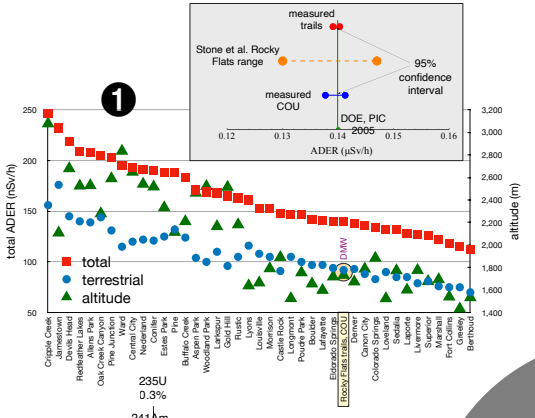
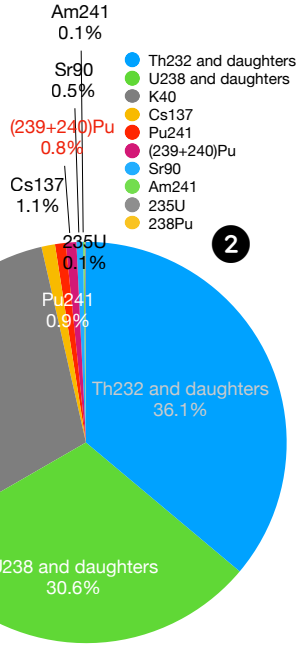
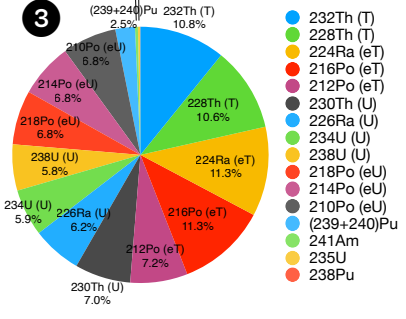
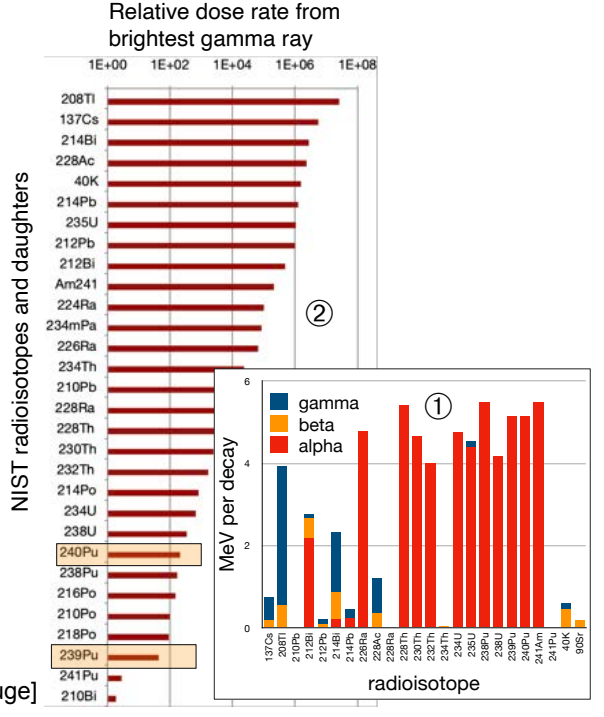
Refuge/COU have ordinary background radiation. Why? Pu contributes about 0.8% of total soil radioactivity, less than fallout isotopes. Among alpha emitters, about 2.5%







Pu is very similar to natural alpha emitters. But ^{239}Pu emits about 10,000 times less gamma radiation than most soil radioistopes. Gamma rays cause radiation doses to the entire body at once; alpha particles are stopped by skin. Only route to Pu exposure is inhalation or swallowing.



❶ Front Range background radiation dose rate [Inset: measured values, COU and Refuge]
❷ Contributions to total soil radioactivity by radioisotope or decay chain [NIST]
❸ Contributions to soil alpha-particle activity by radioisotope [NIST]

① Energy per decay from alpha, beta, gamma radiation for Pu and natural radioisotopes
② Relative dose rates (unnormalized) from gamma rays emitted by soil radioisotopes. Note log scale.

