Rocky Flats, radiation, and risk

D. M. Wood, November 2017

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Contents

This document describes 'ground truth' around the Rocky Flats National Wildlife Refuge. (The situation *within* the Refuge is briefly discussed at the end; for more information as of 2017, see the fourth 5-year DOE Legacy Management review [1]). It contrasts simple estimates of excess cancer risks and compares them with a simple benchmark calculation using RESRAD, the tool used by the Department of Energy to estimate offsite (or, for that matter, onsite) cancer risks due to radioactive contamination. The credentials of RESRAD-Onsite were discussed in the document From radiation dose to cancer risk, which would be helpful to read if you have not already.

Important: All discussions of cancer risk below are based on the *linear, no threshold* assumption for dose (radiation absorption) vs. response (cancer rates) using the most recently published data. There is now strong evidence that this assumption, while useful for regulatory compliance, overestimates (possibly considerably) cancer risks. The document Recent developments in low-dose radiation response should be consulted for a modern perspective.

Introduction

The book *The Ambushed Grand Jury* makes a strong case that the DOE covered up lots of details about what went on inside the Rocky Flats plant. Given the history of the DOE in managing nuclear facilities (including ongoing problems [2]) I am inclined to believe almost all of it. However, does this behavior change the *results* of the cleanup or the current reality? Not in the slightest. It is part of the sloppy management history of Rocky Flats, but not of its present. I regard the Rocky Flats contamination and cleanup as having had a beginning and an end, and personally regard ongoing complaints about whether the public got 'the cleanup we paid for' as pointless and of only historical interest. Instead, I choose to focus on what can be and has been *measured* and what its impact is on those moving into new developments around the Rocky Flats National Wildlife Refuge..

One achievement of the Rocky Mountain Peace and Justice Center and its followers has been imparting to the Department of Energy's Office of Legacy Management an awareness that it is being monitored by the public. Dr. Anne Fenerty deserves special credit for ongoing vigilance, dating back at least as far as actually publishing her objections to the article *Science-based cleanup of Rocky Flats* in the physics news journal *Physics Today* [3].

Since 1989 the Walnut Creek drainage no longer enters any municipal water supply; since 1996 the Woman Creek Reservoir prevents surface water from that creek's drainage from entering Standley Lake [4]. Since to my knowledge none of the new developments draw municipal water from contaminated watersheds within the Rocky Flats boundary, we will focus on surface soil contamination.

A little background on Rocky Flats **data**

An excellent and accessible [5] overview was prepared in 2014 for the City of Westminster by Hydros Consulting. I strongly recommend this as the first document to read for background about the area around Rocky Flats.

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A less digestible but extremely important document [6] was published in June 1996 (volume I of III) entitled Resource Conservation and Recovery Act Facility Investigation/Remedial Investigation Report, Operable Unit 3 (Offsite Areas). It rejoices in the document label RF/ER-96-0029.UN and surveys what was at that time 25 years of research into contamination of the areas around the Rocky Flats plant. 'Operable Unit 3' is DOE parlance for the offsite areas around the original Rocky Flats boundaries. This document—devoted only to the offsite areas—is 300 pages long and details the history of radiation monitoring.

Radiation levels around Rocky Flats

The original "Krey/Hardy" map [7] has been redrawn several times, and a fairly recent version is shown in Fig. 1; please enlighten me about where this version came from—I believe it was used in the 'Cook case' settlement [8]. An excellent cleanly redrawn version is at the Kristen Iversen site, here.

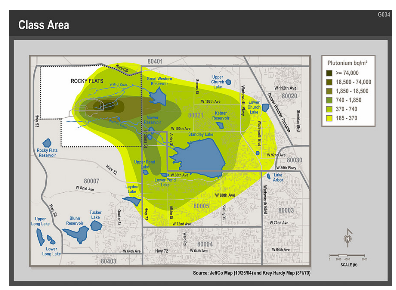

Figure 1: Map drawn from Krey-Hardy data of 1970, from God knows where.

The main virtue of this map is that it cites Pu contamination levels in an easy-to-interpret form, as becquerel per square meter ($\mathrm{Bq\,m^{-2}}$). A perfect radiation detector would detect, for example, 185-370 counts per second from each square meter of the least-contaminated zone. (I used this map to make estimates of expected Geiger-Müller counts in 2013—see the document Seeking clarity in Fall 2013 for more.) We will assume radioactivity around Candelas, for example, is about $370\,\mathrm{Bq\,m^{-2}}$. The contour lines originally present in the map were based on 33 (!) data points, considered grossly inadequate by later workers.

