

Ground truth at Rocky Flats

or, 'How to feel completely safe in or around the Refuge'

A word cloud of terms related to the Rocky Flats incident, arranged in a circular pattern. The words are: hot particles, anecdotal, weasel, feckless, Conflicting tests, CDPHE, DOE, selection bias, 2nd test shows lower level, findings, 5 times, Cancer clusters, divide, epidemiology, Coloradoans, conspiracy theory, alpha particles, cleanup standard, DOE, additional testing needed.

- B.A. physics, Princeton 1974; Ph.D physics, Cornell 1981, 2-year postdoc Ohio State
- Solar Energy Research Institute (now National Renewable Energy Laboratory), Golden 1982-1989 + 1 year visiting scientist
- Colorado School of Mines 1989-2017; retired physics professor
- Intimately involved as citizen scientist with Rocky Flats safety, 2013-present. Member SAFECAST (non-governmental radiation measurement network).

Why should you trust me?

- Plenty of 'due diligence' before buying in Candelas, much more after.
- Sufficient technical expertise to read any of the literature in health physics and radiation safety, math, epidemiology, nuclear physics, enough biology.
- 28 years of experience explaining. Purpose of rockyflatsneighbors.org is to provide from scratch (DOE-independent) estimates of RF radiation safety using only *measured* data. Then *explain* this to others.
- Unlike DOE or Colorado Department of Public Health and Environment (CDPHE), I can call things as I see them without fear of political repercussions.

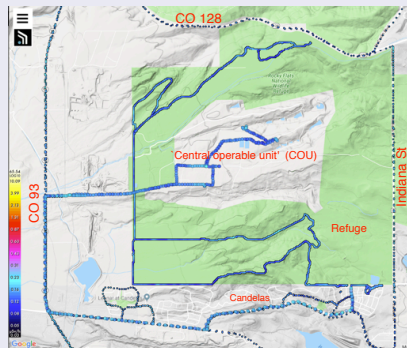
My purpose

- Review old science, new measurements related to Refuge safety
- The Great Jefferson Parkway Hot Particle Kerfuffle
- Common misinformation continues
- Answer *your* questions (at end)

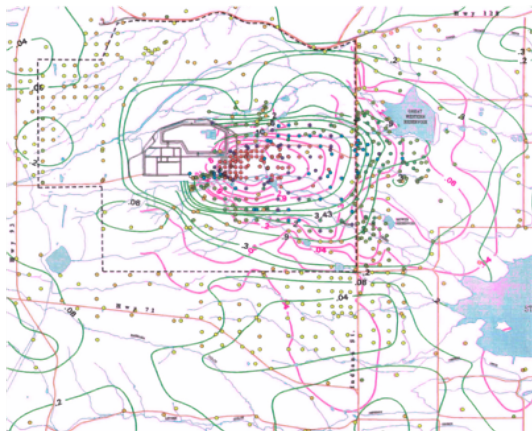
Goal: Deep, intuitive feel for why where we live is *safe*.

Provide ammunition against misinformation from well-intentioned 'activists'.

The Refuge



SAFECAST measurements of 'ambient dose equivalent [radiation] rate'. Trails: DMW, April 2019; COU: Kim Griffiths, June 2019.



Green: $^{239}+^{240}\text{Pu}$
Pink: ^{241}Am (from
trace ^{241}Pu)

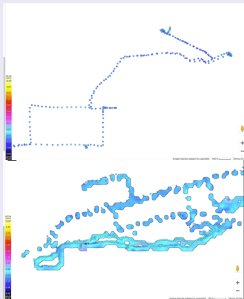
Important

- Radioactivity measureable at very low levels.
- Measureable does not imply dangerous.
Context is everything.

2006 DOE map: pre-cleanup, still relevant outside COU. Direct measurements of Pu, Am; units are picoCuries per gram of soil (pCi/g).

An example

SAFECAST network (90M+ data points around world in Fall 2018) has downloadable data sets of 'ambient radiation dose equivalent' (ADER) measured with a standardized, well-calibrated data logging, geotagging, Geiger-Müller counter

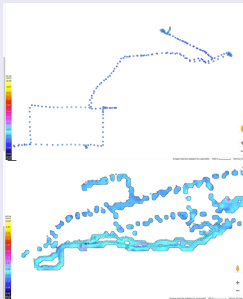


Lower location has higher radiation levels than the other. Higher cancer rates?