A

Soil plutonium and radiation

- Radiation levels on Rocky Flats are as expected for the Front Range (since Pu accounts for 0.8% of total soil radioactivity [NIST]. The natural radioisotopes ^{40}K (half life 1.3 billion years), ^{238}U (half life 4.5 billion years), and ^{232}Th (half life 14.2 billion years) and their 'decay daughters' account for almost all of the rest. NIST measurements: there is more fallout isotope ^{137}Cs from the '60s and '70s than Pu in Rocky Flats soil.
- Pu is very similar to natural radioisotopes but emits very few gamma rays, so only exposure route is inhalation and ingestion.
- Over the Refuge+COU, Pu contributes less than 0.6% of soil *alpha* radioactivity. Were excess cancers due to alpha radiation found downwind (they have **not**), the 'attributable fraction' due to *natural* alpha emitters would be 99.4%
- The radiation dose from Pu (or Am) in Rocky Flats soil is **physically constrained by scarcity** to be *very small*.
- More than 80% of Jefferson Parkway samples on the eastern Refuge boundary *and* DOE samples showed less than 1 pCi/g, 50 times smaller than the negotiated cleanup standard. Total soil radioactivity from NIST-measured standard samples and daughters is about 53.5 pCi/g.
- Ketterer's measured hot particles (9 cases out of 348 samples) contribute not more than 0.5 pCi/g.

website

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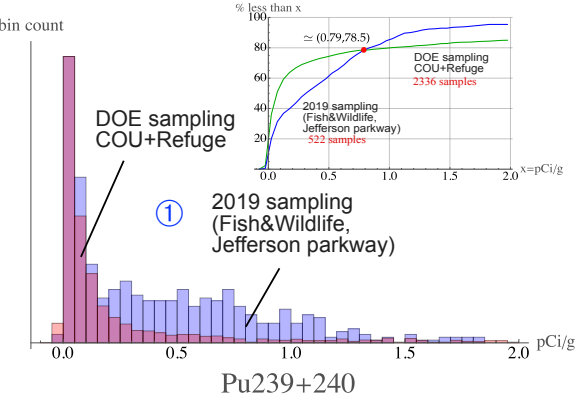
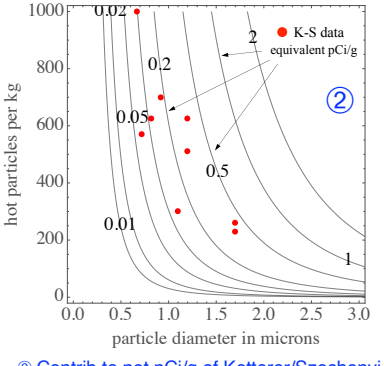
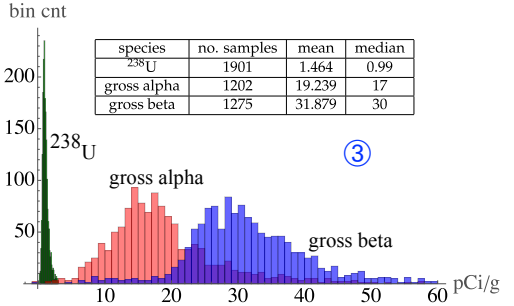


① Soil Pu value histogram (max bin count aligned); inset: % of all samples less than specified pCi/g



② Contrib to net pCi/g of Ketterer/Szechenyi hot particles by location (348 samps)



species	no. samples	mean	median
^{238}U	1901	1.464	0.99
gross alpha	1202	19.239	17
gross beta	1275	31.879	30

③ Histograms for ^{238}U and gross alpha and beta soil activity

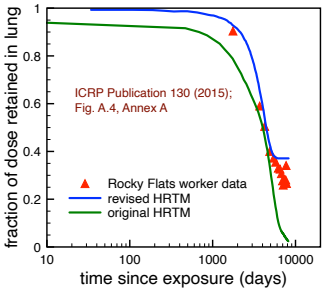
set	HP	samps	pCi/g	$\bar{d}(\mu)$	HP/kg
C1	4	32	2.23	1.2	625
C2	4	39	2.32	1.2	510
C3	2	43	3.95	1.7	230
C4†	2	34	1.37	1.1	300
C5†	2	39	1.08	1.7	260
RF-26†	6	43	1.07	0.92	700
RF-28*	5	40	0.38	0.82	625
RF-29†	9	43	0.30	0.67	1000
RF-30†	4	35	0.30	0.72	570

