RMPJC Comments on the Draft Programmatic Environmental Impact Statement for the Production of Plutonium Pits (DOE/EIS-0573)

July 16th, 2026

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Sent by email to: PitPEIS@nnsa.doe.gov

I respectfully submit these comments on the draft Programmatic Environmental Impact Statement (PEIS) Statement for the production of plutonium pits, as provided for by the National Environmental Policy Act (NEPA). I join with community groups and fellow citizens around the nation in opposing NNSA's plans for expanding production of plutonium "pit" bomb cores while evading its moral responsibility for comprehensive cleanup.

Introductory Themes and Questions

1. **First and foremost, we ask, will DOE/NNSA include a <u>True No Action Alternative</u> in the final draft of the PEIS?**
    a. The No Action Alternative in the draft PEIS does not provide a pathway to prevent construction of a new plutonium bomb plant at the Savannah River Site. Nor does the No Action Alternative prevent further plutonium pit production at LANL. <u>We believe a True No Action Alternative would provide a pathway to end plutonium pit production entirely.</u>
    b. Past environmental impact statements for plutonium pit production such as the 2025 SWEIS for LANL have failed to include a True No Action Alternative. Failure to include a True No Action Alternative demonstrates NNSA's neglect for the gravity of concerns being brought forth by impacted communities.

2. **Second, we ask, will DOE/NNSA include an appendix in the final draft of the PEIS which includes all of the public comments that were submitted?**
    a. In the interest of public transparency, we urge DOE/NNSA to include an appendix of all comments submitted within the final draft of the PEIS.

The Purpose and Need for Agency Action is Fatally Flawed

The draft PEIS states the following:

"U.S. national security policy requires the maintenance of a safe, secure, and reliable nuclear weapons stockpile and the core competencies necessary to design, manufacture, and sustain nuclear weapons; consistent with 50 U.S.C. § 2538a and U.S. Department of Defense (DoD)1 requirements, NNSA must establish workforce and infrastructure capabilities to produce no

fewer than 80 plutonium pits per year as soon as practicable, eliminate single-point failures, and provide flexible production capacity. "

The mandate to produce 80 pits per year is unnecessary, highly controversial, dangerous, and immoral. I will aim to demonstrate this point by providing evidence from scientific studies, legal precedents, context of international law, treaty obligations, and the lived experience of impacted communities from plutonium pit production at the Rocky Flats Plant.

DOE/NNSA have encountered consistent roadblocks, cost overruns, public opposition, and logistical setbacks to achieving this goal. At what point will DOE/NNSA acknowledge that the deadly consequences to public health and the environment are too great to continue pursuing this goal of 80 plutonium pits per year?

The Precedent of the Rocky Flats Plant in Colorado

Rocky Flats, located on the Colorado Front Range 16 miles NorthWest of Denver, operated between 1952-1989 until it was shut down by an FBI raid and the contractor Rockwell International was found guilty of environmental crimes. The Rocky Flats Plant has caused significant hardship for downwind communities in Colorado. The environment continues to be plagued by widespread contamination resulting in long term public health impacts and environmental hazards. We urge the Department of Energy to heed the lessons from this catastrophe of criminal activity, environmental contamination, and human rights violations at Rocky Flats - Cease production of plutonium pits immediately.

The lingering contamination at Rocky Flats is well documented. Most recently, in April of 2024, Dr. Michael Ketterer conducted air monitoring and documented evidence that plutonium continues to be transported through the air downwind of Rocky Flats. The most dangerous pathway for exposure to plutonium is through inhalation. This proves that plutonium and other contaminants from Rocky Flats continue to be a serious public health issue for Arvada, Westminster, Denver, and all downwind communities.

The public and local governments have remained engaged in monitoring this issue and advocating against public recreation at Rocky Flats. The opening of Rocky Flats to public recreation in 2016 was the result of manufactured consent and regulatory capture, which we reject. There continues to be a building movement of precedents that oppose recreation and construction near Rocky Flats. The Department of Energy has failed to conduct a thorough cleanup of the region and instead misleads people into living and building nearby a highly contaminated area. We do not wish to see this history repeated by harming the communities downwind of LANL and SRS. The Department of Energy's actions with nuclear bomb production are morally unacceptable and rooted in a paradigm of systemic violence. We refuse to cooperate with the production of weapons of mass destruction.

In January of 2026 Boulder County and Westminster established warning signage on the North and East borders of Rocky Flats to warn anyone considering entering the Rocky Flats National Wildlife Refuge.

The attached documents included in Appendix B of this comment further demonstrate this information:

- Attachment A: Boulder County Rocky Flats Warning Signage
- Attachment B: Ketterer RF affidavit 21May2024
- Attachment C: Record of Opposition to Public Recreation and Construction at Rocky Flats 7_10_2026.

The Value of NEPA

The tangible value of public comments under NEPA must be acknowledged. NEPA processes result in tangible benefits for both the public and the government. A compelling example is that in response to public comment the Department of Energy (DOE) included detailed wildfire analysis in a 1999 final LANL SWEIS. Most importantly wildfire protection measures were undertaken that helped to prevent the very real 2000 Cerro Grande Fire from reaching ~44,000 plutonium waste barrels at Area G. NNSA would be wise to take to heart formal public comments as something far more valuable than just checking off a required NEPA compliance box.

NEPA regulations must be preserved. President Trump has unilaterally terminated long-standing NEPA regulations promulgated by the Council of Environmental Quality. This rollback is shortsighted, irresponsible, and ultimately dangerous. NEPA has played a vital role in protecting the public from dangerous and poorly conceived projects by enabling citizen input. Gutting NEPA benefits industry and government interests at the expense of public health, environmental sustainability, and accountability. The final PEIS should evaluate the impacts of gutting NEPA.

In September 2024 a federal judge ruled that NNSA had violated NEPA by not conducting a nationwide programmatic environmental impact statement (PEIS) on simultaneous pit production at two sites (LANL and the Savannah River Site in South Carolina).

Plutonium Toxicology

These questions pertain to scientific evidence for the danger of plutonium.

1. Does the DOE/NNSA acknowledge the 1997 Columbia University study by Tom K. Hei and Colleagues which demonstrated that a single particle of plutonium can cause mutations in mammal cells?
    a. (Proceedings of the National Academy of Sciences, vol. 94 [Apr. 1997], pp. 3765-3770; and vol. 98 [4 Dec. 2001], pp.14410-14415).

2. What programs currently exist to compensate and cure workers who have been exposed and harmed by radioactive materials?
3. What is the total number of workers within the U.S. nuclear weapons complex who have sought help for health impacts from their job? How many have received support? How many have died from illness received by exposures from their workplace?
4. What is the annual budget for compensation and healthcare for workers seeking support for workplace health impacts?
5. What is the annual budget for compensation and healthcare for downwinders seeking support for health impacts?

The attached documents included in Appendix B of this comment provide further evidence regarding the toxicology of plutonium:

- Attachment D: Risk from Plutonium in the Environment at Rocky Flats
  LeRoy Moore, Ph.D., Rocky Mountain Peace & Justice Center, 7-31-15
- Attachment E: PNAS-1997-Hei-3765-70
- Attachment F: Radiation Standards for Hot Particles, 1974

Treaties and International Law

The NonProliferation Treaty (NPT) must be honored. The draft PEIS falsely claims that NNSA nuclear weapons programs comply with the NPT. The nuclear weapons powers have never honored the NPT's Article VI mandate to enter into serious negotiations leading to nuclear disarmament. The U.S. should lead the world by example with a True No Action Alternative of not expanding nuclear weapons programs.

The United Nations Treaty on the Prohibition of Nuclear Weapons (TPNW). It is striking that there is no mention of the nuclear weapons ban treaty now ratified by 75 countries. Granted that the U.S. has no "treaty obligation" under the TPNW because it is vehemently against it and has pressured other nations to not sign it. The PEIS should fully explain and justify why that is so, and why the United States does not at least maintain observer status at the formal Meetings of the State Parties to the Treaty on the Prohibition of Nuclear Weapons held at the United Nations.

1. Does DOE/NNSA support reparations to the Western Band of the Western Shoshone for brazenly violating the Treaty of Ruby Valley to establish the Nevada Test Site and attempting to establish the Yucca Mountain waste repository? More than 900 nuclear bombs were detonated on Western Shoshone territory. This is a human rights violation which demands investigation by an international court for crimes of genocide against the Western Shoshone nation.
2. How does the DOE/NNSA justify ongoing violations of Article VI the Nuclear Nonproliferation Treaty through the proposed production of new plutonium pits and entirely new bomb designs?
3. Does DOE/NNSA support reparations to the people of the Marshall Islands?

4. How will the U.S. respond as more countries continue to sign the U.N. Treaty on the Prohibition of Nuclear Weapons? How does the U.S. justify building more nuclear bombs when much of the Global South supports abolition of nuclear weapons? Currently as of July 14th 2026, 75 countries have ratified the TPNW as states parties, as well as a further 25 signatories.

Pit Life Study

There must be a new pit life study before plutonium pit production begins. NNSA has not fully disclosed the issue of plutonium pit aging, or rather the lack of it, since a 2006 pit life study concluded that pits last at least 100 years (their average age is now ~42). There are already at least 15,000 existing pits stored at NNSA's Pantex Plant outside Amarillo, TX.

On July 15th 2026, Nuclear Watch New Mexico and the Union of Concerned Scientists (UCS) received the *Plutonium Aging: Executive Summary (Unclassified)* in response to Freedom of Information Act (FOIA) requests to the National Nuclear Security Administration (NNSA).[1]

It is just three pages, one title page and two pages of text, both completely redacted. The claimed FOIA exemption is (b)5, which "incorporates the attorney-client privilege, attorney work-product privilege, and deliberative process (or pre-decisional) privilege." We think this is an outrageous abuse of FOIA given NNSA's often repeated claims that potential aging concerns drive the $60 billion+ plutonium pit production program and the Pit Production PEIS comment period expires tomorrow. In contrast, a JASON 2006 Pit Life study's executive summary concluded that most pit types last at least 100 years and those that don't have easy fixes. [2] (Average plutonium pit age is now ~43).

The FY 2019 Senate Energy and Water Development Committee report (S.R. 115-258) mandated a new JASON study that should:

> "…include recommendations of the study for improving the knowledge, understanding, and application of the fundamental and applied sciences related to the study of plutonium aging and pit lifetimes, an estimate of minimum and likely life-times for pits in current warheads, and the feasibility of reusing pits in modified nuclear weapons. The report shall be submitted in unclassified form but may include a classified annex." [3]

The universal presumption is that an unclassified summary will be released and made publicly available. The JASON 2006 Pit Life study's executive summary was released and made fully available to the public. A follow-on JASON's 2019 "Letter Report" was released and make fully available to the public.[4] Senator Elizabeth Warren and Rep. John Garamendi have unsuccessfully demanded release of the new pit life study.[5] A July 6 letter of demand by Nuclear Watch's lawyers at the South Carolina Environmental Law Project remains unanswered.[6] Nuclear Watch New Mexico's and the Union of Concerned Scientists' requests for expedited FOIA processing precisely because of the Pit Production PEIS public comment period was denied. Instead, they got a completely redacted version the day before the comment period expires on July 16, which ironically is the 81st anniversary of the Trinity Test of the world's first plutonium pit.

Nuclear Watch New Mexico believes this is an unlawful attempt to further violate NEPA. We remind NNSA that "An agency's hard look should include neither researching in a cursory manner nor sweeping negative evidence under the rug." [7]

The final Pit Production PEIS must answer this question, what is NNSA hiding by completely redacting the *Plutonium Aging: Executive Summary (Unclassified)*?

[1] Redacted *Plutonium Aging: Executive Summary (Unclassified*, https://ucs-documents.s3.us-east-1.amazonaws.com/nuclear-weapons/JASON-Plutonium-Aging-Executive-Summary-Unclassified-Redacted.pdf

[2] *Pit Lifetimes*, JASON, November 2006, www.nukewatch.org/facts/nwd/JASON_ReportPuAging.pdf This JASON study came about because Nuclear Watch New Mexico, knowing of the earlier *Remanufacture* JASON report, suggested to then-Senator Jeff Bingaman that a new JASON pit lifetime study would be appropriate. He then successfully passed that requirement through an amendment to the 2004 Defense Authorization Act.

[3] Senate Report 115-258, ENERGY AND WATER DEVELOPMENT APPROPRIATIONS BILL, 2019, page 104, https://www.congress.gov/115/crpt/srpt258/CRPT-115srpt258.pdf

[4] Letter Report to the NNSA, JASON, November 13, 2019, but not transmitted by NNSA to Congress until April 6, 2020, https://irp.fas.org/agency/dod/jason/pit-aging.pdf

[5] Joint Senator Warren- Rep. John Garamendi letter to DOE secretary, December 16, 2025, https://www.warren.senate.gov/wp-content/uploads/media/doc/letter_to_doe__nnsa_re_pit_production_mismanagement.pdf

[6] SCELP's letter of demand to NNSA is available at https://nukewatch.org/demand-letter-for-pit-peis-critical-documents-and-extension-of-public-comment-period

[7] *Nat'l Audubon Society v. Dep't of Navy*, 422 F.3d 174, 194 (4th Cir. 2005).

Plutonium Pit Production is Not Needed

No future production is to maintain the safety and reliability of the existing stockpile. Instead, future production is for speculative new-design nuclear weapons that can't be tested because of the international testing moratorium. Alternatively, these new designs could prompt the U.S. to return to testing which would have severe international proliferation consequences.

This again argues for a True No Action Alternative in the PEIS that reduces nuclear weapons programs and conservatively maintains the stockpile while the U.S. leads the world toward nuclear disarmament.

Tritium Releases

LANL plans to vent tritium headspace gases from Flanged Tritium Waste Containers. The draft PEIS fails to provide a comprehensive assessment of this release and its possible impacts. NNSA must reconsider the planned venting process and conduct a more thorough environmental review that accounts for these risks.

Environmental Justice Issues

On his second day in office, President Trump revoked federal requirements for evaluating environmental justice issues. Will environmental justice analyses be included in the final PEIS?

Wildfire Threat at LANL Needs Serious Analysis

The risk of wildfires will increase with adverse climate change and global warming. The pending final PEIS should have a comprehensive wildfire analysis like the 2000 LANL SWEIS did. That document and related wildfire mitigation measures clearly helped to avert greater catastrophe during the Cerro Grande Fire, including the possible rupture of above-ground waste drums at Area G that could have sent respirable plutonium across northern New Mexico. There is a serious need for a credible, comprehensive analysis of the wildfire threat to LANL and the surrounding public, which the final PEIS must provide.

Plutonium Contamination at LANL

Plutonium contamination is still widespread at LANL and impacts on the public must be analyzed in this PEIS. Highly elevated detections of 239Pu and 240Pu are found in Acid Canyon sediments, hundreds to thousands of times higher than can plausibly be attributed to atomic weapons testing fallout.

Material Disposal Area C and other remaining waste dumps must be excavated for full treatment. MDA C at LANL is an 11.8-acre landfill. The total amounts of waste disposed of are unknown. The extent of the migration of wastes from MDA C is unknown. The RCRA hazardous wastes and the radioactive wastes leaking from the site are comingled and the extent is unknown. Given the amount of TRU waste, such as plutonium-239, that is likely to be buried in MDA C, leaving the wastes buried 25 feet deep in a landfill rated for only 1,000 years is simply not acceptable. Cleanup of Area C should be a model for the rest of the Lab.

Plutonium Contamination at Rocky Flats

The Superfund cleanup at Rocky Flats only conducted remediation in the Central Operable Unit (COU). The COU remains an active EPA Superfund Site. The Peripherable Operable Unit (POU), Operable Unit 3 (OU3), and downwind communities received no remediation.

Numerous studies have documented that widespread contamination remains in the POU, which is now designated as Rocky Flats National Wildlife Refuge (RFNWR), and downwind communities. The following documents provide evidence for these statements.

- Attachment G:
  - Plutonium Hazard in Respirable Dust on the Surface of Soil
    Author(s): Carl J. Johnson, Ronald R. Tidball and Ronald C. Severson
    Reviewed work(s):
    Source: Science, New Series, Vol. 193, No. 4252 (Aug. 6, 1976), pp. 488-490
    Published by: American Association for the Advancement of Science
- Attachment H: RPS JPAC Position Paper 5/17/2018
- Attachment I: 16-11-21 Letter to Colo Dept of Public Health & Environment
- Attachment J: 20060214 Jury Verdict Form - Merilyn Cook v Dow Chemical and Rockwell

Cleanup Not Addressed

1. How does the DOE justify allocating nearly $2 trillion over the next 30 years to create new bombs when former nuclear weapons sites have not yet been cleaned up?
2. What is the 10 year plan for cleanup of the Hanford site? What is the 50 year plan? What is the 100 year plan? What is the 500 year plan?
3. What is the long-term plan for infinity rooms which still contain plutonium and other contaminants buried under the soil at the Rocky Flats Central Operable Unit? What is the 100 year plan for how climate change will impact the geology of the front range and communities downwind of Rocky Flats? What is the 500 year plan for how climate change will impact the geology of the front range and communities downwind of Rocky Flats?
4. Following from the above questions: What is the 100 year plan for how climate change will impact the geology of the region surrounding LANL and SRS? What is the 500 year plan for how climate change will impact the geology of the region surrounding LANL and SRS?
5. What is the current status of PFAS at Rocky Flats? How is the issue of PFAS being monitored at LANL, SRS, Lawrence Livermore Laboratory, and the Kansas City Plant?

The Final State of Any Cultural Resources Must Be Provided

Under the Modernized and Expanded Operations Alternatives at LANL, as many as 33 known cultural resources could be physically impacted or damaged by the proposed projects. Of these resources, 19 are considered significant and would likely require mitigation before construction. DOE wants to mitigate impacts but not completely avoid them. As always, unnecessary nuclear weapons production is prioritized, this time above irreplaceable traditional cultural resources.

The Potential Impacts of a Microreactor at LANL Must be Specified

Buried in the 2025 LANL SWEIS is the plan to bring microreactors to LANL to power the proposed photon x-ray operation for the nuclear weapons program. The exact purpose and need must be stated.

Further Concerns Regarding LANL

Plans for a Biosafety Level-3 Facility must have its own environmental impact statement. LANL's expanded operations alternative includes plans for constructing a Biosafety Level-3 (BSL-3) facility. The 2025 draft SWEIS for LANL did not identify what bioagents may be used or specify what research will be conducted. This lack of information raises serious safety concerns about potential work combining infectious agents and high explosives. There is no justification provided for the need to locate this facility at LANL when other non-military federal agencies could do the work. If it goes forward, LANL's proposed BSL-3 facility should have a standalone environmental impact statement.

Construction of facilities should cease until seismic risks are fully understood. The mapping of the fault lines and fracture zones under the Lab is presently incomplete, yet many new nuclear weapons facilities are being planned. The fact is that LANL is located in a severely fractured fault zone between a rift valley and a dormant supervolcano. The largest risk to the public from LANL is a site-wide wildfire started because of an earthquake.

Cleanup must be comprehensive and not include "cap and cover" of unlined waste dumps. All radioactive and toxic waste dumps must be excavated for full treatment. DOE must analyze the impacts of leaving waste behind as a perpetual threat to groundwater in comparison to full treatment.

LANL must not allow more contaminants to reach the aquifer or the Rio Grande. PFAS chemicals must be specifically analyzed. The fact is that tritium, perchlorates, chromium, and high explosives contaminants from Lab operations have already reached the regional aquifer.

LANL's economic benefits should be more widely distributed. The Counties of Los Alamos, Rio Arriba, and Santa Fe were analyzed for socioeconomic effects in the 2025 LANL SWEIS. Please state if Los Alamos County is expected to continue to receive a disproportionately large percentage of the economic benefits from the Lab and remain the 11th richest county in the U.S. The SWEIS must analyze whether alternative missions would be of greater economic benefit to all of northern New Mexico instead of the privileged nuclear weapons enclave.

Plutonium Inventory

1. What is the current status of plutonium that was shipped to the Savannah River Site from the Rocky Flats Plant?
2. After the Rocky Flats Plant closed, in 1994 Secretary of Energy Hazel O'Leary announced that 1.191 metric tons (1.31 U.S. tons) of plutonium were lost from inventories at Rocky Flats. What is the current status of plutonium that is missing from DOE inventories?
3. How does the DOE justify selling weapons grade plutonium to commercial private industries?
    a. DOE began the "Surplus Plutonium Utilization Program" in 2025.

These comments are respectfully submitted,

Sincerely,

Chris Allred
Nuclear Guardianship Coordinator
Rocky Mountain Peace and Justice Center

Appendix A: Summary of Questions for DOE/NNSA Included in This Comment

1. **First and foremost, we ask, will DOE/NNSA include a <u>True No Action Alternative</u> in the final draft of the PEIS?**
    a. The No Action Alternative in the draft PEIS does not provide a pathway to prevent construction of a new plutonium bomb plant at the Savannah River Site. Nor does the No Action Alternative prevent further plutonium pit production at LANL. <u>We believe a True No Action Alternative would provide a pathway to end plutonium pit production entirely.</u>
    b. Past environmental impact statements for plutonium pit production such as the 2024 SWEIS for LANL have failed to include a True No Action Alternative. Failure to include a True No Action Alternative demonstrates NNSA's neglect for the gravity of concerns being brought forth by impacted communities.

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    a. In the interest of public transparency, we urge DOE/NNSA to include an appendix of all comments submitted within the final draft of the PEIS.
3. Does the DOE acknowledge the 1997 Columbia University study by Tom K. Hei and Colleagues which demonstrated a single particle of plutonium can cause mutations in mammal cells?

    a. (Proceedings of the National Academy of Sciences, vol. 94 [Apr. 1997], pp. 3765-3770; and vol. 98 [4 Dec. 2001], pp.14410-14415).
4. At what point will DOE/NNSA acknowledge that the deadly consequences to public health and the environment are too great to continue pursuing this goal of 80 plutonium pits per year?
5. What programs currently exist to compensate and cure workers who have been exposed and harmed by radioactive materials?
6. What is the total number of workers within the U.S. nuclear weapons complex who have sought help for health impacts from their job? How many have received support? How many have died from illness received by exposures from their workplace?
7. What is the annual budget for compensation and healthcare for workers seeking support for workplace health impacts?
8. What is the annual budget for compensation and healthcare for downwinders seeking support for health impacts?
9. Does DOE/NNSA support reparations to the Western Band of the Western Shoshone for brazenly violating the Treaty of Ruby Valley to establish the Nevada Test Site and attempting to establish the Yucca Mountain waste repository? More than 900 nuclear bombs were detonated on Western Shoshone territory. This is a human rights violation which demands investigation by an international court for crimes of genocide against the Western Shoshone nation.
10. How does the DOE/NNSA justify ongoing violations of Article VI the Nuclear Nonproliferation Treaty through the proposed production of new plutonium pits and entirely new bomb designs?
11. Does DOE/NNSA support reparations to the people of the Marshall Islands?
12. How will the U.S. respond as more countries continue to sign the U.N. Treaty on the Prohibition of Nuclear Weapons? How does the U.S. justify building more nuclear bombs when much of the Global South supports abolition of nuclear weapons? Currently as of July 14th 2026, 75 countries have ratified the TPNW as states parties, as well as a further 25 signatories.
13. **The final Pit Production PEIS must answer this question, what is NNSA hiding by completely redacting the *Plutonium Aging: Executive Summary (Unclassified)*?**
14. Will environmental justice analyses be included in the final PEIS?
15. How does the DOE justify allocating nearly $2 trillion over the next 30 years to create new bombs when former nuclear weapons sites have not yet been cleaned up?
16. What is the 10 year plan for cleanup of the Hanford site? What is the 50 year plan? What is the 100 year plan? What is the 500 year plan?
17. What is the long-term plan for infinity rooms which still contain plutonium and other contaminants buried under the soil at the Rocky Flats Central Operable Unit? What is the 100 year plan for how climate change will impact the geology of the front range and communities downwind of Rocky Flats? What is the 500 year plan for how climate change will impact the geology of the front range and communities downwind of Rocky Flats?
18. Following from the above questions: What is the 100 year plan for how climate change will impact the geology of the region surrounding LANL and SRS? What is the 500 year

plan for how climate change will impact the geology of the region surrounding LANL and SRS?

19. What is the current status of PFAS at Rocky Flats? How is the issue of PFAS being monitored at LANL, SRS, Lawrence Livermore Laboratory, and the Kansas City Plant?
20. What is the current status of plutonium that was shipped to the Savannah River Site from the Rocky Flats Plant?
21. After the Rocky Flats Plant closed, in 1994 Secretary of Energy Hazel O'Leary announced that 1.191 metric tons (1.31 U.S. tons) of plutonium were lost from inventories at Rocky Flats. What is the current status of plutonium that is missing from DOE inventories?
22. How does the DOE justify selling weapons grade plutonium to commercial private industries?
    a. DOE began the “Surplus Plutonium Utilization Program” in 2025.

Appendix B: Documents Provided for Evidence in Support of This Comment

- Attachment A: Boulder County Rocky Flats Warning Signage
- Attachment B: Ketterer RF affidavit 21May2024
- Attachment C: Record of Opposition to Public Recreation and Construction at Rocky Flats 7_10_2026.
- Attachment D: Risk from Plutonium in the Environment at Rocky Flats
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- Attachment F: Radiation Standards for Hot Particles, 1974
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  Reviewed work(s):
  Source: Science, New Series, Vol. 193, No. 4252 (Aug. 6, 1976), pp. 488-490
  Published by: American Association for the Advancement of Science
- Attachment H: RPS JPAC Position Paper 5/17/2018
- Attachment I: 16-11-21 Letter to Colo Dept of Public Health & Environment
- Attachment J: 20060214 Jury Verdict Form - Merilyn Cook v Dow Chemical and Rockwell

The Full Documents included in Appendix B follow:

DANGER

RADIOACTIVE

Visiting Rocky Flats National Wildlife Refuge May Expose You to Radioactive Materials

The Rocky Flats Plant leaked plutonium and hazardous materials onto the land and into the water.
From 1951 - 1989, the Rocky Flats Plant, located 1.5 miles south of here, produced plutonium components used to assemble nuclear weapons. During its operations, radioactive and other hazardous materials were released at the site creating risks to human health.

After years of hazardous waste removal, Rocky Flats was designated as a wildlife refuge.
Clean-up of the Rocky Flats site began in the early 1990's resulting in the demolition of 800 structures and the removal of contaminated soil and water. In 2006 the area was designated as the Rocky Flats National Wildlife Refuge. While the refuge is now open to visitors year-round, radioactive and hazardous materials remain in the soil and ground water and may be present in airborne dust particles. Nearby communities and industry professionals continue to express concern about the area's safety and its risks to human health.

Hikers, Bikers, and Equestrians are encouraged to make informed decisions before entering the refuge.
Visitors to this area are encouraged to make informed decisions about their travel. If you are concerned about the potential risks of using trails at Rocky Flats National Wildlife Refuge, please consider alternative trails.

Declaration of Michael E. Ketterer, PhD

Detection of airborne plutonium in air filters collected along Indiana Street under the episodic high-wind conditions of April 6, 2024

I am Michael E. Ketterer, an analytical/environmental chemist who holds the position of Professor Emeritus of Chemistry and Biochemistry at Northern Arizona University. I currently serve as an Adjunct Professor of Chemistry and Biochemistry at the University of Denver. I reside in both Colorado and Arizona and am a registered voter in Rep. Joe Neguse's Congressional district. I hereby declare as follows:

1. I am a specialist in the chemical analysis of trace and ultra-trace elements using mass spectrometry; I have approximately 25 years of experience in its use for the detection of low levels of long-lived radioisotopes of uranium, neptunium and plutonium. I have conducted many extensive field and laboratory investigations of these elements in the Earth's surface environment at localities around the world, and have studied well-known sites including Chernobyl affected areas of eastern Europe, the Nevada Test Site regional/tropospheric fallout-affected zones of the western US, and Trinity Test-affected portions of New Mexico. In my career, I have analyzed on the order of 50,000 individual environmental samples to determine quantities of plutonium-239 and plutonium-240 present; in all of these samples where sufficient Pu was detected, I have used the measured atom ratio $^{240}Pu/^{239}Pu$ to distinguish between the ubiquitous "global fallout" background atom ratio of 0.18 vs. local/regional sources such as "weapons-grade" plutonium. The latter, used at Rocky Flats, is characterized by a much lower (0.02-0.07) $^{240}Pu/^{239}Pu$ ratio. My work is founded upon well-known established science, much of which has been conducted and/or funded by the United States Department of Energy (e.g., the above quoted $^{240}Pu/^{239}Pu$ figures are based on the following 1999 Pacific Northwest National Laboratory paper: https://www.sciencedirect.com/science/article/pii/S0048969799001606

2. The plutonium measurements are conducted at a licensed radioisotopes laboratory in Building 36 at the Chemistry/Biochemistry Department at Northern Arizona University. I collaborate with the

Radiation Safety Officer, James Biddle, to maintain the security and conduct licensed usage of the plutonium-242 tracer solution, as essential to our laboratory's work (refer to Attachment 1). I collaborate with NAU chemistry faculty and students to maintain the Thermo X2 inductively coupled plasma mass spectrometer, the chemical preparation facilities and equipment, and the laboratory infrastructure. In the NAU labs, I perform fee-for-service plutonium analytical work, and receive part-time salary through the Trace Element Analysis Center, directed by Prof. Jani C. Ingram (Regents Professor of Chemistry and Biochemistry). From mid-2022 to present, the Center has provided plutonium activities and isotopic provenance of fallout and/or other Pu sources, for approximately 2000 samples, to external researchers from the US, Canada, Spain, Iceland, Denmark, Germany, and New Zealand. Nearly always, the plutonium being detected is "global fallout" from 1950's-1960's thermonuclear tests; the TEA's clients are using these data for Anthropocene tracer applications such as soil erosion modeling, soil profile development, and sediment chronology. Much of the Anthropocene tracer work I have performed at NAU is represented in collaborative publications, where I have contributed the experimental data and interpretations as an integral part of an interdisciplinary research team.

3. Examples of my peer-reviewed publications on the subject matter of plutonium and related elements, their detection/source ID, and usage as environmental tracers may be viewed at: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C6&q=Ketterer+flagstaff+plutonium&btnG=

4. I am familiar with the history of the Rocky Flats plutonium and neptunium pit production site in Colorado, now containing the US DOE-managed CERCLA (Superfund) site referred to as the "Central Operating Unit". The COU is surrounded on four sides by the former plant buffer zone, now known as the "Rocky Flats National Wildlife Refuge" or RFNWR. I lived at three different Boulder County locations in Boulder County between 1980-1986, and was recognizant of the plant's environmental problems with plutonium at that time. I was a GS-11 Chemist working for the US EPA in June 1989, at the time when my organization, the National Enforcement Investigations Center, provided field and lab technical assistance to USEPA's Special Agents and the FBI team of Special Agents. During the time of my EPA employment, I contributed limited-scope technical advice to EPA and FBI personnel, but was mainly assigned by the Laboratory Services Division to other casework during my

1987-1993 employment with EPA. During my work at USEPA, I gained an understanding of forensic sciences as applied to environmental questions, and practices for the collection/preservation of physical evidence. In the early 1990's, EPA sent me to short courses in environmental sampling methods, and I completed a mandatory 40-hour OSHA certification for working in the field at hazardous waste sites. At EPA-NEIC, I acquired experience in the collection of many types of environmental and hazardous waste samples as part of field work in onsite investigations, including criminal search warrants, at contaminated sites across the United States. As an EPA employee, it was my duty to testify, when required, in Federal or State legal proceedings as an expert and/or fact witness on behalf of the Government.

4. Since 2000, I have been using mass spectrometry in the labs at Northern Arizona University to study soils in non-Federal lands near the Rocky Flats COU and buffer zone; I have personally collected and/or analyzed hundreds of samples from the Indiana Street Corridor and areas emanating away from the buffer zone. To summarize this work, the mass spectrometry confirms that essentially 100% of the "excess plutonium" has a weapons-grade signature, has been added to the soils located east of the buffer zone, and is without question, derived from Rocky Flats. Within an identifiable zone of effect, this added Pu from Rocky Flats overwhelms the "global fallout" background. To wit, I have measured plutonium inventories (depth-integrated content per unit area) in 2002-collected soil cores to 30 cm depth from the Westminster Dog Park that were between 1000 and 10,000 Becquerels of plutonium-239+240 per square meter, as compared to fallout-derived inventories of less than 150 Becquerels per square meter in unaffected, similar environments elsewhere in Colorado (e.g., the Kathy Fromme Prairie in Larimer County). In a 2003 paper, I identified uranium-236 as another Rocky Flats-derived radionuclide present in soils in contaminated areas on non-US Government property east of the RFNWR buffer zone: https://www.sciencedirect.com/science/article/abs/pii/S0265931X02001868?casa_token=2X2AXO9VTkkAAAAA:FoeM83GD-kuTmN1wcs4FYvieYrkAzV92AdLS7GyP5tYyBOmT5KQnKOfuwAGf2ClAa9oOX5ck. My work concurs with Federal and State studies of the same areas, all of which indicate, that within the 1970's "Krey-Hardy map" contamination plume (Attachment 2), elevated activities and inventories of plutonium are indeed still present in the 2020's. Both my work, as well as studies conducted by the US

Government (for example: https://journals.lww.com/health-physics/abstract/1976/02000/remote_plutonium_contamination_and_total.9.aspx) have used mass spectrometry to "fingerprint" the plutonium near the site, showing it is "weapons-grade" Pu originating from Rocky Flats. My own studies also concur with the Government's recognition of the 903 Pad as a major point source; both US Government-funded studies and my own work also demonstrate the presence of additional plutonium dioxide particles from fires and incineration that routinely took place during the 1952 – 1989 pit production operations.

5. Commencing in 2019, I have been conducting research aimed at the detection/size characterization of plutonium dioxide (PuO_2) particles in Rocky Flats-affected soils, using chemical procedures and mass spectrometry accessible to me at the NAU lab. In work that is ongoing and not published in peer-reviewed literature, I have developed an assay which can systematically identify and size-characterize PuO_2 particles exceeding a size detection threshold of approximately 0.2 microns. The particle work has demonstrated the widespread presence of plutonium dioxide particles with mass-equivalent diameters between 0.2 and 2.0 microns, in soils from the Indiana Street corridor and Westminster Dog Park (Attachment 3). Several larger PuO_2 particles with diameters between 2.0 and 3.4 microns have also been identified in soils on Jefferson County right-of-way west of Indiana St., and in 2002-collected soils from the Westminster Dog Park; however, this ongoing work has yet to observe any particles quite as large as the 8.8-micron diameter "Bill Ray Particle" of plutonium dioxide that was disclosed to the public in August 2019 by the Jefferson Parkway Public Highway Authority. The assembled evidence indicates that it is very reasonable to assume that wherever significant Rocky Flats plutonium is identified *via* $^{240}Pu/^{239}Pu$ provenance, plutonium dioxide particles from nanometers to a few microns can be assumed to be present in the surface soils and dusts.

6. In June 2023, I became aware that my Rep. Joe Neguse and Rep. Brittany Pettersen had written a letter to DOE Secretary Jennifer Granholm and EPA Administrator Michael Regan (Attachment 4). In their letter, Reps. Neguse and Pettersen requested that the DOE conduct ambient air monitoring along the Indiana Street corridor and points east, in order to ascertain if windborne transport of plutonium-contaminated dust was occurring. I am recognizant that this request was made by two members of Congress, addressed to two Cabinet-level appointees, following DOE Legacy Management career employee Carmelo Melendez's written refusal to conduct air monitoring, as had been requested by Mayor Guyleen Castriotta (Attachment 5). The Broomfield Mayor and other local elected officials urged DOE to conduct air monitoring at Rocky Flats, on account of downwind residents' concerns following the aftermath of the catastrophic December 2021 Marshall Fire, recognizing the possibility of a similar fire at Rocky Flats.

7. As of early 2024, it was my understanding that the DOE had been unresponsive to the local community, as well as to Congressional requests for air monitoring. It was my understanding from a fellow Coloradan, who learned from email conversations with DOE and Fish and Wildlife Service officials, that both Federal agency stewards had essentially zero fire contingency plan for response in the event of a large wildfire occurring in the Pu contaminated soil areas; instead, my colleague related the Federal officials' position: ***the local communities would be the first responders***. I also was also familiar, as a Boulder County resident, with the catastrophic December 2021 Marshall Fire, and the speed and intensity with which a similar wildfire could develop anywhere along the Front Range, including on Pu-contaminated soils at the COU and RFNWR. I was also aware of scientific studies pointing to surface soil radionuclide inventory loss during wildfires, controlled burns, and high-wind events. It is not difficult to imagine a scenario, where a Tesla being charged at a residence along the north perimeter of Arvada's Candelas neighborhood ignites during a high-wind event, whereupon swirling winds ignite several homes and blow the sparks from the ensuing 25 kg lithium metal fire onto the RFNWR, igniting a fire conflagration that burned through the entire Refuge and COU in minutes, spreading contaminated smoke over dozens of square miles into Boulder and Broomfield counties, in a north-to-east 90-degree arc pattern.

8. I therefore concluded that it was my individual responsibility as a knowledgeable, proactive United States citizen, and as resident of Colorado possessing appropriate professional skills and with access to the essential lab capabilities, to address the following question: ***is there plutonium, originating at the Rocky Flats COU and/or buffer zone, being carried towards non-Federal lands and populated areas, under the episodic high-wind conditions that occur regularly onsite?***

9. On April 6, 2024, the Denver metropolitan area experienced an extended period of high winds, with particularly strong steady winds and violent gusts occurring at Rocky Flats on the afternoon of that date. Local Coloradans will recall news reports of the unexpected, proactive, precautionary electrical grid shutdowns experienced on that date by residents in some areas along the foothills.

10. On April 6, 2024, I was accompanied by Jon S. Lipsky, MAS/FBI Retired, and we visited the Rocky Flats proximity. We observed that there had been recent excavation and earthmoving on Federally-managed Refuge lands at the eastern edge of the contaminated buffer zone. We both observed large, rapidly moving suspended dust clouds extending from ground level up to heights of hundreds of feet, originating from areas on the COU and/or contaminated buffer zone. These clouds persisted for some minutes and traveled/dissipated in multiple directions in a stochastic manner. Photos of the wind conditions present are given in Attachment 6. I affirm that Mr. Lipsky was present during all of the sample collections; retired Special Agent Lipsky is able to recount/confirm my description of the conditions, and corroborate my photos with additional video and high-resolution still photos.

11. On April 6, 2024, Jon Lipsky and I collected three samples of the particulate matter present in the ambient air near Rocky Flats. We used a laboratory-constructed portable high-volume air particulate sampler, consisting of a 1590 cfm Harbor Freight 8" cylindrical blower, and two thicknesses of 3M MERV-12 furnace filter affixed to the inlet to retain airborne particles. The inlet of the sampler was pointing to directly into the wind, originating mainly from the west. The sampler was powered by a 1 kWh portable power station (Jackery), and was stationed on the tailgate of Mr. Lipsky's vehicle with the inlet situated approximately three feet above ground height. A photo of the sampling unit and its usage in the field on April 6 is shown in Attachment 7.

12. The sampler was operated for periods of 20 to 22 minutes to obtain individual air filter samples at three locations:

i) Sample 01, west shoulder of Indiana St. at the former East Gate of the weapons plant;
ii) Sample 02, west shoulder of Indiana St. at the posted southeast gate of the RFNWR;
iii) Sample 03, north shoulder of Colorado 128 at the Rock Creek culvert underpass.

The three air filter samples were retained in my continuous custody following collection. A copy of my original field notes is given in Attachment 8.

13. Following the operation of the sampler, the individual sample filters contained visibly evident material, despite the brief operational periods of less than 30 minutes (Attachment 9). The samples were secured and transferred in my custody *via* locked private vehicles and padlocked containers to the NAU laboratories in Flagstaff, AZ, where the samples were handled, stored, processed, and analyzed in a secure, ID card-accessed laboratory area on the NAU campus.