Context is everything

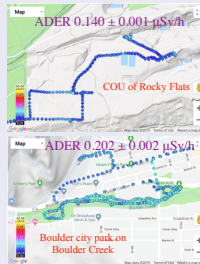
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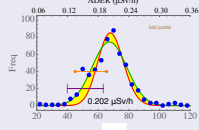
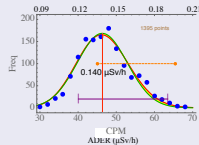


Lower location has higher radiation levels than the other. Higher cancer rates?

Details



Boulder city park: 44% higher ambient radiation levels than the Rocky Flats Central Operable Unit!



Where's the plutonium?

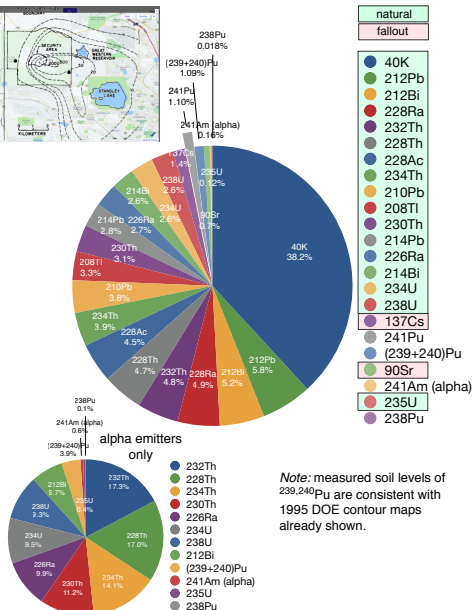
What's in Rocky Flats soil?

Ask the National Institute of Standards and Technology

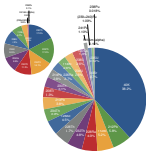
Comprehensive radiation 'soil standards' produced 1984, 2007 from samples collected 1978 from west, east sides of what is now Refuge 2007: 14 labs from Austria, Germany, U.K., U.S.

Important

- Plutonium isotopes represent about 2% of *total soil radioactivity* in Refuge. Thus Pu can only be detected using specialized equipment. **Fallout isotope ^{137}Cs is more common than $^{239,240}\text{Pu}$ in RF soil!**
- Soil alpha particle emitters (range <4"): Pu, Am account for < 5% of total.



Significance



Consequences

- Since $< 3\%$ is due to Pu, Am isotopes, total ambient radioactivity in Refuge should be *ordinary Colorado background*. This is what we *measure* (April-June 2019) at right. No surprise.
- 97+% of radiation in windblown dust is due to *natural* radioisotopes (^{40}K , thorium, uranium).
- 95% of alpha-particle emission (pie chart) comes from natural radioisotopes.

Why even clean up a 2% trace contaminant?

Superfund cleanup stemmed from EPA mandate to clean up **man-made messes**.

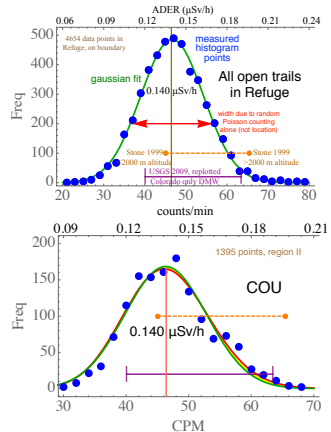


Figure: The trails in the Refuge and roads/paths in COU both show an ambient radiation level well within the range of *background* radiation in Colorado (orange connected dots and purple bracket).

Plutonium is special because it's man-made

No, it's *not*.

- Dangerous, but not remarkably toxic.
- Pu, Am are not radiologically different than dozens of other *natural* radioisotopes. Your body doesn't care if an alpha particle came from a thorium or a plutonium nucleus.

24,000 year half life!

- 24,000 is *short* compared to natural alpha emitters.
- True *short* half lives (days-months) yield intense radioactivity (medical imaging, radiopharmaceuticals).

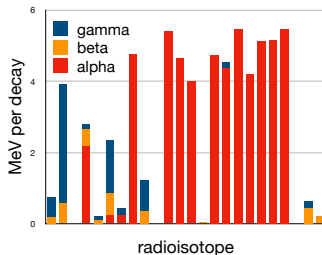


Figure: Which is ^{239}Pu ? Pu is **not** special. MeV = unit of typical nuclear energy.