To place this level of contamination in a non-US-centric perspective, consider the more hazardous fission product isotope ^{137}Cs (half life 30.17 years, very water soluble) present around Europe as a result of the Chernobyl disaster. "Around 23% (46,450 km^2) of the territory of Belarus was subjected to more than 37,000 $\mathrm{Bq\,m^{-2}}$ contamination by ^{137}Cs" [9],[10]. The *average* ('mean') radioactivity due to this isotope over all of Germany after the disaster was 2000-4000 $\mathrm{Bq\,m^{-2}}$ (Wikipedia's entry on ^{137}Cs). No Colorado resident would get much sympathy from a European.

The 1996 DOE report [6] by contrast, was based on 568 validated soil samples and quotes soil radioactivity in terms of pCi/g (picoCuries per gram of soil). A map of the distributions of ^{239}Pu and ^{240}Pu as of 2006 is available from the Department of Energy's Legacy Management site ([6], linked document page 176).

I have carefully superimposed this map on a recent Google maps view of the same area. It should be noted that (since plant buildings are shown) this data was taken well before the cleanup was completed, but values outside the cleanup region (that is, in OU3, outside the boundary of the original Rocky Flats) are unaffected since they were not subject to remediation.

Because of Google's business model, some newer developments at the time the map was prepared pop up more prominently than others.

Parts of the Candelas development directly on the southeastern boundary of the Wildlife Refuge have concentrations of 0.2 pCi/g as do regions west of Leyden near the Leyden Rock development. Most of Candelas has levels no higher than 0.08 pCi/g. It is worth noting (for purposes of epidemiology) that much older developments around Standley Lake have comparable levels.

Citizen involvement

Suspicion about what the DOE reported is not new, but it is undeserved. In the article *Risks to the public from historical releases of radionuclides and chemicals at the Rocky Flats Environmental Technology Site* [11] it was observed that

> Early in Phase II [Results submitted to the Colorado Department of Public Health and Environment in September 1999 [12]—*Ed*], a meeting was held with members of the public to identify and discuss their concerns about the project. Transcripts of the meeting were used to understand existing criticisms about the work. These issues were cataloged as part of the permanent project record so each item could be addressed as well as possible. As Phase II continued, the list of citizens' concerns was updated based on letters, written reports, electronic mailings, and questions at public meetings, and responses for them were developed.
>
> (Meyer et al., 1999). It was not possible to respond to every issue, but from 210 questions and issues that were raised, responses were developed for more than 200. The few that remain unresolved are issues that lie beyond the scope of the study, or for which there was inadequate historical information with which to work