14. At the NAU labs, a series of preparation steps were required to process the samples into a two-milliliter volume of aqueous solution needed for analysis by the mass spectrometer. The filter material was placed in a Pyrex beaker; samples were ashed individually using an electric muffle furnace at 600 degrees Centigrade placed in a fume hood. The ashing of the April 6th filters was completed on April 29, 2024. For Sample 01 (former East Gate), 02 (RFNWR SE Gate) and 03 (Rock Creek), the respective amounts of ash recovered were 46.5, 127.7, and 63.9 milligrams. Attachment 10 is a photo of the vials containing the inorganic material recovered from these air filters after ashing; this is the material that is subsequently dissolved/extracted to yield a 2 mL Pu "nectar".

15. The ash material recovered from air filter Samples 01, 02, and 03 was weighed into 40 mL Pyrex vials prior to fusion with sodium hydrogen sulfate. A known quantity (28 picograms) of licensed plutonium-242, prepared as a dilute aqueous solution from NIST SRM 4334i, was added to each weighed ~ 25 mg sub-sample; the mixtures were heated for 45 minutes in a muffle furnace at 450 degrees Centigrade, and then the cooled, solidified flux was dissolved with dilute aqueous nitric acid. Purified plutonium fractions of 2 mL volume were produced from each sample using a commercially available solid-phase extraction reagent (EIChrom TEVA resin, https://www.eichrom.com/); the chemical procedures were completed on May 2, 2024. A photo of the final chemical purification setup for chemical isolation of Pu from the air filter solutions with TEVA resin is shown in Attachment 11; the columns labeled 1, 2, 3 correspond to the respective April 6th samples; 21, 22, 23 and 25 represent three additional 25 mg preparations of Sample 2, and one additional 15 mg preparation of Sample 1. Columns 4 through 9 in this photo consist of a negative control along with several positive control samples exhibiting global fallout and/or other Pu sources; Columns 10 through 20 and 24 are being used for another project's similar matrix, small-mass unknown samples that were processed/analyzed in parallel with the April 6 air filter study.

16. The samples were analyzed using a Thermo X2 quadrupole inductively coupled plasma mass spectrometer, depicted in Attachment 12. Using the instrument's software, a dataset containing mass spectral scanning instructions and a data storage space for the results was constructed to acquire atom count rate information from the sample solutions. Signals were collected at masses 237, 238, 239, 240, and 242, representing the isotopes neptunium-237, uranium-238, plutonium-239, plutonium-240, and plutonium-242. The isotopes neptunium-237, plutonium-239, and plutonium-240 are being determined as unknown analytes in the air filter samples; uranium-238 is a ubiquitous natural component of the Earth's crust, which is being monitored to confirm sufficient uranium removal *via* the TEVA chemical separations. The signal at mass 242 calibrates the mass spectrometer's response by acting as an "internal standard" or "tracer" based upon the mass spectrometer's response for the Pu recovered from 28 picograms of an equilibrated Pu-242 spike addition; it is noted that plutonium-242's indigenous content in the Rocky Flats samples is negligible in comparison to the added 28 pg spike. The instrument's software repeatedly switches the quadrupole mass analyzer's transmitted m/z between the five selected isotopes with 10 millisecond dwell times, and collects multiple 58-second integration "runs", each representing the accumulated average atom count rate per second for that sample from 1000 sweeps of the five selected masses. The output from the analyses of the sample solutions was stored in a digital dataset on the instrument computer entitled "Ketterer Desert Glow 02 May 2024.tee".

17. The mass spectrometer was used to collect results for the April 6^{th} air filter samples, along with ion count data for relevant positive and negative controls. A portion of the instrument output from the air filters as it appears in real-time on the computer screen is shown in Attachment 13. Therein, ion count results are shown for Samples 03 (Rock Creek culvert), and two different preparations of Sample 01 (former East Gate), with time stamps 1:53:54 PM, (1:59:57 and 2:04:56 PM), and 2:08:55 PM, respectively.

18. The ion count rate data, with reference to the columns underlying the "Pu239" and "Pu240" labels, show that plutonium is "not detected" in the 1:53:54 PM scan sequence of Sample 03 (Rock Creek underpass). The mass spectrometer's average response is less than 2 counts per second at mass 239. and less than one count per second at mass 240. These are responses are consistently seen for samples known to lack plutonium-239, as well as for samples containing amounts of plutonium-239 that cannot be detected under the instrumental conditions. Similar responses for plutonium-239 and plutonium-240 are also routinely observed in analyses with this mass spectrometer for "negative control" samples such as Moenkopi Sandstone, a Triassic-age sedimentary rock prevalent in Flagstaff. During the time of collection of Sample 3, the wind was coming from Boulder County lands to the north and northwest of our sampling locations, and appeared to be crossing over areas well northwest of Rocky Flats. ***The isotopes plutonium-239 and plutonium-240 are not detected in airborne dust collected at the Rock Creek location during the April 6, 2024 sampling episode.***

19. Six complete scans of Sample 01 (former East Gate) were collected in the series of 58-second runs with time stamps 1:59:57 and 2:04:56 PM; one partial scan was collected at the end of the 2:04:56 PM acquisition as the solution expended. The ion count data demonstrate that both plutonium-239 and plutonium-240 are present at levels well above instrumental detection thresholds (corresponding to 2 counts per second at mass 239 and 1 count per second at mass 240). Further, the ratio of ion counts collected at mass 240 vs mass 239 demonstrates that the Pu in the air filter material not "global fallout", but appears to consist of "weapons grade" composition, consistent with Rocky Flats contamination.

20. A second independent preparation of ashed material from Sample 01 was produced, and its ion count rate results are also seen in Attachment 13, with the time stamp 2:08:55 PM. This preparation was completed with 15.3 milligrams of Sample 01, as compared to the 23.5 mg of material dissolved in the preparation for time stamps 1:59:57 and 2:04:56 PM. Hence, the lower ion count rates for the 2:08:55 PM preparation reflect the smaller sample mass; however, the integrations of a second Sample 01 preparation also resulted in the detection of both plutonium-239 and plutonium-240.

21. Four preparations of approximately 25 mg of the ashed material from Sample 02 (RFNWR Southeast Gate) each resulted in the positive detection of Rocky Flats-originating plutonium-239 at the second monitoring location along Indiana Street during the episodic high winds of April 6, 2024. The ion count rates for plutonium-240 in three of these preparations are insufficient to positively detect plutonium-240 in addition to the detected plutonium-239; however, considering the 0.05-0.06 atom ratio exhibited by Rocky Flats material, one does not expect to be able to detect plutonium-240 for Rocky Flats-related samples exhibiting less than approximately 20 counts per second for plutonium-239.

22. Two air filter samples (01 and 02) collected at different locations from the Indiana Street corridor on April 6, 2024 have been analyzed *via* a total of six independent sub-sample preparations. All of these mass spectrometric results positively and unequivocally indicate the presence of plutonium, of proven Rocky Flats origin, as has been exemplified in the Attachment 13 screenshot. ***It is concluded, to a reasonable level of scientific certainty, that Rocky Flats plutonium is being dispersed under episodic high-wind conditions prevalent at the site, from contaminated source areas on the COU and/or RFNWR, and is being transported eastward towards non-Federal lands and populated areas.***

23. Using the plutonium-239 and plutonium-240 signals from each integration of the unknown samples, and the corresponding plutonium-242 signals obtained from 28 picograms of added NIST 4334i "spike", the amounts of plutonium-239 and plutonium-240, atom ratios, and detection limits in the unknown samples can be estimated:

Mass of Pu-239 = (239 signal / 242 signal) * (28 picograms)

Mass of Pu-240 = (240 signal / 242 signal) * (28 picograms)

^{240}Pu / ^{239}Pu = (240 signal / 239 signal)

Detection limit for Pu-239 = (2 / 3060) * (28 picograms)

Detection limit for Pu-240 = (1 / 3060) * (28 picograms) where the number 3060 is the matrix-specific average count rate obtained from for the 28 picogram plutonium-242 tracer as was added to each of the air filters analyzed in the May 2 analytical run. The above calculation is considered to be demonstrative in nature, while not including known/understood effects such as background subtraction, mass discrimination originating in the ICPMS ion extraction/transmission system, uranium hydride isobar corrections at mass 239, and the differing nuclidic masses of these specific Pu isotopes. The results of these demonstrative calculations are given in Attachment 14.

24. The activity result for Sample 01, Lab ID 1, is 1.19 $\pm$ 0.05 pCi/g $^{239+240}$Pu, expressing the sum of the activities for the two most abundant isotopes, as is conventional in reporting plutonium measured by alpha spectrometry and in US regulations. ***The $^{239+240}$Pu activity of particulate matter in the air on April 6, 2024 thus exceeds the State of Colorado "construction standard" of 2 decompositions per minute of $^{239+240}$Pu per gram of soil***, equivalent to 0.88 pCi/gram. The Colorado "state construction standard" is noted in the following communications: https://lmpublicsearch.lm.doe.gov/SiteDocs/OU01-A-000859.pdf and https://www.osti.gov/servlets/purl/4264339. The "construction standard" recommends that areas exceeding this threshold remain undisturbed, and if disturbed, "special techniques" are required including dust suppression, ceasing excavation on windy days, minimizing vehicular spread of contaminated soil, and mandated usage of PPE by workers. Colorado's "state construction standard" is very unusual as a State-level regulation for $^{239+240}$Pu in soil; this statute likely originated out of an abundance of caution during the 1970's, shortly following publication of the Poet/Martell study in 1972. The Poet-Martell study, conducted at a private research organization (NCAR) in Boulder, closely followed the public's growing recognition of the 1969 Mother's Day fire and the true function of Rocky Flats as a plutonium fabrication plant. The work of Poet and Martell was an important event that compelled Rocky Flats contractors and the US Government to stipulate to the presence of off-site Pu from Rocky Flats, including disclosing the contaminated area known as the 903 Pad: https://journals.lww.com/health-physics/abstract/1972/10000/Plutonium_239_and_Americium_241_Contamination_in.12.aspx .

25. The summed activity of $^{239+240}Pu$ in Preparation 1 of Sample 01 exceeds, and the activity in Preparation 3 is approximately equal to the Colorado "construction standard" level of 0.88 pCi/g, further indicating that a dust transport situation regularly exists that would, under Colorado statutes, require respiratory protection and dust suppression techniques, along with direct workers to avoid soil disturbance activities under high-wind conditions such as existed at Rocky Flats on April 6, 2024. Moreover, the results are indicative of the ambient air quality experienced by persons traveling along Indiana St. under episodic high-wind conditions, as well as persons on public open space at the Westminster Dog Park and/or Rocky Flats National Wildlife Refuge.

26. The elevated activities in ***all*** of the preparations of Samples 01 and 02 point to non-fallout sources of Pu-bearing material containing higher $^{239+240}Pu$ activity than explicable by fallout-containing Front Range surface soils (i.e., 0.1 pCi/g $^{239+240}Pu$ or less). The measured $^{239+240}Pu$ activities, ranging from 0.15 to 1.19 pCi/g, in the particulate matter in Samples 01 and 02, are not credibly explainable as being derived from fallout-containing surface soils; the activities, independent of the Pu provenance, invoke the presence of a non-fallout source.

27. For Preparation 1 of Sample 01 (former East gate), the signals observed at mass 240 were adequate to measure a $^{240}Pu/^{239}Pu$ atom ratio of 0.057 ± 0.009 (one standard deviation). This value completely negates the possibility that the plutonium is of non-Rocky Flats origin; the results are instead congruent with the atom ratio of 0.056 ± 0.009, which was measured in a positive control in this study. The positive control was 25 mg of sieved/ashed soil from a composite sample I personally collected in July 2019, from Jefferson County right-of-way property, west of Indiana St. near the April 6 Sample 01 location.

28. The four separate ~ 25 mg preparations for air filter Sample 02 (RFNWR Southeast Gate) yielded results interpretable as revealing the presence of a discrete PuO_2 particle in one of the trials. Note that Attachment 16 reports activities of 0.15 to 0.20 pCi/g, while Preparation 2 exhibited 0.85 pCi/g $^{239+240}Pu$. The "excess activity" of 0.67 pCi/g in Preparation 2 is accounted by the presence of a PuO_2 particle in the 0.85 pCi/g subsample, having a mass equivalent diameter of 0.35 microns. Although additional measurements are planned, so as to collect more sample mass under additional episodic wind conditions, this initial result suggests that the same PuO_2 particles detected in surface soils along the Indiana St. corridor and in the Westminster Dog Park are being entrained into the ambient air under high-wind conditions, such as existed on April 6, and are transported away from the RFNWR and Central Operating Unit.

29. For the three air filters collected on April 6, there remains a small portion of material, ranging from a few mg to a few tens of mg that is now in locked storage at NAU. This writer is familiar with DOE-EM's and DOE-LM's bad-faith responses of denial, incredulity, ridicule and retaliation following releases of important environmental findings to community members. Accordingly, the following pledge is made: I will work directly with staff in the DOE Office of the Undersecretary for Science and Innovation, ***and arrange for DOE to receive a split of 50% of the remaining material for each of the three April 6th air filter samples***. However, I will not supply any additional information to DOE beyond the contents of this Declaration, nor will I communicate with any other DOE or CDPHE officials and/or their contractors. The splitting would be performed by me personally, under DOE supervision while in-person at Northern Arizona University, or if DOE prefers, observed by video link. The DOE would be responsible for advancing costs for all travel expenses and *per diem* for conducting the splitting, for supplying the sample to DOE, and for subsequent in-person observation of a similar mass spectrometric analysis at a DOE National laboratory with the same or superior capabilities as were used herein. The DOE would also agree to reimburse me for professional time at hours at charge-out rates that are similar to senior staff in National laboratories performing similar analytical work. Any observations of DOE's own analytical work on the split samples would also be open to attendance by Mr. Jon Lipsky (also participating at DOE's travel/*per diem*/charge-out time expense), as well as additional observers that DOE wishes to invite.

I hereby affirm that these statements are true to the best of my knowledge, and that I am aware that knowingly false statements are predicate acts under 18 USC 1001, subject to potential criminal prosecution and penalties, including substantial fines and incarceration.

By:

Michael E Ketterer

MAY 21, 2024

Michael E. Ketterer, PhD

State of Colorado, County of Boulder

Signed and sworn to [or affirmed] before me on

May 21, 2024

by Michael K. Ketterer (name(s) of individual(s) making statement).

Scott Kassner

(Notary's official signature)

Notary Public

(Title of office)

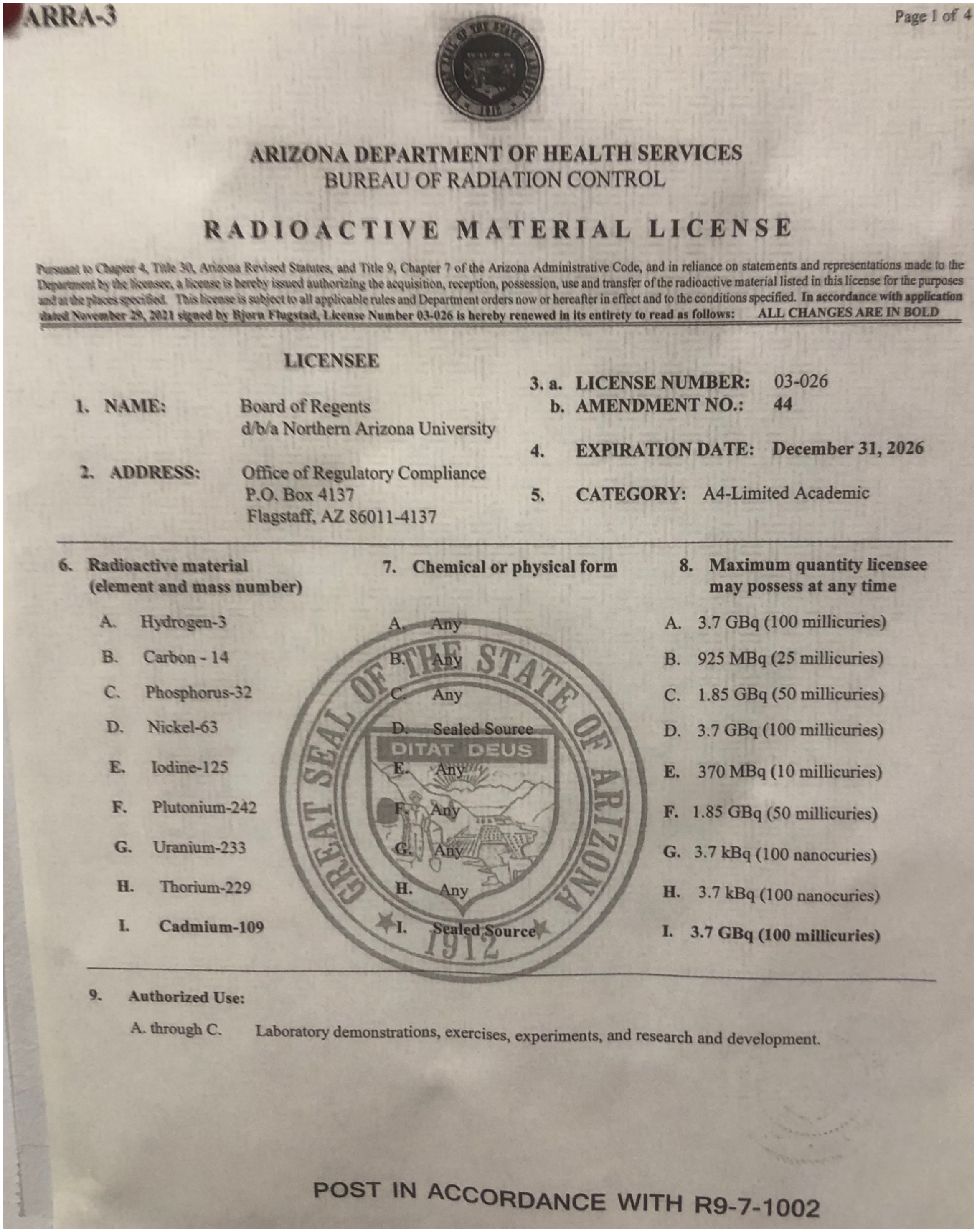
07/24/2026

(Commission Expiration)

SCOTT KASSNER
NOTARY PUBLIC
STATE OF COLORADO
NOTARY ID 19944011774
MY COMMISSION EXPIRES 07/24/2026

COPIES EFFECTIVE AS ORIGINALS: Photocopies of this document shall be effective and enforceable as originals, and third parties shall be entitled to rely on photocopies of this document for the full force and effect of all stated terms.

Attachment 1. Radioactive materials license posted in laboratory area at Northern Arizona University



ARRA-3

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ARIZONA DEPARTMENT OF HEALTH SERVICES
BUREAU OF RADIATION CONTROL

RADIOACTIVE MATERIAL LICENSE

Pursuant to Chapter 4, Title 30, Arizona Revised Statutes, and Title 9, Chapter 7 of the Arizona Administrative Code, and in reliance on statements and representations made to the Department by the licensee, a license is hereby issued authorizing the acquisition, reception, possession, use and transfer of the radioactive material listed in this license for the purposes and at the places specified. This license is subject to all applicable rules and Department orders now or hereafter in effect and to the conditions specified. **In accordance with application dated November 29, 2021 signed by Bjorn Flugstad, License Number 03-026 is hereby renewed in its entirety to read as follows:** ALL CHANGES ARE IN BOLD

LICENSEE

1. NAME: Board of Regents
d/b/a Northern Arizona University

2. ADDRESS: Office of Regulatory Compliance
P.O. Box 4137
Flagstaff, AZ 86011-4137

3. a. LICENSE NUMBER: 03-026
b. AMENDMENT NO.: **44**

4. EXPIRATION DATE: **December 31, 2026**

5. CATEGORY: A4-Limited Academic

6. Radioactive material (element and mass number)	7. Chemical or physical form	8. Maximum quantity licensee may possess at any time
A. Hydrogen-3	A. Any	A. 3.7 GBq (100 millicuries)
B. Carbon - 14	B. Any	B. 925 MBq (25 millicuries)
C. Phosphorus-32	C. Any	C. 1.85 GBq (50 millicuries)
D. Nickel-63	D. Sealed Source	D. 3.7 GBq (100 millicuries)
E. Iodine-125	E. Any	E. 370 MBq (10 millicuries)
F. Plutonium-242	F. Any	F. 1.85 GBq (50 millicuries)
G. Uranium-233	G. Any	G. 3.7 kBq (100 nanocuries)
H. Thorium-229	H. Any	H. 3.7 kBq (100 nanocuries)
I. Cadmium-109	**I. Sealed Source**	**I. 3.7 GBq (100 millicuries)**

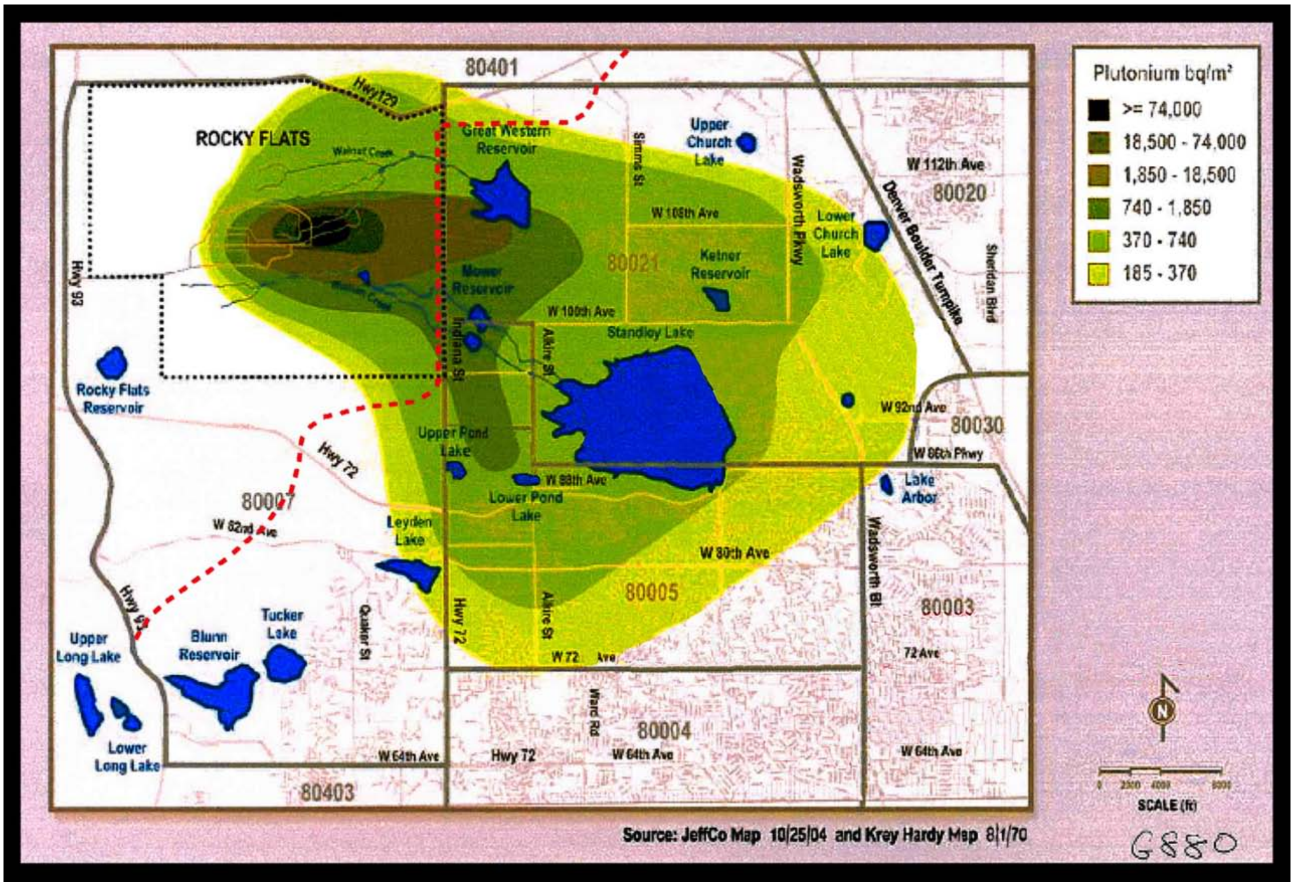
9. Authorized Use:

A. through C. Laboratory demonstrations, exercises, experiments, and research and development.

POST IN ACCORDANCE WITH R9-7-1002

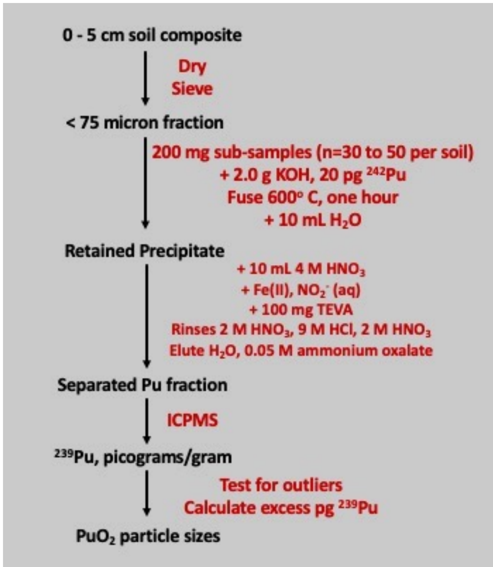
Attachment 2. Krey-Hardy map, constructed in the 1970's using limited data and revealed to the public following the 1969 fire.

Image source: https://www.psrcolorado.org/news/wwe0yp56yg5n4n0kqe9nhs1r31alfp



Attachment 3. Presentation materials from an April 2022 symposium hosted by Colorado Physicians for Social Responsibility, describing detection of PuO_2 particles

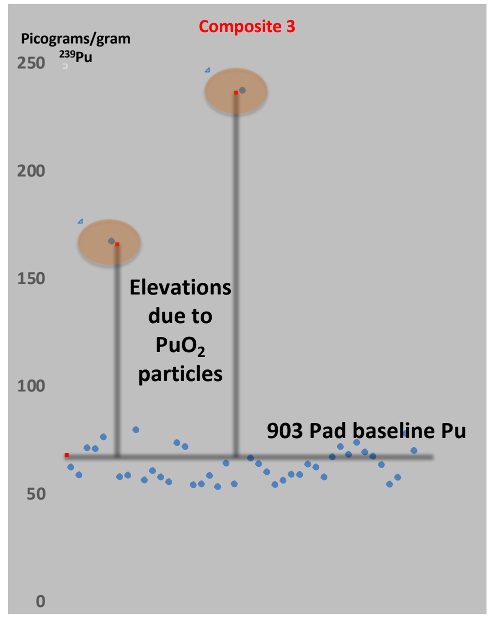
Dissolution assay for PuO_2 (s) in particulate solids: soil, dust, sediment



Large number of repeat dissolutions of many individual aliquots of a specific soil sample reveal the presence of individual Pu-bearing particles – operationally assumed to be PuO_2 (s)

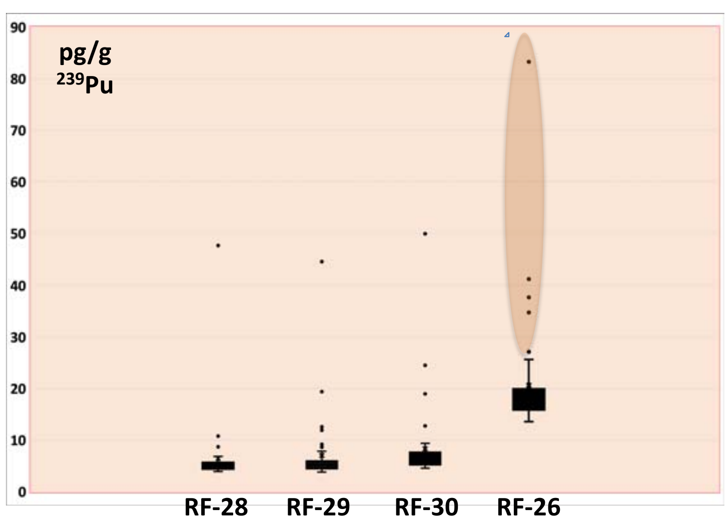
Attachment 3. Presentation materials from an April 2022 symposium hosted by Colorado Physicians for Social Responsibility, describing detection of PuO_2 particles

	A	B	C	D	E	F
2		Composite 3				
3		pg/g 239	pg/g sd			
4		62.68	5.29		53.58	
5		59.08	0.46		54.42	
6		71.70	4.93		54.54	
7		71.30	1.75		54.80	
8		76.69	1.44		54.88	
9		167.59	2.75		54.88	
10		58.31	3.43		55.89	
11		58.97	2.28		56.63	
12		80.01	3.25		56.65	
13		56.65	4.81		58.02	
14		61.02	5.39		58.13	
15		58.13	0.51		58.15	
16		55.89	1.21		58.31	
17		74.09	1.60		58.76	
18		72.30	1.34		58.97	
19		54.42	0.65		59.08	
20		54.88	1.48		59.25	
21		58.76	0.30		59.31	
22		53.58	2.23		60.43	
23		64.58	1.20		61.02	
24		54.88	1.84		62.68	
25		237.67	6.65		62.72	
26		66.98	2.36		63.78	
27		64.20	4.29		64.14	
28		60.43	12.48		64.20	
29		54.54	4.77		64.58	
30		56.63	1.88		66.98	
31		59.31	4.63		67.45	
32		59.25	2.89		67.74	
33		64.14	3.92		68.54	
34		62.72	1.99		69.72	
35		58.15	2.81		70.37	
36		67.45	0.92		71.30	
37		72.17	1.53		71.70	
38		68.54	1.75		72.17	
39		74.13	2.80		72.30	
40		69.72	3.91		74.09	
41		67.74	1.40		74.13	
42		63.78	2.65		76.69	
43		54.80	1.48		78.23	
44		58.02	1.37		80.01	
45		78.23	3.90		167.59	
46		70.37	1.05		237.67	
47					Exceed 3*SD threshold	



PuO_2 (s) is present in all of the 2019 surface soil composite samples from the Jefferson County right-of-way (immediately west of Indiana Street)

PuO_2 (s) is also present in all of the 2001 surface soil composite samples from the Colorado Hills Open Space (City of Westminster)



Attachment 4. Letter to DOE Secretary and EPA Administrator from Reps. Pettersen and Neguse

Congress of the United States
Washington, DC 20515

June 20, 2023

The Honorable Jennifer M. Granholm
Secretary
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

The Honorable Michael S. Regan
Administrator
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue NW
Washington, DC 20460

Dear Secretary Granholm and Administrator Regan,

We write regarding the need for robust federal investments in air quality monitoring at the Rocky Flats Plant and surrounding communities in Colorado. In 1989, the EPA declared Rocky Flats a Superfund site. In 2005, the physical cleanup was completed except for the central area, which remains a Superfund site. The ongoing risks from Superfund sites are pervasive even after the completion of the clean-up at the Rocky Flats Superfund site, and we continue to hear concerns from the communities we represent.

In December of 2021 the Marshall Fire swept through Colorado—destroying over 1,000 structures in Boulder County as winds barreled across the state with gusts of up to 100 miles per hour. The impacts of the Marshall Fire have been lasting, and our communities are continuing to recover. The Marshall Fire particularly devastated communities north of Rocky Flats and underscored the risks, including wildfire and air quality, posed to those living near contaminated sites.

In response to requests made by local municipalities and counties, including the cities of Arvada and Broomfield, and Boulder County, we request that the Department of Energy (DOE) and the Environmental Protection Agency (EPA) invest in air quality monitoring surrounding the Rocky Flats site. Specifically, the DOE and EPA should share the data collected with the public and local and state governments. The presence of air quality monitors would demonstrate any impacts on our communities resulting from the dispersion of contaminated materials during and following a wildfire. This is a necessary investment to protect the health and integrity of the communities that live alongside Rocky Flats. We encourage you to work with other state and federal partners, including the U.S. Fish and Wildlife Service and the Colorado Department of Public Health and Environment, as you work to develop and implement any air quality monitoring.

Thank you for giving your full and fair consideration to this request in accordance with all applicable rules, regulations, laws, and guidelines. We look forward to hearing from you and working together on this issue.

Sincerely,

Brittany Pettersen
Member of Congress

Joe Neguse
Member of Congress

cc: U.S. Fish and Wildlife Service
Colorado Department of Public Health and Environment

Attachment 5. Letter to DOE Office of Legacy Management Director Carmelo Melendez from Broomfield Mayor Guyleen Castriotta

Mr. Carmelo Melendez
Director, U.S Department of Energy, Office of Legacy Management
1000 Independence Avenue, SW
Washington, DC 20585

Dear Mr. Melendez:

With continued drought and increased fire activity throughout the state of Colorado, the City and County of Broomfield - similar to other communities surrounding Rocky Flats - are concerned about the multilevel impact from a wildfire at Rocky Flats. Our community has suffered public health impacts from the Rocky Flats areas for decades, and now, adding to the potential concerns, includes wildfires.

The Marshall Fire on December 30, 2021, which devastated communities immediately north of Rocky Flats and stopped just shy of our community's border, drives our request to immediately seek the strategic deployment of air quality monitors in the vicinity of Rocky Flats. This deployment would identify, through data collection, any impacts on our communities resulting from the transport of material during and following a wildfire.

Through our extensive air quality monitoring program, the City and County of Broomfield is well versed with the deployment of air quality monitoring devices, data collection techniques, and the power of understanding the air quality impacts on public health. The heightened sense of urgency is twofold - one, knowing that wildfires will be occurring at a much higher rate in the future, and secondly and most concerning, what is buried at Rocky Flats.

If we have learned anything over the last few years of monitoring Oil & Gas operations, gathering data to establish a baseline prior is critical to understanding the actual change in air quality and allows for better public policy and decision making.

We stand ready to share our experience in the air quality monitoring arena: strategic monitoring area deployment, data signatures in the results, understanding public health impacts and community communications, lessons learned, making data driven decisions, and robust stakeholder involvement/engagement.

The City and County of Broomfield is committed to work with DOE, Environmental Protection Agency, Colorado Department of Health and Environment, United States Fish and Wildlife Service, and all community partners to gather data, share resources, and better understand the impact of air quality on Coloradans health.

Thank you for your attention to this important issue.

Mayor Guyleen Castriotta

Cc: Jill Hunsaker Ryan, Executive Director, Colorado Department of Health and Environment
Kathleen Becker, Regional Administrator, EPA Region 8
Congressman Ed Perlmutter, U.S. House of Representatives, Colorado District 7
Congressman Joe Neguse, U.S. House of Representatives, Colorado District 2
Rocky Flats Stewardship Council
City and County of Broomfield City Council

Attachment 6. Photos of prevailing wind conditions at the Rocky Flats air sampling locations along the west shoulder of Indiana Street on April 6, 2024

Attachment 7. Photo of the air sampler in operation on April 6, 2024 at the location of Sample 01

Attachment 8. Field notes for the air filter collection activities of April 6, 2024 near Rocky Flats

MEK

4-6-2024

Accompanied by Jon Lipsky in his vehicle, we used a 8" cylindrical blower sampler assembled by Brian Perez.