Background radiation and epidemiology

Epidemiology

Analysis of the distribution, patterns, and determinants of health and disease in well-defined populations. Cornerstone of public health and evidence-based practice. Identifies and quantifies risk factors.

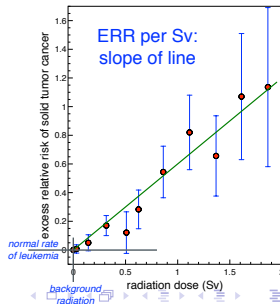
Risk

- The fact you can *measure* something does not mean it represents a health risk.
- Is a toxin a *threat*? Focus on ‘excess risk’—the risk *beyond* what is normal for given situation.
- This in turn relates to the excess *concentration* of toxin over what is *always* present—the *background value*.
- Background radiation is *always* neglected in calculation of cancer risks. No excess cancers even in ‘high natural background radiation’ areas of India, China, Brazil (background radiation almost $100 \times$ Colorado)

Cancer rates in Colorado

- Front Range has 60% of Colorado’s population, *highest* background radiation in U.S.
- Colorado has the *lowest* overall cancer rates in U.S.

$$\text{ERR} = \frac{\text{excess cancer rate due to extra dose}}{\text{cancer rate due to background radiation}}$$



“Plutonium in soil sample near Rocky Flats five times higher than cleanup standard”. [std=10 pCi/g]

Meaning?

- Single 8.8 micron diameter PuO_2 particle in one sample from Jefferson Parkway corridor [human hair: about 50 micron]. One such ‘hot particle’ can completely dominate a sample’s radiation level.—Like finding a roach in your glass of water and complaining Arvada has poor water standards. Unpleasant surprise, but not typical. (Figure)
- Many thousands of DOE samples post-cleanup: no hot particles. 42 Michael Ketterer samples, 143 from Parkway sampling: none hot so far.
- 10 pCi/g was never a health-related threshold! *Negotiated* compromise between higher levels (DOE), lower level (LeRoy Moore & company)

Measured

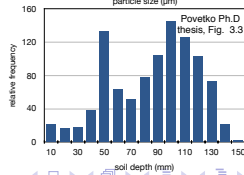
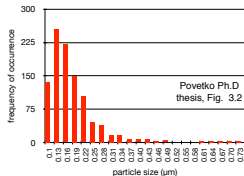
Average in Refuge: 1.1 pCi/g

Average in COU: 2.3 pCi/g

Average in corridor (previous): 1.4 pCi/g

Maximum in corridor (previous): 8.8 pCi/g

Natural soil radiation level: at least 41 pCi/g [NIST]



'Hot particles'

Will 1 inhaled hot particle cause cancer?

- 'Hot particle' = tiny, very radioactive fleck of insoluble alpha particle emitter (like PuO_2).
- NIST soil standard: about 1.8 hot particles per 90 gram sample. You'd need to inhale, swallow golf ball's weight in soil for 50-50 chance of encountering one.
- Health concerns about inhaled hot particles stuck in the lung raised in 1974. Intense research for 3-4 years. Clear by 1978 (animal experiments) that respirable hot particles were not especially toxic since (i) their non-uniform dose was *less* dangerous than an equivalent dose of radiation *uniformly* and (ii) they produce *fewer* cancers.
- PuO_2 absorbs many of its own alpha particles ('self shielding'), important for particles bigger than around 1 micron. My estimate: **for 3 micron PuO_2 particles, inhaling 3600 would raise cancer risk by 1%** (DOE estimate: 5000).
- **For large (almost non-respirable) 8.8 micron hot particle could still inhale 400. Inhaling even one very unlikely.**

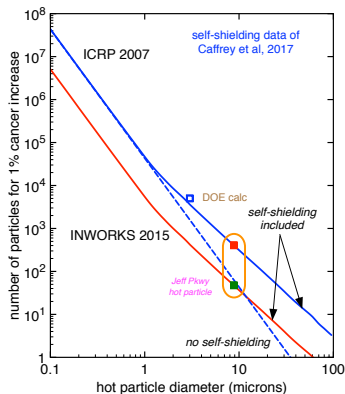


Figure: Number of particles you'd need to inhale for a 1% increased risk of (solid tumor) cancer. Red and blue indicate different sources of ERR per unit dose.

Absolutely not!

Cancer clusters around Rocky Flats?