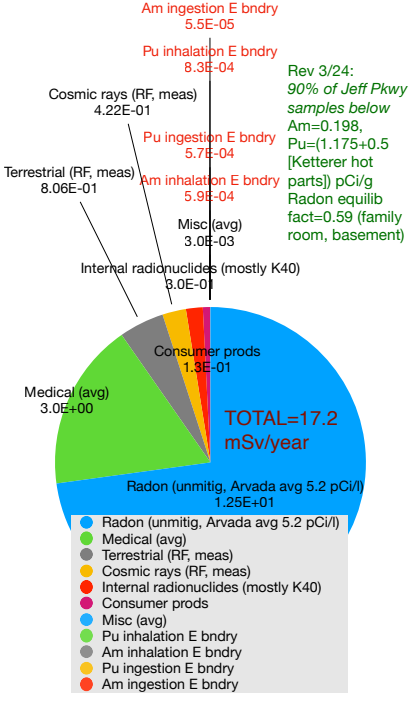
Ketterer/Szechenyi data

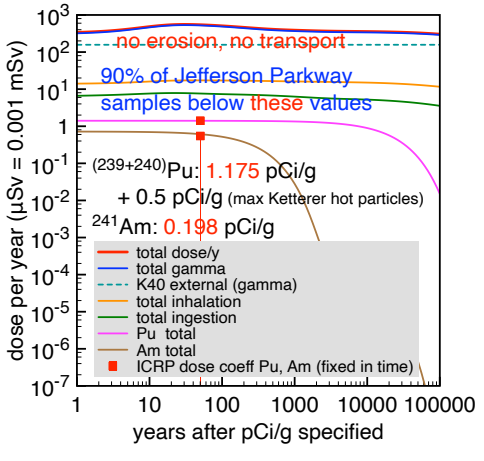
B

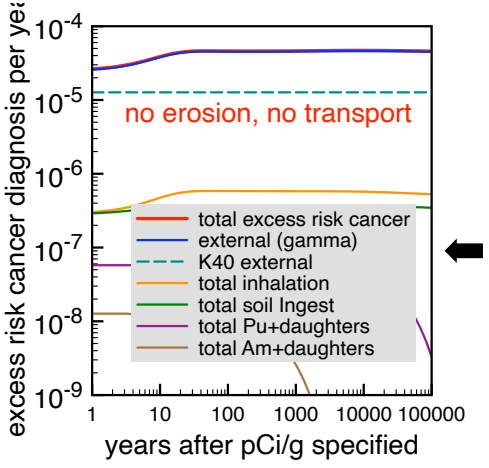
Pu radiation dose and risk

- The International Commission on Radiological Protection [ICRP, founded 1928] consists of experts from around the world. Essentially all radiation regulations in all countries stem ultimately from ICRP findings, published and updated frequently. The EPA, DOE, and other agencies all rely on carefully vetted ICRP 'dose coefficients' which relate measured radioactivity to radiation dose. These reflect the mode of exposure (inhalation, swallowing, or whole-body exposure from gamma rays), including very extensive biokinetic information. These always include a safety margin and are available for a very large number of radioactive compounds of different chemical forms. Rocky Flats worker data (graphic shown) directly impacted ICRP guidelines.
- The ICRP also maintains *risk* coefficients based on the total impact of radiation exposure, often in the form of lifetime (70-year) risk of developing cancer. These are based on often revised epidemiological studies, e.g., the INWORKS study (10.7 million person-years of followup among nuclear workers in mutliple countries).
- ICRP Publication 150 is *Cancer risk from exposure to plutonium and uranium* was published in 2021.









Assumptions underlying radiation risk

Measurements of radioactivity (decays per second) and radiation (what comes out during these decays) are precise and reliable. Radiation *dose*, mostly a complex geometry problem is more difficult. Relating dose to health risks depends on very careful epidemiology and is the least certain.