Collected 3 samples on media (MERV-12 double thickness) ~~[illegible]~~ MEK

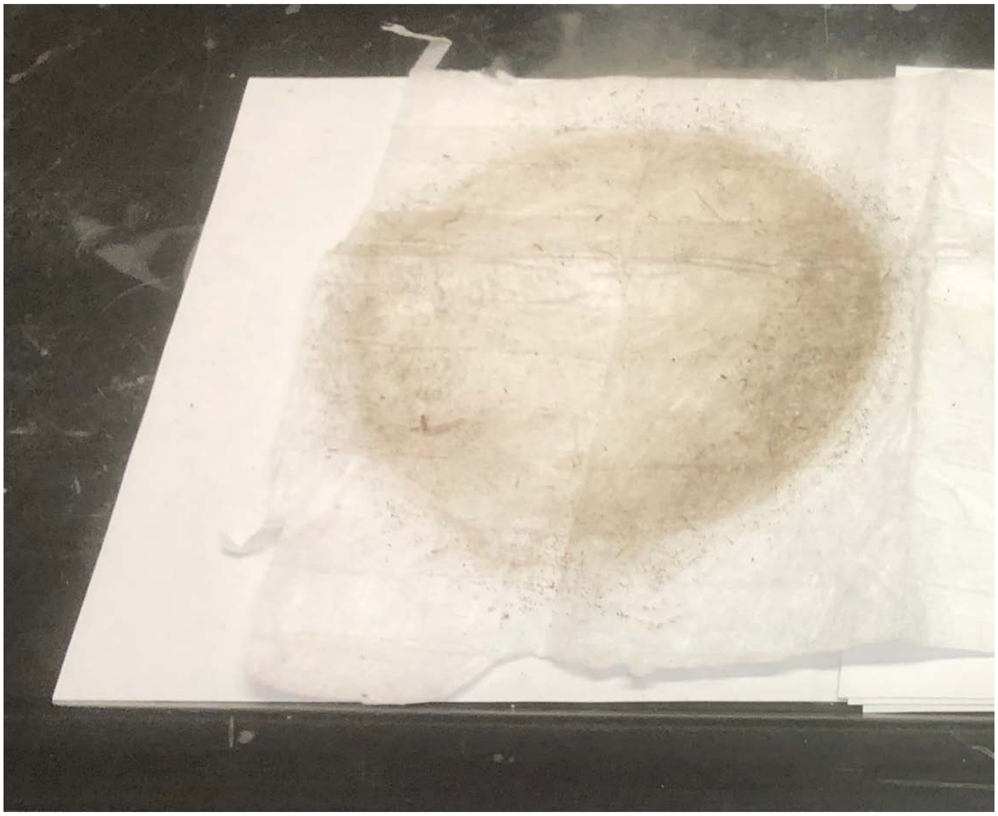
Exposures were ~~15 ± 1~~ 20 ± 2 MEK min each. ← See times

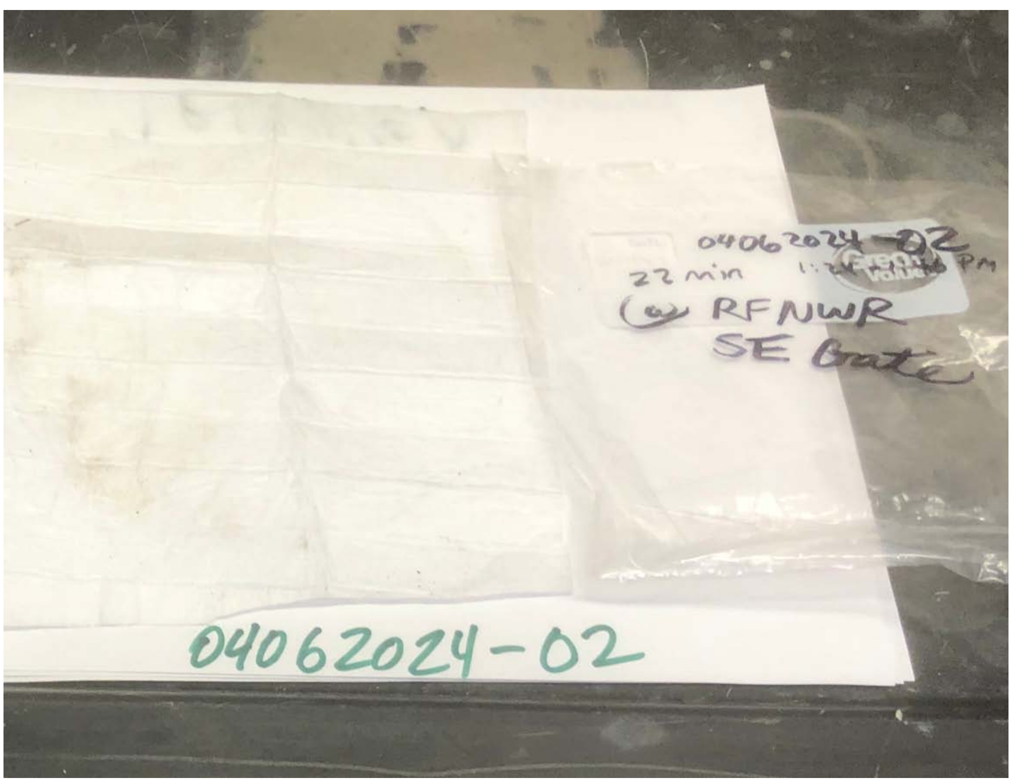
04062024-01 = Former Plant East gate Indiana
12:44 → 1304

04062024-02 . Current location of REFUGE SE Gate Indiana
13:24 → 13:46

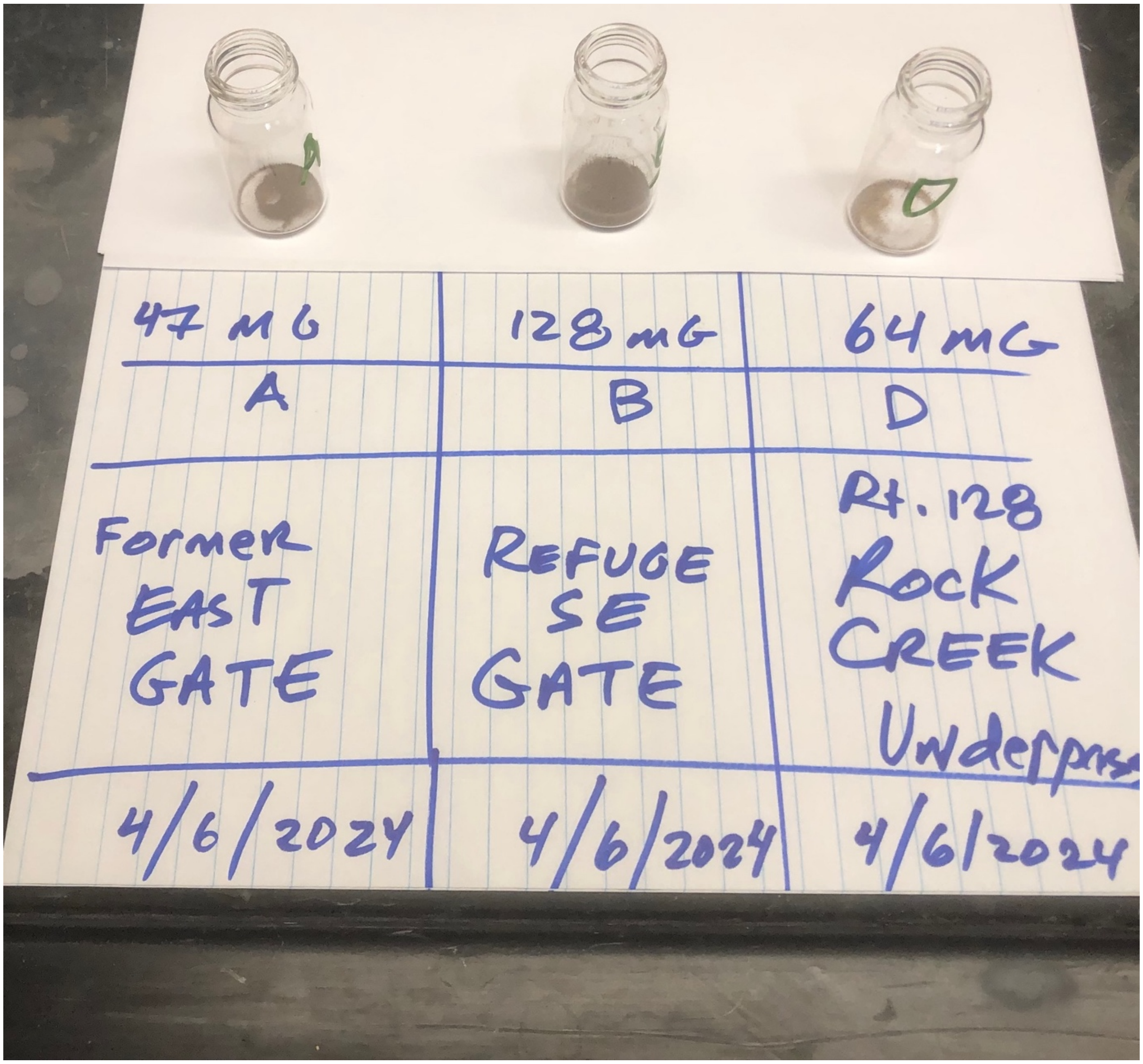
04062024-03 Hwy 128 @ Rock Creek
14:24 → 14:44

Attachment 9. Photos of MERV-12 air filter substrate, Sample 2, collected with a 22-minute sampling period on April 6, 2024 at the RFNWR Southeast Gate

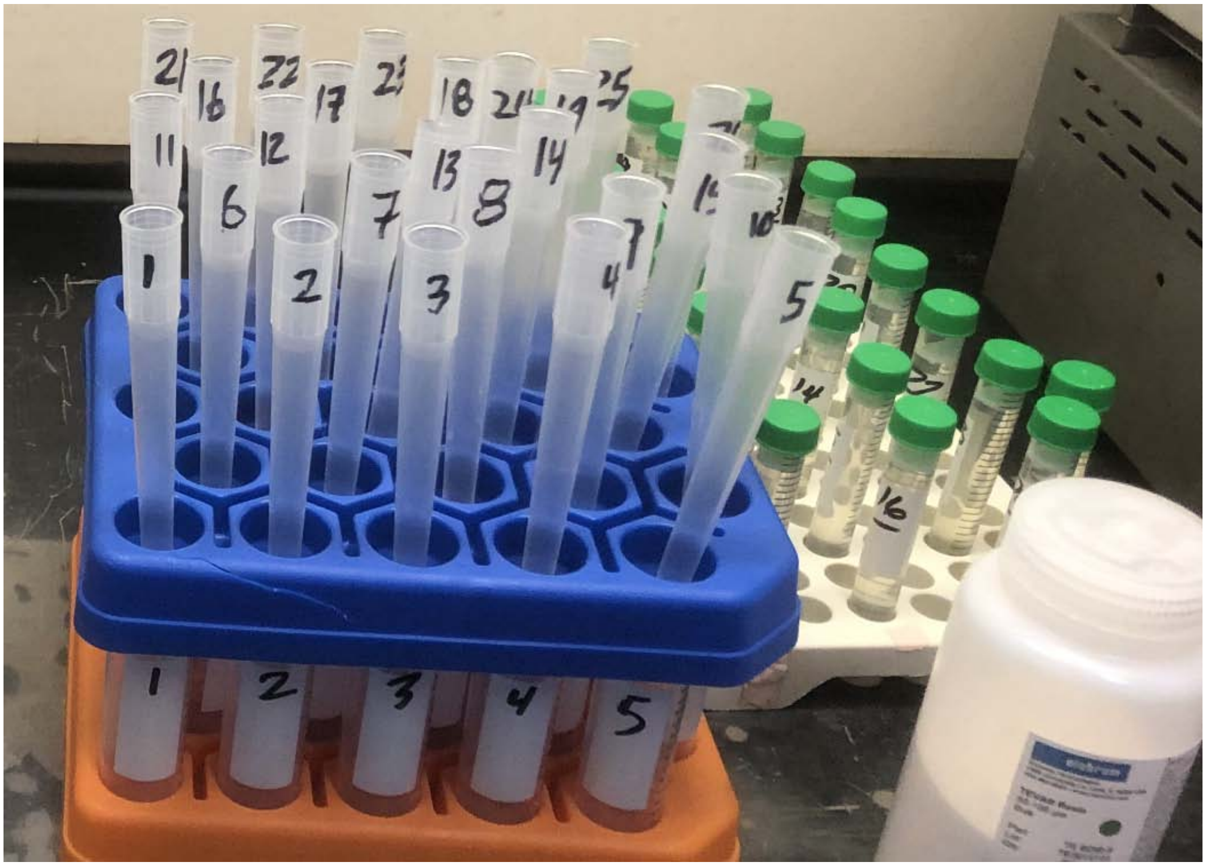




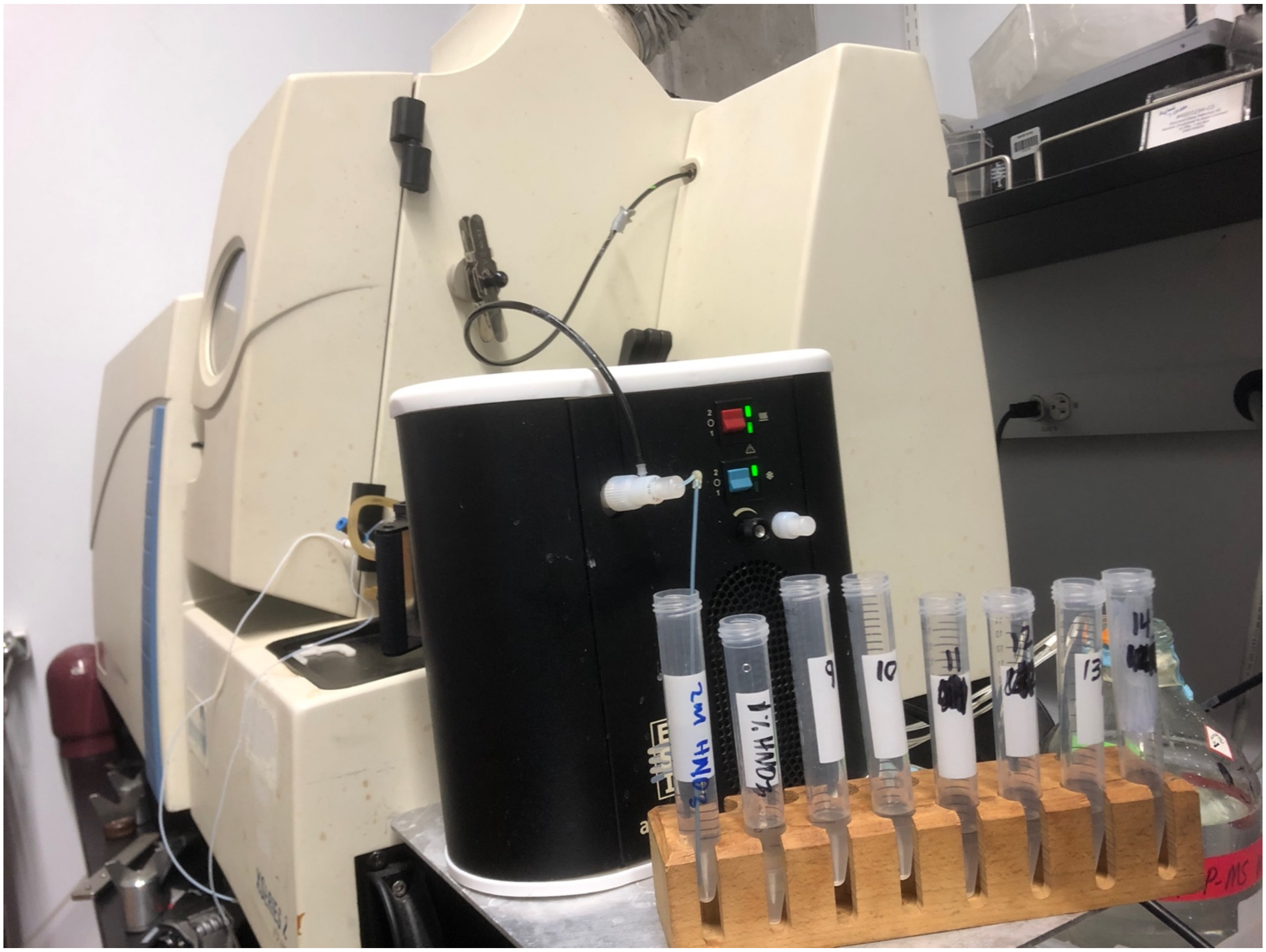
Attachment 10. Photos of ash recovered from the air filters collected near the Rocky Flats site during high-wind events of April 6, 2024



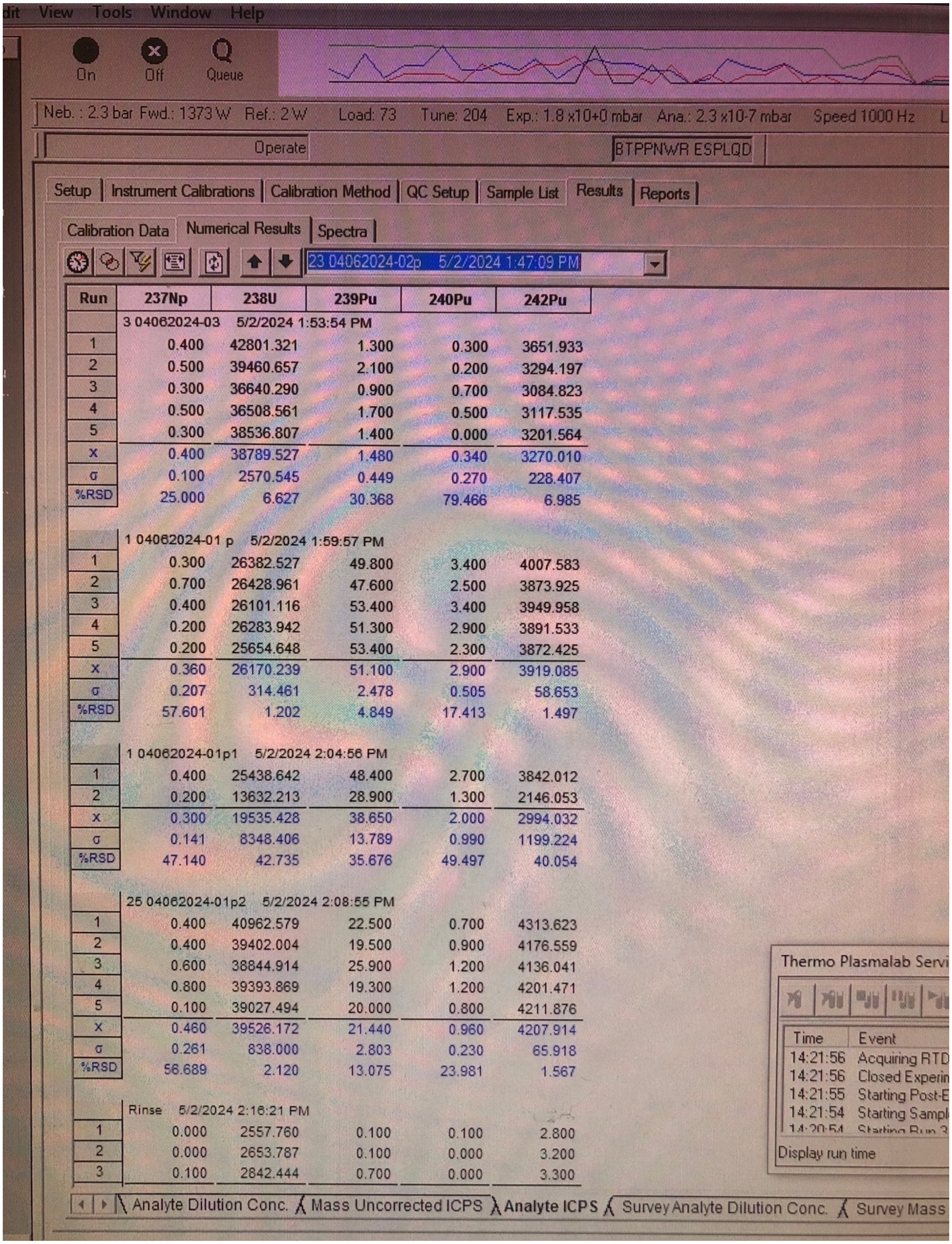
Attachment 11. Photo of solid-phase extraction columns used in the isolation of Pu from the specific samples and controls analyzed in the study; the chemistry and analyses by mass spectrometry were completed on May 2, 2024.



Attachment 12. Photo of the NAU Thermo X2 quadrupole ICPMS and ESI APEX HF sample introduction system used in the study of the April 6, 2024 air filter samples; photo taken on May 3, 2024 on the day following analyses of the samples from the air filter study



Attachment 13. Photo of ion count rate data as presented in real time during the analysis of the Rocky Flats proximity air filter samples on May 2, 2024



Run	237Np	238U	239Pu	240Pu	242Pu
	3 04062024-03	5/2/2024 1:53:54 PM			
1	0.400	42801.321	1.300	0.300	3651.933
2	0.500	39460.657	2.100	0.200	3294.197
3	0.300	36640.290	0.900	0.700	3084.823
4	0.500	36508.561	1.700	0.500	3117.535
5	0.300	38536.807	1.400	0.000	3201.564
x	0.400	38789.527	1.480	0.340	3270.010
σ	0.100	2570.545	0.449	0.270	228.407
%RSD	25.000	6.627	30.368	79.466	6.985
	1 04062024-01 p	5/2/2024 1:59:57 PM			
1	0.300	26382.527	49.800	3.400	4007.583
2	0.700	26428.961	47.600	2.500	3873.925
3	0.400	26101.116	53.400	3.400	3949.958
4	0.200	26283.942	51.300	2.900	3891.533
5	0.200	25654.648	53.400	2.300	3872.425
x	0.360	26170.239	51.100	2.900	3919.085
σ	0.207	314.461	2.478	0.505	58.653
%RSD	57.601	1.202	4.849	17.413	1.497
	1 04062024-01p1	5/2/2024 2:04:56 PM			
1	0.400	25438.642	48.400	2.700	3842.012
2	0.200	13632.213	28.900	1.300	2146.053
x	0.300	19535.428	38.650	2.000	2994.032
σ	0.141	8348.406	13.789	0.990	1199.224
%RSD	47.140	42.735	35.676	49.497	40.054
	25 04062024-01p2	5/2/2024 2:08:55 PM			
1	0.400	40962.579	22.500	0.700	4313.623
2	0.400	39402.004	19.500	0.900	4176.559
3	0.600	38844.914	25.900	1.200	4136.041
4	0.800	39393.869	19.300	1.200	4201.471
5	0.100	39027.494	20.000	0.800	4211.876
x	0.460	39526.172	21.440	0.960	4207.914
σ	0.261	838.000	2.803	0.230	65.918
%RSD	56.689	2.120	13.075	23.981	1.567
	Rinse	5/2/2024 2:16:21 PM			
1	0.000	2557.760	0.100	0.100	2.800
2	0.000	2653.787	0.100	0.000	3.200
3	0.100	2842.444	0.700	0.000	3.300

Attachment 14. Results for plutonium activities and isotope compositions for Samples 01, 02, and 03 collected on April 6, 2024 along Indiana Street and Colorado Highway 128

Sample	Lab ID	Location	pCi/gram $^{239+240}Pu \pm$ standard deviation[1]
01	1[2]	Former East Gate	1.19 ± 0.05
01	25	Former East Gate	0.69 ± 0.09
02	2	RMNWR Southeast Gate	0.85 ± 0.06
02	21	RMNWR Southeast Gate	0.20 ± 0.03
02	22	RMNWR Southeast Gate	0.15 ± 0.04
02	22	RMNWR Southeast Gate	0.18 ± 0.02
03	3	Colorado 128 at Rock Creek	Not detected
		Detection limit[3]	**0.13**

[1]Activities were calculated from the masses of ^{239}Pu and ^{240}Pu found, the sample mass, and the following specific activities: 1 pCi ^{239}Pu = 15.7 pg ^{239}Pu; 1 pCi ^{240}Pu = 4.3 pg ^{240}Pu

[2]For Preparation 1 of Sample 01 (former East Gate of the weapons plant), the counting statistics were favorable enough to permit calculation of $^{240}Pu/^{239}Pu = 0.057 \pm 0.009$ (one standard deviation), confirming a definitive Rocky Flats origin.

[3]The stated detection limit, expressed in picocuries $^{239+240}Pu$ per gram ashed dust, was computed using the thresholds of 2 and 1 cps for ^{239}Pu and ^{240}Pu, along with an average ^{242}Pu signal of 3060 cps and a nominal 25 mg sample.

7/10/2026

Record of Precedent for Opposition to Public Recreation at Rocky Flats, the Rocky Mountain Greenway, Private Toll Road Construction, and Controlled Burns at Rocky Flats

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Westminster City Council:

- January 26th, 2026, Westminster City Council received a staff update about posting Rocky Flats warning signage identical to the Boulder County signage.
  - Link to 1/26/2026 meeting video
- September 23rd 2024, Westminster voted 4-3 to withdraw from the Rocky Mountain Greenway
- July 15th 2024, Balanced Study Session on the Rocky Mountain Greenway
  - Video of Part 1
  - Video of Part 2

Boulder County:

- January of 2026 Boulder County installed warning signage on the north side of Rocky Flats
- 3/3/2025 the Town of Lyons voted 6-1 to approve a resolution opposing the Rocky Mountain Greenway. The resolution passed 6-1 on the consent agenda 3/17/2025.
  - Video 3/3/2025
  - Video 3/17/2025
- 2/10/2025 the Town of Superior unanimously passed a resolution opposing the Rocky Mountain Greenway.
  - Video

- January 30th 2024, Boulder County Commissioners voted to officially oppose recreation at Rocky Flats

- 2021 Sign-on Letter to Halt the Rocky Mountain Greenway

Broomfield City Council:

- October 27th 2020 Broomfield withdrew from the Rocky Mountain Greenway
  - Video
  - Minutes
- February 25th 2020 Broomfield voted unanimously to withdraw from the Jefferson Parkway
  - Video
  - Minutes
- June 18th 2019, Balanced Study Session on the Jefferson Parkway
  - Video

U.S. House of Representatives:

- 6/20/2023 Letter from Rep. Neguse and Rep. Pettersen Re: Air Monitoring

- 2/2/2024 Letter from Rep. Neguse and Rep. Pettersen Re: Air Monitoring

2022 Letters from 3 local governments to DOE LM supporting air monitoring

- Arvada (7/22/2022)
- Broomfield
- Boulder County

2018 Sign-On Letter To Halt Recreation at Rocky Flats:

- Local legislators, local school boards, and community groups from around the nation oppose public recreation at Rocky Flats.
    - Link to November 2018 Sign On Letter

Colorado State Legislators:

- 4/22/18 at a public townhall with 3 Colorado State Legislators, Senator Steve Fenberg, Representative Edie Hooton, and Representative KC Becker, stated that they would support keeping Rocky Flats National Wildlife Refuge closed to public recreation.

7 School Districts, representing nearly 300,000 students, committed to NO field trips to Rocky Flats:

- Boulder Valley School District - board resolution 3/14/17
- St. Vrain Valley School District - commitment by the superintendent 5/10/17
- Westminster Public Schools - commitment by the superintendent 9/29/17
- Adams 14 School District - board resolution 10/10/17
    - Meeting minutes
- Adams 12 School District - commitment by the superintendent 12/6/17
- Jeffco Public Schools - commitment by the superintendent 2/8/18
- Denver Public Schools - board resolution 4/26/18

Town of Superior:

- 4/25/16 the Superior Board of Trustees voted unanimously to oppose the Federal Land Access Program Grant for the Rocky Mountain Greenway (a bike trail proposed to traverse Rocky Flats)

Rocky Flats Downwinders:

- 11/21/16 Letter to CDPHE from Rocky Flats Downwinders, a non-profit community organization. Preliminary results from a health survey found rare cancers in the area downwind of Rocky Flats.

Cook V. Rockwell

- A 2016 CLASS ACTION LAWSUIT SETTLEMENT SET A COURT PRECEDENT THAT CONTAMINATION REMAINS EAST OF ROCKY FLATS
    - Jury Verdict Form - Marilyn Cook v Dow Chemical and Rockwell

Air Quality Control Commission:

- The USFWS smoke management permit for the Rocky Flats NWR expired on 12/31/2015.

Metro Mayors Caucus:

- 2/17/15 letter from 41 mayors of the Metro Mayors Caucus who opposed the controlled burn at Rocky Flats.

2004 Draft EIS Public Comment:

- 81% of public comments to the 2004 Draft EIS opposed public recreation at Rocky Flats

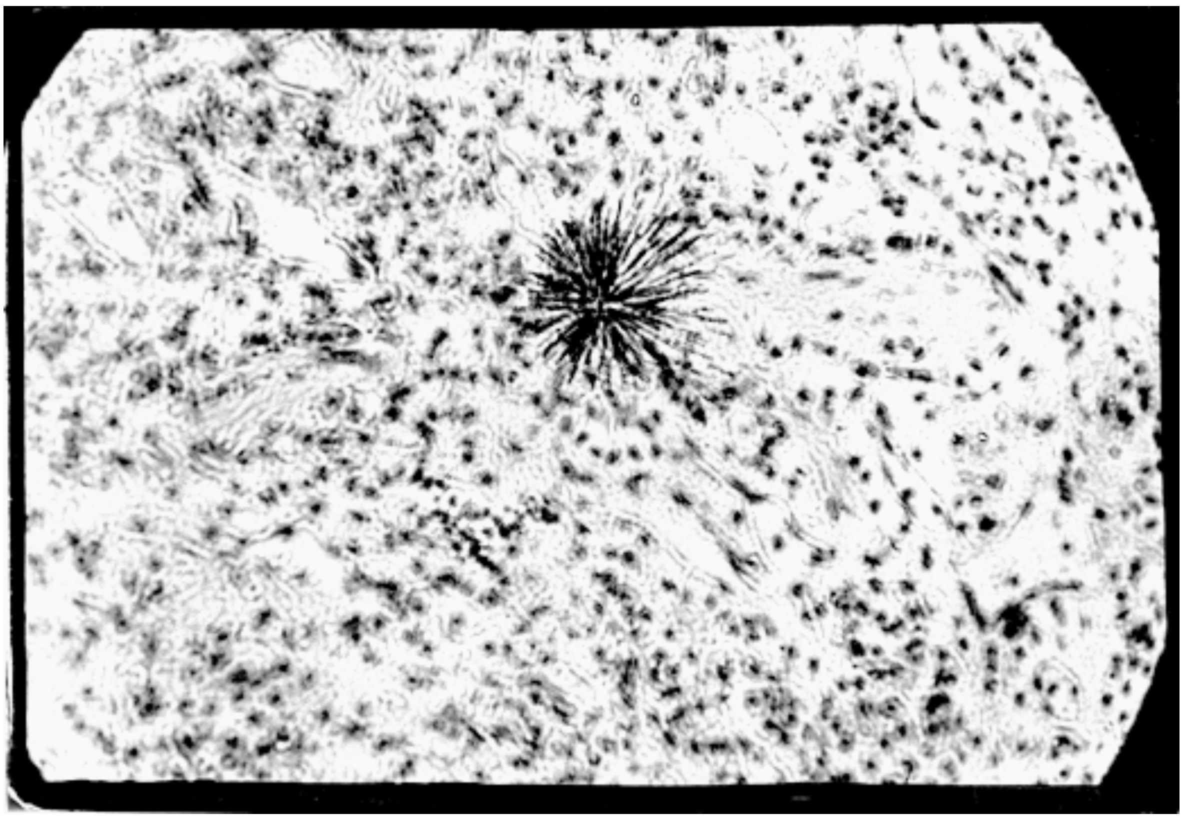
Risk from Plutonium in the Environment at Rocky Flats

LeRoy Moore, Ph.D., Rocky Mountain Peace & Justice Center, 7-31-15

• **Toxic:** All radioactive materials emit energy in the form of electron volts that can damage human tissue. But the highly concentrated energy emitted by plutonium makes it "fiendishly toxic, even in small amounts" (Glenn Seaborg, who in 1941 isolated and named plutonium, quoted in Jeremy Bernstein, *Plutonium* [2007], p. 105).

• **Long-term danger:** Plutonium 239, the material of principal concern at Rocky Flats, has a half-life of 24,110 years. It remains dangerously radioactive for more than a quarter-of-a-million years. Tiny particles left in the environment pose an essentially permanent danger.

• **Potentially lethal if internalized:** The alpha radiation emitted by plutonium cannot penetrate skin like x-rays or gamma radiation. But tiny particles inhaled, ingested, or otherwise taken into the body through an open wound may lodge in the lungs, liver, surface or marrow of bone, the gonads or elsewhere. For as long as plutonium resides in the body it continually bombards the immediately surrounding tissue with radiation. The result may be cancer, genetic defects, harm to the immune system. The latent period for cancer is likely to be 20 to 30 years.



• **Plutonium particle in lung tissue:** "The black star in the middle of this picture shows the tracks made by alpha rays emitted from a particle of plutonium-239 in the lung tissue of an ape. The alpha rays do not travel very far, but once inside the body, they can penetrate more than 10,000 cells within their range. This set of alpha tracks (magnified 500 times) occurred over a 48-hour period" (Robert Del Tredici, *At Work in the Fields of the Bomb* [1987], plate 39).

• **Hazardous in very small amounts**: Plutonium particles of 10 or less microns can be inhaled. The average diameter of human hair is about 50 microns. Meteorologist W. Gale Biggs concluded that most airborne particles at Rocky Flats were probably smaller than 0.01 microns ("Emissions and Monitoring of Plutonium from Rocky Flats," April 26, 2007). Particles too small to see are not too small to do harm.

• **More harmful than other forms of radiation:** Internal alpha emitters like plutonium are much more harmful than the equivalent dose from penetrating gamma or x-ray radiation. To account for the difference, the International Commission on Radiological Protection (ICRP) refers to the "relative biological effectiveness" (RBE) of alpha emitters. Looking at the potential harm to different organs and for different disease end-points, ICRP concludes that the average RBE for alpha emitters is 20. This means that, on average, internalized plutonium is 20 times more harmful than penetrating radiation of the same dose. But because 20 is an average, for some body organs and certain cancers as well as for particular individuals the actual RBE can be higher, sometimes much higher. For example, the RBE for bone cancer ranges as high as 320. (Helen A. Grogan et al, *Assessing Risk of Exposure to Plutonium*, Feb. 2000 [Risk Assessment Corporation], pp. 6.27-6.39)

• **Plutonium RBE and the Rocky Flats cleanup standards:** Those who set the cleanup standards for Rocky Flats followed the ICRP in using 20 as the RBE for plutonium. This averaging approach disregards the harm that may result from plutonium exposure to certain organs of the body or to given individuals; it does not protect the most vulnerable members of the population. The Rocky Flats Cleanup Agreement allows 50 picocuries of plutonium per gram of soil to remain in the top 3 feet of soil after "cleanup," much larger quantities below 3 feet. Doubling the plutonium RBE to 40 would reduce the 50 picocuries allowed in upper soil to 25; each RBE doubling would reduce by half the amount of plutonium allowed in the top 3 feet of soil. To provide maximum protection for those susceptible to bone cancer (RBE of 320), the cleanup level would be 0.015 picocuries per gram.

• **All the Rocky Flats site contaminated:** Historically, while some areas at Rocky Flats were more heavily contaminated than others, plutonium particles released in fires, accidents, and routine operations were laid down across the whole of the site. This conclusion is suppoted by soil sampling done at predominantly upwind locations by F. Ward Whicker of Colorado State University and Harvey Nichols of the University of Colorado.

• **Inadequacy of the Rocky Flats cleanup:** Plutonium left in the Rocky Flats environment is in the form of very fine particles that can be inhaled or ingested. The government agencies responsible for the cleanup made no effort to clean the site to the maximum extent possible. They knowingly left an unknown quantity of plutonium in the environment. Their assumption that this plutonium would remain "relatively immobile" is countered by M. Iggy Litaor's discovery in the wet conditions of 1995 that plutonium in soil at Rocky Flats migrates. Also, in 1996 Shawn Smallwood identified18 species of burrowing animals at the site that dig down to as much as 16 to 20 feet below the surface and constantly move soil and its contents. Plutonium particles brought to the surface can be picked up by wind and moved to other locations near and far. There is no guarantee that plutonium left in the Rocky Flats environment will remain safely in place or even on the site.

• **Excess cancers among Rocky Flats workers exposed to purportedly safe levels:** In 1987 Gregg S. Wilkinson of DOE's Los Alamos Lab published results of his study showing that some exposed Rocky Flats workers with internal plutonium deposits as low as 5% of DOE's purportedly safe permissible lifetime body burden developed a variety of cancers in excess of what was normal for workers who had not been exposed (*American Journal of Epidemiology*, vol. 125, no. 2 [1987], pp. 231-250).

• **Harm from a single particle:** Tom K. Hei and colleagues at Columbia University demonstrated that a single plutonium alpha particle induces mutations in mammal cells. Cells receiving very low doses were more likely to be damaged than destroyed. Replication of these damaged cells constitutes genetic harm, and more such harm per unit dose occurs at very low doses than would occur with higher dose exposures. "These data provide direct evidence that a single alpha particle traversing a nucleus will have a high probability of resulting in a mutation and highlight the need for radiation protection at low doses." In a follow-up study, they found that "a single alpha particle can induce mutations and chromosome aberrations in [adjacent] cells that received no direct radiation exposure to their DNA" (*Proceedings of the National Academy of Sciences*, vol. 94 [Apr. 1997], pp. 3765-3770; and vol. 98 [4 Dec. 2001], pp. 14410-14415).

• **Plutonium and genetic harm:** A British research team concluded that the RBE for chromosomal damage from plutonium exposure is essentially "infinite," because the extent of harm to the human gene pool is incalculable (M. A. Khadim et al, *Nature*, vol. 355, no. 20 [Feb. 1992], pp. 738-740). Herman Muller, awarded a Nobel Prize for his discovery that radiation exposure had genetic effects harmful to future generations, predicted gradual reduction of the survival ability of the human species due to the effect on DNA of exposure to very low levels of radiation over several generations ("Radiation and Heredity," *American Journal of Public Health*, 1964, vol 54, no. 1, pp. 42-50).

• **"Genetic uncertainty problem" for wildlife:** Genetic specialist Diethard Tautz says that effects of radiation exposure on a given species of wildlife may not be readily apparent in individuals of that species until the passage of several generations. ("A genetic uncertainty problem," *Trends in Genetics*, vol. 16 [Nov. 2000], pp. 475-477). This finding suggests that wildlife at Rocky Flats could in the long-term be hurt by conditions at the site.

For more detail on environmental conditions at Rocky Flats and on plutonium health effects see "Plutonium and People Don't Mix" at http://media.wix.com/ugd/cff93e_c22798032f2e468f9af7d9ccb317169f.pdf

Proc. Natl. Acad. Sci. USA
Vol. 94, pp. 3765–3770, April 1997
Cell Biology

Mutagenic effects of a single and an exact number of α particles in mammalian cells

TOM K. HEI*†, LI-JUN WU*, SU-XIAN LIU*, DIANE VANNAIS‡, CHARLES A. WALDREN‡, AND GERHARD RANDERS-PEHRSON*

*Center for Radiological Research, College of Physicians and Surgeons, Columbia University, New York, NY 10032; and ‡Department of Radiological Health Sciences, Colorado State University, Fort Collins, CO 80523

Communicated by Donald C. Malins, Pacific Northwest Research Foundation, Seattle, WA, February 3, 1997 (received for review December 10, 1996)

ABSTRACT **One of the main uncertainties in risk estimation for environmental radon exposure using lung cancer data from underground miners is the extrapolation from high- to low-dose exposure where multiple traversal is extremely rare. The biological effects of a single α particle are currently unknown. Using the recently available microbeam source at the Radiological Research Accelerator Facility at Columbia University, we examined the frequencies and molecular spectrum of $S1^-$ mutants induced in human–hamster hybrid (A_L) cells by either a single or an exact number of α particles. Exponentially growing cells were stained briefly with a nontoxic concentration of Hoechst dye for image analysis, and the location of individual cells was computer-monitored. The nucleus of each cell was irradiated with either 1, 2, 4, or 8 α particles at a linear energy transfer of 90 keV/μm consistent with the energy spectrum of domestic radon exposure. Although single-particle traversal was only slightly cytotoxic to A_L cells (survival fraction $\approx$ 0.82), it was highly mutagenic, and the induced mutant fraction averaged 110 mutants per 10^5 survivors. In addition, both toxicity and mutant induction were dose-dependent. Multiplex PCR analysis of mutant DNA showed that the proportion of mutants with multilocus deletions increased with the number of particle traversals. These data provide direct evidence that a single α particle traversing a nucleus will have a high probability of resulting in a mutation and highlight the need for radiation protection at low doses.**

Accurate risk assessment of human exposure to ionizing radiations traditionally has been compromised, in that reliable data are available only for relatively high doses, so that extrapolations must be made down to the relevant, low-dose region of interest in radiation protection. However, this approach in risk assessment is often complicated by concurrent exposure to other chemical and physical environmental contaminants. Data indicate that exposure of the lung to α-emitting radon progeny is the largest component of background radiation received by the general public in the United States (1). Epidemiological studies have shown that uranium miners exposed to high levels of radon progeny have the largest incidence of radiation-induced lung cancers of any exposed population (2, 3). However, studies designed to identify a link between lung cancer and the low levels of radon commonly found in the home have been inconclusive because of confounding factors. The recent estimate by the Environmental Protection Agency of 21,600 deaths per year (confidence limits between 7,000 and 30,000) illustrates the uncertainties inherent in environmental risk assessment using epidemiological data (see ref. 4 for review).

Radon, a secondary decay product of uranium-238, is a colorless, odorless gas that decays with a half-life of 3.82 days into a series of solid, short-lived radionucleotides, including polonium-218 and polonium-214 that emit α particles during decay. Radon is ubiquitous in indoor environments, including homes and schools, and, in general, at concentrations hundreds of fold lower than in underground mines.

To have a better quantitative assessment of lung cancer risk associated with residential radon exposure, it is essential to have a better database for low-dose exposure. It has been estimated that 96% of the target bronchial cells of an average uranium miner will be traversed by more than one α particle each year. In contrast, only 1 in 10^7 bronchial cells will be hit by multiple particles from an average household exposure (4). The biological effects of a single α-particle traversal are unknown. Several relevant questions arise: Is a single traversal by these high linear energy transfer (LET) particles lethal to a cell? If not, will the surviving cells have a higher propensity to undergo chromosomal aberrations, mutations, and neoplastic transformation than nonirradiated cells? How does the number of particle traversals affect the kinds of mutations induced? The availability of a microbeam irradiation facility at the Radiological Research Accelerator Facility at Columbia University, where individual cells can be irradiated with either a single or an exact number of α particles, provides a unique opportunity to address these questions.

Since individual cells are irradiated one at a time so as to limit the number of cells available for analysis, a sensitive mutagenic assay system is essential to give meaningful data. The A_L cells developed by Waldren and Puck (5) fulfill this requirement. These cells contain a standard set of hamster chromosomes, but only one human chromosome (chromosome 11), which carries specific cell-surface antigenic markers. By the use of appropriate antibodies, mutations in the human chromosome can be quantified. Because only a small segment of this human chromosome (11p15.5) is needed for viability of the hybrid cell, this mutation system is particularly sensitive to agents such as ionizing radiations and asbestos fibers that induce multilocus deletions (6, 7). The A_L surface antigens (S1, S2) are effective genetic markers, because their presence or absence can be easily measured, and their distribution on opposite arms of chromosome 11 permits identification of lesions involving the long, short, or both chromosome arms. In the present studies, we have determined the dose response with regard to toxicity, mutant induction, and the kinds of mutations at the S1 locus found in cells whose nuclei were exposed to either a single or an exact number of α particles. Our data provide the first demonstration that a single α

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Abbreviation: LET, linear energy transfer.

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particle hit in the nucleus, which kills only 20% of the cells, is indeed mutagenic.