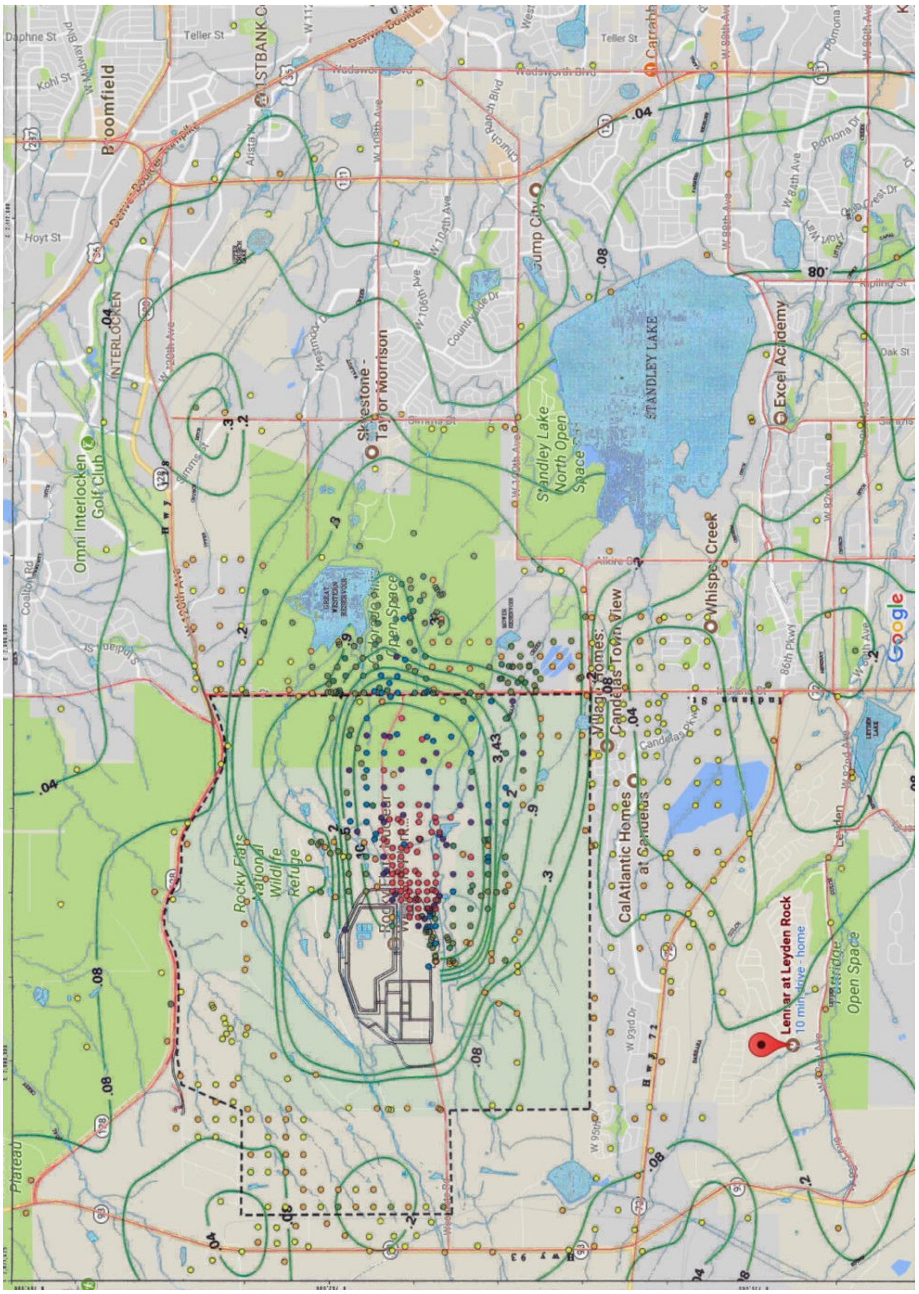

Figure 2: Superimposed levels of Pu soil concentration in pCi/g (pre-cleanup) and a Google map of areas around Rocky Flats.

> Meetings of the HAP [the Governor's Health Advisory Panel, set up in 1991—*Ed*] were open to the public and evening public meetings were also held to report progress. During Phase II, public meetings were held on a wide variety of topics ranging from atmospheric transport to developing source terms for releases to the environment. These meetings and one-on-one conversations with interested members of the public were a primary means of communicating the technical work as it progressed and the findings. In addition to direct communication with people, newsletters, fact sheets, and layman summaries of technical reports

See also the section *Public Interaction and Risk Communication* in the Radiological Assessments Corporation report [Broken link Nov. 2023] [12]

Results of field studies carried out in 1994 by *citizens* (the Citizens Environmental Sampling Committee, formed in 1992) with assistance of local academic institutions were published in 2004 [13]. They found "The distribution of plutonium (as ^{239,240}Pu) in soil was consistent with past sampling conducted by DOE, the Colorado Department of Public Health and Environment, and others. . . . No biases in past sampling due to choice of sampling locations or sampling methodology were evident. The study shows that local citizens, when provided sufficient resources, can design and implement technical studies that directly address community concerns where trust in the regulated community and/or regulators is low." Their abstract also noted "Over 60 soil samples, including both surface and core samples, were collected from 28 locations where past human activities would have minimal influence on contaminant distributions in soil. Cesium-137 activity was used as a means to assess whether samples were collected in undisturbed locations."

Radiation dose from these data

As mentioned elsewhere, the Department of Energy relies on the freely-distributed software package RESRAD to model radiation exposure due to site contamination. The problem with results from a large, complex computer code like RESRAD, however, is that it puts a large conceptual distance between the 'input' (radiation or contamination levels) and the 'output': expected cancer rates. A physicist confronted with this conundrum would attempt a *back of the envelope* calculation, so called because it is so simple that it could be at least set up on the back of a (possibly largish) envelope. Here we report results from calculations shown in the document Four simple radiation dose estimates. The non-RESRAD calculations are each exceedingly simple, but are spun off to a separate document so as not to interrupt the narrative here.

As John A. Wheeler told my sophomore class, "Never do a calculation before you know the answer", meaning that you should understand the basic physics of the problem before undertaking something careful.

We discuss (i) direct estimates using the calibration of a Geiger-Müller counter, (ii) the Krey-Hardy map above to make estimates of (ii) γ-only and (iii) α-only doses, and (iv) the RESRAD-Onsite code in a simplified scenario assuming (as is the case in the new developments around the Rocky Flats National Wildlife Refuge) a uniform surface contamination by ^{239}Pu of 0.08 pCi/g of soil.