- Risk (say, of cancer) is assumed linearly proportional to dose (the 'linear no threshold' description.

website

flyer/bibliography

RESRAD

- The RESRAD ('RESidual RADioactivity' packages (Argonne National Labs, freely distributed) assess radiation dose and risk within a comprehensive environmental framework using occupation scenarios. Refined over 36 years, it is in active use by 100 countries and is the *de facto* international standard. It includes full tracking of multiple radioisotopes and multiple routes to radiation exposure (via water, food, meat, fish, crops, inhalation, ingestion, and whole-body exposure to soil isotope gamma rays).
- Like virtually all radiation protection frameworks, it uses ICRP 'dose coefficients' and faithfully reproduces ICRP values for radioisotopes of interest [see small red squares in dose chart]
- In results shown we use 1.175 pCi/g of Pu plus 0.5 pCi/g equivalent for PuO_2 hot particles, and 0.198 pCi/g from Am; 90% of all Jefferson Parkway samples have lower values. All erosion and transport is 'switched off' to show half-life effects We also include other radionuclide quantities found by NIST.
- *Results:* The half-lives of ^{239}Pu (24,100 years) and ^{241}Am (432 years) are obvious in both sets of curves (colored purple and brown). It is obvious that gamma rays contribute virtually all of radiation doses and risks.
- Yearly doses from Pu are 1.40μSv and 0.67μSv from Am while *total* annual doses from RESRAD are 547 μSv, of which 522 is due to gamma rays. Thus Pu contributions are 400 times smaller than the total dose, partly due to its tiny soil concentration and partly due to its very low gamma emissions.

What about the single large Jefferson Parkway hot particle?

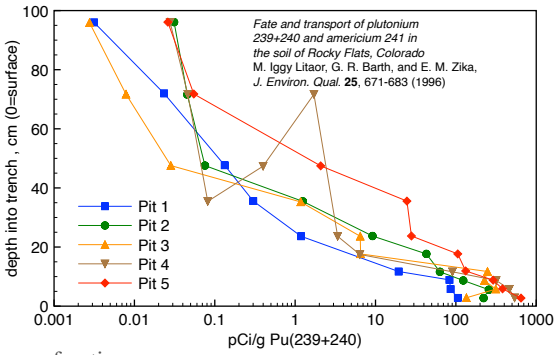
1 of 440 Jefferson Parkway samples contained a *very large* 8.8μ hot particle (upper limit of respirable size) yielding 264 pCi. We can still ask *how many* identical inhaled particles would raise the lifetime risk of cancer by 1%?

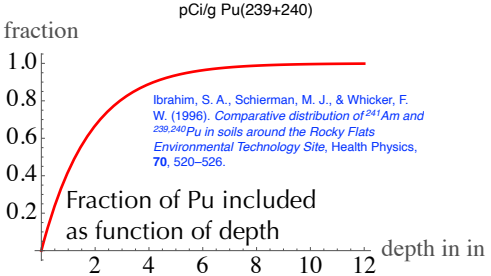
- The activity (in decays per second, Bq) for a PuO_2 particle of diameter d in microns is:

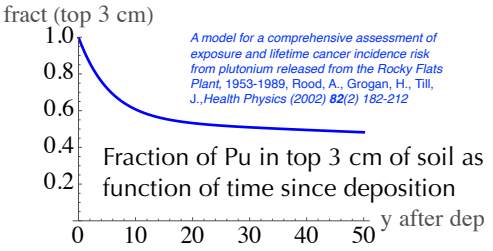
$$\frac{4\pi}{3}\frac{1}{2}(d/a)^3 \times \frac{\ln 2}{t_{\frac{1}{2}}} = .01214\, d_\mu^3$$

with a is the 'lattice constant' of fluorite PuO_2.

- With the ICRP value of 0.055 excess cancer diagnosis risk per Sv of radiation dose, the required dose D obeys .01 = .055 D(Sv), or D = 0.18 Sv. Each 8.8 μ hot particle has an activity of 8.273 Bq (decays/sec). Using the ICRP dose coefficient for inhaled ^{239}Pu, this activity contributes a dose of 16.0 μSv/Bq, or 132.4 μ Sv/particle. Thus to achieve a dose of 0.1818 Sv, about 1375 particles are required. [RESRAD 'slope factors' (risk per Bq) yield about 1350 particles, confirming how RESRAD relies directly on ICRP data.]
- **Many more** of the largest (about 1.7μ diameter) hot particles detected by Ketterer would be required, since the activity depends on the cube of the diameter: about 190,000 particles.
- The chances of inhaling or ingesting 1375 large hot particles given that 440 samples showed **one** is extremely tiny.