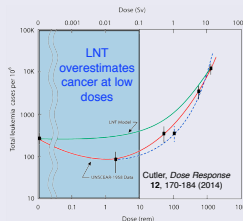
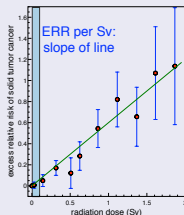
How can Rocky Flats influence cancer rates? [*Mechanism*]

Remember: [NIST]: RF isotopes are 3% correction to natural soil background radiation

- Direct radiation from plutonium? *No*: range of alpha particles is 2 inches; betas: few feet; gammas: hundreds of meters (almost none from plutonium, americium).
- Inhaled radioactive dust? *Probably*: But Pu is 2% correction to background radiation (ignored in epidemiology). Included in DOE modeling already.
- 'Hot particles'? *Extremely implausible*: rare. RF typical is 0.12 microns (negligible dose); 3600 3 micron or 400 8.8 micron particles raise cancer risk 1%.

How can Rocky Flats influence cancer rates? [*An estimate*]

Fit straight line to cancer risk data: "ERR per Sv" (Sv=sievert=tissue radiation dose)

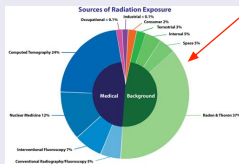
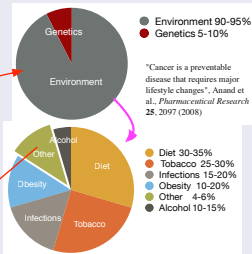
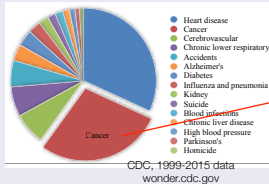


Breast cancer: (INWORKS, 2015) ERR=0.47/Gy.

- For typical American: 6.2 milli Sv/year: 34 years to develop a 10% higher risk
- Conservative estimated dose from RF isotopes: 2 microSv/year: 82,000 years to raise breast cancer risk by 10%

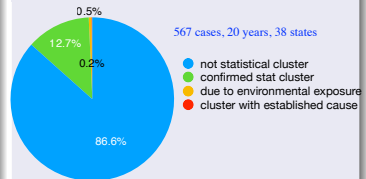
Cancer clusters around Rocky Flats? Statistics

Radiation-induced cancers in context



Lifestyle changes can change your lifetime cancer risk by 20%, roughly 1 million times the impact of Rocky Flats soil plutonium.

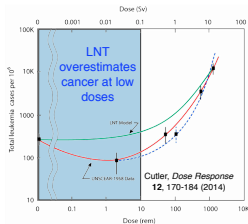
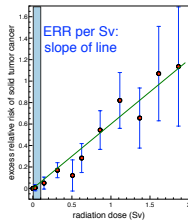
Outcomes of cancer cluster investigations



Cancer cluster studies around nuclear sites in United Kingdom, France, Australia, Germany: no evidence.

"The argument has become very familiar—that radionuclides introduced into the environment from nuclear installations, fall-out from weapons testing, or whatever source, are responsible for substantial increases in cancer rates, and, because current risk estimates do not support this conclusion, they must be very wrong. It is argued that there must be some way in which low levels of artificial radionuclides, levels that result in tissue doses lower than from naturally-occurring radionuclides, pose a risk that is yet to be appreciated." John Harrison, 2003

Gravy: an extra margin of safety



The 'linear, no-threshold' model [LNT]

- Straight line through data for cancer rates vs. radiation dose works reasonably well at *high doses*, say doses > 0.1 Gy (gray)
- Epidemiology can say little about low doses: statistics unreliable
- **Experiments indicate LNT overestimates cancer at low doses**
- Considerable evidence that low-dose radiation *protects* against effects of higher dose radiation by 'priming' immune system.

Consequences

- LNT relegated to *regulatory* status at low doses. Used by governments to assure compliance with radiation contamination statutes.
- Controversy: LNT is extremely convenient but may provoke fear even for low doses (skipped medical diagnostics, Fukushima evacuations, etc)