MATERIALS AND METHODS

Cell Culture. The A_L hybrid cells that contain a standard set of Chinese hamster ovary-K1 chromosomes and a single copy of human chromosome 11 were used. Chromosome 11 encodes cells surface markers that render A_L cells sensitive to killing by specific monoclonal antibodies in the presence of complement. Rabbit serum complement was from HPR (Denver, PA). Antibody specific to the S_1 antigen was produced from hybridoma culture as described (5, 8, 9). Cells were maintained in Ham F-12 medium supplemented with 8% heat-inactivated fetal bovine serum, 25 μg/ml gentamycin, and 2× normal glycine (2×10^{-4}M) at 37°C in a humidified 5% CO_2 incubator, and passaged as described (6, 7).

Irradiation Procedure. The layout and irradiation procedure using the microbeam facility at the Radiological Research Accelerator Facility have been described (10). Approximately 500 exponentially growing A_L cells were inoculated into each of a series of microbeam dishes constructed by drilling a ¼-inch hole in the center of 60-mm-diameter non-tissue-culture dishes. A 3.8-μm-thick polypropylene film was epoxied over the bottom of the hole, creating a miniwell that was then coated with Cel-Tak to enhance cell attachment. The DNA of attached cells was stained with a 50 nM solution of Hoechst 33342 dye for 30 min, and the location of individual nuclei was determined by optical imaging of the fluorescent staining pattern at 366 nm. The image analysis system then located the centroid of each nucleus, which were irradiated one at a time with an exact number of α particles. On average, it took 2 sec to locate and irradiate a cell so that up to 10,000 cells could be irradiated per day. We used 15,000–20,000 irradiated cells per group per experiment in the present study. The overall spatial precision of the beam, including positioning and beam spread, is about ± 4 μm. Because the average cross-sectional area of the nucleus of live, attached A_L cells was determined to be 108 μm^2, we estimated by Monte Carlo modeling of the collimators that the particle beam would hit the targeted nucleus 98.4% of the time. Due to the lag time of shutter closure, about 4 per 1,000 nuclei would have received one extra α particle. After every cell on a plate had been irradiated, the dish was removed from the stage, and the cells were trypsinized and replated to measure both survival and mutation as described (6, 11, 12). The percent recovery of irradiated cells from the polypropylene dishes was >98% as determined by cell count of representative dishes.

Dose Response for Cytotoxicity. Irradiated and control cells recovered from each miniwell were trypsinized and replated into 100-mm-diameter Petri dishes for colony formation. Cultures were incubated for 7–12 days, at which time they were fixed with formaldehyde and stained with Giemsa. The number of colonies was counted to determine the surviving fraction as described (11, 12).

Quantification of Mutations at the S1 Locus. Irradiated and control cultures from each miniwell were replated into 25-cm^2-area tissue-culture flasks and cultured for 7 days. This expression period is needed to permit surviving cells to recover from the temporary growth lag caused by irradiation and to multiply such that the progeny of the mutated cells no longer express lethal amounts of the S1 surface antigen. To determine mutant fractions, 5×10^4 cells were plated into each of six 60-mm dishes in a total of 2.5 ml of growth medium as described (6, 7, 11). The cultures were incubated for 2 h to allow for cell attachment, after which 0.2% S1 antiserum and 1.5% freshly thawed complement (vol/vol) were added to each dish. After overnight incubation, the medium in each dish was changed to remove the antiserum and complement. The cultures were further incubated for 7 to 8 days, at which time they were fixed, stained, and the number of $S1^-$ mutants scored. Controls included identical sets of dishes containing antiserum alone, complement alone, or neither agent. The cultures derived from each well were tested for mutant yield for 2 consecutive weeks to ensure full expression of the mutations. Mutant fractions were calculated as the number of surviving colonies divided by the total number of cells plated after correction for any nonspecific killing due to complement alone.

Analysis of Mutant Spectrum by Multiplex PCR. $S1^-$ mutants were isolated by cloning and expanded in cultures as described (6, 7, 11). We isolated no more than two well-separated colonies per culture dish to ensure their clonal origin. A minimum of 25 mutants from each irradiated group and over 50 spontaneous mutants were analyzed. DNA was extracted by a simple salting-out procedure as described (11, 13).

Five DNA markers on chromosome 11 (Wilms tumor, parathyroid hormone, catalase, RAS, and apolipoprotein A-1) were chosen for multiplex PCR analysis because of their map positions relative to the MIC1 gene, which codes for the S1 antigen (14), and the availability of PCR primers for the coding regions of these genes (15–17). PCR amplifications were performed for 30 cycles using a DNA Thermal Cycler 480 (Perkin–Elmer Cetus) in 20-μl reaction mixtures containing 1 μg of the *Eco*RI-digested DNA sample in 1× Stoffel fragment buffer, 0.2 mM dNTP, 3 mM $MgCl_2$, 0.2 mM each primer, and 2 units of Stoffel fragment enzyme. Each PCR cycle consisted of denaturation at 94°C for 1 min, annealing at 55°C for 1 min, and extension at 72°C for 1 min. After the last cycle, the samples were incubated at 72°C for an additional 20 min, electrophoresed on 2% agarose gels, and stained with ethidium bromide.

RESULTS

Irradiation of Cell Nuclei with the Microbeam. Fig. 1 shows the fluorescent image of a representative population of A_L cells as seen by the image analysis system under a 40× objective lens. Each nucleus was outlined by the image analysis program, and the precise center of each nucleus was located and placed over the exit aperture of the beam. Selected numbers of α particles then were automatically delivered within the 5 μm diameter of the beam line. These areas are shown by the small circles in the center of each nucleus (Fig. 1). Because the

FIG. 1. Fluorescent imaging of A_L cells stained with Hoechst dye viewed by the image analysis system under a 40× objective lens. The nucleus of each cell is outlined in white, and the circles indicate the area where the particle is delivered.

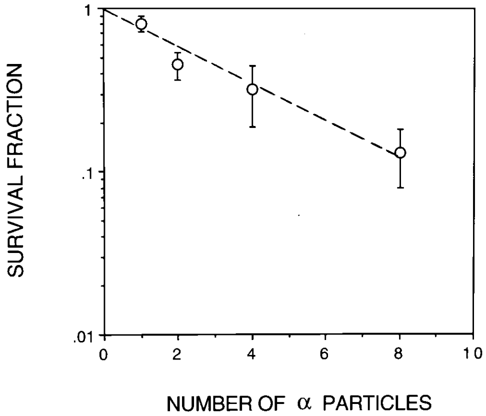

FIG. 2. Survival of A_L cells irradiated in the nucleus with either a single or an exact number of α particles. Data were pooled from 3–4 independent experiments. Bar represents ± SEM.

particle detector was positioned behind the monolayer of cells, every α particle registered would have traversed the nucleus. Given the track length of $\approx$40 μm for the 5.5-MV α particles used here when they entered attached mammalian cells, and the thickness of the A_L cell nucleus measured to be less than 4 μm, it was unlikely that any α particle would be stopped within the nucleus. The pixel position of irradiated nuclei was recorded to prevent multiple exposure of the same cell. It should be noted that the 50 nM dose of Hoechst dye used in the imaging step had been determined to be nontoxic and nonmutagenic under the conditions used in these studies§ and verified here.

Lethality of a Single-Particle Traversal. There is considerable interest in the carcinogenic effects of low doses of high LET radiations, such as α particles. It has been estimated for attached mammalian cells, for example, that the mean number of α-particle traversals required for cell killing ranges from 2 to 6 (18). Direct measurement of the lethality of a single α particle was, until recently, not possible. Fig. 2 shows the dose–response clonogenic survival of A_L cells irradiated with defined numbers of α traversals through the nucleus. The curve was best fitted by a linear quadratic model with α = 0.285 ± 0.01 and β = 0, yielding a mean lethal dose of $\approx$3.7 particles. It is clear from these data that most of the cells ($\approx$80%) survived to form colonies after exposure of their nuclei to a single particle. In fact, more than 10% of the cells survived after nuclear traversal by eight particles.

Mutagenicity of a Single α Particle. The relatively high mutagenic sensitivity of the A_L cell system made it possible to assess the mutagenic potential of a single α particle from relatively few irradiated cells. Mutation data were analyzed using the least-square method with the following parameters: $y = 108x - 7.7x^2$ where y was the number of induced mutants and x represented the number of particle traversals. Fig. 3 shows the number of induced mutant (background subtracted) per 10^5 clonogenic survivors at the S1 locus in A_L cells irradiated with either a single or an exact number of α particles. The fraction of preexisting $S1^-$ mutants in the A_L cell population used in these experiments averaged 45 per 10^5 survivors. The induced mutant yield by a single α particle was 2-fold of this background level and increased to 8-fold for eight particles. The dose–response curve yielded an initial slope of $\approx$100 mutants/10^5 cells per particle.

Analysis of Mutant Spectrum. The S1 surface antigenic marker is encoded by the MIC1 gene mapped to chromosome 11p13. With the mapping of over 200 genes on both the short and long arm of chromosome 11, together with the availability of primer sequences for some of these genes, it is relatively easy to determine the spectrum of $S1^-$ mutants induced. A total of 167 mutants, including 57 spontaneous ones, were analyzed. Fig. 4 shows a representative gel of PCR products using DNA from $S1^-$ mutants as template and primers synthesized for specific regions of marker genes located on either the long arm (Apo-A1) or short arm (CAT, WT, PTH, and RAS) of the human chromosome 11. The presence or absence of the corresponding PCR products indicates that the particular segments of DNA containing these genes are present or missing, respectively. Fig. 5 shows the cumulative deletion maps of these $S1^-$ mutants. Previous studies have shown that a small segment of the human chromosome 11 near the RAS gene is required for survival of the $S1^-$ mutants (11, 19). The obligate presence of this region identified here by the RAS probe in all the mutants provides a convenient internal PCR control. Fig. 4 shows that the majority of spontaneous $S1^-$ mutants (50 of 57 or 88%) had retained all of the markers analyzed. Likewise, the majority of mutants induced by a single α particle resulted from mutations involving the loss of S1 marker only (24 of 32 or 75%), whereas the remaining 25% of the mutants had lost at least one additional marker. In contrast, the proportion of mutants suffering loss of additional chromosomal markers increased with increasing number of particle traversals such that 19 of 24 (79%) of the mutants induced by eight particles had lost all four markers examined, which spanned both arms of the human chromosome 11. These mutants were further characterized by Southern blotting using the centromeric probe p82H (20). Approximately 50% of the mutants had lost the centromere, indicating a loss of the entire human chromosome 11 except for the 11p15.5 fragment that had translocated to a hamster chromosome (data not shown).

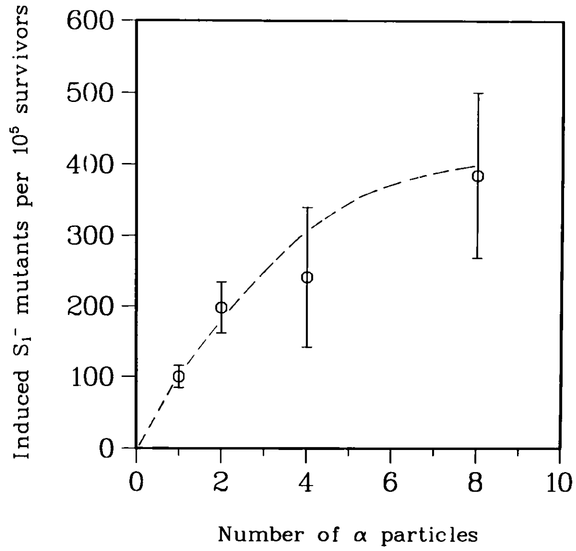

FIG. 3. Induced mutants per 10^5 survivors at the S1 locus in A_L cells irradiated with an exact number of α-particle traversals at 90 keV/μm. Induced mutant yield = total mutant yield minus background incidence. The background mutant fraction in A_L cells used in these experiments averaged 45 per 10^5 survivors. Data were pooled from three experiments, and the curves fitted using the least-square method. (Bars represent ± SEM.)

DISCUSSION

It is of societal importance to provide realistic risk estimate for the carcinogenic effects of domestic radon exposure, currently estimated at 15,000 lung cancer deaths per year. This number is based largely on extrapolation from the high-dose exposure

§Hei, T. K., Wu, L.-J., Liu, S.-X., Vannais, D., Waldren, C. & Randers-Pehrson, G. Proceedings of the Annual Radiation Research Society Meeting, April 14–17, 1996, Chicago, IL.

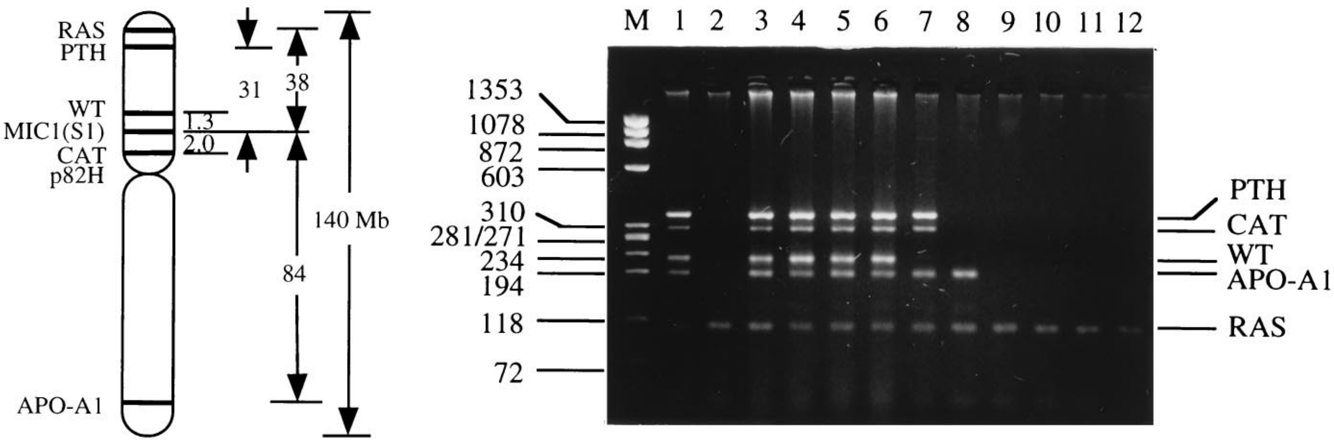

FIG. 4. (*Right*) Gel electrophoresis of multiplex PCR products using DNA from S1^{-} mutants as templates and primers for parathyroid hormone (PTH), Wilms tumor (WT), catalase (CAT), apolipoprotein A1 (APO-A1), and RAS. *Hae*III-digested ϕX174 DNA provided the size markers (lane M). Lane 1, wild-type A_L cells with all of the markers present. Lane 2, a positive control showing the loss of all the markers examined except RAS. Lanes 3 and 4, spontaneous mutants showing no marker loss. Lanes 5 and 6, mutants induced by a single α particle where none of these markers was lost. Lanes 7–12, mutants induced by eight α particles showing mostly deletions of various sizes. (*Left*) The relative location of the marker genes on human chromosome 11 used in the multiplex PCR and their relative distance from the M1C1 gene.

data for underground miners where the majority of the target bronchial epithelial cells received multiple α-particle traversals (4). However, environmental radon exposure levels are such that multiple traversals are extremely rare, so that the effects of a single α-particle hit are the most relevant to environmental risk analysis (21). Our data provide a direct measurement of the genotoxicity of a single α particle.

The question of whether traversal of a single α particle through the nucleus is lethal has been debated for more than three decades. Earlier studies by Barendsen (22) suggested that traversal of the nucleus by a single α particle would be lethal. Moreover, studies based on measurement of induced DNA double-strand breaks in C3H10T½ cells indicated that virtually 100% of the cells traversed by a single α particle would be

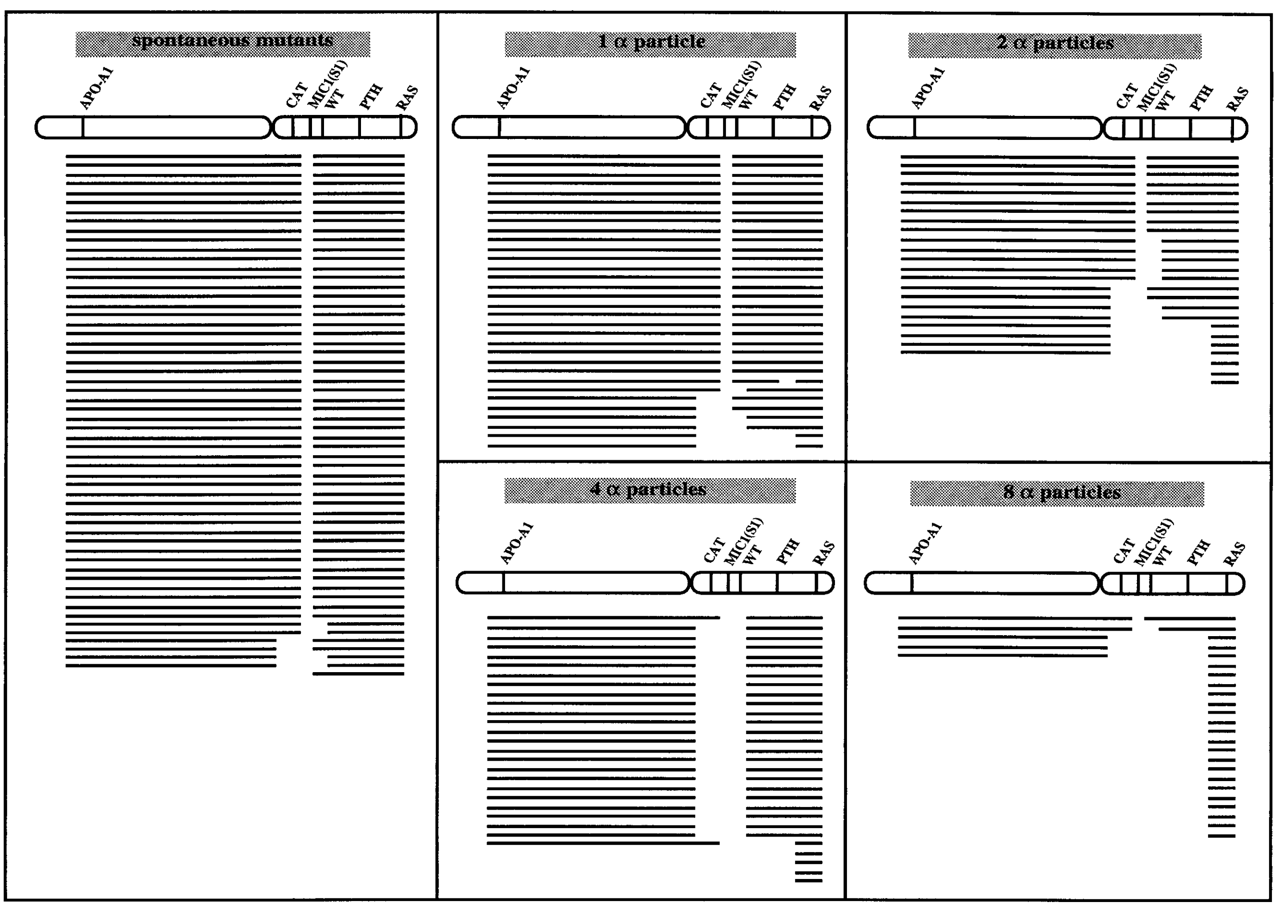

FIG. 5. Cumulative deletion spectra of S1^{-} mutants either of spontaneous origin or from cells exposed to either a single or an exact number of α-particle traversals through the nucleus. Each line depicts the spectrum from a single, independent mutant. The absence or presence of marker genes among the mutants was determined by multiplex PCR. Blank spaces depict missing markers.

killed by direct action (23). On the other hand, microdosimetric studies based on particle track structure suggested that the probability of an α-particle traversal resulting in lethal damage was only 17% in rodent fibroblasts, i.e. it takes six hits to kill a cell (24). Our direct measurement of a single particle survival is consistent with an estimate of a low probability of cell inactivation: only 20% of the irradiated cells were killed. It is amazing that roughly 10% of cells irradiated with eight α particles were still viable enough to form colonies even though they carried a much higher mutagenic potential.

Using the nuclear crosssectional area of 108 μm^2 measured for A_L cells, we calculated that a dose of $\approx$12 cGy of 90 keV/μm α particles from track segment irradiation where attached cells are exposed to a broad beam of monoenergenetic particles would be required to deliver an average of one particle traversal per nucleus based on random, Poisson distribution. At this dose, about one-third of the nuclei would not be hit, another third would sustain one α-particle hit, and the remaining third would receive multiple hits. The dose response for survival of A_L cells irradiated with an exact number of α particles was not significantly different from recent data obtained using average particle traversals (11, 12). These results suggest that, at least for cell lethality, the Poisson estimation gives a fairly accurate projection of the biological effects of either a single or an exact number of α particles.

The numbers and kinds of mutants induced by α particles at several gene loci, including thymidine kinase and hypoxanthine-guanine phosphoribosyltransferase, have been reviewed recently (25, 26). High LET radiation, such as α particles, induced more mutant per mean lethal dose (D_o) than low LET radiation such as x- and γ-rays ($\approx$280 $S1^-$ mutants/D_o for 90 keV/μm α particles versus 150 mutants/D_o for γ-rays; refs. 11, 12). The number of induced mutants is both dose- and LET-dependent. Our present data provide the first demonstration that a single α particle induces mutations in mammalian cells. Using the highly sensitive A_L assay system, we were able to show that a single-particle traversal induced a mutant fraction 2 times greater than the background value. This mutant yield was comparable to the frequency induced by an equivalent mean of one particle traversal based on a Poisson distribution (11). Our results are consistent with those of Nelson *et al.* (27) who demonstrated a linear dose response with regard to the induction of micronuclei among Chinese hamster ovary cells irradiated with up to five α particles using a 3.2-MV microbeam. However, at a dose of eight particle traversals per nucleus, where we found the induced frequency was 8 times background level, the incidence was significantly higher than the yield obtained with a mean of eight particles as determined by the Poisson distribution (data not shown). It is possible that many cells in the latter group may received either very few particle traversals and subsequently fewer mutations, or many more than eight particles that are lethal to the cells. Thus, it is likely that this difference is due to distortion of the cell population at the time of the assay in the track segment experiment (Poisson distributed) because of differences in radiation-induced division delay. The cells that received a small number of traversals would be expected to expand more rapidly during the expression period than those that received a large number of particle hits. Thus, there is a closed correlation between the effects of exactly one and a mean of one particle, the single cell irradiation allows a more accurate extrapolation from high to low doses.

While the majority of radiation-induced mutants showed deletions of varying sizes (11, 28, 29), there is recent evidence to indicate that the percentage of multilocus deletions is dose- and LET- dependent as well (11, 12). As shown in Fig. 4, the majority of spontaneous S1 mutants (88%) have lost only the S1 marker, presumably as a result of either a point mutation or a small deletion involving the MIC1 gene. These findings are consistent with our previous studies when only a limited number of marker genes were used (7, 11). However, due to the distance of the two nearest marker gene (WT and CAT) from the M1C1 gene, mutants that are classified as $S1^-$ only have the potential of losing up to a 3.3-Mb region of the human chromosome 11. As the number of particle traversals increase, the relative proportion of mutants losing only the S1 marker decreased from 75% among mutants induced by a single particle to 4% among those induced by eight α particles. Because the mutant fraction induced by a single α particle was two times higher than the spontaneous background, it is likely that one out of three mutants analyzed could be of spontaneous origin. Nevertheless, the mutant spectrum from the single-particle group was not significantly different from that of spontaneous. This data suggest that most mutants induced by a single particle harbored deletions that were smaller than those traversed by multiple particles. These results further confirmed our previous finding that the relative proportion of mutants with large gene/chromosomal deletions is dose-dependent (11, 12).

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RADIATION STANDARDS FOR HOT PARTICLES

A REPORT ON THE INADEQUACY OF EXISTING RADIATION PROTECTION STANDARDS RELATED TO INTERNAL EXPOSURE OF MAN TO INSOLUBLE PARTICLES OF PLUTONIUM AND OTHER ALPHA–EMITTING HOT PARTICLES.

FEBRUARY 14, 1974

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ERRATA

Radiation Standards for Hot Particles

by

Arthur R. Tamplin and Thomas B. Cochran

Page 36, footnote in Table V:			
	line 8	--	change "low" to "long"
	line 11	--	change "uCi" to "pCi"
	line 13	--	change "uCi" to "pCi"
Page 42, line 17		--	change "reduct on" to "reduction"
Page 50, line 5		--	change "(MPCS)" to "(MPSC)"
Page 3, footnote 2, line 3		--	change "Actnide" to "Actinide"

TABLE OF CONTENTS

I. Introduction

This report is written in support of a petition by the Natural Resources Defense Council to the Environmental Protection Agency (EPA) and the Atomic Energy Commission (AEC) requesting (1) a reduction of the existing radiation protection standards applicable to the internal exposure of man to insoluble alpha-emitting hot particles and (2) the establishment, with respect to such materials, of standards governing the maximum permissible concentrations in air and maximum permissible surface contamination levels in unrestricted areas.

Before proposing modifications to existing radiation protection standards related to plutonium exposure[1], we review in the following section the gravity of the public health concern as plutonium becomes a principal article of commerce in the nuclear power industry.

1/ While much of this report focuses narrowly on plutonium-239, the discussion is, nevertheless, germaine to all radionuclides [illegible] definition of specific activity and other technical terms in this report are given in the Glossary). The justification for focusing on plutonium has been aptly stated by the International Commission on Radiological Protection (ICRP): "the emphasis on plutonium is clearly a reflection of the general consensus that, in terms of amount available, projected usage, extent of anticipated accidental human exposure, and radiotoxicity, plutonium is the most formidable radionuclide in the periodic table." [ICRP Publication 19, "The Metabolism of Compounds of Plutonium and Other Actnides," Pergamon Press, 1972, p.1.]

This is followed in Section III by a review of the specific radiation protection regulations that are in force in the United States today and which are at issue. This section focuses on the existing guidelines for Pu-239, but it is to be understood that, in this and subsequent sections, it should be applied to all alpha-emitting radionuclides that meet the hot particle criteria developed in this report. Before reading Section III, those unfamiliar with the national and international organizations which have primary responsibility for recommending or establishing radiation protection standards, may find it useful to read Appendix A, where these organizations and their authority are reviewed.

Section IV presents assumptions inherent in the existing radiation protection standards and identifies those assumptions that are inappropriate when applied to insoluble alpha-emitting particulates. The biological data which demonstrate that these assumptions are inappropriate when applied to hot particles are discussed in Section V.

Utilizing the data presented in Section V, the criteria that define a hot particle are developed in Section VI. Recommendations for exposure standards for hot particles are then developed in Section VII and summarized in Section VIII.

II. Plutonium Use and Public Health

Plutonium occurs in nature, although in such small amounts that it does not constitute a practical source of the element[2]. Plutonium is bred in nuclear reactors by the capture of neutrons in uranium-238. To date, the nuclear weapons program has been the principal source of plutonium. However, it is anticipated that the commercial nuclear power industry will become the principal source of this material within the next two decades. In today's commercial reactors plutonium is produced as a by-product in the production of electricity.

As a result of the growth of the nuclear power industry, the AEC estimates that the total cumulative production of plutonium in the commercial sector of the United States will be some 4.5 million kilograms by the year 2000[3]. Since plutonium, like uranium, can serve as a reactor fuel, both are recovered from spent reactor fuel in anticipation that they will be recycled. The reactor together with the variety

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2/ The ratio of the concentrations of plutonium-239 to uranium in ores varies from 4×10^{-13} to 1.5×10^{-11}. Katz, J.J., Chapter VI, The Chemistry of Actnide Elements, Methuen and Co., Ltd., London, 1957, pp. 239-330.

3/ Environmental Statement, Liquid Metal Fast Breeder Reactor Demonstration Plant, USAEC, WASH-1509, April 1972, p. 149.

of support activities required both to provide raw fuel and to recover and recycle the uranium and plutonium make up what is known as the nuclear fuel cycle. The AEC has projected that over 4 million megawatts of nuclear capacity will be installed between 1970 and 2020[4]. Over the lifetimes of these plants this installed capacity could result in a cumulative flow of approximately 200 million kilograms of plutonium through the nuclear fuel cycle.

In today's commercial reactors the plutonium is in oxide form, PuO_2[5]. At various facilities in the nuclear fuel cycle, aerosols of PuO_2 are released to the environment on a routine basis. In addition, there are numerous points in the fuel cycle where accidents, particularly those associated with fire or explosions, can release significant amounts of PuO_2 as aerosols that can be inhaled by man.

These small aerosol particles of PuO_2 are highly radioactive. An appreciable fraction of the inhaled PuO_2 particles are trapped in the deep respiratory tissue of the lung, where, because they are insoluble in human tissue,

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4/ Updated (1970) Cost-Benefit Analysis of the U. S. Breeder Reactor Program, USAEC, WASH-1184, January 1972, p. 34. Four million megawatts (Mw) corresponds to 4000 nominal-size nuclear reactors -- 1000 Mw each.

5/ Some advanced reactors of the future may use fuel in carbide and nitride, rather than oxide, form.

they can remain for long periods of time and deliver a very intense radiation dose to the surrounding lung tissue.

Plutonium is one of the most potent cancer producing agents known to man. A machinist of plutonium metal carried 0.08 micrograms of plutonium-239 imbedded at the site of the puncture wound in the palm of his hand. Within the four year period before it was excized, it produced a nodule which displayed precancerous changes[6]. There is little doubt from experimental animal studies that inhaled plutonium is one of the most potent respiratory carcinogens known. There is experimental and observed evidence that plutonium concentrations in the lungs of dogs as low as 0.2 microcuries (3 micrograms of plutonium-239) produce cancer[7]. Hence, the flow of 200 million kilograms of plutonium represents a flow of over 10^{17} cancer doses, a staggering number which, as will be demonstrated subsequently, may be an underestimate of the cancer doses by several orders of magnitude.

The persistance of this toxic material, once lost to [illegible] Roughly two-thirds of the plutonium flowing in the nuclear

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6/ Lushbauch, C.C. and J. Langham, "A Dermal Lesion from Implanted Plutonium," Archives of Dermatology, 86, October 1962, pp. 121-124.

7/ There are 0.061 curies per gram of plutonium-239. Two-tenths of a microcurie of plutonium-238 would have a mass of only 0.01 micrograms since plutonium-238 has a much higher specific activity, 17.47 curies per gram.

fuel cycle will be plutonium-239 which has a 24,400 year half-life. In other words, in 240,000 years the inventory of this hazardous material would be reduced by only a factor of 1000 due to natural radioactive decay. This material must be isolated from the environment in perpetuity.

III. Existing Standards for Plutonium Exposure

Radiation exposure standards have been established because radiation is known to produce cancer and genetic mutations in individuals irradiated. The mutations can in turn cause genetic defects in subsequent generations. The intent of the exposure standards is to limit this biological damage. The magnitude of the biological effect has been shown to be related to the radiation dose. The higher the dose the greater the effect. Therefore, the primary radiation exposure standard is one that limits the radiation dose. This primary standard is generally referred to as the maximum permissible dose and is given in units of rem/yr. We shall discuss the nature of this unit subsequently.

An individual can be exposed to radiation from sources that are external to his body as, for example, an X-ray machine or from radionuclides which emit X-ray like radiation deposited on the ground (this occurred with fallout from nuclear weapon tests). Alternately, an individual can be irradiated by internal sources; that is, by radionuclides incorporated in body tissues. These radionuclides gain entrance into the body through inhalation or through contaminated food or water. Once inside they behave like their non-radioactive counterparts. Radioactive iodine, for example, accumulates in the thyroid gland in the same fashion as stable iodine, and radioactive strontium or calcium accumulate in the bone similar to their naturally occurring non-radioactive counterparts. The radioactive iodine will thus deliver a dosage to the thyroid gland that is many times larger than that to the other organs or to the whole body, and the radioactive strontium and calcium will mainly irradiate the bone.

Because of the uneven distribution of radionuclides in the body organs, radiation exposure standards have been developed not just for the whole body, but also for individual organs. In this report we will be referring to the maximum permissible whole body and lung doses.

Largely as a matter of convenience, secondary or derived radiation standards have been developed. These secondary standards, which limit radionuclide concentrations or organ burdens, are often more easily employed than the primary dose standards. We shall examine two secondary standards in this report; the maximum permissible lung burden (MPLB) and the maximum permissible concentration in air (MPC_a). The MPLB is the total amount of a given radionuclide in the lung of an average size man that will result in the lung being irradiated at the maximum permissible lung dose (MPLD). The MPC_a is the concentration in air that will result in an average adult male obtaining a MPLB and hence a MPLD by breathing the air.

It is important to recognize that the MPLD is the primary standard; it applies to all radionuclides and radiation sources. The MPLB and the MPC_a are <u>derived standards and are specific for a radionuclide</u>. These derived standards are related to the biological properties of a radionuclide and to the form of radiation it emits.

Table I lists the existing exposure standards for employees of the nuclear industry that apply to Pu-239 in insoluble form. The MPLD of 15 rem/yr is included in the recommendations of the International Commission on Radiological Protection (ICRP)[8], the National Council on Radiation Protection and Measurements (NCRP)[9], and the Federal Radiation Council

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8/ ICRP Publication 9, Recommendations of the International Commission on Radiological Protection (Adopted September 17, 1966), Pergamon Press, New York, 1966, p. 14.

9/ NCRP Report No. 39, Basic Radiation Protection Criteria, NCRP Publications, Washington, D. C., Jan. 15, 1971, p. 106.

(FRC)[10]. The MPC_a is included in the ICRP recommendations[11] and is also an AEC radiation standard[12]. Of the standards in Table I only the MPC_a is designated in the AEC regulations. However, this MPC_a corresponds to that tabulated in ICRP Publication 2[13] which is derived on the basis of the MPLD listed in Table I. The MPLB is also derived on the basis of the MPLD[14]. The MPLB is not included in either the recommendations of ICRP, NCRP, the guidelines of FRC, or the AEC regulations. In summary, in Table I the MPC_a (designated in AEC regulations) is consistant with the MPLD and MPLB. In Table I the MPLD applies to all forms of ionizing radiation. The MPLB and MPC_a apply specifically to Pu-239 in insoluble form[15].

10/ FRC Report No. 1, Op. cit., p. 38. The FRC has been abolished and its duties transferred to EPA.

11/ ICRP Publication 2, Report of Committee II on Permissible Dose for Internal Radiation, Pergamon Press, New York, 1960. [Appeared in Health Physics, Vol. 3, Pergamon Press, June 1960.]

12/ 10 CFR 20, Appendix B.

13/ ICRP Publication 2, Op. cit.

14/ Mann, J.R. and A.R. Kirchner, "Evaluation of Lung Burden Following Acute Inhalation of Highly Insoluble PuO_2," Health Physics, Vol. 13, 1967, pp. 877-882.

15/ The MPLB could apply to most other alpha-emitting radionuclides with long half-lives, since the alpha particle energies do not differ appreciably from the Pu-239 alpha energy.

TABLE I

Existing Occupational Exposure Guidelines

that Apply to Pu-239 in Insoluble Form*

MPLD	(ICRP, NCRP, FRC)	15 rem/yr
MPLB		0.016 uCi
MPC_a	(ICRP, AEC)	4×10^{-11} uCi/ml

*Note: See Glossary for definitions of symbols.

The exposure guidelines for Pu-239 that apply to non-occupational exposure of the general public are tabulated in Table II. Two guidelines are applied here. One is for the limiting exposure to an individual and the other is for the average exposure of a population sample. These two guidelines differ by a factor of 3. The ICRP recommendations include only the guidelines for individuals. The MPLD values within the parentheses in Table II correspond to the latest recommendation of the NCRP[16]. These latest recommendations of the NCRP have not, at this time, been incorporated into either the AEC or EPA regulations.

16/ NCRP Report No. 39, *Op. cit.*, p. 95.

TABLE II

Existing Exposure Guidelines for Non-Occupational Exposure that Apply to Pu-239 in Insoluble Form*

	Individual	Population Average
MPLD (ICRP, NCRP, FRC)	1.5 (0.5) rem/yr	0.5 (0.17) rem/yr
MPLB	0.0016 (0.0005) uCi	0.0005 (0.00017) uCi
MPC_a (ICRP, AEC)	10^{-12} ($3x10^{-13}$) uCi/ml	$3x10^{-13}$ (10^{-13}) uCi/ml

* The MPLD values in parentheses refer to the latest recommendations of the NCRP. The MPLB and MPC_a values in parentheses correspond to the new NCRP dose recommendations.

IV. Calculating the Dose Due to Insoluble Alpha-Emitters

The purpose of this section is to examine the assumptions in the radiation standards above that are inappropriate when applied to insoluble alpha-emitting particulates such as aerosols of PuO_2. The assumptions are [illegible] review of basic definitions of radiation dose and the factors used to calculate the dose.

A. The Dose Equivalent

When an X-ray or the radiation emitted by a radionuclide passes through tissue it transfers energy to the cells in these tissues. This energy produces chemical changes in the molecule of the cells; for example, such a chemical change could be a mutation in a gene. The radiation dose is actually a measure of the energy transferred to or absorbed by the tissue. The basic unit of dose is the rad (one rad represents the absorption of 100 ergs of energy per gram of material).

In addition to X-rays, radionuclides emit gamma rays (high energy X-rays), beta particles (electrons), and alpha particles (helium nuclei). In radiobiological experiments, it was determined that, while these various types of radiation produced the same biological effects, such as cancer, the magnitude of the effect was not the same per rad. For example, it was found that 100 rad of alpha radiation would produce roughly 10 times as many cancers as 100 rad of X-rays. Moreover, it was found that because of the special way in which Pu-239 deposits in the bone, its alpha particles were 5 times more effective in producing bone cancer than the alpha particles from radium[17]. To account for these differences in the magnitude of the observed effects at the same absorbed dose in rad, the maximum permissible dose limits are given in rem rather than rad.

The MPLD is given in rem in Tables I and II. The

17/ ICRP Publication 11, "A Review of the Radiosensitivity of the Tissues in Bone," Pergamon Press, New York, N. Y., 1967, p. 21.

rem is the unit of Dose Equivalent (DE)[18]. The DE is obtained by multiplying the absorbed dose in rad by modifying factors to correct for these observed differences in the magnitude of the effect. As a consequence, the magnitude of the effect will be the same for a given DE regardless of the nature of the radiation or the manner of radiation.

B. Modifying Factors

At the present time, two modifying factors are employed. One is the Quality Factor (QF) which accounts for differences in producing biological effects among various forms of radiation. The other is the Distribution Factor (DF) which accounts for the modification of the biological effects when a radionuclide is nonuniformly distributed in an organ. For example, the DE for X-ray to bone tissue is determined by using QF=1 and DF=1, while that for Pu-239 in the bone is determined by using a QF=10 (to account for the greater effectiveness of alpha particle irradiation) and a DF=5 (to account for the peculiar distribution of Pu in the bone)[19].

A DE of 50 rem from X-rays or Pu-239 would [illegible] number of cancers in bone but the absorbed dose from the X-rays would be 50 rad while that from Pu-239 would be only 1 rad.

18/ NCRP Report No. 39, Op. cit., p. 81.

19/ ICRP Publication 11, Op. cit., p. 21.

In obtaining the derived values in Tables I and II, MPLB and MPC_a for Pu-239, a QF=10 was employed. This QF implies, as mentioned above, that the particles of Pu-239, which emit alpha particle radiation, are 10 times more effective in inducing cancer than X-rays. Although the irradiation of tissue by insoluble plutonium particles is highly nonuniform, no DF value has been assigned to these particles and hence, a DF=1 was employed in determining the derived values in Tables I and II. Ideally, the DF should be determined by the ratio of the observed effects in an organ following uniform and nonuniform radiation of the tissue with the same radionuclide; for example:

$$DF = \frac{\text{Number of cancers (nonuniform irradiation)}}{\text{Number of cancers (uniform irradiation)}}$$

Since direct experimental data are not available, it is necessary to derive the DF for insoluble Pu-239 particles from collateral data. In a subsequent section, we shall present the biological evidence that strongly suggests that a DF=1 grossly underestimates the DE for insoluble particulates of Pu-239 and, consequently, that the derived standards, MPLB and MPC_a for this radionuclide, are greatly in error[20]. In fact, it will be shown that the biological data strongly suggests that for such particles one should use a DF=115,000.