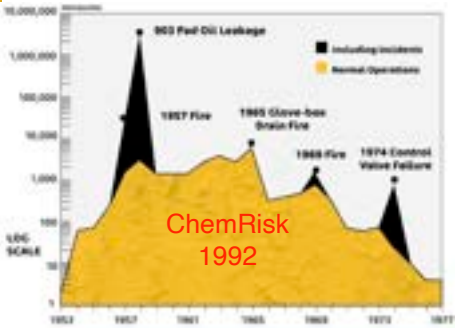


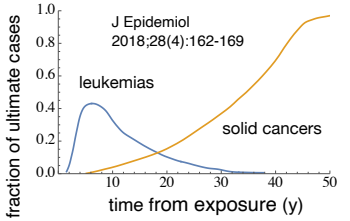


How deep does contamination go?

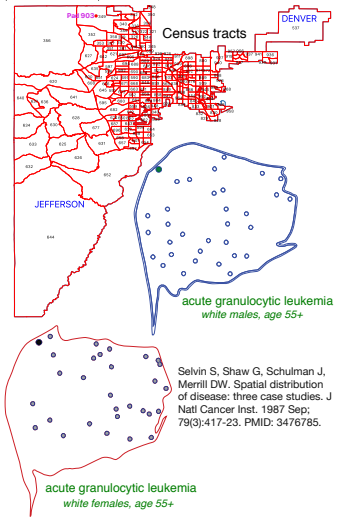
- Pu releases came via wind-blown dust from the the '903 pad' area, 1957 and 1969 fires, and a couple of other accidents. **All** would end up on the **surface**.
- Pre-cleanup research identified the scrape depth required. 1996 trench data [graphic] for highly contaminated soil shows very high Pu levels in the top 20 cm, dropping exponentially to very low levels by 1 meter. Roughly linear behavior on a semilog plot shows exponential decay.
- There is no data to support claims [*e.g.*, by Jon Lipsky] that Pu levels rise hugely (as is permitted by the agreement) beyond the 3-foot cleanup depth; this is physically very implausible.
- A fit to many measurements [graphic] shows 90% of Pu is found within roughly the top 4 inches.
- As might be expected from soil erosion and other processes, "…it is difficult to reconcile the few measurements made by Krey with over 116 measurements from other researchers that show a clear decrease in surface soil plutonium inventory over time" (Rood et al, 2002). A fit and extrapolation [graphic] is shown.

website flyer/bibliography





Japanese Legacy Cohorts: The Life Span Study Atomic Bomb Survivor Cohort and Survivors' Offspring



C

Blunders by anti-nuclear activists

I found the license plates GLJ450 and YKO261 in my garage. **What is the probability to find these two particular numbers there?** This sounds astronomically tiny: given the pattern, about 1 in 3×10^{14} (two independent random choices from finite lists).

But the actual probability is 1. If you understand why, you are smarter than 'applied mathematician' Randy Stafford, who fell into this simple trap in his eagerness to blame Rocky Flats plutonium for two nearby cases of cardiac angiosarcoma.

- The key is *random sampling of an appropriate population*. In fact, I knew the plate numbers were in the garage *before* posing the question, collapsing the calculation into meaninglessness. (Physicists know this example thanks to Feynman.) Stafford knew about the angiosarcomas by word of mouth (anecdote) since 2018.
- In careful epidemiology any foreknowledge is a form of 'selection bias' which should be automatically excluded. The 2016 the RF Downwinders asked a self-selected population (who'd been told for decades to blame Rocky Flats for exotic diseases) to fill out a health survey. This is selection bias compounded by *anecdata*.