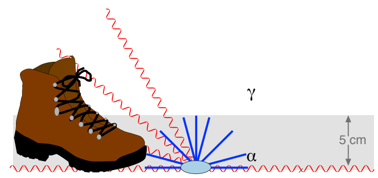

Figure 3: Range of α and γ rays on scale of human foot—γ range is tens of meters in air, so is truncated to fit in diagram.

It would be helpful to have read the document A crash course in radiation biology and health physics before these estimates. For later reference, we note that (see the document Radiation doses: large, small, and unavoidable) the radiation dose from *natural background* in Colorado is near 4 millisieverts per year (4 mSv/yr).

Table 1 below shows results from the very different approaches.

Estimate	yearly dose	50-yr dose	50-yr ERR
GM	0.73 mSv	36 mSv	—
direct: α only	0.13 mSv	6.6 mSv	—
direct: γ only	0.17 µSv	8.3 µSv	4.2×10^{-6} 2015 tables
RESRAD	0.25 µSv	12.5 µSv	9.4×10^{-7} reported
RESRAD	0.25 µSv	12.5 µSv	6.4×10^{-6} 2015 tables
Colo bkgrnd	3.8 mSv	190 mSv	—

Table 1: Summary of 'back-of-envelope' estimates of annual dose, 50-year lifetime dose, excess relative risk of cancer due to exposure, and Colorado annual background dose

In all cases I have used the results from Table 1 of the document From radiation dose to cancer risk) in order to relate the 50-year dose to the excess risk of cancer, the 'excess relative risk' (ERR). Remember that this directly measures the statistical increase in your chances of dying of cancer attributable to your radiation exposure. A 50-year ERR of 1×10^{-6}, for example, means you have an extra 1-in-a-million chance of dying of cancer after 50 years of exposure. (This table is based on 2015 publications, the latest and most comprehensive I could find.) Because *only* the α and RESRAD figures are physically meaningful, I have not given ERR for the Geiger-Müller and α dose cases below. For γ rays (and for RESRAD, since its results are *de facto* for γ exposure) I have converted whole-body doses in Sv directly into whole body doses in Gy because the biological weighting factor for γ rays is 1.

Notes on table:

1. Direct: α only: 5.151 MeV used for αs emitted by ^{239}Pu.
2. Direct: γ only: 129.3 keV used for γs emitted by ^{239}Pu. See Appendix.
3. RESRAD: Only ^{239}Pu contaminant, 0.08 pCi/g, no ero-

sion.

See document Four simple radiation dose estimates. 'Reported' uses RESRAD cancer rate data; '2015 tables' indicates data from Table 1 of document From radiation dose to cancer risk.

Remarks

- These results *are not definitive* in any way. They are simply examples of how different, reasonable ways of estimating radiation exposure translate into 50-year lifetime risks of cancer.
- Lifetime cancer risks associated with living around the Rocky Flats National Wildlife Refuge are in the ballpark of 1 in a million. In principle such risks should be quoted with a 90% confidence interval, for example using the 2015 tables, (2.9-10.) $\times 10^{-6}$ due to statistical uncertainty in the linear no-threshold results in the case of RESRAD dose values. In the α and γ estimates there would be considerable additional uncertainty from the Krey/Hardy map boundaries, etc.
- The exposure from Rocky Flats-related radiation is 15,000 times smaller than natural background radiation in Colorado (due to its altitude and natural soil radioactivity).
- Although we have not used Geiger-Müller or α-only doses to estimate risk, the counts/minute estimate based on the Geiger-Müller measurement very close to the surface using its calibration for ^{137}Cs gives a dose rate in respectable agreement with a direct estimate of α particle dose (relevant only very close to the ground).
- The γ-only dose estimate is in very reasonable agreement with the results of the RESRAD simulation given its simplicity.

Conclusions

1. Our γ-only dose estimate based simply on the nominal $370\,\mathrm{Bq\,m^{-2}}$ contamination from the Krey/Hardy map agrees well with the RESRAD calculation using the 1996 DOE maps (and a contamination level of 0.08 pCi/g) and a carefully-selected scenario meant to mimic the simple 'back of the envelope' calculation. This is very reassuring to a physicist making a plausible estimate, since it means that when applied to a simple test case one can understand from *scratch* (basic knowledge of radiation physics and biology) the total exposure. It also is (yet again) an indication that RESRAD has been calibrated and tested elsewhere.

2. This agreement also tacitly means that the Krey/Hardy and DOE 1996 maps are reasonably consistent with each other, though the latter should be preferred for any quantitative calculations.