20/ This applies as well to other alpha-emitting actnides in insoluble particulate form.

Before turning to the biological data it is appropriate to discuss first the radiation field around a particle of PuO_2 and thereby define the fundamental questions that need to be answered by the collateral data from radiobiological studies.

The unique form of tissue irradiation displayed by insoluble particles of Pu-239 occurs because, when Pu-239 decays, it emits an alpha particle with an energy of 5.1 MeV. This particle has a range (produces biological damage) of only some 40-45 u (0.004 cm) in human tissue. In other words, a Pu-239 particle in tissue will only irradiate a volume of tissue enclosed in a sphere of 45 u radius. As one moves inward from the surface of this sphere, the radiation intensity increases geometrically. About half of the alpha particle energy is dissipated at 20 u (that is, with a volume that is 1/8 the total volume). This means that the average dose delivered in the first 20 u is 8 times that delivered in the remaining 20 u. The first column of Table III describes the radiation field around such a particle in soft tissue; [illegible]. Since the lung is a spongy tissue with a large air volume, the range of alpha particles is longer in the lung and consequently the mass of irradiated tissue is larger. Professor Donald Geesaman made a detailed analysis of plutonium particle irradiation of deep respiratory tissue[21]. The last two columns in Table III describe the radiation field around such a particle in the lung using Geesaman's lung model[22]. The dose rate to the entire organ is given in column 2 of Table III for comparison. From Table III it is significant to note that with an assumed DF=1, the lung dose from the same particle varies by more than 8 orders of magnitude depending on whether one averages the dose over the entire lung or calculates it on the basis of the tissue exposed.

TABLE III

Radiation Dose Rate Due to a Pu-239 Particle

(1 u in diameter, 0.28 pCi[23])

	Soft Tissue Irradiated[24]	Lung: Entire Organ	Lung: Tissue Irradiated[25]	Lung: Closest 20 Alveoli[26]
Mass of Tissue	0.4 ug	1000 g[27]	65 ug	19 ug
Dose Rate (rem/yr)	730,000	0.0003	4000	11,000

21/ Geesaman, Donald P., An Analysis of the Carcinogenic Risk from an Insoluble Alpha-Emitting Aerosol Deposited in Deep Respiratory Tissue, UCRL-50387 and UCRL-50387 Addendum, Lawrence Livermore Laboratory, Livermore, Calif., 1968.

It would take 53,000 particles of the size illustrated in Table III to reach the MPLB of 0.016 uCi which results in 15 rem/yr to the entire (1000 g) lung. However, as Table III indicates, these particles would irradiate only 3.4 g of this 1000 g to the lung, but at a dose rate of 4000 rem/yr[28]. Thus, as Table III indicates, these particles result in an intense but highly localized irradiation. A fundamental question is, then: is this intense but localized irradiation more or less carcinogenic than uniform irradiation? Alternatively, is the DF for this particular form of irradiation equal to, greater than, or less than one? In the remainder of this section, we review the guidance, or more appropriately lack of guidance, for dealing with this hot particle problem.

22/ Geesaman, Donald P., UCRL-50387, pp. 8, 15.

23/ Langham, Wright H., The Problem of Large Area Plutonium Contamination, U. S. Dept. of H. E. W., Public Health Services, Seminar Paper No. 002, Dec. 6, 1968, p. 7.

24/ [illegible] Negligible Consequence," Nuclear News, June 1971, p. 71.

25/ Geesaman, Donald P., UCRL-50387, pp. 8, 15. Based on Geesaman's model for a lung at one-half maximum inflation. Geesaman estimates a total of 68 alveoli at risk, each $8x10^{-6}$ cm^3 in volume, and deep respiratory zone tissue density of 0.12 g/cm^3.

26/ See footnote 23.

27/ Based on a lung mass of a standard man = 1000 g.

28/ This assumes that the radiation field of the 53,000 particles do not overlap.

C. The Hot Particle Problem

It is important to recognize that the ICRP has given no guidance with respect to nonuniform irradiation of the lung by insoluble alpha-emitters such as insoluble plutonium particles. In its Publication 9, the ICRP states:

> ...In the meantime there is no clear evidence to show whether, with a given mean absorbed dose, the biological risk associated with a non-homogeneous distribution is greater or less than the risk resulting from a more diffuse distribution of that dose in the lung.[29]

In effect, the ICRP is saying that there is no guidance as to the risk for non-homogeneous exposure in the lung, hence the MPC_a and the MPLB are meaningless for insoluble plutonium particles.

The NCRP offers the following and similar statement with respect to these particles:

> (210) The NCRP has arbitrarily used 10 percent of the volume of the organ as the significant volume for irradiation of the gonads. There are some cases in which choice of a significant volume or area is virtually meaningless. For example, if a single particle of radioactive material fixed in either lung or lymph node may be carcinogenic, the averaging of dose either over the lung or even over one cubic centimeter may have little to do with this case.[30]

This hot particle problem is also well recognized in the biological community. The following is extracted from a

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29/ ICRP Publication 9, Op. cit., p. 4.

30/ NCRP Report No. 39, Op. cit., pp. 79-80.

paper by Professor Donald P. Geesaman:

> So there is a hot particle problem with plutonium in the lung, and the hot particle problem is not understood, and there is no guidance as to the risk. I don't think there is any controversy about that. Let me quote to you from Dr. K. Z. Morgan's testimony in January of this year before the Joint Committee on Atomic Energy, U.S. Congress. [a] Dr. K. Z. Morgan is one of the United States' two members to the main Committee of the International Commission on Radiological Protection; he has been a member of the committee longer than anyone; and he is director of Health Physics Division at Oak Ridge National Laboratory. I quote: "There are many things about radiation exposure we do not understand, and there will continue to be uncertainties until health physics can provide a coherent theory of radiation damage. This is why some of the basic research studies of the USAEC are so important. D. P. Geesaman and Tamplin have pointed out recently the problems of plutonium-239 particles and the uncertainty of the risk to a man who carries such a particle of high specific activity in his lungs." At the same hearing, in response to the committee's inquiry about priorities in basic research on the biological effects of radiation, Dr. M. Eisenbud, then Director of the New York City Environmental Protection Administration, in part replied, "For some reason or other the particle problem has not come upon us in quite a little while, but it probably will one of these days. We are not much further along on the basic question of whether a given amount of energy delivered to a progressively smaller and smaller volume of tissue is better or worse for the recipient. This is another way of asking the question of how you calculate the dose when you inhale a single particle. [illegible] correct; the problem has come up again.

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[a] Morgan, K. Z., "Radiation Standards for Reactor Siting," in Environmental Effects of Producing Electrical Power Phase 2. Testimony presented at Hearings before the Joint Committee on Atomic Energy, 91st Congress, 1970. Washington, D. C., U. S. Government Printing Office.

[b] Eisenbud, M. Panel Discussion. In: Environmental Effects of Producing Electrical Power, Phase 2. Testimony presented at Hearings before the Joint Committee on Atomic Energy, 91st Congress, 1970. Washington, D. C., U. S. Government Printing Office.

In the context of his comment it is interesting to refer to the National Academy of Sciences, National Research Council report of 1961 on the Effects of Inhaled Radioactive Particles. [c] The first sentence reads, "The potential hazard due to airborne radioactive particulates is probably the least understood of the hazards associated with atomic weapons tests, production of radioelements, and the expanding use of nuclear energy for power production." A decade later that statement is still valid. Finally let me quote Drs. Sanders, Thompson, and Bair from a paper given by them last October. [d] Dr. Bair and his colleagues have done the most relevant plutonium oxide inhalation experiments. "Nonuniform irradiation of the lung from deposited radioactive particulates is clearly more carcinogenic than uniform exposure (on a total-lung dose basis), and alpha-irradiation is more carcinogenic than beta-irradiation. The doses required for a substantial tumor incidence, are very high, however, if measured in proximity to the particle; and, again, there are no data to establish the low-incidence end of a dose-effect curve. And there is no general theory, or data on which to base a theory, which would permit extrapolation of the high incidence portion of the curve into the low incidence region." I agree and I suggest that in such a circumstance it is appropriate to view the standards with extreme caution.[31]

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[c] U. S. NAS-NRC Subcommittee, Effects of Inhaled Radioactive Particles. Report of the Subcommittee on Inhalation Hazards. Committee on Pathologic Effects of Atomic Radiation. National Academy of Sciences - National Research Council, Washington, D. C. 1961. Publication 848. NAS-NRC/PUB-848, 1961.

[d] Sanders, C.L., R.C. Thompson, and W.J. Bair, "Lung Cancer: Dose Response Studies with Radionuclides." In: Inhalation Carcinogenesis. Proceedings of a Biology Division, Oak Ridge National Laboratory, conference held in Gatlinburg, Tennessee, October 8-11, 1969. M.G. Hanna, Jr., P. Nettesheim, and J.R. Gilbert, eds., U. S. Atomic Energy Commission Symposium Series 18, 1970. pp. 285-303. (CONF-691001).

31/ Geesaman, Donald P., "Plutonium and Public Health," Lawrence Livermore Laboratory, Calif., GT-121-70, April 19, 1970, reproduced in Underground Uses of Nuclear Energy, Part 2, Hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works, U. S. Senate, 91st Congress, 2nd Session, August 5, 1970, pp. 1530-1532.

To these comments, referenced by Geesaman, can be added the comments of Dr. A. B. Long:

> ". . . there is an urgent need to dispell the sense of security and certainty that the present limits for the maximum permissible lung burden and the maximum permissible air concentration bring . . . the public should be informed of the uncertainties that exist in these limits."[32]

V. Biological Data Related to Cancer Risk from Insoluble Plutonium Particles

We have shown that insoluble alpha-emitting particles result in intense but localized radiation. They can irradiate at very high doses without being organism- or organ fatal. We said that the available biological data strongly suggests that a DF=1 grossly underestimates the DE for insoluble particulates of Pu-239, and consequently, the derived standards MPLB and MPC_a for this radionuclide are greatly in error. We now turn to the experiments involving cancer induction by intense local exposure, since these are especially relevant in judging whether or not insoluble alpha-emitting particles constitute a unique risk. Geesaman has collected and analyzed the pertinent experiments, and what follows

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32/ Long, A.B., Op. cit., p. 73.

is essentially a review of his analysis[33], which has become known as the "Geesaman hypothesis."

A The Geesaman Hypothesis

Dr. Roy E. Albert and co-workers performed a number of experiments on the induction of cancer in rat skin[34-36]. Albert's study of radiation-induced carcinoma in rat skin gives some quantitative description of a high-dose carcinogenic situation. A skin area of 24 cm^2 was exposed to electron radiation with various depths of maximum penetration. The dose response curves are reproduced in Figure 1. In all cases the response at sufficiently high doses (1000-3000 rem) was large, ~1-5 tumors per rat by 80 weeks post exposure. It was noted by Albert that when the dose was normalized to a skin depth of 0.27 milimeters, the three response curves became continuous (See Figure 2). Since this

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33/ Geesaman, D.P., UCRL-50387 Addendum, Op. cit.

34/ Albert, R.E., F.J. Burns, and R.D. Heimbach, "The effect of penetration depth of electron radiation on skin tumor formation in the rat," Radiation Res. 30, 1967, pp. 515-524.

35/ Albert, R.E., F.J. Burns, and R.D. Heimbach, "Skin damage and tumor formation from grid and sieve patterns of electron and beta radiation in the rat," Radiation Res. 30, 1967, pp. 525-540.

36/ Albert, R.E., F.J. Burns, and R.D. Heimbach, "The association between chronic radiation damage of the hair follicles and tumor formation in the rat," Radiation Res. 30, 1967, pp. 590-599.

depth is near the base of the hair follicle which comprises the deepest reservoir of epithelial cells of the germinal layer, it was suggestive that this might be a critical region in the observed carcinogenesis. The suggestion gained significance from the observations that most of the tumors are similar to hair follicles, and that in the non-ulcerogenic dose range the number of tumors per rat was in nearly constant ratio (1/2000-1/4000) with the number of atrophied hair follicles. Thus the carcinogenesis in this experiment was remarkably correlated with the dose to and specific damage of a particular skin structure. When exposures were made with stripe and sieve patterns of roughly 1 mm scale, geometrical effects were observed: most notably the cancer induction in the sieve geometry was suppressed at doses of 1700 rad but not at doses of 2300 rad. The reduction, however, was again consistent with the reduction in damage as characterized by atrophied hair follicles.

To summarize this important experiment, a high incidence [illegible] and the carcinogenesis was proportional to the damage or disordering of a critical architectural unit of the tissue, the hair follicles.

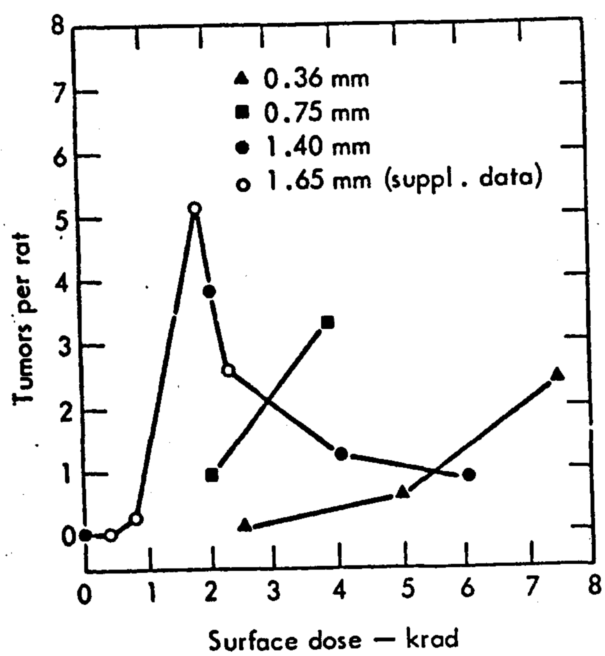

Fig. 1. Tumor incidence with respect to surface dose at 80 weeks for three penetration depths of electrons.

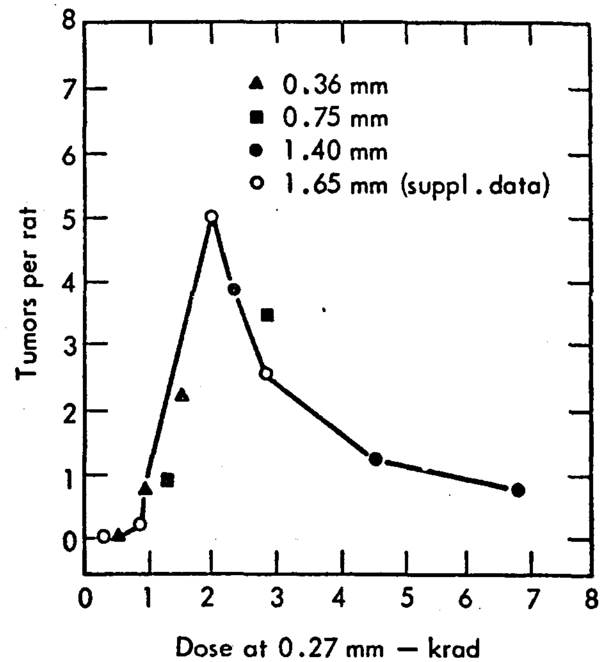

Fig. 2. Tumor incidence with respect to the dose at a depth of 0.27 mm in the skin at 80 weeks for three penetration depths of electrons.

Source of Figures: Albert, R. E., et al., <u>Radiation Res.</u> <u>30</u>, <u>Op. cit.</u>, pp. 515-524, Figures 5 and 7; reproduced in Geesaman, UCRL-50387 Addendum, <u>Op. cit.</u>, p. 2.

Others have observed carcinomas and sarcomas in rats and mice after intense exposure of the skin to ionizing radiation[37-43]. Cancer induction is generally a frequent event in these experiments. Even at elevated doses, such as 12,000 rad of 1 MeV electrons, Boag and Glucksmann induced ~5 sarcomas/100 cm^2 in rats[37].

A few results for rabbits, sheep, and swine were obtained at Hanford[38-41]. Despite the small number of animals

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37/ Withers, H.R., "The dose-survival relationship for irradiation of epithelial cells of mouse skin," Brit. J. Radiol. 40, 1967, pp. 187-194.

38/ Hulse, E.V., "Tumours of the skin of mice and other delayed effects of external beta irradiation of mice using ^{90}Sr and ^{32}P," Brit. J. Cancer 16, 1962, pp. 72-86.

39/ Boag, J.W. and A. Glucksmann, "Production of cancers in rats by the local application of Beta-rays and of chemical carcinogens," Progress in Radiobiology, J.S. Mitchell, B.E. Holmes, and C.L. Smith, eds. Proceedings of the Fourth International Conference on Radiobiology held in Cambridge, 14-17 August 1955. Edinburgh, Oliver and Boyd, 1956, pp. 476-479.

40/ George, L.A. and L.K. Bustad, "Gross effects of beta rays on the skin," Hanford Atomic Products Operation, Biology Research Annual Report for [illegible]

41/ George, L.A. II, R.L. Pershing, S. Marks, and L.K. Bustad, "Cutaneous fibrosarcoma in a rabbit following beta irradiation," Hanford Atomic Products Operation, Biology Research Annual Report for 1959, HW-65500, 1960, pp. 68-69.

42/ Ragan, H.A., W.J. Clarke and L.K. Bustad, "Late effects of skin irradiation," Battelle-Northwest Laboratory Annual Report for 1965 in the Biological Sciences, BNWL-280, 1956,pp. 13-

43/ Karagianes, M.T., E.B. Howard and J.L. Palotay, Battelle-Northwest Laboratory Annual Report for 1967 to the USAEC Division of Biology and Medicine, Vol. I, Biological Sciences, BNWL-714, 1968, pp. 1.10-1.11

involved, surface doses of 16,000 rad from a P^{32} plaque induced an average of 1 cancer/animal which is indicative that larger mammals are similarly susceptible to skin cancer after intense radiation insult. Again, these gross observations demonstrate that enhanced tumor incidence does occur after very high doses.

Intense localized radiation of the subcutaneous and intraperitoneal tissue of animals by Pu-239 has also been shown to cause a high frequency of cancer induction[43-45].

Now what are these experiments trying to tell us? Certainly a reasonable interpretation of these experimental results is: when a critical architectural unit of a tissue (e.g., a hair follicle) is irradiated at a sufficiently high dosage, the chance of it becoming cancerous is approximately 10^{-3} to 10^{-4}. This has become known as the "Geesaman hypothesis."

B Related Human Experience

Since the above experiments relate to cancer induction in animals, it is pertinent to ask whether man is more or less

44/ Sanders, C.L. and T.A. Jackson, "Induction of Mesotheliomas and Sarcomas From 'Hot Spots' of PuO_2 Activity," Health Physics, Vol. 22, No. 6, June 1972, pp. 755-759.

45/ Lisco, Herman, et al, "Carcinogenic Properties of Radioactive Fission Products and of Plutonium," Radiology, Vol. 49, No. 3, Sept. 1947, pp. 361-363.

sensitive to such intense localized radiation. C. C. Lushbaugh reported on a lesion that developed as the result of residual Pu-239 from a puncture wound[46]. The particle contained 0.08 ug (0.005 uCi) of Pu-239. Commenting on the histological examination of the lesion, the authors state, "The autoradiographs showed precise confinement of alpha-tracks to the area of maximum damage and their penetration into the basal areas of the epidermis, where epithelial changes typical of ionizing radiation exposure were present. The cause and effect relationship of these findings, therefore, seemed obvious. Although the lesion was minute, the changes in it were severe. Their similarity to known precancerous epidermal cytologic changes, of course, raised the question of the ultimate fate of such a lesion should it be allowed to exist without surgical intervention..." In this case, less than 0.1 ug of Pu-239 produced precancerous changes in human tissue. The dose to the surrounding tissue was very intense. There is every reason to believe that a smaller quantity of Pu-239 would have [illegible] changes. This precancerous lesion indicates that a single Pu-239 particle irradiates a significant (critical) volume of tissue and is capable of inducing cancer. The Lushbaugh study was

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46/ Lushbaugh, C.C. and J. Langham, *Op. cit.*, pp. 461-464.

published in 1962. At that time the total number of puncture wounds in man was less than 1,000[47]. The treatment of such wounds was excision so that the total number of wounds displaying residual contamination by plutonium particles was certainly less than 1,000. Therefore, this wound data would suggest that insoluble plutonium particles could offer a risk of cancer induction in man that is even greater than 1/1000 per particle. In other words, when a critical unit of tissue is irradiated, man may be more susceptible to cancer than the Albert data as analyzed by Geesaman would suggest.

A second case of plutonium particle induced cancer is that of Mr. Edward Gleason. He was not associated with the nuclear industry but was a freight handler who unloaded, rotated and reloaded a crate that was contaminated by the leaking carboy of Pu-239 solution which it contained. He subsequently developed an infiltrating soft tissue sarcoma on the left palm which eventually resulted in his death. Although this case is not as clear cut as the case of the plutonium worker, there is an overwhelming medical probability that his cancer was induced by plutonium. Mr. Gleason's unfortunate contact with Pu-239 lead to a lawsuit,

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47/ Vanderbeck, J.W., "Plutonium in Puncture Wounds," HW-66172, Hanford Laboratories Operation, July 25, 1960.

Edward Gleason, et al v. NUMEC. This suit was eventually settled out-of-court. A discussion of the evidence in this case by one of the authors is presented in the Appendix B of this report.

These two cases, drawn from the relatively small number of individuals so contaminated, strongly suggest that Pu-239 particles offer a unique carcinogenic risk. They indicate that a single particle is capable of delivering an intense radiation dose to a critical volume of tissue and that this disruptively irradiated tissue, like an atrophied hair follicle, has a high probability (maybe as high as 1/1000) of becoming cancerous.

C. Related Lung Experiments

The skin experiments with animals are remarkable in that a highly disruptive dose of radiation to a small portion of repairable mammalian tissue produced frequent carcinogenesis. The chance of producing one cancer per animal is essentially unity. It is reasonable to expect that a comparable development could occur in lung tissue. While a number of radioactive substances have been used to induce lung cancers in mice and rats[48], it is difficult to derive any characterization of carcinogenesis from these experiments.

48/ Cember, H., "Radiogenic lung cancer," Progress in Experimental Tumor Research, F. Homburger, ed. New York, Hafner Publishing Company, Inc., Vol. 4, 1964, pp. 251-303.

The work of Laskin, _et al_, though not specifically involving deep respiratory tissue, does demonstrate a source intensity-response curve for lung tissue[49]. A Ru-106 cylindrical source was implanted in the bronchi of rats, and cancers were observed to arise from the bronchial epithelium. The response curve indicates a substantial response (7 percent) even at 0.008 uCi burden, and a slow, approximately logarithmic increase of tumor incidence over three orders of magnitude in the source intensity. Corresponding first-year doses to adjacent bronchial epithelium varied from 10^3 rad to 10^6 rad[50]. Animals were followed until death and it was observed that the tumor incidence generally increased with the dose accumulated at death. The lowest accumulated dose associated with a cancer was 1400 rad. For an accumulated dose of the order of 10^6 rad the incidence was approximately two-thirds. Cember fortified glass beads (0.3 u diameter) with several microcuries of Sr-90, and single beads were implanted in the lungs of rats. Tumors were observed in 7 of 23 animals. In a second experiment Cember exposed rat lungs to Ce-144 particles. For

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49/ Laskin, S., M. Kuschner, N. Nelson, B. Altshuler, J.H. Harley and M. Daniels, "Carcinoma of the lung in rats exposed to the beta-radiation of intra-bronchial ruthenium^{106} pellets. 1. Dose response relationships," _J. Natl. Cancer Inst. 31_, 1963, pp. 219-231.

50/ Altshuler, B., "Dosimetry from a Ru^{106}-coated platinum pellet," _Radiation Res. 9_, 1958, pp. 626-632.

a burden range of 0.5 uCi to 50 uCi the observed tumor incidence fluctuated between 0.04 and 0.3[51].

All of these lung experiments involved intense exposures and a significant level of carcinogenesis. Severe damage and disruption of tissue were associated with the exposures.

The most relevant lung experiment is Bair's $Pu^{239}O_2$ inhalation study with beagles[52-54]. Exposure was to particulates of 0.25 u or 0.5 u median diameter; burdens were in the uCi range. Twenty of the 21 dogs that survived more than 1600 days post exposure had lung cancer. Many of these cancers were multicentric in origin. The cancers again appeared in conjunction with severe lung injury. Since the natural incidence of the disease is small, it appears that at this level of exposure the induction of lung cancer is a certainty during the normal beagle life span. At the same

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51/ Cember, H., Op. cit.

52/ Bair, W.J., J.F. Park, and W.J. Clarke, "Long-term study of inhaled plutonium in dogs," Battelle Memorial Institute [illegible]

53/ Park, J.F., W.J. Clarke and W.J. Bair, "Chronic effects of inhaled $^{239}PuO_2$ in beagles," Battelle-Northwest Laboratory Annual Report for 1967 to the USAEC Division of Biology and Medicine, Vol. I, Biological Sciences, BNWL-714, 1968, pp. 3.3-3.4.

54/ Park, J.F., et al, "Progress in Beagle Dog Studies with Transuranium Elements at Battelle-Northwest," Health Physics, Vol. 22, No. 6, June 1972, pp. 803-810.

time, since the pathological response is saturated in this experiment, it is inappropriate to draw any inference about the magnitude of the response at smaller burdens. The smallest burden (at death) in a dog showing lung cancer was 0.2 uCi. Presumably this would correspond to a particle burden of about 10^7 particles. Burdens which are smaller by orders of magnitude may still induce a substantial incidence of cancer. Indeed, the cancer risk may, as for skin and soft tissues, correspond to a risk per particle in the neighborhood of 1/1000 to 1/10,000.

VI. Critical Particle Activity

Not all particles would be expected to result in these high cancer probabilities. As the particle size or specific activity per particle is reduced so is the dosage to the surrounding tissue. Indeed, at sufficiently small particle size or specific activity, one would expect the radiation insult to behave similar to uniform irradiation. The study of Albert on induction of cancer in rat skin indicates a precipitous change in the dose response curve as the dosage exceeds 1,000 rem[55]. (See Figure 2). This suggests that a particular level of tissue damage must occur before this unique carcinogenic response occurs. The experiments of

55/ Albert, R.E., et al, Radiation Res. 30, Op. cit., pp. 515-524, Figure 7; reproduced in Geesaman, UCRL-50387 Addendum, Op. cit., p. 2.

Laskin, et al, indicate a significant carcinogenic response in the lung at 1400 rem, suggesting a comparable sensitivity of lung tissue[56]. Geesaman indicates that the tissue repair time in the lung is of the order of one year[57]. It therefore seems appropriate, but not necessarily conservative, to accept as guidance that this enhanced cancer risk occurs when particles irradiate the surrounding lung tissue at a dose rate of 1000 rem/yr or more.

TABLE IV

Particle Activity and Size to Give a Dose of 1000 rem/year to the Surrounding Lung Tissue[58]

	Particle Activity (pCi)	Particle Diameter (u)[59]	
		$^{239}PuO_2$	$^{238}PuO_2$
3/4 max inflated (138 alveoli)	0.14	0.8	0.12
1/2 max inflated (68 alveoli)	0.07	0.6	0.09
Closest 20 alveoli	0.02	0.4	0.06

56/ Laskin, et al, Op. cit.

57/ Geesaman, Donald P., UCRL-50387, Op. cit., p. 11.

58/ Ibid

59/ Based upon specific activity given by Langham, W.H., Op. cit., p. 7.

As seen from Table IV, using Geesaman's lung model, a particle with an alpha activity between 0.02 pCi and 0.14 pCi is required to give a dose of 1000 rem/yr to irradiated lung tissue. For purposes of establishing a maximum permissible lung particle burden we will use 0.07 pCi from long half-lived (greater than one year) isotopes as the limiting alpha activity to qualify as a hot particle. Thus, throughout the remainder of this report, hot particle will imply a particle with at least this limiting alpha activity which is insoluble in lung tissue.

A. Exposures at Rocky Flats

The AEC has a plutonium facility associated with its nuclear weapons program at Rocky Flats, Colorado. This facility is operated under contract to the AEC by the Dow Chemical Company. The employees, the environment and undoubtedly the surrounding population have been contaminated with plutonium particles as a result of the operation of this plant.[60-62] It is, therefore, pertinent here to examine the information

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60/ Mann, J.R. and A.R. Kirchnev, Op. cit.

61/ Poet, S.E. and E.A. Martell, "Plutonium-239 and Americium-241 in the Denver Area," Health Physics, Vol. 23, 1972, pp. 537-549.

62/ Richmond, Chet, Transcript of Plutonium Information Meeting of the Advisory Committee on Reactor Safeguards, Los Alamos, N. Mex., 5 January 1974, pp. 319-320.

available on the exposure of employees of the Rocky Flats facility and to relate this to the hot particle problem.

J. R. Mann and R. A. Kirchner discuss the exposures that resulted from a plutonium fire at Rocky Flats on 15 October 1965.[63] Some 400 employees were working in the room at the time the fire occurred. These employees were subsequently placed in a whole body counter to determine their lung burdens of Pu-239. However, Mann and Kirchner reported only on those 25 employees who were exposed above the MPLB of 0.016 uCi.

Table V presents the information on the exposure of these 25 employees. Utilizing the other information presented by Mann and Kirchner, we have also estimated in Table V the fraction of the lung burden activity (uCi) associated with hot particles and the number of hot particles that this represents.

63/ Mann, J.R. and R.A. Kirchner, Op. cit.

TABLE V

Rocky Flats Exposure*

Number of Cases	Total Lung Burden (uCi)	Hot Particles Lung Burden (uCi)	Number of Hot Particles
1	0.272	0.033	137,000
1	0.160	0.019	79,000
1	0.111	0.013	54,000
3	0.064	0.008	33,000
19	0.024	0.003	12,500

* Mann and Kirchner presented the lung burdens as number of MPLB. These have been converted to uCi in column two using MPLB=0.016 uCi. (For the groups with 3 and 19 cases, we selected the midpoint of the reported range.) The hot particle burden in column three was estimated by multiplying the total burden by 0.17, the fraction of the activity on particles above 0.6 u, and 0.70, the fraction of initial deposited activity that was involved in low term retention in the lung. Based on particle size data reported by Mann and Kirchner, we estimate the average hot particle activity is about 0.24 uCi. The numbers of hot particles in the last column were obtained by dividing the hot particle burdens in column three by the average hot particle activity (0.24 uCi).

Allowing a risk of cancer equal to 1/2000 per hot particle, suggests that the individuals whose exposures are presented in Table V stand a very high chance of developing lung cancer -- the probability is essentially unity. In this respect, it is significant to note that in the experiments reported by Park, et al, the beagle dog with the smallest lung burden, i.e., 0.2 uCi, developed lung cancer.[64] The highest burden in Table V is comparable to the lowest beagle exposure; the lowest exposure in Table V, the 19 cases with lung burdens in the 0.024 uCi range are only an order of magnitude less than the lowest beagle exposure. We would suggest that this is potentially a serious situation.

As of this time, none of these individuals has developed lung cancer.[65] However, it is only 9 years since the exposure and there is good reason to suggest that the latent period (the time between exposure and the development of cancer) is much longer than this. In the beagle dog experiments, the lowest lung burden was associated with a latent period of 11 years. The latent period may be longer in man and particularly at these lower dosages and the small number of cases involved. Therefore, while these exposed individuals will be expected to supply pertinent data relative to this hot particle carcinogenesis over the next 10 [illegible] years, these exposures give us no information at this time that would warrant modifying the risk per particle or the critical particle activity.

64/ Park, J.F., et al, Health Physics, Op. cit. p. 805.

65/ Richmond, Chet, Op. cit., p. 320.

B. Manhattan Project Workers

Another study of human respiratory exposure to plutonium relates to 25 young men exposed to plutonium during the Manhattan Project.[66] The latest examination of this group found them to be free of lung cancer although the report states, "The bronchial cells of several subjects showed moderate to marked metaplastic changes, but the significance of these changes is not clear." Such metaplastic changes are a possible indicator for detecting incipient or actual lung cancer. In one case the report indicates that the subject was a heavy smoker (3 packs/day) and undoubtedly this contributed to the changes. Nevertheless, these findings suggest that lung cancer may become manifest in some of these subjects in the future. Indeed, one would not be surprised to find one lung cancer even in such a group of non-exposed subjects. During the latest examination of these workers, *in vivo* measurement of the plutonium lung burdens were conducted with these results:

> An average MDA for a 2000-sec counting time is about 7 nCi if one uses the 95% confidence level.[67] For the 68% confidence level and a similar counting time, the comparable value is about 3.5 nCi.

66/ Hemplemann, L.H., *et al*, "Manhattan Project Plutonium Workers; A Twenty-Seven Year Follow-Up Study of Selected Cases."

67/ MDA refers to the minimum detectable amount.

Positive counts were obtained for 14 of 21 persons measured. These counts suggested chest burdens ranging from 3 to about 10 nCi. However, in no case did the estimated chest burden exceed the MDA at the 95% confidence level. Seven of the 14 subjects with positive chest counts had estimated chest burdens of 7 nCi or greater and may be considered (at the 68% level of confidence) to have statistically significant chest burdens of from 7 to 10 nCi.[68]

Since the plutonium is still in the lung cavity, 27 years post-exposure, it is correct to assume that it was initially in the insoluble form and hence pertinent here.[69] At the time of this measurement, however, most of the material would be expected to be in the lymph nodes. Nevertheless, we could estimate the initial particle burden in these subjects from these data if we knew the initial particle size at the time of contamination. This particle size data is unavailable.

The nature of the contaminating events suggest that the particle size might have been somewhat larger than those that result from plutonium fires where most of the respirable activity resides on particles in the size range of 0.1 u to 0.5 u in diameter.[70] Much of the contamination of the

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68/ Hemplemann, L.H., *Op. cit.*, p. 474.

69/ ICRP Publication 19, The Metabolism of Compounds of Plutonium and Other Actnides, Pergamon Press, New York, 1972, p. 7.

70/ Mann, J.R. and A.R. Kirchner, *Op. cit.*, p. 880.

Manhattan workers resulted from aspiration of droplets of liquid solutions of plutonium into the air wherein much larger particle sizes would result. At the same time, the activity of the plutonium in the particle would be considerably less than that for a particle of PuO_2. For example, it is stated that 14 of the 25 subjects with measurable body burdens of plutonium worked in the recovery operation and that this occurred when working with solutions containing 1-40 g/liter of plutonyl nitrate to which H_2O_2 was being added with vigorous stirring in an open hood. This resulted in considerable fizzing and the discharge of droplets into the air outside the hood. A droplet 1 u in diameter (0.5 u^3) from the solution with the highest concentration (40 g/liter) would therefore contain only 6×10^{-4} pCi compared with a 0.07 pCi particle of PuO_2 [71] (a specific activity that is lower by a factor of 100).[72] In other words, the particles involved in this study do not qualify as hot particles. They are delivering dosages lower than 1000 rem/yr to the

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71/ Recall from Table IV that a 0.07 pCi, the limiting activity for a hot particle, would give a dose of 1000 rem/yr to the surrounding tissue in a lung inflated to 1/2 maximum.

72/ Of the particles of an inhaled aerosol that are deposited in the deep respiratory zone of the lung, virtually all are less than 5 u in diameter [Geesaman, UCRL-50387, Op. cit., p. 3]. A 5 u droplet from the 40 g/liter solution would correspond roughly to the limiting activity of a hot particle.

surrounding tissue (roughly 10 rem/yr).

C Weapons Test Fallout

Another source of human contamination that is suggested as being pertinent to this problem is the plutonium in the fallout from nuclear weapon tests. The plutonium from weapon tests is incorporated in or deposited on particles that contain other materials and, like that for the Manhattan workers, the specific activity in these particles is much smaller than that in hot particles.

VII Exposure Standards for Hot Particles

Thus the existing biological evidence strongly suggests that an insoluble particle of Pu-239 deposited in deep respiratory tissue represents a risk of cancer induction between 1/1000 and 1/10,000. Prudent public health practices should assess the risk associated with environmental plutonium and establish exposure guidelines on the basis of these probabilities.

The existing standards for uniform radiation exposure of the whole body or lung can be used as the basis for establishing particle exposure standards by equating the risk of cancer induction between the two types of exposure (uniform vs. grossly non-uniform). The most recent assessment of the risk associated with uniform irradiation of man was performed by the NAS-MRC Advisory Committee on the Biological Effects of Radiation. Their report, published in 1972, is referred to as the BEIR Report.[73]

A. Occupational Exposure

The existing occupational exposure standard for uniform whole body irradiation is 5 rem/yr and for the lung, 15 rem/yr. the BEIR Report estimates that exposure of the whole body of an individual to 5 rem/yr would lead to a cancer risk between 4.5×10^{-4} and 2.3×10^{-3}/yr.[74] Their best estimate is 10^{-3}/yr.[75] Their estimate of the risk of cancer to the individual from a lung exposure of the 15 rem/yr is 3×10^{-5}/yr.[76] Allowing a risk of cancer induction between 1/1000 and 1/10,000 per particle, Table V presents the maximim permissible lung particle burdens (MPLPB) that result in risks comparable to these uniform radiation standards for occupational exposure.

The MPLPB values in Table V represent a very substantial reduct on in the MPLB. A hot particle of Pu-239 at the lower limit activity contains only 0.07 pCi while the MPLB for occupational exposure is 1.6×10^{4} pCi. Thus the

73/ NAS-NRC, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," (BEIR Report), NAS-NRC, Washington, D. C. , Nov. 1972.

74

74/ Ibid, p. 91.

75/ Ibid, p. 91.

76/ Ibid, p. 156.

TABLE V

Occupational Exposure Guidance for Insoluble Alpha Emitters, Maximum Permissible Lung Particle Burden (MPLPB)[77]

Cancer risk due to 5 rem/yr whole body exposure[78]	Assumed Risk in Particle		
	1/1000	1/2000	1/10,000
4.5×10^{-4}	0.45	0.9	4.5
10^{-3} (best estimate)	1.	2.	10.
2.3×10^{-3}	2.3	4.6	23.

largest MPLPB in Table V, 23 particles, represent a reduction of the existing MPLB and MPC_a by a factor of 10,000. It is recommended here that the best estimate of the effects of uniform exposure by the BEIR Committee be used together with a risk of cancer induction of 1/2000 per hot particle in determining the MPLPB for insoluble alpha-emitting radionuclides in hot particles. This is a somewhat arbitrary compromise and is not the most conservative value that could be recommended. Thus, the recommended MPLPB for occupational exposure from hot particles of alpha-

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77/ The number of particles required to give a cancer risk equal to that from uniform radiation.

78/ Source: BEIR Report, *Op. cit.*, p. 91. The MPLPB corresponding to a lung cancer risk of 3×10^{-5} due to 15 rem/yr lung dose [BEIR Report, *Op. cit.*, p. 156] are 0.03, 0.06 and 0.3 for assumed particle risks of 1/1000, 1/2000 and 1/10,000 respectively.

emitting radionuclides in the deep respiratory zone is 2 particles. This corresponds to a MPLB of 0.14 pCi and represents a reduction of 115,000 in the existing MPLB. This implies that the DF for hot particles is 115,000. Moreover, it requires a reduction of the MPC_a for Pu-239 by 115,000 to a value of 3.5×10^{-16} uCi/ml unless it is determined that the plutonium is not in hot particles.