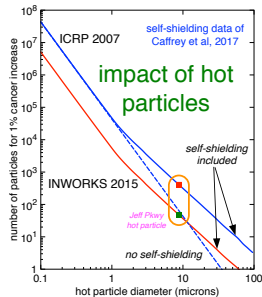
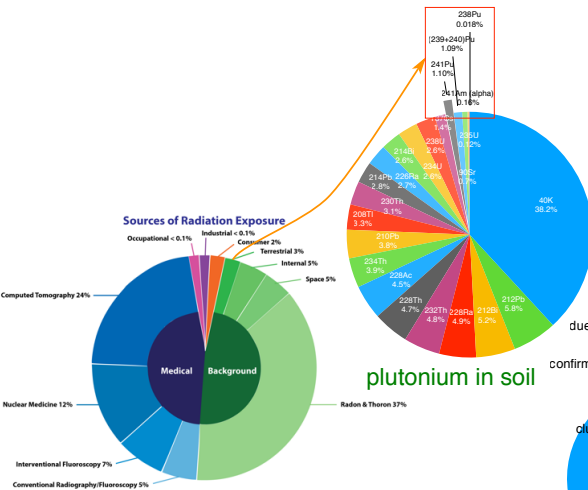
Big picture

- The science is **unambiguous and unequivocal**: there *is negligible health risk* either around the Refuge or within it
- Simple estimates are sufficient to understand extremely low risk.
- Cancer clusters are *extremely unlikely* based on 20 years of experience in the U.S., U.K., Switzerland, France, Germany around former nuclear sites: COMARE (UK), National Cancer Institute (US), National Research Council 2012 [104 operating nuclear reactors at 65 sites in 31 states review, ongoing effort]
- Activist ‘points’ are factually wrong or are out of date by 40 years. Not one piece of *evidence*. They provide reliable historical info, however.
- My experience: CDEPHE provides readable, reliable info. DOE: Reliable, not very readable. Rocky Flats Stewardship Council: good documentation.

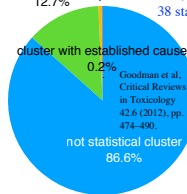
Science evidence

- NIST soil standards puts RF isotopes in context: less than 3% of RF total soil radioactivity. 97+% is *natural*. Radiation epidemiology (ERR) ignores background radiation anyway.
- *Look-back epidemiology* of cancer rates around Rocky Flats: never a ‘smoking gun’ (possible higher rates of some cancers for RF plant workers). *Much* less exposure post-cleanup: no more fires, no ‘Pad 903’, only low-level residual soil contamination.
- *Simple*, understandable calculations independent of DOE generally agree fairly well with DOE estimates.
- Direct measurements of ambient radiation in the Refuge (even Central Operable Unit) show normal background radiation—just what we’d expect based on NIST data.
- Pu is *not* special radiologically, ‘hot particles’ are *not* a special risk.

Remember these pictures when in doubt



567 cases, 20 years,
38 states



likelihood of cancer clusters

- not statistical cluster
- confirmed stat cluster
- due to environmental exposure
- cluster with established cause

Status

- Activist side has failed to educate itself for 30 years. Complete ignorance of published literature on radiation epidemiology, radiation
- Completely unable to bolster their case with data
- Elementary blunders in attempted health surveys. Metro State refused to renew connection with the 2016 Downwinders survey
- Spokesmen on record as believing in large conspiracy
- Attempting to close Refuge, an amenity for those around. True motives? Maybe anti-development, or to use closed Refuge as monument to Cold War (long anti-nuclear agenda).
- Attempting to subvert local municipalities with misinformation under guise of preventing cancer
- Standard pseudo-science approach

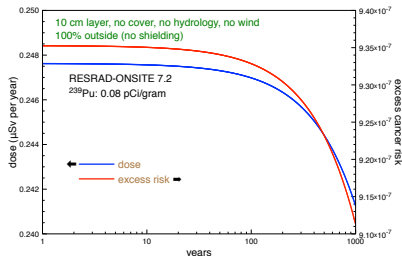
New paradigm: Why not put burden of proof on the ACTIVIST groups?

More info if asked:

- 1 Recent activist claims
- 2 Alpha, beta, gamma radiation dose rates from Rocky Flats soil (NIST data)
- 3 More on background radiation in Colorado
- 4 How does the DOE model radiation risk? About RESRAD.
- 5 Timeline of research on hot particles health impact
- 6 A little on radiation itself
- 7 The flavor of a calculation: hot particle doses
- 8 Observations on activist cancer cluster 'data'
- 9 SAFECAST results: compare Rocky Flats with serious radiation.
- 10 Last recap of science

Last-ditch lobbying of Broomfield City Council, since Broomfield is last municipality that needs to commit to *fund* it. Apart from manifestly incorrect statements (which I corrected in responses), some points recently made:

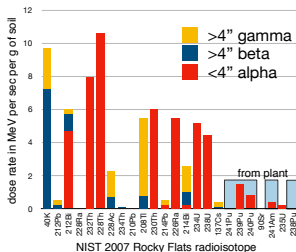
- **Parkway corridor could have secretly buried radwaste barrels in it.**
Speculation! Corridor is 1.5 miles from the COU where waste generated; why move it such a long way? Process of burying it would be visible from Indiana Street, busy since the 1950s.
- **Don't believe DOE RESRAD software**
Paranoia! DOE cannot be trusted. RESRAD benchmarked against several European and United Kingdom suites, used by several foreign countries. I have skimmed its large manual and reports describing its structure and inputs—very sensible. I have used RESRAD for test cases (0.08 pCi/g of ^{239}Pu only, compared with hand calculations) with decent agreement.



- **Geiger-Müller counter used to survey Refuge can't detect alpha particles**
Nonsense: they can and do. SAFECAST protocol is for *ambient* radiation (what you would *experience*), not *surface* radioactivity, to which alpha particles *would* contribute.
- **Evidence that a single alpha particle traversing a nucleus will produce a mutation.** —Used 'particle microbeam', very different than natural or medical radiation, need dose equivalent to about 1000 chest X-rays.

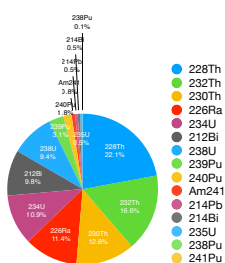
Radiation dose rates from Rocky Flats soil (NIST data)

Knowing radioactivities of each radioisotope, use nuclear tables to find dose rates of alpha, beta, gamma radiation

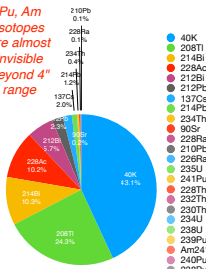


radiation dose from alpha emitters only
(range <4")

radiation dose from beta and gamma emitters (range>4")



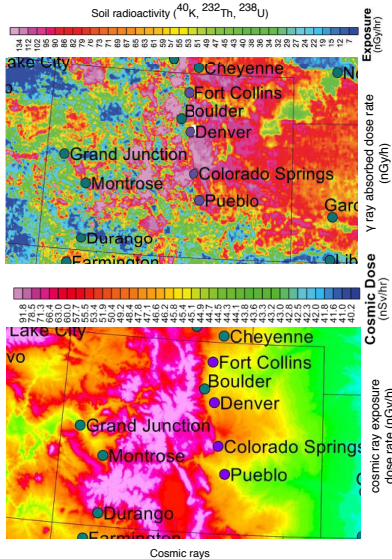
Pu, Am isotopes are almost invisible beyond 4" range



- 40K
- 208Tl
- 214Bi
- 228Ac
- 212Bi
- 212Pb
- 137Cs
- 214Pb
- 234Th
- 90Sr
- 228Ra
- 210Pb
- 226Ra
- 235U
- 241Pu
- 228Th
- 232Th
- 230Th
- 234U
- 238U
- 239Pu
- Am241
- 240Pu
- 240Pu

- Surprise: plutonium, americium emit so little beta, gamma that they are practically invisible beyond 4 inch range of alphas. In this sense Pu *is* special.

More on background radiation



Well understood, measured: see bars in Geiger-Müller count fits.

What is background radiation?

- In Colorado, about 2/3 of total background radiation comes from soil ('terrestrial'); 1/3 from cosmic rays (protons, muons)
- Terrestrial: almost entirely radioisotopes of potassium, thorium, uranium. Varies by factor of 20 from place to place in Colorado.
- Cosmic rays: depend strongly on altitude since atmosphere absorbs cosmic rays.
- Colorado experiences 'double whammy': high soil concentration of radioactive minerals (which *also* give rise to radon), also high altitude. Front Range has highest background radiation in the U.S.
- In cancer epidemiology, background radiation is assumed to *not* contribute to cancer rates. Colorado cancer rate is *lowest* in U.S.

How does the DOE model radiation risk?

Cancer risk vs. radiation dose

- ‘Linear no threshold’ picture assumes 50-year risk of cancer is *linearly proportional* to radiation exposure. Leukemias are ‘canary in the coal mine’; ‘solid’ cancers take decades to develop.
- Best data comes from INWORKS pooled consortium of nuclear workers (wore dosimeters), 8.2 million person-years of exposure.
- LNT happy to predict finite cancer risk even when none has ever been shown to occur (background rad, doses below $\simeq 0.1$ Gy). Thus at low doses (like those due to Rocky Flats) even RESRAD predictions (cautious!) probably overestimate cancer rates.
- Considerable evidence that low doses of radiation prime immune system, suppress cancer

Radiation dose from contaminant concentrations

RESRAD: Argonne National Lab, used by 100 countries, vetted against other. Used by DOE and CDPHE for Rocky Flats.