Epidemiology around Rocky Flats

- The scientific literature suggests that, for example (i) inhaled Pu in dust should primarily impact lung cancer rates because of the very short range of alpha particles; (ii) the incidence of cancers (say per 1000 people) should be higher closer to Rocky Flats, if it is the source of Pu.
- By 1983, published claims by Carl Johnson of high cancer rates downwind of Rocky Flats had been discredited as sloppy: "The strongest statistical correlation found was between cancer incidence and proximity to the State Capitol Building …The trends towards higher cancer incidences closer to the Rocky Flats plant …were also reaffirmed. However, when the census tracts were stratified by distance from the State Capitol Building, the correlation of cancer incidence with proximity to Rocky Flats largely disappeared."
- Careful epidemiological checks on Johnson's claims were nonetheless pursued. It is plausible to look for cancers known to be highly radiation sensitive and which do not take decades to develop (as do 'solid cancers'). Leukemias are often examined around radiation sites [graphic].
- As computers became more accessible, more sophisticated tools permitted correction for a serious complication, the very non-uniform population density around Rocky Flats at that time. Uncorrected, areas of high population density would appear to be cancer clusters even with normal cancer incidence. (Census blocks all have roughly the same population so small blocks have large population density.)
- Cartograms which distort geographical areas to make the population density constant preserve statistical information. These show no correlation with distance from Rocky Flats. (Random distributions would be found with no excess cancers.) Several additional examinations confirmed this.
- Ongoing CDPHE surveys show no excess cancers around and downwind of Rocky Flats.
- Detection of variations in cancer risk with background radiation are at the limit of what large-scale epidemiology can measure. Pu doses on the eastern edge of the Refuge are about 400 times smaller than background dose.

When does repeated misinformation become lying?

"It's not what they don't know that scares me, it's what they know for sure that just ain't so."–Mark Twain.
Anti-nuclear groups have deliberately misrepresented facts for decades. Many beliefs reflect complete non-comprehension of radiation, physics, math, and what has been long know about Rocky Flats. As a result, their spokespeople shoot themselves in the foot and (properly) reinforce stereotypes about them.
The examples below are drawn specifically from the March 11, 2024 Westminster City Council meeting. Where possible, time stamps for parts of the transcript are given.

D

Making **our** point

Alesia Casey [1:03:25] "…the Colorado Department of Health gave a presentation in 2015, which outlined a field north of the Candelas development that had 38 test spots. Each of those test spots came back positive for levels of plutonium." No, really!? Where has she been for the last 55 years?
Wrong: the year (it was 2019), the agency (it was Fish &Wildlife), and the locations (mostly), but the sample number is right. [Look here for maps and histograms.]
Sampling was for proposed changes for the Rocky Mountain Greenway. The data: on the north side, 20 samples with median value (10 higher, 10 lower) of 0.03 pCi/g. In the southwest: 15 samples, median 0.04 pCi/g. On the east side (partly in 'windblown area'), 13 samples with a median of 1.5 pCi/g. **The cited samples are thus 1670, 1250, and 33 times lower than the nominal 50 pCi/g cleanup criterion.**

How deep does contamination go?

Jon Lipsky [1:11:55]: "But the point of it is the soil disturbance, the digging below three feet, the standard changes from 50 picoCuries per gram and below three feet is 1000 to 7000. And below six feet, it's unlimited."
As expected from Mr. Lipsky, this statement is correct. What was *negotiated* and what is *present* are two different things. Based on 2336 DOE samples the highest measured soil value (COU) is 183 pCi/g, with the next 51.9. I know of no places where high levels *actually* occur (possible exception: non-mobile contaminants in the small number of buried foundations within the COU). Measurements instead show (i) Pu levels rapidly **decrease with depth** and (ii) surface levels appear to be **decreasing with time**. [p. Ⓒ]

Ancient claim

Giselle Herzfeld [1:43:31] "We are dealing with the most dangerous material known to man." This claim dates to Ralph Nader, anti-nuclear since the 1970s, and was never true. The LD50 [the dose which kills 50% of test animals] for ^{239}Pu is about 0.74 mg/kg (animals). For nerve agents (sarin, VX): below 0.1 mg/kg; for diphtheria, tetanus toxin: below 0.001; botulin toxin: about 0.000001 mg/kg. As Botox users can attest, 'the dose makes the poison'.

Cascades of misinformation

Chris Allred (Peace&Justice) [1:49:15]: "…this is the area that Dr. Carl Johnson said should never be developed. That's the 1976 study." 'Appeal to authority' (not citing data or facts) using 48 year old, discredited Johnson findings is typical conspiracy theory argumentation.
"…be mindful that the DOD has a vested interest in protecting nuclear bomb production. Our interest is protecting public health." More conspiracy theory! The Department of Energy is not controlled by DOD. Cloaking scare tactics as concern for 'public health' is typical; no anti-Refuge person can tell you anything about radiation dose or measurements.
Citing school district bans on Refuge visits or decisions of other cities does not justify anything: here are two example:
"…I thought that, in solidarity with our partners, like Denver Public Schools and Adams (county school districts) that it would be beneficial to forgo those field trips." Kyla Armstrong-Romero, quoted in *sentinelcolorado.com*, 20 November 2019). More here, with transcripts and citations. "Lisa Flores [Denver Public Schools] herself cited the Jeffco field trip ban as a precedent for her own decision. Now she's provided cover for politicians and even higher office to do the same." (Paul Karolyi, *Changing Denver* RF podcasts episode 5).