B. Exposure of the General Public

As indicated in Table II, the MPLB for non-occupational exposure (members of the public) is tenfold less than that for occupational exposure. Such an exposure limit for a hot particle would be 0.2 particles. Exposure at this level implies that on the average one out of five individuals would be contaminated by a particle and the other four would not. Obviously the exposed invididuals would be assuming a disproportionate fraction of the risk. In fact, since an individual is exposed to whole particles, any non-occupational exposure to hot particles would be an overexposure. This condition does not meet the recommendations and admonitions of the FRC, ICRP and NCRP.

> Under certain conditions, such as widespread radioactive contamination of the environment, the only data available may be related to average contamination or exposure levels. Under these circumstances, it is necessary to make assumptions concerning the relationship between

> average and maximum doses. The Federal Radiation Council suggests the use of the arbitrary assumption that the majority of individuals do not vary from the average by a factor greater than three. Thus, we recommend the use of 0.17 rem for yearly whole-body exposure of average population groups. (It is noted that this guide is also in essential agreement with current recommendations of the NCRP and the ICRP.) It is critical that this guide be applied with reason and judgment. Especially, it is noted that the use of the average figure, as a substitute for evidence concerning the dose to individuals, is permissible only when there is a probability of appreciable homogeneity concerning the distribution of the dose within the population included in the average.[79]

Strict adherence to these guidelines implies that the ambient air standard should be zero particles.[80] While a variety of suggestions could be proposed, we recommend a slight deviation from these guidelines and the acceptance of the disproportionate risk implicit in the 0.2 particle standard. This is a workable solution since best estimates of lung burdens can be fractional quantities. Thus, we recommend that the MPLPB for members of the public be 0.2 hot particles, and the average lung burden for members of the public be 0.07 hot particles, a factor of 3 less than the maximum.

79/ FRC Report No. 1, Op. cit., p. 27.

80/ Had we based the standard on a 1/10,000 risk per particle (See Table V), the MPLPB would have been one particle and this problem would not exist.

The MPLPB=0.2 particles implies that the existing MPC_a for non-occupational exposure to Pu-239 should also be reduced by a factor of 115,000 to a value of $9x10^{-18}$ uCi/ml unless it is determined that the plutonium is not in hot particles.

C. <u>Exposure from Accidental Releases</u>

There are no direct statements by standard-setting organizations regarding an "acceptable" exposure associated with release of radioactivity in an accident.[81] For purposes of evaluating sites for nuclear reactors, establishing site boundaries, and preparing safety analysis reports, however, the AEC has adopted specific criteria. The reactor site boundary (surrounding the exclusion area) must meet the following criteria (10 CFR 100.11(a)(1)):

> (1) An exclusion area of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product release would not receive a total radiation dose to the whole body in excess of 25 rem[2] or a total radiation dose in excess of 300 rem[2] to the thyroid from iodine exposure.

<u>81</u>/ Fish, B.R., G.W. Keilhalte, W.S. Snyder, and S.D. Swisher, Chapter 7 of early draft version of B.R. Fish, <u>et al</u>, "Calculation of Doses Due to Accidental Released Plutonium from an LMFBR," ORNL-NSIC-74 (Nov. 1972), p. 128. This chapter was deleted from the final version at the direction of AEC-Division of Reactor Development and Technology because it was judged to be not directly applicable to the objective of the study, and the information base from which it was developed was already available in other documents. AEC-DRDT further stated that it was not removed because of the quality of the work.

[2] The whole body dose of 25 rem referred to above corresponds numerically to the once in a lifetime accidental or emergency dose for radiation workers which, according to NCRP recommendations may be disregarded in the determination of their radiation exposure status (see NBS Handbook 69 dated June 5, 1959). However, neither its use nor that of the 300 rem value for thyroid exposure as set forth in these site criteria guides are intended to imply that these numbers constitute acceptable limits for emergency doses to the public under accident conditions. Rather, this 25 rem whole body value and the 300 rem thyroid value have been set forth in these guides as reference values, which can be used in the evaluation of reactor sites with respect to potential reactor accidents of exceedingly low probability of occurrence, and low risk of public exposure to radiation.

Fish, et al, made the following comments regarding the applicability of these criteria to the case of plutonium release. These comments are also applicable to hot particle case.

> First, the wording of sections 100.11(a)(1) clearly limits the application to the irradiation of the whole body and the thyroid; no other organ or tissue is mentioned or implied. Furthermore, only fission products in general and iodine in particular are identified as reference substances. Finally, footnote (2) states unequivocally that the guides are not to be considered as acceptable limits for emergency doses to the public under accident conditions.[82]

Without addressing whether the guideline values, 25 rem to the whole body and 300 rem to the thyroid, should

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82/ Ibid, p. 129.

be considered as acceptable limits, or whether design basis accidents that are currently evaluated under these criteria are "of exceedingly low probability of occurrence," we recommend that 10 CFR 100.11(a)(1) be modified as follows in order to establish a hot particle standard that is equivalent to the risk associated with 25 rem whole body irradiation:

> (1) An exclusion area of such size that an individual located at any point on its boundary for two hours immediately following onset of the postulated fission product <u>or other radionuclide</u> release would not receive a total radiation dose to the whole body in excess of 25 rem[2] or a total radiation dose in excess of 300 rem[2] to the thyroid from iodine exposure, <u>or receive a lung particle burden in excess of 10 hot particles.[3]</u>

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[2] (Unchanged from original text)

[3] A hot particle is a particle that contains sufficient activity to deliver at least 1000 rem/yr to the surrounding lung tissue. For isotopes having half-lives greater than one year, this would correspond to particles containing at least 0.07 pCi of alpha activity.

We also recommend that similar criteria be established limiting hot particle releases for nuclear facilities not now covered under 10 CFR 100.

D. <u>Surface Contamination</u>

Hot particles deposited on land surfaces can be resuspended into the air by any number of means, including wind, automobile traffic, human or animal movements, Following an accident wherein surfaces are contaminated with hot particles, it is necessary to have a standard to apply to decontamination measures.

The number of particles that can be resuspended from surfaces has been the subject of a number of experiments. These experiments have usually resulted in the determination of a resuspension factor (RF). The RF is defined by:

$$RF\ (m^{-1}) = \frac{\text{concentration in air (uCi/m}^3)}{\text{concentration on surface (uCi/m}^2)}$$

R. L. Kathren has reviewed the data obtained on RF values.[83] He indicates that, "reported [RF] values for plutonium and its compounds range over 11 orders of magnitude." This 11 orders corresponds to values between 10^{-1} to 10^{-11} m^{-1}. Kathren indicates that, "an RF of 10^{-4} m^{-1}, although conservative is appropriate."[84] Langham indicates that a member of the Danish scientific team used an $RF=10^{-3}$ m^{-1} during the Thule deliberation.[85] We would recommend that

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83/ Kathren, R.L., "Towards interim acceptable surface contamination levels for environmental PuO_2," BNWL-SA-1510, Battelle Northwest Laboratory, Richland, Washington, April 1968, pp. 3-4.

84/ *Ibid*, p. 4.

85/ Langham, Wright H., *Op. cit.*, p. 5. The Thule Deliberations refer to the deliberations following the accidental crash of a B-52 bomber carrying nuclear weapons near Thule Air Force Base in Greenland. The high explosives in the weapons detonated and dispersed the plutonium.

the value selected by Kathren be used when the RF is unknown to determine the ambient ground contamination standard. Applying an $RF=10^{-4}\ m^{-1}$ to the ambient MPC_a standard recommended in the previous section, we obtain a maximum permissible surface contamination (MPCS) level for hot particles of $9x10^{-8}\ uCi/m^2$.[86] This is roughly 1 hot particle/m^2. In areas where an RF greater or less than $10^{-4}\ m^{-1}$ could be shown to apply, the MPSC could be altered appropriately.

E. As Low as Practicable Hearings

It is to be understood that the above recommendations do not represent endorsement on our part of the risk inherent in the existing radiation protection guidelines upon which these recommendations are based. Rather, we offer the admonition that the exposures should be kept as far below these guidelines as is practicable. Therefore, we further recommend that these guidelines be incorporated into the existing regulations without delay and that the appropriate agency or agencies convene hearings to determine for the regulations what constitutes as low as practicable limits for exposure to hot particles.

86/ This value is derived as follows: The recommended MPC_a for hot particles is $9x10^{-18}$ uCi/ml which corresponds to $9x10^{-12}\ uCi/m^3$. The maximum ground contamination level, using $RF=10^{-4}\ m^{-1}$, is $9x10^{-12}/10^{-4} = 9x10^{-8}\ uCi/m^2$.

VIII Summary of Recommendations

The following recommendations apply to alpha-emitting hot particles where a hot particle is defined as a particle that contains sufficient activity to deliver at least 1000 rem/yr to the surrounding lung tissue. For isotopes having half-lives greater than one year, this would correspond to particles containing at least 0.07 pCi of alpha activity.[87]

It is recommended that:

1. For occupational exposure

   MPLPB = 2 hot particles

   MPC_a for Pu-239 = 3.5×10^{-16} uCi/ml[88]

2. For non-occupational exposure

   MPLPB = 0.2 hot particles

   MPC_a for Pu-239 = 9×10^{-18} uCi/ml[89]

87/ These particulates would consist of compounds of Pu and the other actnides which fall into Class Y material in the ICRP Task Group Lung Model. These materials would be retained for years in the lung. See for example, ICRP Publication 19, *Op. cit.* p. 6. Since only particles in the size range of 5 u and below in diameter would be deposited in the deep respiratory tissue, this in effect sets an upper limit for the particle size of interest here. If the half-life is less than or close to 1 year the limit of 0.07 pCi can be adjusted upward through appropriate calculation

88/ This MPC_a applies for particles containing 0.07 pCi of Pu-239. For particles containing more than 0.07 pCi the MPC_a could be increased proportionately. For particles containing less than 0.07 pCi the existing $MPC_a = 4 \times 10^{-11}$ pCi/ml would apply. The MPC_a for hot particles of other isotopes and mixtures of isotopes should be established on a similar basis with consideration given to the half-life of the isotope.

89/ *Ibid*.

3. For accidental releases exposure (10 CFR 100.11(a)(1))

   MPLPB (2 hours exposure) = 10 hot particles

4. For unrestricted areas

   MPSC = 1 hot particle/m^2 [90]

5. Hearings should be convened to determine as low as practicable regulations.

90/ This value is meant for guidance with respect to decontamination of an unrestricted area that has been contaminated with hot particles. In areas where an RF greater or less than 10^{-4} m^{-1} could be shown to apply, the MPSC could be altered appropriately.

APPENDIX A

Radiation Standards Setting Organizations

and Their Roles

The organization which recommends basic radiation criteria and standards at the international level is the International Commission on Radiological Protection (ICRP). It was established in 1928 under the auspices of the Second International Congress of Radiology. During the early period and until 1950, the ICRP was concerned primarily with recommendations designed to provide protection to members of the medical profession in their diagnostic and therapeutic use of X-rays and gamma radiation from radium. However, since the advent of atomic energy, and radiation uses on a large scale, it has extended its efforts to include studies of radiation protection matters covering the whole gamut of radiation applications. It works together with its sister commission, the International Commission on Radiation Units Measurements (ICRU), and relies on the ICRU for background knowledge on radiation measurements.

The National Council on Radiation Protection and Measurements (NCRP) was organized in 1929, a year after the ICRP, as a combined effort of several radiation protection committees in the United States to consolidate their scattered efforts and to present a unified voice at meetings of the ICRP.[1] The ICRP and NCRP are private groups whose recommendations are purely advisory.

In 1934 the NCRP adopted the simple level of 0.1 roentgen per day, measured in air as the tolerance dose. In 1940, it recommended a permissible body burden of 0.1 microgram for ingested radium. The latter standard, still in effect today, corresponds to an average dose to the skeleton of about 30 rem/yr or a dose to the critical endosteal tissue out to a distance of 5-10 microns of about 10 rem/yr.

1/ Initially the NCRP was known as the Advisory Committee on X-rays and Radium Protection; in 1946 the name was changed to the National Committee on Radiation Protection and Measurements, and in 1964 it received a Federal charter and took its present name.

In 1949, the maximum permissible dose for radiation was lowered to 0.3 roentgen per week. It was lowered again in 1957 to 5 rem/yr as the permissible dose for radiation workers. This standard is still in effect.

The AEC has also played a significant role in setting radiation standards. However, the AEC's regulatory authority over materials was, and still is, limited by the Atomic Energy Act of 1954, as amended, to source, by-product, and special nuclear material. Before the Federal Radiation Council (FRC) was formed, the AEC, when setting radiation standards, generally followed closely the recommendations of the NCRP, which in turn paralleled the ICRP recommendations.

In 1959, after the advent of the atomic age had aroused public fears over fallout from nuclear weapons, the U. S. government, because of uncertainty of government influence over radiation protection standards, organized the FRC. It was authorized by Congress to "...advise the President with respect to radiation matters directly or indirectly affecting health, including guidance for all federal agencies in the formulation of radiation standards and in establishment and execution of programs in cooperation with the states..."[2] The final authority with respect to radiation standards rested not with the FRC but with the President. Such a subordinate agency as the AEC, for example, had to make its rules, e.g., those governing licensed reactors, compatible with the overall guides developed by the FRC.

Throughout the 1950's the ICRP and NCRP continued to revise and refine the basic recommendations concerning permissible radiation exposure standards. Standards were recommended for some non-occupational groups and for the whole population. Maximum permissible body burdens and maximum permissible concentrations of radionuclides in the air and in water were recommended as secondary standards. Most of these recommendations were incorporated by the FRC and the AEC.

In 1970 the FRC was abolished and its duties were transferred to the EPA. Since that time, the setting of population exposure standards has resided in EPA. Population standards,

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2/ FRC Report No. 1, <u>Background Material for the Development of Radiation Protection Standards</u>, Government Printing Office, Washington, D. C., May 13, 1960, p. 1.

in this case, mean exposure to persons "outside the fence" of an AEC (or AEC-licensed) facility. Criteria, required to meet these standards, for plant operation and design remained with the AEC. Hence, present responsibility for assessment of health effects resides in EPA, while the responsibility for developing technology to control emissions resides in AEC. The Office of Management and Budget (OMB) in a recent letter to EPA and AEC clarified the delegation of responsibility between these agencies for promulgating regulations to limit the radioactivity that may be emitted from facilities in the nuclear power industry. OMB stated:

> AEC should proceed with its plans for issuing uranium fuel cycle standards, taking into account the comments received from all sources, including EPA; that EPA should discontinue its preparations for issuing, now or in the future, any standards for types of facilities; and that EPA should continue, under its current authority, to have responsibility for setting standards for the total amount of radiation in the general environment from all facilities combined in the uranium fuel cycle, i.e., an ambient standard which would have to reflect AEC's findings as to the practicability of emission controls.[3]

There are other agencies and groups which are concerned with radiation standards and in some cases have regulatory authority. These include, but are not limited to, the Department of Health, Education and Welfare, Department of Labor, Bureau of Mines, the American National Standards Institute, and state agencies. The radiation standards of these organizations are not at issue here. For the most part they play a secondary role, or where applicable, follow the guidance of the NCRP, EPA and AEC.

3/ Memorandum for Administrator Train and Chairman Ray from Roy L. Ash, Dec. 7, 1973.

APPENDIX B

Statement Submitted to Attorneys for Mr. Edward Gleason

Re: Edward Gleason, et al vs. NUMEC

by: Arthur R. Tamplin

The following is my analysis of the origin of Mr. Edward Gleason's soft tissue sarcoma that ultimately resulted in his death and of the Consultation Report, submitted by Dr. Niel Wald, dated Jan. 29, 1973.

Mr. Gleason unloaded, rotated, and loaded a crate containing a leaking carboy of plutonium-239 (Pu-239) solution. This could not have occured without contaminating the palmar surface of his left hand, which was bare. The question is: did this Pu-239 contamination cause Mr. Gleason to develop a sarcoma? Since radiation induced cancers are identical with those that occur spontaneously, it is necessary to consider the relative chances that the cancer was spontaneous or Pu-239 induced.

The United States Vital Statistics, record a death rate for malignant neoplasms (other than melanoma) of the skin in the upper extremity of less than one per million per year. Since synovial sarcoma is a rare form that often metastasizes and hence has a poor prognosis, its occurrence rate is certainly less than the total skin cancer death rate of one per million per year. Thus it is highly unlikely that anyone who handled this crate would spontaneously develop this sarcoma on the contaminated hand (less than one chance in a million).

Now let us consider what the chances are of the development of cancer as a result of plutonium contamination of the skin. Experimental data from plutonium contaminated animals demonstrate that injection of 1 microgram of Pu-239 into the skin of rats promptly produced cancer in up to 5% of the animals (Exhibit 1). The particular tumors are fibrosarcomas.

Now the analysis done by LASL indicated that the Pu-239 concentration was about 160 micrograms per milliliter. This is reason to suspect, since the volume of liquid was reduced, the Pu was actually more concentrated in 1963. But setting that aside, one drop would be expected to contain between 8 and 16 micrograms of Pu-239. One-one hundredth of a milliliter (a very small amount of liquid) would have been sufficient to produce sarcomas in animals. There is little reason to doubt that this small amount of liquid (0.01 milliliter) or even more found its way below the surface of Mr. Gleason's palm. In this event, his chance of developing cancer would be one in twenty. This is at least 50,000 times higher than his chances of developing the cancer spontaneously. In other words, the evidence is overwhelming in favor of the tumor resulting from Pu-239 contamination.

The above relative probability is based upon data from animals. It is quite possible that man is more sensitive than animals to cancer induction by Pu-239. In fact, the biological evidence strongly suggests that man is more sensitive. Exhibit 2 is a case report of a nodule removed from a man. This nodule contained only 0.08 ug of Pu-239. Commenting on the histological examination of the lesion, the authors states,"The autoradiographs showed precise confinement of α-tracks to the area of maximum damage and their penetration into the basal areas of the epidermis, where epithelial changes typical of ionizing radiation exposure were present. The cause and effect relationship of these findings, therefore, seemed obvious. Although the lesion was minute, the changes in it were severe. Their similarity to known precancerous epidermal cytologic changes, of course, raised the question of the ultimate fate of such a lesion should it be allowed to exist without surgical intervention..." In this case, less than 0.1 ug of Pu-239 produced precancerous changes in human tissue. The dose to the surrounding tissue was very intense. There is every reason to believe that a smaller quantity of Pu-239 would have produced similar changes.

When I consider the above human and animal data together with the relative probability of 50,000, I can come to no other conclusion than that this sarcoma was a direct result of the contamination of Mr. Gleason's left palm by Pu-239.

Turning now to Dr. Wald's Consultation Report, it can be stated that he has presented no evidence to disprove the claim that this sarcoma was caused by Pu-239 contamination. I shall discuss Dr. Wald's report in the order that it was written.

According to the Division of Inspection Report submitted by Anson M. Bartlett on April 11, 1963, pages 29-30, the January 19 examination was conducted not on Mr. Gleason, but on his home, clothing and automobile. The single urine and feces samples collected subsequent to January 20 gave negative results. The only thing that this demonstrates is that no detectable level of Pu-239 was found. Even following the injection of large volumes of Pu-239 solution into the skin and muscle of animals, the Pu-239 is slowly absorbed and appreciable fractions, up to 70%, remain at the site of injection. Moreover, of the quantity absorbed only a small fraction appears in the urine or feces (see page 3, Exhibit 3 and Exhibit 4). In Mr. Gleason's case we are concerned with only a very small volume of solution and hence we should not be surprised if we obtain negative results in an individual urine or feces sample. (See also Exhibit 5)

The physical examination performed by Dr. Roy E. Albert on January 23, 1963, has no relevance. One would expect no overt signs of radiation injury at this early date from the small quantity of Pu-239 which is at issue here. We are concerned here with the long term effects, not the acute effects.

The medical history of Mr. Gleason as recorded by Dr. Wald appears to be accurate, however, he omitted the conclusions of the Pathology Report of the Hospital for Special Surgery wherein the unanimous opinion of the pathologists was stated to be that this lesion was a synovial sarcoma.

The negative findings in the feces and urine in April of 1970 are of no more relevance than the similar findings in the January 1963 samples. The whole body counter has a detection limit of 0.3 u Ci of Pu-239. At issue here are quantities below 0.06 u Ci and, hence, well below the detectable limit.

There are three reasons for setting aside the negative findings in the initial tissue removed from Mr. Gleason. First, since the pathologist report indicated "no evidence of atypical or malignant changes," it is quite possible that this mass was unrelated to the sarcoma. Recall here that the histology of the small nodule in Exhibit 2 showed severe changes that resembled precancerous changes. Third, the site of contamination was not necessarily removed with the mass or it could have trimmed from the mass prior to production of the paraffin blocks and slides. Consider here that the nodule in Exhibit 2 was only 1/10 of a millimeter in diameter. Since Mr. Gleason eventually developed an infiltrating soft tissue sarcoma, and this original tissue removed showed no atypical change, there is no basis for assuming that the origin of the sarcoma was included in this tissue mass.

The negative results on the clavicle specimen are also equivocal. The issue here is a small quantity of Pu-239 that remained localized in the palmar area of the left hand. This bone specimen indicates only that the amount of systemically absorbed Pu-239 was too small to be detected in this bone specimen.

None of these clinical findings are able to set aside the strong possibility that Mr. Gleason's sarcoma was a direct result of the plutonium contamination. The most likely course of events is that a small quantity of the Pu-239 solution (less the 0.01 milliliter) was deposited in the tissue below Mr. Gleason's palm. This may have occured through a small cut or via a sliver. The body then reacted to this material as a foreign body, and encapsulated it. Eventually, a lesion similar to that discussed in Exhibit 2 developed. This nodule progressed beyond the precancerous stage to become an infiltrating soft tissue sarcoma. The chances are some 50,000 times greater that the sarcoma developed in this fashion than that it occured spontaneously.

I think that it is important to point out that all of the information relevant to this case was available in 1963. Had Mr. Gleason been informed of the potential cancer risk subsequent to the incident, he could have informed his physicians. As a result they would probably have treated him more cautiously and the tradegy could have been substantially mitigated.

Exhibits

1 Lisco, Herman, et al, Radiology, Vol. 49, No. 3, Sept. 1947, pp. 361-363.

2 Lushbaugh, C.C., et al, Arch. of Dermatology, Vol. 86, Oct. 1962, pp. 461-464.

3 Vanderbeck, J. W., HW-66172, Hanford Laboratories Operation, July 25, 1960.

4 Matsuoka, Mr., et al, Health Physics, Vol. 22, June 1972, pp. 713-722.

5 Lisco, Herman and Walter E. Kesiekeski, American J. of Pathology, Vol. 29, No. 1, Jan. - Feb. 1953, pp. 305-321.

GLOSSARY

Absorbed Dose:	The absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest. The unit of absorbed dose is the rad. One rad is 100 ergs/gram.
AEC:	Atomic Energy Commission.
Ci:	Abbreviation for curie.
Curie:	The quantity of a radioactive nuclide disintegrating at the rate of 3.7×10^{10} atoms per second.
D:	Abbreviation for Absorbed Dose.
DE:	Abbreviation for Dose Equivalent.
DF:	Abbreviation for Dose Distribution Factor.
Dose Distribution Factor:	A modifying factor used in calculating dose equivalent which accounts for non-uniform distribution of radiation.
Dose Equivalent:	The product of absorbed dose D, quality factor (QF), dose distribution factor (DF), and other necessary modifying factors (The dose equivalent is numerically equal to the absorbed dose in rads multiplied by the appropriate modifying factors). The unit of dose equivalent is the 'rem.'
EPA:	Environmental Protection Agency.
FRC:	Federal Radiation Council. The FRC has been abolished, and its functions taken over by EPA.
g:	Abbreviation for gram.
Half-life:	Time required for a radioactive substance to lose 50 percent of its activity by radioactive decay. Each radionuclide has a unique half-life.

ICRP:	International Commission on Radiological Protection.
m:	Abbreviation for meter.
micron:	One-millionth of a meter.
ml:	Milliliter = 0.001 liters.
MPC_a:	Maximum permissible concentration (of a radionuclide) in air. The average concentration above background of a specific radionuclide to which an individual can be exposed without exceeding the guidelines.
MPC_w:	Maximum permissible concentration (of a radionuclide) in water. (See definition above.)
MPLB:	Maximum permissible lung burden.
MPLD:	Maximum permissible lung dose.
NCRP:	National Council on Radiation Protection and Measurements.
nCi:	Abbreviation for nanocurie, which is one-billionth of a curie, or 10^{-9} curie.
pCi:	Abbreviation for picocurie, which is one-millionth of a microcurie, or 10^{-12} curies.
QF:	Abbreviation for Quality Factor, which is assigned on the basis of a number of considerations. A quality factor is a modifying factor used in calculation of dose equivalent which accounts for differences in producing biological effects among various forms of radiation (e.g., alpha, and X-radiation).
Rad:	Unit of absorbed dose (D), which is 100 ergs/gram. The rad is a measure of the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.
Radionuclide:	A nuclide of an element that is radioactive.

Rem: Unit of dose equivalent. When the appropriate modifying factors are used to calculate dose equivalent one rem is the quantity of any type of ionizing radiation which when absorbed in man produces an effect equivalent to the absorbtion of one rad of X- or gamma-radiation at the place of interest.

Roentgen: The quantity of X- or gamma-radiation such that the associated corpuscular emission per 0.001293 grams of air produces, in air ions carrying one electrostatic unit of electricity of either sign. For the purposes here, the roentgen is roughly equivalent to the rad.

Specific activity: Total radioactivity of a given material (isotope, element, or compound) per gram of the material -- curies/gram.

u: Abbreviation for micron, which is one-millionth of a meter.

uCi: Abbreviation for microcurie, which is one-millionth of a curie.

ug: Abbreviation for microgram, which is one-millionth of a gram.

gered by an external event, such as lightning or a bush fire.
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15. This work was supported in part by the Sherman Fairchild Foundation while one of us (Y.K.B.) was a Fairchild Scholar at the California Institute of Technology. We express our thanks to both the Foundation and the Institute. We acknowledge the help of A. Chodos, California Institute of Technology, who carried out the microprobe analyses. We also thank Dr. A. E. Engel, Scripps Institution of Oceanography, and Dr. G. J. Wasserburg for reading the manuscript and for their helpful comments.

12 February 1976; revised 21 April 1976

Plutonium Hazard in Respirable Dust on the Surface of Soil

Abstract. *Plutonium-239 in the fine particulate soil fraction of surface dust is subject to suspension by air currents and is a potential health hazard to humans who may inhale it. This respirable particulate fraction is defined as particles ≤ 5 micrometers. The respirable fraction of surface dust was separated by ultrasonic dispersion and a standard water-sedimentation procedure. Plutonium concentrations in this fraction of off-site soils located downwind from the Rocky Flats Nuclear Weapons Plant (Jefferson County, Colorado) were as much as 380 times the background concentration. It is proposed that this method of evaluation defines more precisely the potential health hazard from the respirable fraction of plutonium-contaminated soils.*

Methods of evaluating Pu inventories in soils are important because of the possibility of soil contamination near Pu processing plants and nuclear generating stations and areas where Pu has been accidentally released—for example, at Palomares, Spain, and Thule, Greenland, where Pu was released in airplane accidents in January 1966 and January 1968, respectively. Evaluation of Pu (*1*) in the soil is of special importance in contaminated areas that are now considered for residential development. One such area is in the vicinity of the Rocky Flats Nuclear Weapons Plant (Jefferson County, Colorado), which is currently operated by Rockwell International for the Energy Research and Development Administration (ERDA). Activities at the plant include processing radioactive chemicals and making weapons from radioactive metals (*2*).

The Colorado State Health Department in 1973 proposed an interim standard for soil contaminated with Pu, setting the maximum allowable concentration at 2 disintegrations per minute per gram (dpm/g) (*3*). Land with Pu concentrations in excess of the standard would require ameliorative treatment before residential development could be approved. However, the standard fails to define "soil." Either single or composite samples of the soil at a depth of 0 to 0.5 cm from numerous locations in a development area are required. Because such samples include soil particles much too large to be resuspended or inhaled, the possible risk to health cannot be properly evaluated (*4*). Further, no provision is made to prevent the treated soil from being recontaminated by redeposition of Pu from more highly contaminated soils upwind. This redeposition mechanism potentially exists because winds in the area exceed 30 km/hour for 500 to 600 hours yearly. Wind speeds commonly reach 130 km/hour or more, with winds blowing predominantly to the east and southeast toward the Denver metropolitan area (Figs. 1 and 2).

The plant is located about 16 km northwest of Denver and about 8 km from the cities of Boulder, Westminster, and Arvada. Approximately 200,000 people live within 16 km and 600,000 people within 32 km of the plant. Residential development is now proposed within about 5 km of the plant (Fig. 1), involving as many as 3000 homes or a potential population of about 10,000 persons (*5*).

Since the plant began operation in 1953, there have been two major fires (1957 and 1969), a large release of Pu to off-site soils from a spill of metal-laden cutting oil, and an accidental release of Pu to the air in 1974. The major sources of off-site contamination are considered to be emissions from the 1957 fire and the oil leakage from corroded barrels of contaminated cutting oil that were stored

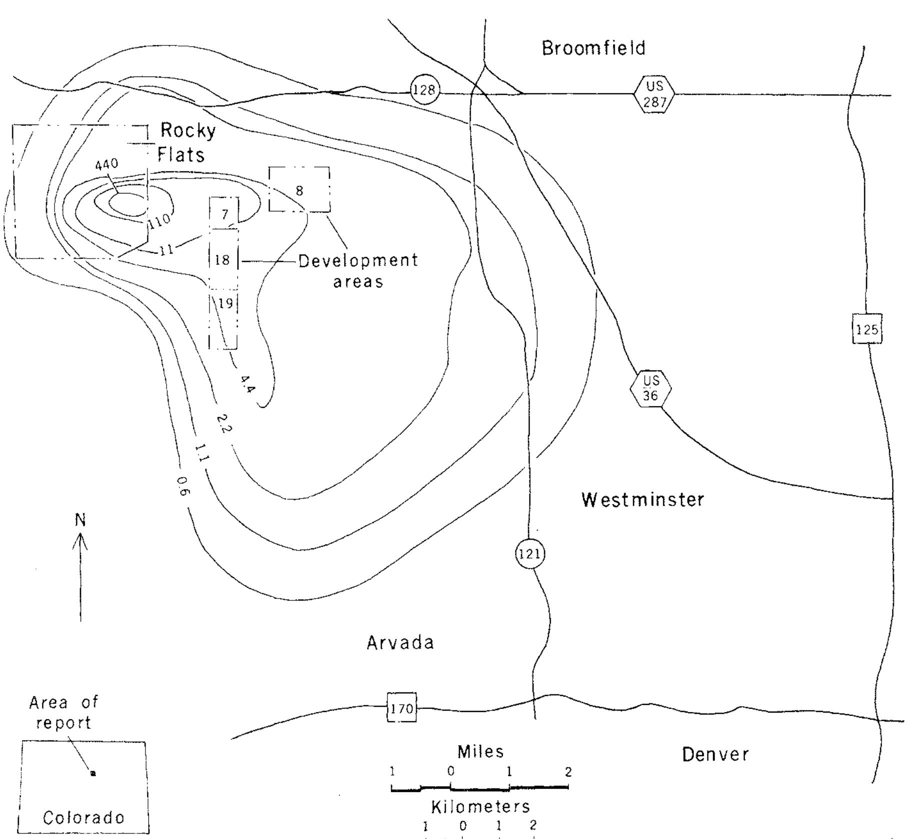

Fig. 1. Rocky Flats Nuclear Weapons Plant and proposed housing development area. Isopleths are labeled in disintegrations per minute per gram of whole soil, calculated from values in (*2*).

outside beginning in 1958 (2, 6). Although leakage of the barrels was first detected in 1964, storage in this manner continued until 1968. The oil-spill area has since been partially covered with asphalt.

A survey of Pu inventories in off-site soils was conducted by the Health and Safety Laboratory of the Atomic Energy Commission in 1970 (2). The results are used in Fig. 1. An off-site area of more than 50 km^2 had concentrations of Pu in excess of 10 mc/km^2. Soil samples were collected to a depth of 20 cm, which was considered sufficiently deep to account for the total deposition of Pu. The Pu inventory was based on the weight of the whole soil sample, including plant parts but excluding larger rocks.

Contaminated soils must be measured against a background of Pu released during atmospheric weapons testing. Of the 300 to 500 kc of Pu released worldwide, about 10 to 15 kc is estimated to be present in the soils of the United States and less than 10 percent is still suspended in the atmosphere. In Colorado the background level has been estimated to be 0.04 pc/cm^2 or 0.08 dpm per gram of whole soil (7).

Sampling localities, each about 4 ha in area, were selected within proposed residential development areas downwind from the plant (Fig. 1). Several sampling sites were randomly selected within each locality. In addition, one stream-sediment sample in section 18 and one sample of eolian sediment in section 19 were collected. Within a 4-m^2 area at each site, when the ground surface was dry, a representative quantity of loose, surficial (about 0 to 0.5 cm deep) soil material was collected with a clean brush and a clean plastic container. This area provided a sufficiently large composite sample. All samples were compared against a background level estimated from a control sample collected about 23 km south-southeast of the Rocky Flats plant.

The samples were analyzed in random order so that any systematic laboratory error would be converted to a random error. The objective in sample preparation was to disperse the soil microaggregates to expose the Pu as much as possible. Each sample was sieved through a 2-mm stainless steel screen; only the material that passed through the screen was retained for analysis. Approximately 50 g of material in the size fraction ≤ 2 mm was placed on a steam bath and treated with hydrogen peroxide to oxidize the organic material, particularly that present as grain coatings or cementing agents.

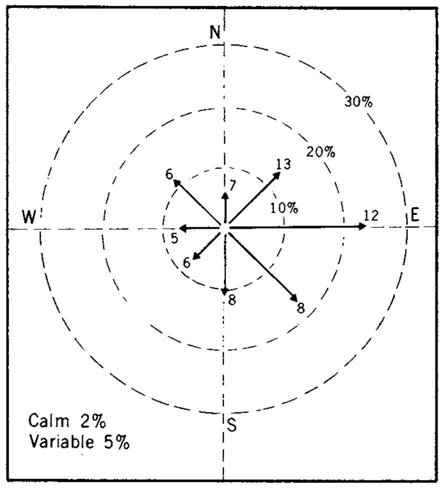

Fig. 2. Rose diagram showing average direction and velocity of wind at Rocky Flats for 1953 to 1970. Arrows point in the direction of wind movement; velocity (miles per hour) is given at the end of each arrow; concentric circles show frequency of wind direction (2).

Table 1. Analyses of Pu in respirable dust (size fraction ≤ 5 μm in soil material ≤ 2 mm) and in whole soil. In column 2 respirable dust is shown as the percentage of whole soil (≤ 2 mm). Localities are shown in Fig. 1. Values are given as disintegrations per minute per gram of material ≤ 5 μm; for Health Department samples these are averages of two analyses. Relative enrichment (RE) is the ratio of measured value to background value.

Locality	Health Department samples: Respirable dust (%)	Pu in respirable dust: dpm/g	Pu in respirable dust: RE	Contractor's samples (13): dpm/g	Contractor's samples (13): RE
		Section 7			
7-1	36.1	83	180	13.5	169
7-2	41.4	59	130		
7-3	17.9	120	270	14.1	176
7-4	18.8	170	380		
		Section 18			
18-1	19.8	36	80	0.2	2.5
18-2	29.6	24	53	0.14	1.8
18-3	27.0	26	58	2.96	37
18-4	25.1	40	89	0.14	1.8
		Section 19			
19-1	62.2	1.4*	3.1		
19-2	46.3	2.1†	4.7	0.23	2.9
19-3	36.5	1.3†	2.9		
		Section 8			
8-1	47.7	1.1†	2.4	0.05	0.6
8-2	51.2	1.0†	2.2		
8-3	42.1	3.8†	8.4		
8-4	31.5	2.8†	6.2		
8-5	47.0	9.6	21	0.72	9.0
8-6	48.8	8.1	18		
8-7	37.6	11	24		
8-8	33.3	7.7	17		
8-9	24.8	14	31	0.72	9.0
8-10	25.7	19	42		
8-11	34.5	9.4	21		
8-12	37.9	6.9	15		
		Background			
Control	48.9	0.45	1	0.08	1

*Eolian sediment from ground surface. †Sample from recently disturbed soil.

The samples were washed and filtered to remove soluble salts and dispersed with a 300-watt ultrasonic probe for 15 minutes (8).

Particles were separated according to size by a standard water-sedimentation technique (9). Sodium metaphosphate was added when necessary to avoid flocculation. The suspension containing the desired size fraction was collected and freeze-dried (10). The sedimentation technique is an arbitrary measure of the "effective" diameter of particles with irregular shapes that have settling rates equivalent to those of spheres of the same diameter and density. The threshold parameters used were based on particles of plutonium oxide having an effective maximum diameter of 5 μm and a density of 11.46 g/cm^3. The soil particles separated include other mineral grains that have an equivalent maximum settling velocity, but that also have some combination of smaller density and larger diameter. The size fraction thus defined is hereafter called the soil material ≤ 5 μm or "respirable dust" because we assume this size fraction to be an adequate measure of the respirable material.

Plutonium concentrations are given in Table 1. The results shown are the averages of the determinations for duplicate split samples by two laboratories (1). Averaging the two determinations is justified because a t-test indicates no significant difference between determinations at P = .05. Analytical procedures used for Pu were those described by Talvitie (11, 12).

Our estimate of background is 0.45 dpm per gram of soil material ≤ 5 μm. Samples from areas immediately downwind from the plant show evidence of Pu contamination considerably above background in the respirable dust. The sampling area in section 7, which is about 2.4 km immediately downwind from the plant area, has the largest amounts of Pu: 59 to 170 dpm/g. Sites 7-3 and 7-4 are on the flat crest of a low ridge that trends east from the plant, and sites 7-1 and 7-2 are on the north-facing slope of the same ridge but about 12 m lower in elevation. Section 8, which is on the principal wind vector but about 5 km downwind, has 1 to 19 dpm/g. Although sample sites in section 18 are nearly the same distance from the plant as those in section 7, we measured less Pu there, perhaps because section 18 lies away from the principal wind vector. Section 19, which is farther from the plant and from the principal wind vector, has the lowest values. Eolian sediment (sample 19-1) that was derived from a freshly plowed field upwind had only 1.4 dpm/g. The field is located in a zone of expected contamination about 3.3 km southeast of the plant area. Plowing tends to distribute the Pu throughout the plowed layer and reduce its probability of entrainment for the present, but it also creates a more erosive surface until plant cover is reestablished. Stream sediment collected in section 18 contained 9.4 dpm/g. This sediment could be susceptible to wind erosion during periods when the stream was at low flow or dried up.

The distribution of Pu in respirable dust may be compared with previous determinations by other methods in the same areas (*13*). However, the different denominators used to express concentrations make it inappropriate to draw direct comparisons between Pu in respirable dust and in whole soil. The present maximum allowable level in Colorado, 2 dpm per gram of whole soil, represents an enrichment of 25 times the background level for whole soil (0.08 dpm/g). Corresponding enrichment factors based on respirable dust are given in Table 1: for example, sample 7-1 contains 180 times more Pu in the respirable dust fraction than is contained in our background sample.

The surficial soil materials at different locations contain different percentages of material ≤ 5 μm (Table 1). The Pu concentration per gram represents a potential dose rate. This concentration is to be distinguished from a total inventory of respirable Pu. The greatest long-term hazard, expressed as the largest total inventory, occurs at sites where both the concentration per gram and the percentage of material ≤ 5 μm are high.

Several sampling sites appear to have been disturbed recently by land-development activity. In particular, sites 8-1 through 8-4 lie in a zone where elevated levels of Pu could be expected. These samples have Pu enrichment factors of no more than about eight times background, compared with 15 to 40 times background only 0.6 km closer to the source (samples 8-5 through 8-12). Disturbance of the ground surface may account for this diminished concentration, or the local topography may have produced a fallout "shadow."