3. Under general conditions RESRAD includes a very much more sophisticated and comprehensive description of the paths to radiation exposure and should be preferred whenever possible to simple estimates.

4. While the α-only estimate is in rough agreement with the rate deduced from the Geiger-Müller measurement, it is physically irrelevant (because of the short range of α particles). The calibration of the Geiger-Müller counter with $^{137}\mathrm{Cs}$ means that close agreement is not expected anyway.

Appendix A: From Krey/Hardy to DOE maps: 2D to 3D contamination

If we use the Krey/Hardy map (but remember that it is based on a grossly inadequate sampling grid), we might wish to convert from its radiation units ($\mathrm{Bq\,m^{-2}}$) to those used in later DOE maps (pCi per gram), which we will denote by ρ^*. We assume for simplicity (and in the absence of any better description) that the contamination is uniform (constant).

For a slab of thickness t and cross sectional area A the net activity enclosed is then ρAt, where ρ is the radioactivity per unit volume. For a plane of area A and radioactivity per unit area σ, the net enclosed activity is σA. Using either description if we are above either the (large) plane OR the (large) slab, we should be accounting for the same number of radioactive nuclei, so that

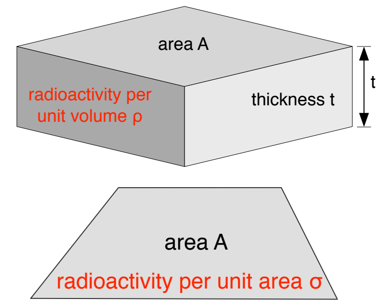

Figure 4: Plausible way to go from a uniformly contaminated layer (radioactivity measured in pCi per cm^3) to a surface contamination (radioactivity in $Bq\,m^{-2}$).

$$\rho At = \sigma A. \qquad (1)$$

This means that $\rho = \sigma/t$ or $\sigma = \rho t$. *Example:* The Krey/Hardy map suggests $\sigma \simeq$ 370-740 $Bq\,m^{-2}$ in the same area of Candelas where the DOE map shows $\rho^* \simeq 0.08$ pCi per gram. To get ρ per cubic centimeter, we must multiply ρ^* by the mass density ρ_m of dirt in grams per cubic centimeter. What t (in cm) is needed for the two map figures to agree? We require

Plausible values [14] range from 1.22 (loose dirt) to 1.6 (clay) grams/cm^3; RESRAD uses a default value of 1.5 g/cm^3, which we will also use.

$$t = \sigma/\rho = \sigma/(\rho^* \rho_m) = \frac{370\,\mathrm{Bq\,m^{-2}} \text{ to } 740\,\mathrm{Bq\,m^{-2}}}{0.08\ \mathrm{pCi/g} \times 1.5\,\mathrm{g\,cm^{-3}}} \times$$
$$\times \frac{1\ \mathrm{m}^2}{10^4\ \mathrm{cm}^2} \times \frac{1\ \mathrm{pCi}}{10^{-12}\ \mathrm{Ci}} \times \frac{1\ \mathrm{Ci}}{3.7 \times 10^{10}\ \mathrm{Bq}} = (8.3 \text{ to } 16.7)\ \mathrm{cm} \qquad (2)$$

Because (only) 30 years have elapsed since the Pu was actively deposited on the soil, 16.7 cm seems somewhat large.

This is an example of how knowing how to interconvert between two sets of measurements—one very difficult and time consuming (the measurement of pCi/cm^3) and the second probably considerably easier (the surface contamination)—sheds some light on the actual level of contamination and enhances confidence (in this case) in *both* measurements.

Appendix B: Remarks about Wildlife Refuge users

When I have time, I will add calculations and comments about the particular scenarios run for the Rocky Flats National Wildlife Refuge. For the moment, based on the RESRAD version 5 manual, I wil note that

1. Recreational users are assumed not to be eating fish or plants, or drinking water or milk produced in the contaminated region. They are assumed to ingest 36.5 grams of contaminated soil per year, corrected by the fraction of the time they spend exposed.

2. The effects of 'hot spots' of area 25 m^2 or less can be included in the code; larger 'hot spots' are already taken care of as part of the criteria.

3. Recreational users are assumed to actually breathe faster than residents, and radiation exposure due to inhaled contaminated soil is included in an average way. (Don't forget to read *Hot particles no longer*!)

4. It's worth remembering that a site 'can be released for use without radiological restrictions' provided the base dose limit of 0.25 mSv per YEAR is not exceeded.

A slightly out-of-date manual [15] is available from Argonne National Laboratory and should be examined if you are curious about what radiation pathways are included in a full-fledged RESRAD calculation.

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