- 1 Knows about all radioisotopes, their decay chains, what they emit
- 2 Resolves radiation into biological impacts on organs via ‘radiation phantom’
- 3 Specify contaminants, concentrations at reference time (half-lives)
- 4 Permits non-uniform spatial distribution if needed (not at RF)
- 5 Includes effects of soil overburdens, water tables (shielding and transport)
- 6 Specify a variety of exposure routes: soil (external), water, ingestion, inhalation (internal ‘committed’ dose)
- 7 Evolve forward in time for later concentrations, long-term cancer risks

Timeline of hot particles

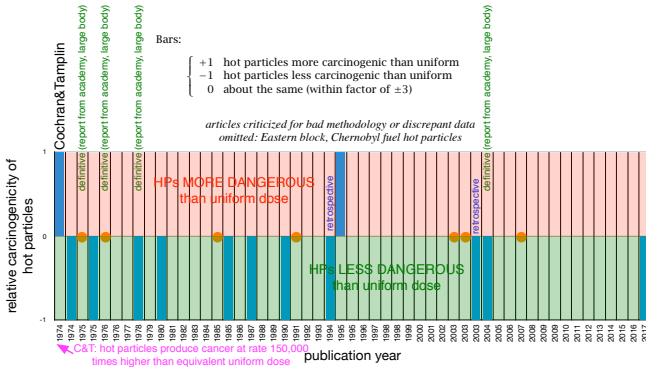


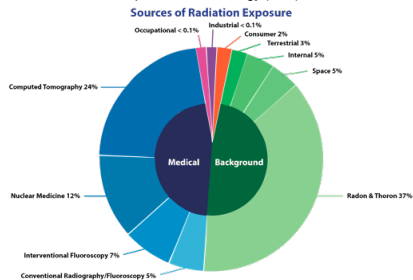
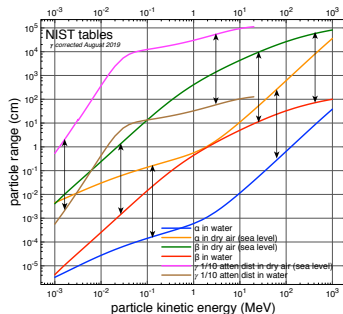
Figure: Significant journals articles, review articles, official reports since Cochran & Tamplin, 1974. Red: hot particles found *more dangerous* than uniform dose; green: hot particles found *less dangerous*; dark orange: about the same.

Terminology

- **Radioactivity:** Decays per second (pico Curies or Becquerel): [pCi, Bq].
Examples: pCi/g (per gram of soil), Bq/square meter (surface radiation)
- **Radiation:** What comes out. Most radioisotopes emit *either* alpha or beta particles. Gamma rays are very penetrating light
- **Range in air** [much less in tissue (water)]
 - alphas: 2-3 inches in air, stopped by layer of paper or skin
 - betas: tens of feet
 - gammas: hundreds of feet, very penetrating

Dose

- **Biological impact:** alphas 20 times more damaging than betas, gammas
- **Dose** = energy (Gray, Gy) to target; 'effective dose': biological impact, tissue sensitivity (Sievert, Sv)



Approach

- Ingredients:
 - ① Calculate number of plutonium atoms in a sphere of given diameter (from crystal structure observed for PuO_2 : solid state physics).
 - ② Look up the decays/sec per atom for desired isotope (^{239}Pu) (nuclear tables)
 - ③ Compute number of decays per second from the particle
 - ④ Weight each decay by energy of alpha particle emitted (nuclear tables), to find rate at which *energy* leaves the particle (Joules/sec)
 - ⑤ PuO_2 is more dense than lead, absorbs its *own* alpha radiation strongly if thick enough. Correct for this self-absorption.
 - ⑥ Divide by mass of target (kg) to find dose rate (Gy/sec)
 - ⑦ Multiply by duration of exposure for total dose in Gy.
- Decide what target is. ‘Hot particle’ results (scientific literature) from mid-1970s indicate that treating as whole-body dose is a good description. Pick average human mass of 75 kg (165 lbs).
- Compute tissue dose. For alpha particles the ‘relative biological effectiveness’ (RBE) is taken as 20: convert dose in Gy into tissue dose in Sv (sievert)
- Select nominal 50 year lifetime (often used in epidemiology)
- Find the ‘excess relative risk’ for the cancer of interest (search international governmental web sites, ICRP, very recent literature) for recent, best-statistics epidemiology.
- Calculate total 50-year dose and from this the excess cancer rate.