Estimates of health hazards from Pu have been made on the basis of air-monitoring data (*14*), measurements of total soil inventories of Pu (*2, 6*), and measurements of Pu concentration on the surface of the soil (*13*). Air-monitoring data are of importance in estimating human exposure through inhalation, and have been used with soil-contamination data to estimate resuspension factors (*15*). These factors are influenced by the moisture content of soil, wind speed, elevation above ground, type of ground cover, and presence of paved surfaces. Mechanical disturbances such as those produced by plowing, vehicular traffic, construction work, or street sweeping can resuspend surface dust. However, air-monitoring data and resuspension factors do not account for the total Pu hazard in residential areas (*16*). Some examples of other types of potential exposure to Pu in the respirable dust on the surface of the soil are listed below.

1) Children playing on the ground or adults working outdoors can pick up mud and dirt on their shoes and clothing and thus introduce dust into their homes. Washing and drying of contaminated clothes can release significant amounts of dust through the exhaust of the dryer. Such a mechanism of exposure has been demonstrated by the finding of characteristic neoplasms in the wives of asbestos workers (*17, 18*). Dust can also enter a house through windows and ventilating systems and be resuspended by household vacuuming and other cleaning operations (*19*). Pets track in fine particulates, which may eventually become airborne. These conditions can occur even if a developed area has grass cover.

2) Children playing outdoors may eat food with soiled hands and in other ways ingest or inhale unusual amounts of dust. Heavy-metal intake by this method was found to be important in children with lead poisoning who lived near a smelter at El Paso, Texas (*20*).

3) Heavily used playgrounds tend to be dusty, and strenuous playground activity can result in suspension and inhalation of dust by children.

4) Local resuspension of dust may occur in the preparation and maintenance of domestic gardens. Plutonium that has been plowed under before residential development may again be exposed by digging for gardens.

The present regulatory code in Colorado requires that soils with radiation contamination that surpass the interim standard of 2 dpm per gram of whole soil must receive special treatment to reduce the hazard to acceptable levels (*7*). Mixing the soil by plowing is presently accepted as one technique for treatment of contaminated land. We believe that this is an insufficient treatment because (i) plowing tends to displace the Pu particles from the ground surface to some position at depth, but the Pu is still in the soil; (ii) a treated area can be recontaminated either from untreated land upwind or from subsequent accidental releases of radioactive material; and (iii) subsequent disturbance of the soil by construction activity or cultivation by home gardeners may expose Pu particles at the surface again.

Useful data for evaluating the health hazards of Pu contamination of soil may be obtained by determining the amount of Pu in the respirable-dust fraction (material ≤ 5 μm) on the surface of the soil. It would be more realistic to base interim standards on the respirable-dust fraction because the very small particles in this fraction have the greatest potential for suspension and inhalation.

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17 February 1976; revised 27 April 1976

The Public Health Risk
of Disturbing the Soil Along Indiana Street
for Jefferson Parkway Construction

Randy Stafford, Member
Jefferson Parkway Advisory Committee
May 17, 2018

Introduction

This paper states my position on the public health risk of disturbing the soil along Indiana Street for construction of the Jefferson Parkway. It is written for contemplation by my fellow members of the Jefferson Parkway Advisory Committee (JPAC), in preparation for our May 17th, 2018 meeting, at which consideration of this topic by the committee will commence.

My position on this issue is informed by intensive research over the last year into studies of offsite soil contamination from the Rocky Flats Nuclear Weapons Plant (RFNWP), and into studies of potential health impact of the contamination on the downwind population. That research involved obtaining copies of pertinent studies and documents, some rare and hard to find, through visits to the CU Norlin Library's Special Collections and Archive unit, Freedom of Information Act requests to the Department of Energy (DoE), and visits to the Federal Records Center and US District Court clerk's office to review the case files and exhibits from *Church v. United States* and *Cook v. Rockwell* (two important lawsuits in Rocky Flats history, both of which were settled or decided for the plaintiffs).

I undertook this research after becoming interested in Rocky Flats contamination and consequences from reading Kristen Iversen's book *Full Body Burden*, and Caron Balkany and Wes McKinley's book *The Ambushed Grand Jury*. In fact the starting points for my research were the endnotes in those books, though the research pulled in additional sources as it fanned out and ran its course.

It is my position, based on all the relevant information I've reviewed, that disturbing the soil along Indiana Street for construction of the Jefferson Parkway could pose a significant risk to public health downwind of the site. That is because:

(i) The soil along Indiana Street is contaminated with plutonium to levels representing hundreds of times background radiation;
(ii) Available evidence demonstrates increased rates of cancers in the downwind population from 1969 (first year studied) through today;
(iii) Inhalation of plutonium-laden dust is the exposure pathway of greatest concern, and construction activities could raise large volumes of respirable plutonium-laden dust into the air and wind; and
(iv) There could exist undetected and unremediated nuclear waste burial sites that could be encountered during parkway construction.

Because of this potential significant public health risk, it is also my position that the Jefferson Parkway Public Highway Authority (JPPHA) should take certain definite steps to further characterize and mitigate the risk prior to commencing construction of the parkway, as a matter of moral obligation.

The remaining sections of this paper provide the substantiation of the contentions listed above, and an enumeration of the definite steps I believe the JPPHA has a moral obligation to take before progressing with the parkway.

<u>Plutonium Contamination in the Indiana Corridor</u>

Eleven studies from a variety of sources spanning 43 years have all consistently found plutonium contamination in the soil along the Indiana Street corridor at levels representing hundreds of times background radiation from fallout from atmospheric nuclear weapons testing. This soil was not remediated in the Rocky Flats cleanup, which was limited to just the former industrial area of the nuclear weapons plant. Since plutonium-239 has a half-life of 24,100 years, that contamination remains in place except to the extent the plutonium is moved by weather elements or the activities of animals and humans. Figure 1 shows the locations of soil samples from these studies, and the multiples of background radiation found in the samples. Subsequent paragraphs summarize each study and contain links to copies of each study.

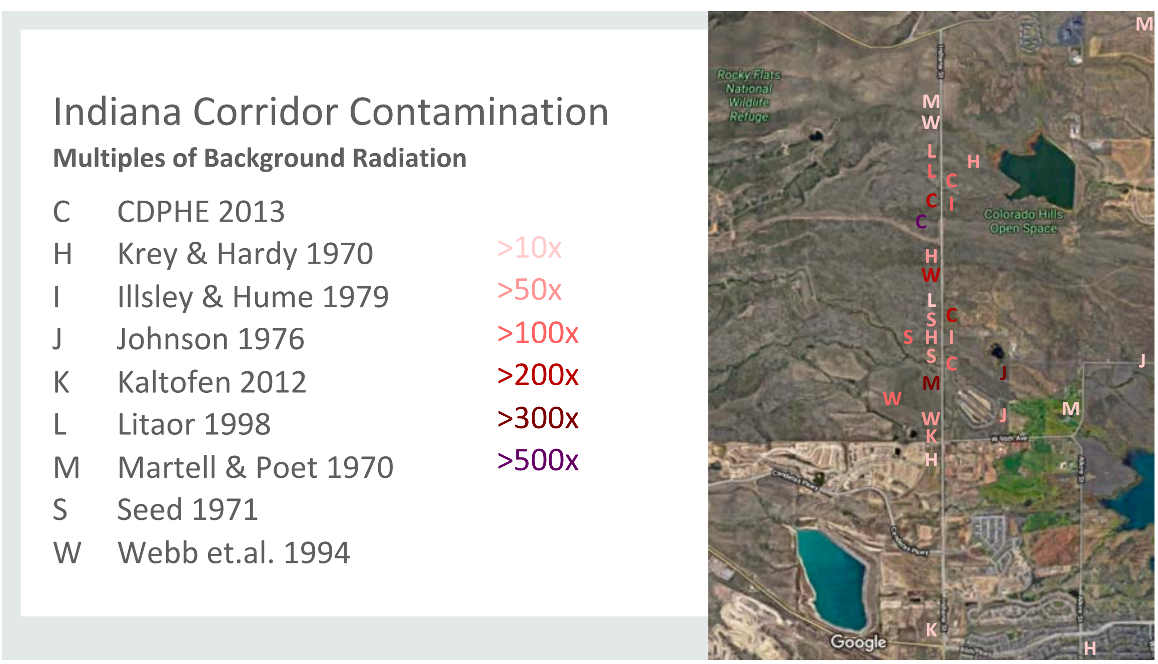

Figure 1: Locations of samples containing high multiples of background radiation from studies of offsite soil contamination. The letter identifies the study containing the sample, and the color indicates the multiple of background radiation found in the sample, using 0.0434 dpm/g as background.

The first study of offsite soil contamination was conducted by Ph.D. radiochemist Dr. Edward Martell, after the Mother's Day 1969 fire at the Rocky Flats plant. A West Point graduate who'd studied radiation effects on humans from nuclear weapons tests in the Pacific, Dr. Martell was working at the National Center for Atmospheric Research in Boulder at the time of the 1969 fire, and became concerned about possible contamination releases. Dr. Martell collected offsite soil samples in August 1969, and first published his findings in a January 1970 letter to the chairman of the United States Atomic Energy Commission (USAEC). Photographs of that letter, and Dr. Martell's report on his findings, are stored in a folder on my Google Drive at https://drive.google.com/open?id=1ovD5Rb-1_bbiLhM2rWDTys-zlzlYib__. He found 311x background at Indiana Street and Woman Creek. Dr. Martell also measured background radiation at 0.0434 disintegrations per minute per gram (dpm/g) of soil at Boyd Lake, CO.

In response to Dr. Martell's findings, the USAEC sent two scientists from its Health and Safety Laboratory, P.W. Krey and E.P. Hardy, to conduct their own study. Krey and Hardy produced a report dated August 1, 1970, which confirmed Martell's findings, and which contained the original "Krey Hardy map" showing offsite plutonium isopleths. An enhanced version of the Krey Hardy map in wide circulation is appended as Figure 2, and a scan of Krey and Hardy's original report is located at https://drive.google.com/open?id=1Uetf4i28YV9IkjghykYukj2ctPWjjeIp.

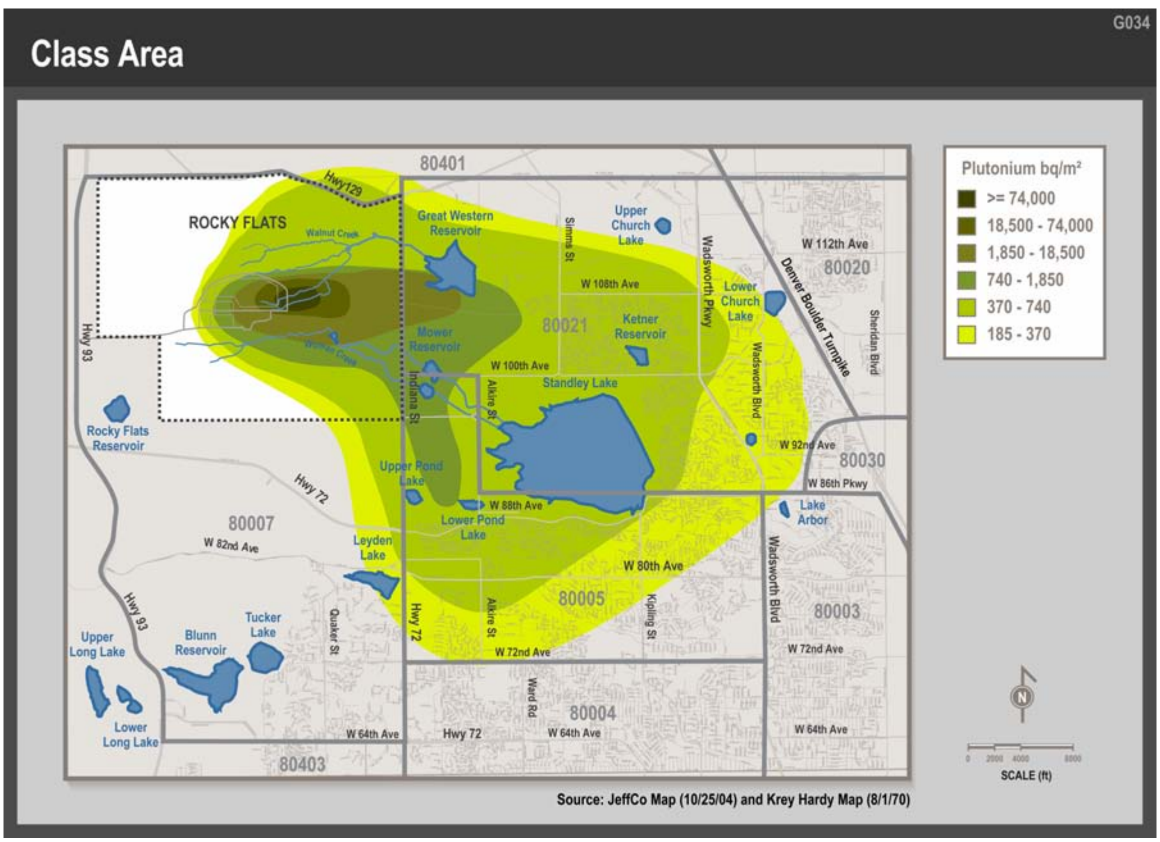

Figure 2: The enhanced version of the Krey Hardy map with colored plutonium isopleths in Bq/m². Note that 1,850 Bq/m² represents 171x background radiation, using 0.0434 dpm/g as background.

RFNWP operator Dow Chemical then conducted its own study to assess the accuracy of Martell's, and Krey and Hardy's, findings and reports. Dow appointed a committee of its employees, chaired by Robert Seed, to do the work. Thus the committee's report became known as "The Seed Report". Not only did The Seed Report corroborate Martell's and Krey and Hardy's findings, but it also produced a new isopleth map, which the authors claimed was more accurate than the Krey Hardy map. That map is reproduced as Figure 3, and a scan of the Seed report is at https://drive.google.com/open?id=1PK5vdsvPy7AsAkm_N2U5SA4OGynpF9hV.

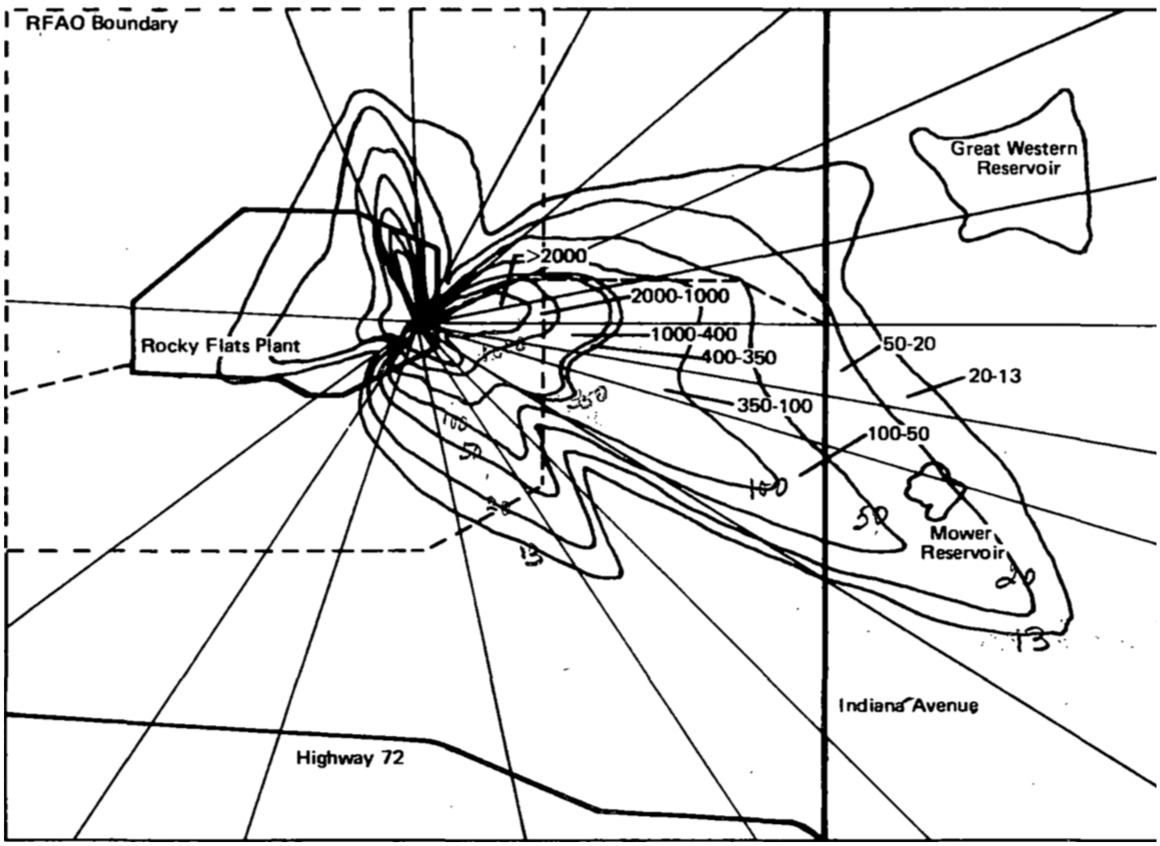

Figure 3: The plutonium isopleth map from The Seed Report, in picocuries per gram (pCi/g) of soil. The 100-50 pCi/g band crossing Indiana Street represents 341-171x background radiation. Note the plant boundary at the time did not include the "buffer zone". Because of the contamination found, The Seed Report recommended purchasing additional land around the plant as a buffer zone, which happened.

After the initial spate of studies triggered by the 1969 fire, the next significant offsite soil contamination study was conducted by Jefferson County Health Director Dr. Carl Johnson and published in Science magazine in 1976. Dr. Johnson held an MD degree from the Ohio State University and an MPH from the University of California at Berkeley, and specialized in radiation and epidemiology. His study was conducted at the request of the Jefferson County Board of Commissioners in relation to planning and zoning requests for new residential development east of Rocky Flats, so Dr. Johnson analyzed soil in sections of land between Indiana and Alkire Streets, and 88th to 112th Avenues. Some of his findings are tabulated in Table 1, and photographs of his Science magazine article are at https://drive.google.com/open?id=1S11NkXwgGyCI3XIoV_d_Py6ZbyHceZua.

Table 1: Dr. Johnson's findings of plutonium concentrations in offsite soils east of Rocky Flats.

Location	Concentration	x Background
Section 7 (Indiana to Alkire, 104th to 112th)	14.1 dpm/g	325x
Section 18 (Indiana to Alkire, 96th to 104th)	2.96 dpm/g	68x
Section 19 (Indiana to Alkire, 88th to 96th)	0.23 dpm/g	5x
Section 8 (Alkire to Simms, 104th to 112th)	0.72 dpm/g	17x

In 1975 Marcus Church, heir of the homesteaded Church Ranch, part of which was appropriated by the United States government in 1951 to create the RFNWP, sued the United States government for contaminating his surrounding ranchland and thereby lowering its value for residential development. As part of the defense in that lawsuit, two employees of Rockwell International Corporation (which succeeded Dow Chemical as RFNWP operator) named C.T. Illsley and M.W. Hume conducted a study in 1979 sampling soil at 71 locations outside the plant boundary. Illsley and Hume found hotspots as high as 174x background just east of Indiana Street, as circled in Figure 4 below. Photographs of their study are at https://drive.google.com/open?id=1UuGwRB7onXLdH6EO1bTx04pPZPgdIAyF.

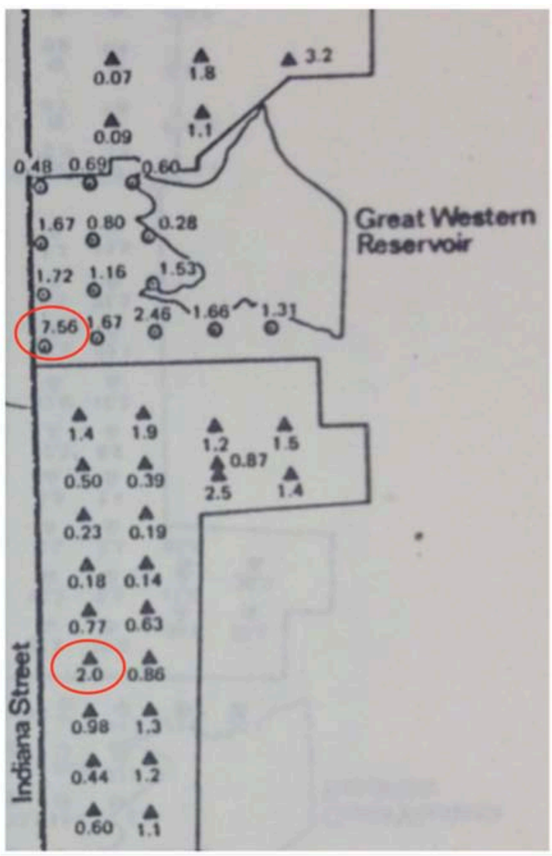

Figure 4: Hotspots found by Illsley and Hume in dpm/g. Note 7.56 dpm/g is 174x background.

Former plant engineer and whistleblower Jim Stone teamed with CSU professor Dr. Ward Whicker and two other authors in 1994 to conduct a study titled "The Spatial Distribution of Plutonium in Soil Near the Rocky Flats Plant." The soil sampling locations in this study are mapped in Figure 5, below. At location AX6 on the southwest corner of Indiana Street and East Gate Road, the study found a hotspot of 211x background radiation. Further south at location CX6 the study found a 100x background hotspot, and at location CX7 a 40x background hotspot 12-15" deep in the soil. A scan of this study is located at https://drive.google.com/open?id=11U7lSZ0CWhYjx7fkAYKB4UeuVCBWLO-O.

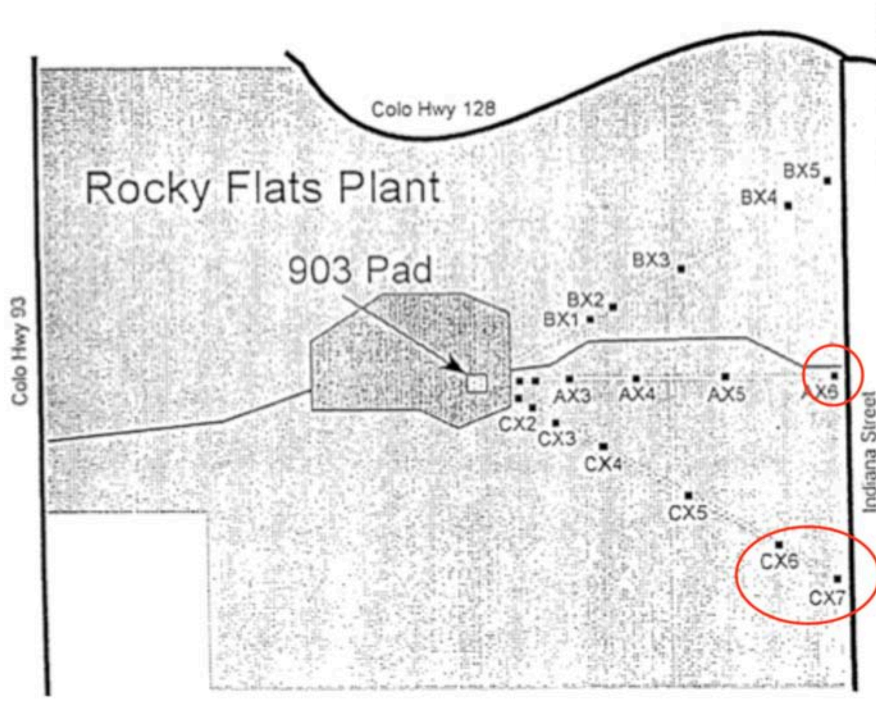

Figure 5: Sampling locations in the Webb / Stone / Ibrahim / Whicker study. A 211x background hotspot was found at AX6, and a 40x background hotspot at CX7 12-15" deep.

Dr. Iggy Litaor published a study titled "Plutonium Contamination in Soils in Open Space and Residential Areas Near Rocky Flats, Colorado" in *Heath Physics* 17: 171-179, 1998. Dr. Litaor held a Ph.D. with post-doctoral research in soil geochemistry, and had worked at Rocky Flats since 1990 for successive operators EG&G and Kaiser Hill. His study not only found plutonium hotspots of 111x and 71x background just east of Indiana Street, but also analyzed the ^{240}Pu:^{239}Pu isotope ratio in the soil samples to confirm Rocky Flats as the origin of the found plutonium (since Rocky Flats plutonium has a different isotope ratio than background fallout plutonium). Figure 6 below shows the isotope ratios, and offsite isopleths found by Dr. Litaor's study. Photos of this study can be viewed at https://drive.google.com/open?id=19FcOUlQyR1rL1LKf7q-r7-MUg0nIAj_T.

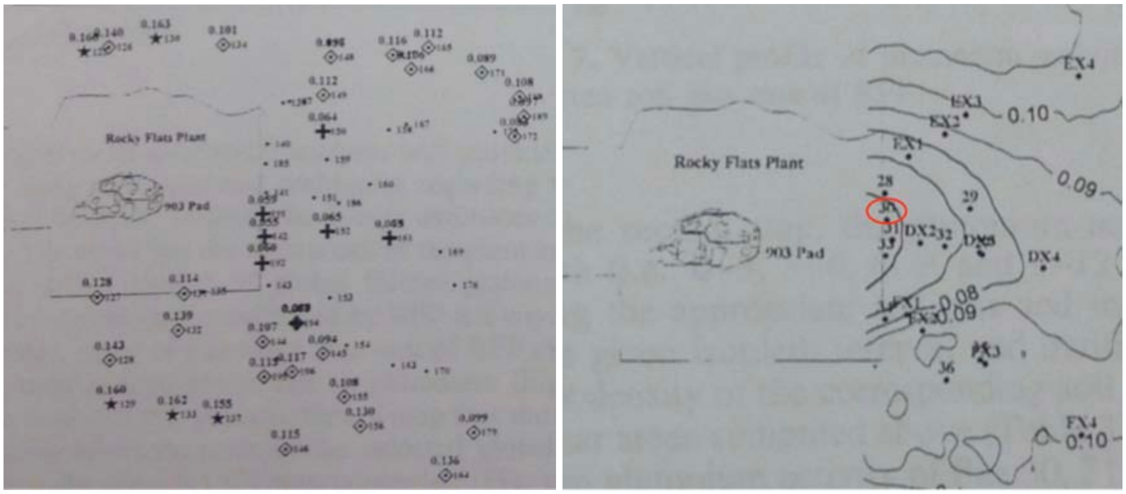

Figure 6: Plutonium isotope ratios (at left) found in Dr. Litaor's study. Ratios of 0.06 are Rocky Flats plutonium. Ratios of 0.16 are fallout plutonium. Ratios in between are a weighted blend. At right, sampling location 30 yielded 111x background radiation, and location 28 yielded 73x.

Colorado Governor Roy Romer appointed a Health Advisory Panel in 1990 to oversee a Rocky Flats Historical Public Exposure Studies project – a dose reconstruction study - administered by the Colorado Department of Public Health and Environment (CDPHE). That Health Advisory Panel in turn created a Citizens Environmental Sampling Committee which collected and analyzed offsite soil samples in 1994. An article describing this work was subsequently published in 2004 in the Journal of Environmental Radioactivity by Todd Margulies, Neils Schonbeck, and three other authors. Their article, a scan of which is available at https://drive.google.com/open?id=15aqk0m4T2ENjU8Fvi34A1f4t95QQhK1V, contains the following conclusion:

> Results in this paper correlate well with concentrations and distribution of ^{239,240}Pu reported by previous investigators and summarized and analyzed by Litaor et al. (1995). Overall, data collected in this study were consistent with prior results in areas known to have been affected by past releases. Activity of ^{239,240}Pu in soil close to the eastern edge of the Rocky Flats Plant boundary was 10–100 times higher than average background from fallout.

Another product from this work, available at https://www.lm.doe.gov/cercla/documents/rockyflats_docs/OU03/OU03-A-000585.pdf, states the following conclusion:

> The sampling results confirm conclusions from past soil studies: plutonium was released by the Rocky Flats Plant to the nearby off-site environment, generating soil concentrations above the upper limit of background

> expected from nuclear weapons testing fallout. The elevated plutonium values correspond in magnitude and location to those reported by other researchers, but the scope of this study cannot exclude the possibility of having missed hot spots.

The Agency for Toxic Substances and Disease Registry (ATSDR), associated with the Centers for Disease Control (CDC), was created by the 1980 "Superfund" legislation (formally, the Comprehensive Environmental Response, Compensation, and Liability Act, or CERCLA). The ATSDR maintains toxicological profile documents for a vast number of environmental contaminants, including plutonium. The ATSDR toxicological profile document for plutonium, available at https://www.atsdr.cdc.gov/toxprofiles/tp143.pdf, states the following with respect to Rocky Flats offsite soil contamination, on page 177:

> The highest off-site concentration of $^{239,240}Pu$ observed during a remedial investigation was 6,500 pCi/kg (240 Bq/kg). A separate sampling study conducted in the 1990s at 42 locations adjacent to RFETS measured $^{239,240}Pu$ concentrations in soil ranging from 0.22 to 14.80 Bq/kg (5.9–400 pCi/kg) (Litaor 1999).

Note that 6,500 pCi/kg represents 332 times background radiation, and 400 pCi/kg represents 20x background. Thus the ATSDR / CDC reports offsite contamination of 20-332x background.

The second most recent study and report of offsite soil contamination was conducted by Marco Kaltofen of Boston Chemical Data Corporation, under contract to Dr. LeRoy Moore of the Rocky Flats Nuclear Guardianship organization. Kaltofen's study collected 50 soil samples in 2010 and 2011 at locations in the Indiana Street corridor and elsewhere. In January 2012 Kaltofen reported his findings, including a detection of 81x background radiation just west of Indiana Street at 96th Avenue. Kaltofen's summation contains the following passages:

> Plutonium exceeded reported background levels by two orders of magnitude at locations that match those noted in the Krey Hardy report. (P. W. Krey and E. P. Hardy, 1970, "Plutonium in Soil Around the Rocky Flats Plant")
> …
> There was no statistically significant difference between this data set and the 1970 data set. Plutonium losses appear to be approximately equal in magnitude to plutonium inputs in the Indiana St. area.

The plutonium inputs to which Kaltofen alludes are most likely from contaminated soil areas upwind. Figure 7 shows the locations of plutonium detections in

Kaltofen's study, and his report may be viewed at
https://drive.google.com/open?id=1Nh-W49VbTU0S0P4BvzW2fNkBwD7Di2eL.

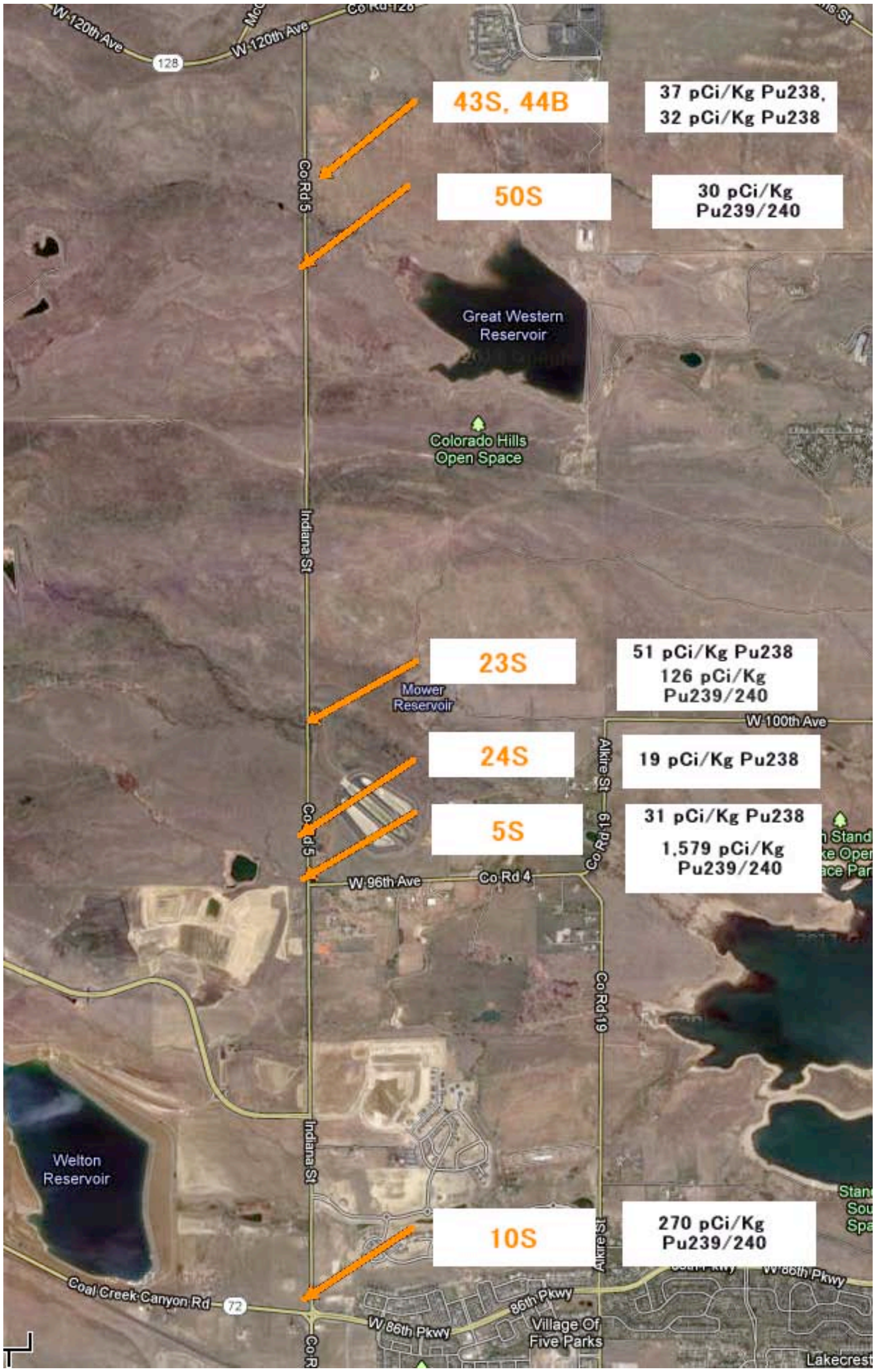

Figure 7: Locations and concentrations of plutonium detections in Kaltofen's 2011 study. Note that 1,579 pCi/kg at Indiana Street and 96th Avenue represents 81x background radiation.

Finally there is the CDPHE's own data, presented to the Rocky Flats Stewardship Council (RFSC) in 2013. At the RFSC's February 4th meeting that year, Carl Spreng of the CDPHE gave a presentation titled "Operable Unit 3 Offsite Areas", explaining the selected remedy / corrective action decision of "no action" in those offsite areas. That presentation is available at http://www.rockyflatssc.org/OU3-RFSC-4Feb13.pdf. Page 7 of that presentation is a CDPHE / DoE plutonium isopleth map in picocuries per gram of soil, reproduced below as Figure 8. Just west of Indiana Street at East Gate Road, there is a 10 pCi/g isopleth line. That concentration of plutonium, 10 pCi/g, represents 512x background radiation. Furthermore there is a 5 pCi/g isopleth, representing 256x background radiation, crossing Indiana Street to the east side.

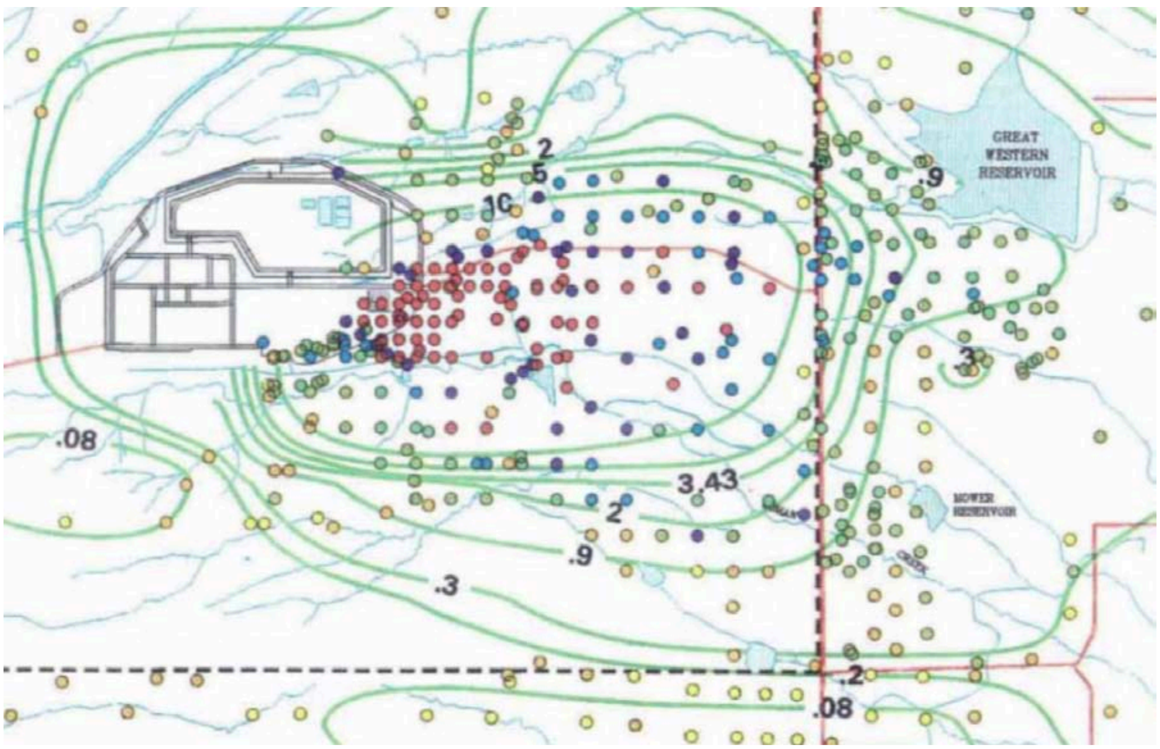

Figure 8: Plutonium isopleths in pCi/g from CDPHE's own 2013 presentation. Note 10 pCi/g just west of Indiana Street at East Gate Road represents 512x background radiation.

Summarizing plutonium contamination in the Indiana Corridor, the eleven studies cited above, spanning the years 1970-2013, have all consistently found plutonium contamination from the Rocky Flats Nuclear Weapons Plant in the Indiana Street corridor at levels representing hundreds of times background radiation.

Evidence of Increased Rates of Disease in the Downwind Population

Compared to the number of offsite soil contamination studies, there have been precious few studies of potential health effects of Rocky Flats contamination in the downwind population. Six studies have been performed, over the course of Rocky Flats history, of cancer incidence in areas surrounding the site. And another study analyzed plutonium content in tissues collected at autopsy from downwind residents compared to a control population. There never has been a comprehensive health-monitoring program for nearby residents, and no studies have been performed on potential health effects besides cancer. However there have been anecdotes about health impacts for nearly as long as the plant site has existed. The following paragraphs summarize and evaluate the available evidence, and the different viewpoints on risk and safety with respect to plutonium exposure.

Former Jefferson County Health Director Dr. Carl Johnson was the first person to study cancer incidence in the population downwind of Rocky Flats in comparison to cancer rates in areas further from the site. He was also the only investigator to ever publish such an epidemiological study in a peer-reviewed medical journal: "Cancer Incidence in an Area Contaminated with Radionuclides near a Nuclear Installation," *Ambio* 10: 176-182, 1981. Dr. Johnson reported the following findings based on comparing cancer incidence between geographical areas in the Denver metropolitan area separated by distance from Rocky Flats. The data were obtained at census tract granularity from the National Cancer Institute's Third National Cancer Survey 1969-1971 (i.e. new diagnoses made in those years).

