A_i is the activity (in pCi/L) for each of the nuclides in the table above, C_i is its dose coefficient in Sv/Bq, and we recognize the product in brackets as the number of minutes per year. If the progeny were in equilibrium with each other then $A_i = A_1$ (all have the same activity as the parent). Much more commonly the progeny are split off using the equilibrium factor f_{eq}, as shown:

$$A_i = \begin{cases} A_1 & i = 1 \quad\quad\quad \text{(parent)} \\ \mathrm{f}_{eq} A_1 & i = 2, 3, 4 \quad \text{(progeny)} \end{cases} . \tag{2}$$

Then the dose becomes

$$D \simeq \mathrm{BR}\ Q_0\ A_1 \left(C_1 + f_{eq} \left[C_2 + C_3 + C_4\right]\right). \tag{3}$$

Occasionally C_1 is ignored since it is small (only a few percent of the dose comes from radon itself). Doing this, we find a compact form for the radon dose including its progeny using *only* the concentration in pCi/L for ^{222}Rn:

$$D_{prog} \simeq \mathrm{BR}\ Q_0\ A_1 f_{eq} \left(C_2 + C_3 + C_4\right) \tag{4}$$

where we have added the subscript *prog* to show that progeny are explicitly included.

It is also common to give a 'one-shot' dose expression for radon. The ICRP gives a current dose coefficient (see also [9]) D_0 = 6.9 nSv/(Bq-h/m^3) using an 'equilibrium factor' of 0.4. Unlike the previous route, which entailed identifying the volume of inhaled radioactivity, the ICRP coefficient already makes assumptions about average breathing rates and is based simply on the radioactivity concentration (in Bq/m^3). The inhaled radon radiation dose is written

$$D_{1-shot} = D_0 \times S \left[\mathrm{Bq/m^3\ T\ (h)}\right] \tag{5}$$

where D_0 is given above, *tacitly using* $f_{eq} = 0.4$. Here S is the total exposure over T hours to a known radioactivity concentration in Bq/m^3. To neatly compare with the full dose expression in Eq. 4 we write S for one year as

$$S = A_1 \times 0.037\ \mathrm{Bq/pCi} \times 1000\ \mathrm{L/m^3} \times \mathrm{hrs/year} \tag{6}$$

with A_1 in pCi/L.

We assume a breathing rate of 10.7 L/min and

- an *outdoor* radon level of 0.4 pCi/L and f_{eq} = 0.6 outdoors
- an *indoor* (radon-mitigated) radon level of 1.5 pCi/L and f_{eq} = 0.4 indoors

and find doses in mSv = 1000 μSv as shown in Table 5.

The point of these is that, while the ICRP is the source of almost all dose coefficients for all radionuclides, slight modifications to assumptions about breathing rates, for example, can give rise to somewhat different doses.

We can explicitly compare doses in μSv per year, noting that both expressions have a number of factors in common, which we cancel. We find

$$\mathrm{BR} \times 60 \times f_{eq} \times 0.0237 = 6.9$$

must hold for the two expressions to agree. Assuming f_{eq}=0.4 (as mentioned for D_{1-shot}) requires BR = 12.1 L/minute, quite close to the assumed breathing rate of 10.7 L/min made earlier. Thus we conclude that the ICRP 1-shot dose expression agrees very well with the somewhat more involved DOE-used data [10].

$$D_{prog} = 460.9\ \mathrm{BR}\ \mathrm{A_{Rn}} \times f_{eq} \tag{7}$$

$$D_{1-shot} = 2236\ \mathrm{A_{Rn}} \times \frac{f_{eq}}{0.4}. \tag{8}$$

source	*dose source*	*dose* (1 y)
radon (indoor)	DOE prog	2.96
radon (indoor)	ICRP 1-shot	3.35
radon (outdoor)	DOE prog	1.18
radon (outdoor)	ICRP 1-shot	1.34
background	direct measurement	1.23

Table 5: 1-year radiation effective doses in mSv from inhalation of indoor and outdoor radon and from background radiation (gamma rays from soil radionuclides + cosmic rays). Indoor radon value assumed as 1.5 pCi/L, outdoor as 0.4 pCi/L. Background is assumed measured outdoors.