Dunning-Kruger effect victim

Randy Stafford [2:09:31]:

- "…Pu is confirmed at levels representing 100s or 1000s of times background radiation, and representing multiples of the allowed cleanup limit". Ratios are a childish ploy to enhance alarm. Background radiation (dose) is about 420 times *larger* than that from Pu. The 2019 single 'hot particle' (264 pCi) is the only significant departure from the 50 pCi/g standard; 85% of values on the eastern Refuge boundary are below 1 pCi/g, 50 times smaller.
- "…Some studies find greater incidence of cancer closer to Rocky Flats than farther away, and a couple of other studies have found the opposite conclusion." *Two* 1981 studies found higher incidence. Johnson's work was discredited by 1983. 7 later studies (1983-1998) and ongoing CDPHE reviews have not found elevated rates—see sample data on p. Ⓒ.
- "All of the safety determinations about the site are ultimately based on modeling and simulation software called RESRAD. It's a closed source program" Nonsense. Given measured pCi/g and yearly amounts of inhaled and swallowed dirt any health physicist in the world would find about the same results as RESRAD directly from International Commission for Radiological Protection publications.For an 'applied mathematician' to reject modeling (there is no simulation in RESRAD) is stunning.
- Stafford's egregious anecdata about angiosarcoma was discussed on p. Ⓒ.

website flyer/bibliography

Hysterical and outlandish prize

Deborah Segaloff, Ph.D: "…Building the overpass above Indiana Avenue to connect it with open space in Westminster would all but guarantee the transfer of plutonium far from the Refuge …Ultimately, the Greenway trails would not only put those using them at risk, but would also allow them to be tracked far outside the Refuge, thereby putting many other individuals including visitors to the Rocky Mountain National Park at risk." Dr. Segaloff apparently has no reputation to jeopardize. Of the 454 Jefferson Parkway samples on the eastern Refuge boundary, 95% showed values less than 2 pCi/g, 25 times below the nominal standard. Values drop abruptly (see the color coded map here off the 'wind-blown area'.) Had she bothered, she could have discovered articles like *Mass transfer of soil indoors by track-in on footwear* which considered, for a variety of shoe treads, what was tracked *onto* a prepared and measured surface. This is a good estimate of what is tracked from one area to another. They noted "Typically no more than 1 g of dry soil was picked-up irrespective of the sole type. ……initial soil contamination is likely to be limited to an area within 7–8 m of the entrance…" On the north side of the Refuge where the link to the Greenway occurs the mean Pu concentraton is 0.03 pCi/g (among the lowest in the Refuge). The total soil radioactivity in Rocky Flats soil is about 53.5 pCi/g, about 1800 times larger. Natural soil radioactivity varies by about 2000% around Colorado.

Ignorance of Rocky Flats data

Deborah Segaloff, Ph.D (Physicians for Social Responsibility) [1:06:51] "Note that this [50 pCi/g, not 50 pg/g] threshold is 500 to 5000 fold higher than background plutonium levels …fallout of atmospheric testing of atomic weapons." There is more ^{90}Sr fallout than Pu in Rocky Flats soil. [p. Ⓐ] Dividing by the lowest background Pu levels she could find increases the ratio, but not the dose. Natural radioisotopes contribute [p. Ⓐ] 99.4% of total soil alpha radiation.
"…sampling of the Refuge along Indiana Avenue detected a particularly hot particle of plutonium. This prompted Broomfield to withdraw from the building of the Jefferson Parkway, as well as the Rocky Mountain Greenway."
As can be seen on p. Ⓑ, such a particle is barely respirable and about 1350 inhaled and stuck in the lung would be needed raise lifetime cancer risk by 1%. Broomfield's choice to ignore advice by the CDPHE and its own physician led to its withdrawal and is a reflection of absence of due diligence and vulnerability to misinformation rather than an actual health risk.