Flavor of calculation: hot particle doses [end]

Decide on tolerable risk

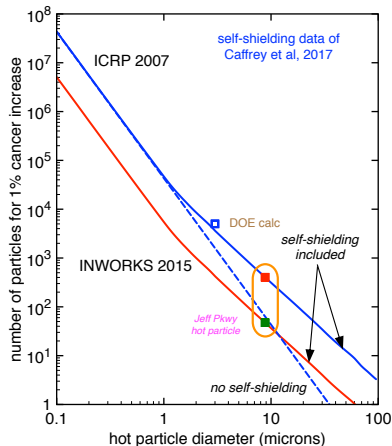
- Find required dose for a selected level of risk.
- If very small (from *one* particle so far!), ask how *many* particles you'd need to inhale to achieve this dose.

Example

Pick 3 micron particle, 1% excess risk:
DMW: 3600 particles
DOE: 5000 (see Figure at right)

Note

DOE calculation didn't specify any details: isotope, mass of target, source of ERR. The 30% difference is so small (given all steps) that we must have essentially done the *same* calculation.



Observations on activist cancer cluster ‘data’

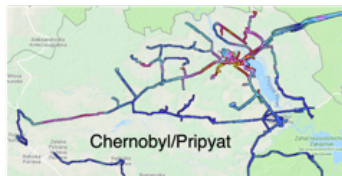
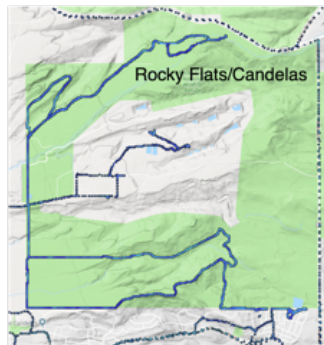


Whereas anecdotal evidence is sometimes the starting point of a proper scientific investigation, it is all too often the ending point and every point of a pseudo-scientific investigation. In the world of pseudoscience, an anecdote is the equivalent of a peer-reviewed, double-blind, repeatable scientific experiment with consistent results.

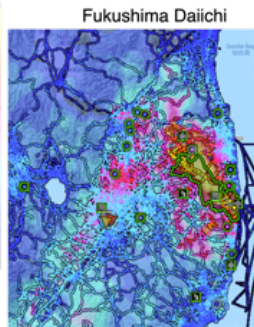
*Anecdotal evidence is often used in politics, journalism, blogs and many other contexts to make or imply generalizations based on **very limited and cherry-picked examples**, rather than reliable statistical studies.*

Anecdotes ...do not constitute evidence. This is because anecdotes only ever apply to individuals or individual experiences and are subject to the biases that this brings with it. It is impossible to say that an individual anecdote is representative and it is also impossible to actually detect the real cause of the [outcome].'

[rationalwiki.org]



SAFECAST (non-governmental)
radiation measurement data



How so?

Independent routes give same conclusion, check each other. May involve different disciplines: nuclear physics, epidemiology, biology, radiation detection ...

Hypothesis: Rocky Flats Pu, Am soil levels are a health hazard to users of Refuge and neighbors

- *NIST soil standards:* Contributions of Pu, Am in total are 3% of natural soil radiation. *Radiation epidemiology:* background radiation (soil, cosmic rays) always ignored Cellular repair mechanisms cope with it (for 4 billion years!) ✓
- *Direct measurement:* ambient radiation in Refuge, COU are typical Front Range Colorado background, not elevated. ✓

...continued

- *Look-back epidemiology* of cancer rates around Rocky Flats: no reliable evidence of any problem
- Direct calculation of cancer risks from Pu, Am (known concentrations, spatial distribution, nuclear physics, radiation epidemiology): extra risk of cancer over 50 years (2 in 10^6) [RESRAD] [Changes lifetime risk of dying of cancer from about 22% to 22.00002%]

Conclude: **Hypothesis wrong:** Pu, Am in Refuge do *not* pose a health hazard.