Background radiation

Background radiation (due to gamma rays from radioisotopes in soil and to cosmic rays) along the Front Range is relatively high because of both altitude (fewer cosmic rays are absorbed in the atmosphere) and hard rock geology containing large quantities of natural radioisotopes. Measured *dose* values directly from survey radiation meters (pressurized ionization chambers or Geiger-Müller counters) indicate a typical level of 0.140 μSv per hour (see for example).
Note By chance, around Rocky Flats (Arvada, CO) annual doses from background radiation and from outdoor radon are comparable. The doses are for 100% outdoor occupation. In fact, significant time spent indoors will *lower* background exposure (from shielding by building materials) and *raise* radon exposure (which can be 10-20 times higher in unmitigated buildings). Thus it is fair to say that the yearly radiation dose due to radon is distinctly higher than from background.

Generally speaking background radiation doses worldwide (annual doses of about 2,400 μSv = 2.4 mSv) per year (apart from a handful of 'high natural background areas' where annual doses are 260 mSv) are believed to have no health impacts, and outdoor levels of radon about 0.4 pCi/L are regarded as safe. By contrast, the EPA recommends radon mitigation for steady radon levels above 4 pCi/L.

We assume an outdoor radon level of 0.4 pCi/L, a breathing rate of 10.7 L/m (as above for Pu) in Eq. 3 we take f_{eq} = 0.6 and find doses as shown in Table 6.

origin	dose (12 h)	dose (1 y)
ICRP one-shot	1.18 μSv	0.861 mSv
DOE granular	1.67 μSv	1.22 mSv

Table 6: 12-hour and 1-year radiation effective doses in μSv due to inhaled radon and radon progeny

The point of the comparisons in the Appendix is that, while the ICRP is the source of almost all dose coefficients for all radionuclides, modifications to assumptions about breathing rates and other regulatory adjustments by, for example, the DOE can give rise to somewhat different doses. Remarkably, around the Front Range background radiation contributes about as much to the annual radiation dose as does radon. The inhaled Pu dose is approximately 15,000 times smaller.

References

[1] Helen A Grogan et al. *Technical Summary Report for the Historical Public Exposures Studies for Rocky Flats Phase II; Part of Task 6: Technical Support for Public Involvement*. Tech. rep. 1999. URL: http://s197420.gridserver.com/wp-content/uploads/2014/12/Rocky_Flats_Technical_Summary.pdf.

[2] Y. Kurosaki and M. Mikami. "Threshold wind speed for dust emission in east Asia and its seasonal variations". In: *Journal of Geophysical Research Atmospheres* 112.17 (2007), pp. 1–13. ISSN: 01480227. DOI: 10.1029/2006JD007988.

[3] Rocky Flats Citizen Advisory Board. *Section 5: Air Monitoring Program*. Tech. rep. URL: https://static1.squarespace.com/static/641cd3744417ce6ff13df850/t/64ad7d73635d8b3319ab1095/1689091444737/envmon_air.pdf.

[4] C H Clement. "ICRP Publication 119: Compendium of dose coefficients based on ICRP Publication 60". In: *Ann. ICRP* 41 (Suppl) (2012), p. 130. ISSN: 01466453. URL: https://bit.ly/3E0jOMw.

[5] Dunstana R. Melo et al. "Dose Coefficients for Internal Dose Assessments for Exposure to Radioactive Fallout". In: *Health Physics* 122.1 (2022), pp. 125–235. ISSN: 15385159. DOI: 10.1097/HP.0000000000001500.

[6] U.S. Department of Energy. *DOE STANDARD: Derived concentration technical standard*. Tech. rep. 2022. URL: https://www.standards.doe.gov/standards-documents/1100/1196-astd-2022/@@images/file.

[7] IRSN (France). "New dose coefficients for radon. recommended in ICRP Publication 137 Explanatory note". In: *Report PSE-DSNTE/2018-00002* (2018). URL: https://en.irsn.fr/sites/en/files/2023-12/IRSN_Report-PSE-SAN-2018-00002_Radon-dose-coefficient.pdf.

[8] Jing Chen. "RISK ASSESSMENT for RADON EXPOSURE in VARIOUS INDOOR ENVIRONMENTS". In: *Radiation Protection Dosimetry* 185.2 (2019), pp. 143–150. ISSN: 17423406. DOI: 10.1093/rpd/ncy284.

[9] J. D. Harrison and J. W. Marsh. "ICRP recommendations on radon". In: *Annals of the ICRP* 49.ICRP 2019 Proceedings (2020), pp. 68–76. ISSN: 1872969X. DOI: 10.1177/0146645320931974.

[10] Richard W Leggett and Michael B Bellamy. *RADON CANCER RISK COEFFICIENTS and AGE-SPECIFIC EFFECTIVE DOSE COEFFICIENTS*. Tech. rep. January. Oak Ridge National Laboratory, 2017. URL: https://rais.ornl.gov/documents/RadonDoseandRiskCoefficientReport.pdf.