1. Cancer incidence in males was 24% higher, and in females, 10% higher in the most contaminated suburban area nearest the plant, compared to the unexposed area.
2. The excess cases of cancer were mostly leukemia, lymphoma and myeloma and cancer of the lung, thyroid, breast, esophagus, stomach and colon, a pattern similar to that observed in the survivors of Hiroshima and Nagasaki.
3. Cancer of the gonads (especially of the testes), liver, and, in females, pancreas and brain contributed to the higher incidence of all cancer in areas near the plant.
4. The increase in incidence of all cancer and for certain classes of cancer in the exposed population supports the hypothesis that exposure of general populations to small concentrations of plutonium and other radionuclides may have an effect on cancer incidence.
5. Preliminary study of congenital malformations coded at birth found a rate of 14.5 per 1000 births for a large suburban city near the plant compared with a rate of 10.4 for the remainder of the county, and 10.1 for the state of Colorado, a difference of interest.
6. A most unexpected discovery was the unusually high incidence of cancer of the testis (40 cases observed/18 expected) throughout

> the exposed area. The incidence of cancer of the ovary was also higher (24%) throughout the exposed areas. The remarkably higher incidence of cancer of the testis in the three exposed areas merits special attention. One possible explanation is the demonstrated propensity of plutonium to concentrate in gonads. The higher incidence of cancer of the ovary is also consistent with this hypothesis.

A reprint of Dr. Johnson's *Ambio* article may be viewed at https://drive.google.com/open?id=1oPbKbMfiwmBp0gGTidYsisU83dX-0nYy.

Complementing Dr. Johnson's study, plaintiffs' counsel in *Church v. United States* Howard Holme, of the law firm Fairfield & Woods, hired CU physicist Stephen Chinn to perform additional analysis on the same Third National Cancer Survey 1969-1971 data set Johnson had studied. With advice from renowned radiation epidemiologist Dr. Alice Stewart and others, Chinn performed multiple regression analysis on the data set studied by Dr. Johnson, to identify which of some 50 factors were most strongly correlated with the increased cancer incidence near the plant discovered by Johnson. Chinn's findings were as follows:

1. Residence downwind of the Rocky Flats facility or in the area with plutonium contamination were the most significant risk correlates [in the higher cancer incidence nearer the plant].
2. Control for the other factors [socioeconomic status, air pollution, urban/rural factors, population mobility, and possible sources of carcinogens], singly or in combination, failed to account for the excess risk.
3. The excess was primarily of organs considered to be radiosensitive by the IRCP [International Commission on Radiological Protection] and was more pronounced in men than in women.

Chinn's report dated September 29, 1981 and titled "The Relation of the Rocky Flats Plant and Other Factors to 1969-1971 Cancer Incidence in the Denver Area", which was essentially part of the plaintiffs' pre-trial statement in *Church v. United States*, is at https://drive.google.com/open?id=1SMizzhf2Bxu4r5JrJOjJN9ryAtKrcCBz, in photographs. Since Chinn found downwind direction from the plant to be one of the most important factors in greater cancer incidence, Figure 9 below, excerpted from Chinn's report, shows an average wind rose from Rocky Flats for the years 1953-1970. As Figure 9 shows, the prevailing winds at Rocky Flats are from the west, sometimes with a northerly or southerly component, with an average velocity of 12mph.

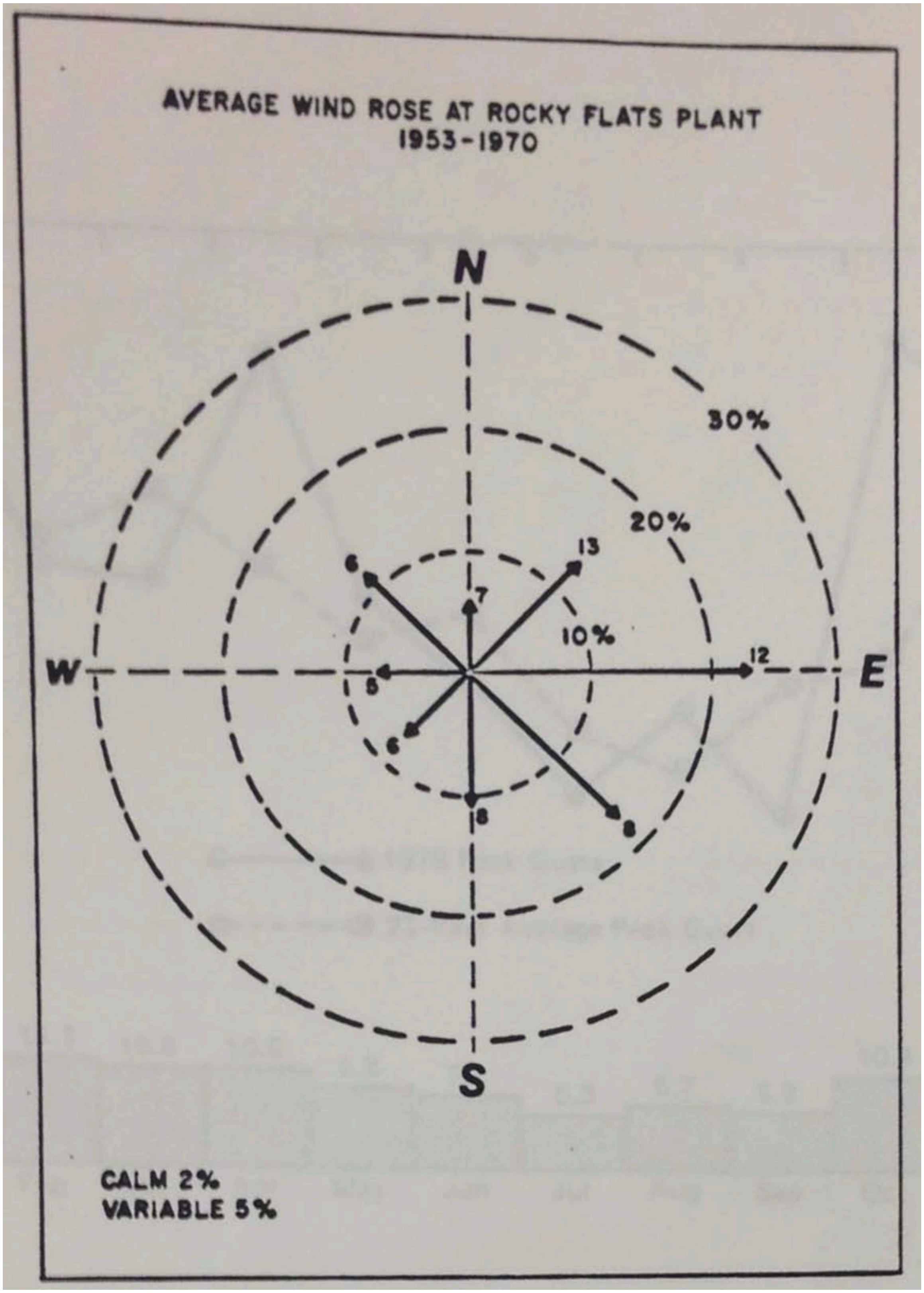

Figure 9: Average wind rose at Rocky Flats Plant 1953-1970. Arrows point in direction wind blows. Numbers at ends of arrows are wind velocity in MPH. Length of arrows and concentric circles reflect frequency of wind direction.

In response to the studies by Dr. Johnson and Stephen Chinn, a DoE-funded cancer incidence study was subsequently conducted, with its report completed in October 1984. This study and report were led by Kenny S. Crump for the Inhalation Toxicology Research Institute, a longtime Atomic Energy Commission contractor. Crump's report, titled "Statistical Analyses of Cancer Incidence Patterns in the Denver Metropolitan Area in Relation to the Rocky Flats Plant", contains the following statements in its executive summary:

> In Section II of this report, cancer incidence data for 1969 to 1971 are analyzed in a manner similar to that reported by Johnson. Ratios of observed/expected cancers were calculated for people living in four exposure areas determined by isopleths of plutonium concentrations in soil (contours of constant plutonium soil concentrations) that were used by Johnson. Area I is the area nearest the Rocky Flats plant and has the highest plutonium soil concentrations; Area IV consists of that part of the Denver SMSA outside of the lowest soil concentration contour. Cancer incidence patterns were analyzed for total cancer and 13 specific cancer types also studied by Johnson. Expected cancer incidences were based upon the cancer incidences in Area IV. *Johnson's results were closely reproduced using data collected for this study* [emphasis mine]. Statistically significant differences occurred between Area I and Area IV in total cancer and in the cancer categories of lung and bronchi, lymphoma and myeloma, colon and rectum, and testes for males, and in total cancer and colon and rectum cancer for females.

In later sections of the report, Crump applied an urbanization adjustment to his (and Johnson's and Chinn's) findings, which negated Johnson's and Chinn's conclusions of greater cancer incidence with closer proximity to Rocky Flats. This adjustment by Crump was later criticized as "highly unorthodox" by Dr. Richard Clapp, expert witness for the plaintiffs in *Cook v. Rockwell*, who holds a Doctor of Science in epidemiology from Boston University and a Master of Public Health from Harvard, and who was a former Director of the Massachusetts Cancer Registry. The study is at https://drive.google.com/open?id=1CfdH3NgLaeXz71NpPapVcn7e3G8LLyMA.

In the landmark case *Cook v. Rockwell*, the courts found in favor of the plaintiff class, homeowners east of Rocky Flats whose property was contaminated by the plant (trespass of contaminants onto their property, and nuisance of those contaminants, were the charges brought), and awarded the plaintiff class $375,000,000 in settlement on May 19, 2016. Plaintiffs' counsel presented Dr. Richard Clapp, described above, as an expert witness in the case, and admitted into evidence a study conducted by Dr. Clapp on cancer incidence downwind of the site. For his role in the case, Dr. Clapp first reviewed all previous studies of cancer incidence in the downwind population, sharply criticized the Crump study as mentioned above, and stated that Johnson's and Chinn's findings "provide justification for purposeful and ongoing medical surveillance of exposed populations" (which never happened). He then analyzed lung and bone cancer incidence for the years 1979-1992 as a function of proximity to Rocky Flats, and wrote the following in his report admitted into evidence.

> The most relevant finding is that for the time period 1989-1992, the risk of lung cancer was elevated in all the exposure scenarios comparing the two contours closest to the Rocky Flats plant to other contours further away. The odds ratios range from 1.09 to 1.29 depending on the exposure scenario and the sex of the cases. ... These years correspond to an approximate latency of 20-35 years from the time of maximum plutonium emissions from the plant and may therefore be more representative of a health effect in the exposed population.
>
> In addition, bone cancer incidence was examined in the same time periods and with respect to plutonium levels in soil (Krey and Hardy, 1970). ... In this analysis, there is evidence that the incidence of bone cancer in the Zip Codes in the inner two contours (the areas associated with the highest plutonium levels) was greater than in areas associated with lower plutonium levels further away. This is especially true in the period 1984-1988 when the adjusted odds ratio was 1.9.

The "odds ratio" of 1.29 for lung cancer means that according to the cancer incidence data, people closer to Rocky Flats had 29% more lung cancer cases than people farther away. The odds ratio of 1.9 for bone cancer means that people closer to Rocky Flats had 90% more bone cancer cases than people farther away. And the relevance of the 20-35-year latency period is that for cancers caused by internal bodily exposure to low-level ionizing radiation, there can be a latency period of decades (for adults) between exposure and disease onset, as documented in the ATSDR's toxicological profile for plutonium cited earlier. Dr. Clapp's report is at https://drive.google.com/open?id=1WkZVLjjye9TC37DmjOb8QwZZ06fb5rEz.

The CDPHE conducted cancer studies in 1998 and 2016, available at https://www.colorado.gov/pacific/cdphe/cdphe-rocky-flats-cancer-study. Though the CDPHE's website states the 1998 study was "independent" (meaning unknown), that study's acknowledgements page states "This project was supported in part by the U.S. Department of Energy State Health Agreement Program through grant #DE-

FG01-94EH89530." The studies analyzed incidence of ten selected types of cancer in ten Regional Statistical Areas (RSA) "selected primarily for their proximity to Rocky Flats." Those ten types of cancer were: esophagus, stomach, colon and rectum, liver, lung, prostate, bone, leukemias, lymphomas, and brain and central nervous system. The 1998 study's findings, echoed by later CDPHE studies, were:

> For the entire 10-RSA region and the 10 individual RSAs, the incidence of all [10 studied] cancers combined for persons of all ages and for children during 1980-1989 was not higher than expected compared to the remainder of the Denver Metro area. Also for the entire 10-RSA region, none of the ten selected cancers for persons of all ages was found to be higher than expected.

However the CDPHE studies have a number of design flaws limiting their ability to detect increased cancer incidence in the downwind population. Those flaws are:

1. The ten RSAs selected "for their proximity to Rocky Flats" include mostly areas that were not downwind and were not contaminated, for example north of US 36 and Highway 128, east of I-25, west of I-70, etc. See Figure 10 for a map of the RSAs studied. Since these areas were not as contaminated, it is expected that cancer incidence in those areas would be lower. That lower incidence dilutes the incidence found across the entire 10-RSA region. In the map in Figure 10, really only RSAs 202 and 203 should have been compared to "the remainder of the Denver Metro area".
2. Even the RSA granularity is too large to isolate cancer incidence increases as a function of distance and direction from the site. For example RSA 202, containing Standley Lake, stretches all the way from Highway 93 to east of US 36. Whereas Dr. Johnson worked at census tract granularity, and Dr. Clapp worked at zip code granularity, allowing their studies to focus on finer geographical units in relation to distance and direction from the site.
3. The list of cancer types studied had important omissions from the perspective of radiosensitive cancers, for example cancers of the gonads and thyroid. Therefore the studies weren't designed to find all of the data necessary to answer the question of whether there is increased incidence of radiosensitive cancers downwind of Rocky Flats.
4. The studies used estimates of population, therefore the accuracy of their findings is sensitive to the quality of their population estimation approach.
5. The 2017 supplement covering thyroid and "rare" cancers only analyzed 1990-2014 data, not also 1980-1989 data as in the 1998 study. Thus the 2017 supplement is incomplete.

As quoted in *The Ambushed Grand Jury* (p.200), radioecologist Bernd Franke, upon reviewing the 1998 CDPHE study, stated "It appears the study design was chosen for public relations purposes, to calm people down, rather than for any real scientific reason." Dr. LeRoy Moore has also sharply criticized the CDPHE study in a paper at https://drive.google.com/open?id=1bl3BCdPU8Os8e4Vf2CooXG1Q2UEk4ANQ.

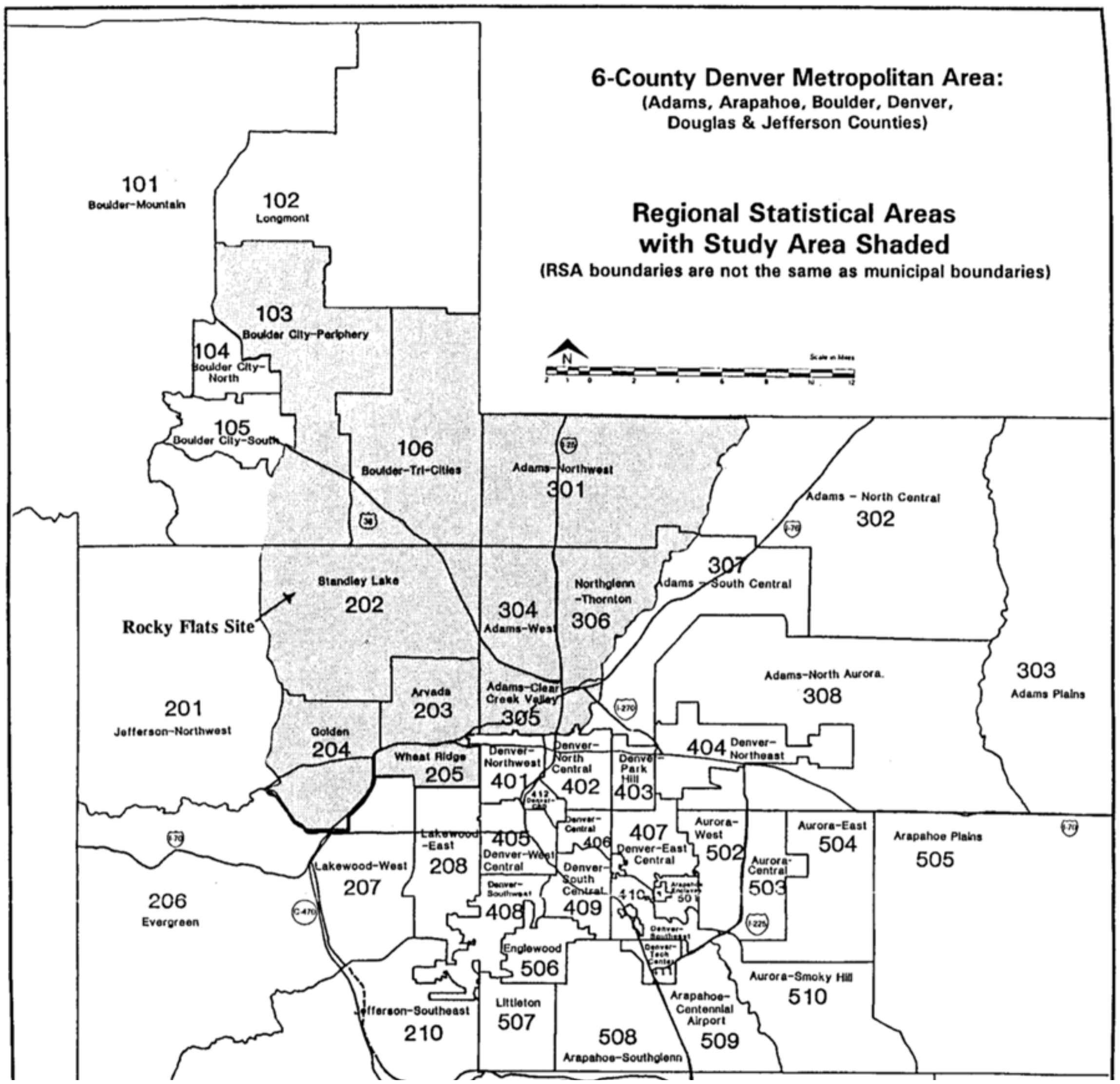

Figure 10: Regional Statistical Areas "selected primarily for their proximity to Rocky Flats" in the CDPHE cancer incidence studies.

In making assessments and representations about the safety of the Rocky Flats area currently, CDPHE relies upon mathematical models based on assumed safe standards of radioactivity in soil and assumed permissible doses of radioactivity in humans. The models relate contaminant concentrations in soil to committed doses of radiation in people, through different exposure scenarios for different groups of people, and relate those committed doses to excess cancer risk.

But a model is not reality. Paraphrasing from Dr. Eberhardt Rechtin's seminal work *Systems Architecting* from the aerospace industry, a model is an abstraction of how its creators think and hope a system works. What is actually observed from the system is almost always different. A quote from test flights of aircraft goes: "before the flight it's opinion; after the flight it's obvious." In this case the "flight" was the release of contaminants from the Rocky Flats plant.

Reality is the findings of Dr. Johnson's, Chinn's, and Dr. Clapp's epidemiological studies. Reality is the findings of Metropolitan State University's (MSU) Rocky Flats Downwinders Health Survey. Though not an epidemiological study, the survey's results suggest the need for new comprehensive epidemiological studies. The survey's preliminary findings revealed that 414 (49%) of 848 reported cancer cases were designated as rare cancers. The survey produced geo-plots, shown in Figure 11, of the addresses of respondents reporting cancer, overlaid with the path of the 1957 fire smoke plume, and with the Krey Hardy map. Those geo-plots are striking visual evidence of the potential correlation between Rocky Flats contamination releases and downwind disease incidence. A report on the survey's preliminary findings is at http://rockyflatsdownwinders.com/wp-content/uploads/2016/05/RFD-Health-Survey-Executive-Summary-Final.pdf.

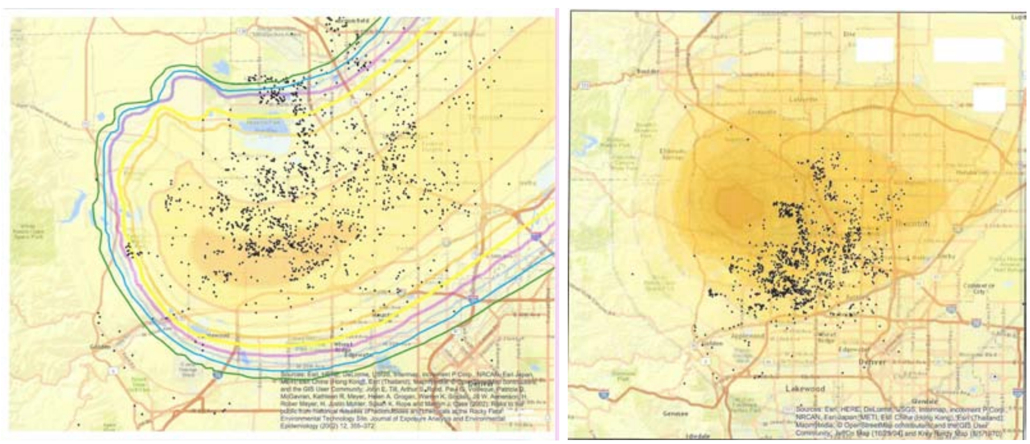

Figure 11: Geo-plots of cancer sufferers' addresses (black dots) from the MSU health survey overlaid at left with the path of the 1957 fire smoke plume and at right with the Krey Hardy map isopleths.

Reality is the disease incidence in Five Parks, a nearby downwind neighborhood at 86th and Indiana, which is only fifteen years old. In the last few years in that neighborhood there have been two cases of an extremely rare heart cancer, cardiac angiosarcoma, multiple cases of other radiosensitive cancers, and multiple cases of neurological disease. That cannot be all coincidence. Former Five Parks resident Elaine McNeely, widow of cardiac angiosarcoma victim Brian McNeely, describes the disease incidence in Five Parks at 59:10 of https://www.youtube.com/watch?v=9XTtu2DRb3k, in a public comment at the most recent Rocky Flats Stewardship Council meeting. KDVR news also ran this story: http://kdvr.com/2018/04/02/safety-concerns-continue-at-rocky-flats-months-ahead-of-new-trails-opening-up/. And there are many, many other anecdotes amongst Arvada residents of multiple family members, neighbors, friends, and classmates all dying of cancer, or having neurological disease, or thyroid conditions. The Facebook groups "Arvada Neighbors" and "Let's Talk, Arvada" are veritable gold mines of anecdotal evidence.

Reality is the study performed by former CU School of Medicine Professor and Department Chair of Preventative Medicine Dr. John Cobb. Dr. Cobb conducted a long-running EPA-funded study of plutonium content in deceased downwinders' lung and liver tissue, compared to plutonium content in the lungs and livers of a control population of deceased persons from Pueblo, Colorado. These tissues were collected at autopsy, with permission, from a total of 519 people. While the amount of plutonium in the downwinders' tissues was only very slightly higher than the amount in the Puebloans' tissues, the really important finding from Dr. Cobb's study was that the downwinders' tissue plutonium was definitely from Rocky Flats, based on analysis of ^{240}Pu:^{239}Pu isotope ratio (Rocky Flats plutonium has a different ratio of those isotopes than does atmospheric fallout plutonium). How did that Rocky Flats plutonium get into those downwinders' lungs and livers? That is an important question. Photographs of an affidavit by Dr. Cobb attesting to these findings are at https://drive.google.com/open?id=1mKMnlJiDSwBKWqulYhoRm0AdauhdnlXq.

Finally, reality is establishing a causal connection between Rocky Flats contamination and cancer, by analyzing tumor tissue or decedents' remains for Rocky Flats –specific plutonium. Precedent for establishing such a causal connection exists in the cases of Lloyd Mixon and Kristen Haag, for example. Lloyd Mixon was a rancher who lived downwind of Rocky Flats and who developed cancer (and who also observed a number of deformities in his ranch animals). In the movie *Dark Circle*, Mr. Mixon describes having his excised malignant tumors analyzed for plutonium, with positive findings. Kristen Haag was a downwind teenager who died of cancer after having a leg amputated because of the same cancer. She was cremated, and her ashes were analyzed for Rocky Flats plutonium, with positive findings. In *Dark Circle* her father Rex Haag tells Kristen's story, and her case is also described in *Full Body Burden*.

In light of those realities, the assumptions upon which CDPHE relies, about safe standards of plutonium in soil, and permissible doses of plutonium in humans, could very well be invalid. In January 1973, then-Director of the Colorado Department of Health (CDPHE's former name) established for the first time a plutonium soil standard of 0.2 dpm/g for Colorado, writing that level of contamination "presents a sufficient radiation hazard to the public health to render the land unfit for residential use, subdivision development, or commercial and industrial uses." But because the existing contamination already exceeded that threshold by an order of magnitude as far away as east of US 36 and south of 64th Avenue, the standard was arbitrarily changed to 2.0 dpm/g just a few months later. A photo of the public notice of the initial (0.2 dpm/g) soil standard is at https://drive.google.com/open?id=1n1imFzFR53h5qaF88lwERczWJXTKAqxD.

Regarding permissible doses of plutonium, pioneers in the fields of health physics, nuclear chemistry, and radiation epidemiology have all stated under oath in court proceedings that there is no safe level of exposure to plutonium for human beings. The documentary film *Decision at Rocky Flats* (https://vimeo.com/groups/161968/videos/45547905), about the 1978 trespassing trial of the Rocky Flats Truth Force, contains the testimony of these pioneers starting at 07:45. Dr. Karl Morgan (https://en.wikipedia.org/wiki/Karl_Z._Morgan) testified that "there is no dose, no exposure, to ionizing radiation so low that the risk is zero" and that "the cancer risk is much, much greater than it was thought to be when these earlier standards [of permissible dose] were established," and that those standards create a false sense of security. Dr. John Gofman (https://en.wikipedia.org/wiki/John_Gofman) testified that "I don't find any permissible dose to be permissible, because to me a standard or a permissible dose is simply a legalized permit to commit murder. So I don't think of things as a permissible, I think of things only in how many deaths there will be per unit dose, which is the only scientifically meaningful thing." A 2004 report by a United Kingdom government committee also found that cancer risk from plutonium may be an order of magnitude greater than previously thought (https://www.newscientist.com/article/dn6152-plutonium-cancer-risk-may-be-higher-than-thought/).

Despite CDPHE's mission stated in its 2016-2019 strategic plan (https://www.colorado.gov/pacific/sites/default/files/OPP-StrategicPlan2016-19-July2017.pdf), "to protect and improve the health of Colorado's people and the quality of its environment," CDPHE has never conducted a health monitoring program for the population downwind of Rocky Flats, instead choosing to rely on modeling and assumptions, and to publish studies with major methodological flaws, and to attack or ignore the large body of dissenting information from highly credible sources, all while being funded by the DoE. Measurement of actual public health would far outweigh modeling of hypothetical health risk, and would better align with CDPHE's stated mission.

Summarizing the evidence of increased rates of disease in the downwind population, three valid epidemiological studies by highly credible investigators have all found significantly increased rates of cancer in close proximity downwind of Rocky Flats than farther away. Two of these studies were expert reports in lawsuits against Rocky Flats that were settled or decided for the plaintiffs. Meanwhile the two DoE-funded studies have used highly unorthodox techniques, or major methodological flaws, to find no significant difference in cancer near Rocky Flats than elsewhere in the Denver Metropolitan area. To claim the area is safe, CDPHE relies on modeling that would be outweighed by measurement of the reality downwind, and on probably invalid assumptions about soil standards and permissible doses for plutonium.

Respirable Plutonium-Laden Dust Likely from Construction Activities

With respect to the plutonium contamination in the soil along the Indiana Street corridor (consistently found by eleven different studies spanning the years 1970-2013), the exposure pathway of greatest concern for the surrounding population is inhalation of plutonium-laden dust. Quoting ATSDR's toxicological profile for plutonium again:

> **Plutonium can enter your body when it is inhaled or swallowed:** When you breathe air that contains plutonium, some of it will get trapped in your lungs. Some of the trapped plutonium will move to other parts of your body, mainly your bones and liver. The amount of plutonium that stays in your lungs depends on the solubility of the plutonium that is in the air you breathe.
>
> A small amount of the plutonium you swallow (much less than 1%) will enter other parts of your body (mainly your bones and liver).
>
> If plutonium gets onto your healthy skin, very little, if any, plutonium will enter your body. More plutonium will enter your body if gets onto injured skin, such as a cut or burn.
>
> **Plutonium in your body will remain there for many years:** Plutonium leaves your body very slowly in the urine and feces. If plutonium were to enter your lungs today, much of the plutonium would still be in your body 30–50 years later. [p.4]
>
> …
>
> Cancer is the major latent harmful effect produced by ionizing radiation and the one that most people exposed to radiation are concerned about. The ability of alpha, beta, and gamma radiation to produce cancer in virtually every tissue and organ in laboratory animals has been well-demonstrated. The development of cancer is not an immediate effect. Radiation-induced leukemia has the shortest latent period at 2 years, while other radiation induced cancers have latent periods >20 years. The mechanism by which cancer is induced in living cells is complex and is a topic of intense study. Exposure to ionizing radiation can produce cancer at any site within the body; however, some sites appear to be more common than others, such as the breast, lung, stomach, and thyroid. [p.D-9]

Further, former Jefferson County Health Director Dr. Carl Johnson's article in the peer-reviewed medical journal *Ambio*, titled "Cancer Incidence in an Area Contaminated with Radionuclides near a Nuclear Installation", states as follows:

> The major route of exposure is the inhalation of airborne particles of Pu and other radionuclides by people living in the path of exhaust plumes from the plant, and (for those living near the plant), the inhalation of Pu in resuspended surface dust.
> …
> Resuspension of Pu-contaminated soil increases with wind speed to the 2.1 power, and the ratio of Pu 238 to Pu 239 increases from about 2 percent (surface soil) to 20-40 percent in airborne soil (31). As much as 50 pCi/g of Pu in airborne soil has been reported in the area. A study of Pu particle size in the soil suggested that single Pu atoms and Pu particles with diameters less than the minimum detectable equivalent diameter (0.09 pm) accounted for the majority of Pu 239 and Pu 240 activity in the soil (32).

The reference (31) cited in Dr. Johnson's article was "G A Sehmel, in Transactions of Meeting on Rocky Flats Buffer Zone, Ecological and Environmental Research Meeting, (Rockwell International, Rocky Flats Plant, Golden, Colorado, 1977)." G.A. Sehmel was an expert on airborne particle resuspension and distribution. The reference (32) was "L M McDowell, S W Whicker, Health Physics 35, 239, (1978)" referring to an article titled "Size Characteristics of Plutonium Particles in Rocky Flats Soil".

Thus it is established that inhalation is the plutonium exposure pathway of greatest concern, and that resuspension of plutonium-containing Rocky Flats soil into the air increases as the square of wind speed at the site. All it takes to get highly carcinogenic Rocky Flats plutonium into a person's lungs is one unlucky breath on a breezy day.

Construction of the Jefferson Parkway will certainly raise dust into the air - dust from plutonium-contaminated soil in the Indiana Street corridor. Figure 12 below depicts construction activity on C-470 between Broadway and Santa Fe Drive at 12:53 p.m. on April 12th, 2018, when the wind at nearby Chatfield Reservoir was blowing 27mph and gusting to 44mph. The dust from a dump truck's tires, and from a bulldozer ahead of it, is plainly evident in the photograph, to the extent that it was creating a driving visibility hazard on westbound C-470. There is no reason to believe the same degree of dust resuspension will not occur during Jefferson Parkway construction, with the amount of cut-and-fill by heavy equipment contemplated by the project, and with the scope of a project the parkway's size.

Figure 12: Dust resuspended by construction on C-470 on a breezy day April 12th. Note the dust kicked up by the dump truck's tires, and a bulldozer ahead raising enough dust to create a visibility hazard.

Wind-borne dust can travel surprising distances. On April 17th the Colorado Front Range had a high wind event. Hurricane-strength gusts were recorded at A Rising Star Equestrian Center at 96th Avenue and Indiana Street. Farther south at Chatfield Reservoir, west winds gusted to 48mph at 3:00 p.m., and over 30mph from noon to 9:00 p.m. Chatfield State Park's facilities are currently undergoing massive reconstruction for the Chatfield Storage Reallocation Project (https://chatfieldreallocation.org). Consequently the swim beach is closed this summer, and the entire western shore of the lake has been excavated and rebuilt by trains of large earth movers. The next afternoon, April 18th, upon visiting my 30-foot sailboat in the marina, I found her white decks to be covered with reddish-brown dirt from the lake's western shore. The distance from the western shore excavation to the marina is over a mile. Dust from that windstorm traveled that distance in a single afternoon.

Undetected Buried Nuclear Waste Possible in Parkway Right-of-Way

There is a possibility, however remote, that undetected nuclear waste burial sites exist in ground that would be excavated for the Jefferson Parkway. Record-keeping as to the location and content of waste burial sites by the plant's operators was incomplete.

In *Church v. United States*, plaintiffs' counsel Howard Holme filed a 500-page pre-trial statement considered the most complete public account of accidents and contamination releases by the plant (see https://www.nytimes.com/1990/02/15/us/weapons-plant-pressed-for-accounting-of-toll-on-environment-and-health.html). During discovery for the court case, Mr. Holme reviewed 60,000 DoE and contractor documents onsite at the Rocky Flats plant. A scan of "the Holme report" is available for viewing at https://drive.google.com/open?id=1NjPLtcUaf7j_7-o_bMtWM1j5ERTu0sry.

On p.12 of Holme's pre-trial statement, he writes: "Besides the Mound, many other burials were made at Rocky Flats between 1954 and 1970. Recordkeeping was poor, and new burials were discovered as recently as the soil sampling hearings in 1977." On p.189 of Holme's pre-trial statement, he writes "due to incomplete record-keeping the number and location of burial sites at Rocky Flats is probably not known." This is in the context of very revealing transcripts of a "plant problems meeting" and a congressional Joint Committee on Atomic Energy meeting, spanning pp. 176-186 of the Holme report.

Jerry Harden worked at Rocky Flats for 37 years, retiring as a Senior Radiation Technician. He was a three-term president of Steelworkers Local 8031, which represented production workers at Rocky Flats. Mr. Harden is described further at https://leroymoore.wordpress.com/2011/02/21/rocky-flats-legacy-nuclear-workers-stories/. He was on the work crew that cleaned up the 903 area in 1968, pumping what remained of plutonium-laced oil from corroded barrels left out in a field into new drums, prior to removing the ~5,200 barrels from the 903 area for paving it over. Mr. Harden has stated publicly that he thinks there will be revelations coming from this site for many decades to come. In 2010 he testified in the Colorado legislature in favor of HB1127 proposing signage at Rocky Flats to inform visitors of the site's history and risks. Mr. Harden has also stated to me that if he could survey the site in its current state with a Micro-R gross survey instrument, he is confident that he "could find things".

Given the incomplete record-keeping as to waste burial locations and contents discovered by Howard Holme, and given the predictions about the site made by a very prominent worker there, it's entirely possible that waste burial locations exist in the former buffer zone that were not identified in the cleanup planning. If a piece of heavy equipment involved in excavation for Jefferson Parkway construction were to plow into an unknown cache of deteriorated barrels of nuclear waste, that would constitute a fairly major environmental crisis.

Steps JPPHA Has a Moral Obligation to Take Before Building

Thus it is my position that, given the well-studied existence of hundreds of times background radiation in the Indiana corridor, and given the evidence of increased cancer and disease in the downwind population, and given the certainty that Jefferson Parkway construction will resuspend highly carcinogenic respirable plutonium-laden dust into the air, and given the unignorable possibility of encountering an unknown nuclear waste burial site during construction, the Jefferson Parkway Public Highway Authority has a moral obligation to the local citizenry, as an inter-governmental entity directed by elected representatives of local governments, for the sake of public health, to take certain steps before proceeding with construction of the project. These steps are enumerated and elaborated in the following paragraphs.

1. The JPPHA should sponsor an independent review, by a qualified national institution independent of the Department of Energy, of all past studies of buffer zone and offsite soil contamination, and of public health impacts of Rocky Flats contamination. The National Academy of Sciences is a leading example of a candidate institution. Such a review would have the potential to quell, for all time, any conflict between any findings of different studies of these matters in the past.
2. The JPPHA should sponsor new studies of current contamination levels of soil that would be disturbed by parkway construction, to understand what contamination and therefore risk is present, prior to commencing construction. We are fortunate to have in Denver a highly-qualified potential investigator of plutonium contamination in Indiana corridor soils, in Dr. Michael Ketterer of Metropolitan State University, who specializes in precisely this field of study.
3. The JPPHA should seek to review ALL available sources of information about buffer zone and offsite contamination, in order to know everything possible about contaminant releases and potential environmental conditions, as part of making a morally responsible decision about whether and how to proceed. In particular, the JPPHA should seek to understand exactly how any cleanup was done in the parkway right-of-way strip, and exactly how it knows the area is “safe”.
4. The JPPHA should consider changing the alignment of the parkway to go up Highway 93 and cut across to the Northwest Parkway from north of Rocky Flats, to avoid the whole controversy. Such an alignment may ultimately have less cost to the JPPHA than dealing with the controversy over, and mitigation of, contamination in the Indiana corridor.

5. Failing step 4 above, the JPPHA should develop very effective techniques for mitigating public health risk if constructing the parkway up Indiana Street. For example, suspending construction activity any time wind speeds increase above Force 2 on the Beaufort scale, and using highly effective dust suppression techniques at all times, which don't cause runoff of soils into local waters near the site.

November 21, 2016

AN OPEN LETTER TO THE COLORADO DEPARTMENT OF PUBLIC HEALTH & ENVIRONMENT

Carl Spreng
State Project Manager for Rocky Flats
Colorado Department of Public Health & Environment
carl.spreng@state.co.us

Re: Residents Living Downwind of the Rocky Flats Nuclear Weapons Plant

Dear Mr. Spreng:

Thank you for attending the Rocky Flats Downwinders Health Survey Preliminary Findings Community Meeting on November 18, 2016. As you were informed at the meeting, and has now been reported on Channels 4, 7, 9 and 31 and in the Denver Post, Boulder Daily Camera, and Westword, the preliminary findings reflect an abnormally high level of thyroid cancer and "rare cancers" (those normally only affecting less than 15 of 100,000 people per year).

At the meeting, you admitted that no prior community health survey has ever been performed in which community members were directly asked about illnesses which may have been caused by Rocky Flats contamination. However, you commented that a Report to the Health Advisory Panel on Rocky Flats was prepared in 1998 by the Colorado Department of Public Health and Environment (the "Public Health Department") which utilized Colorado Central Cancer Registry information to determine that no higher rate of cancer was detected in residents living downwind of Rocky Flats versus the general population (the "1998 Report").

Unfortunately, as pointed out in the meeting by Professor Carol Jensen, the 1998 Report did not include a study of thyroid cancer. This omission is shocking in that thyroid cancer is one of the most common cancers caused by ionizing radiation exposure and it is abnormal levels of thyroid cancer which have been detected in the preliminary results of the Rocky Flats Downwinders Health Survey. The National Cancer Institute reports on its website under cancer causes, radiation and nuclear accidents that radioactive isotopes "accumulate in the thyroid gland, an organ in the neck" and "exposure to radioactive iodine may increase the risk of thyroid cancer many years later, especially for children and adolescents." Furthermore, "Radiation exposure of the thyroid at a young age is a recognized risk factor for the development of differentiated thyroid cancer lasting for four decades and probably for a lifetime after exposure." (Sinnott B, Ron E, Schneider A B, Exposing the Thyroid to Radiation: A Review of its Current Extent, Risks and Implications, Endocrine Reviews, 2010; 31(5), 756-773).

Consequently, Rocky Flats Downwinders, and the thousands of concerned citizens of which it represents, demand that the Public Health Department immediately undertake a comprehensive study of the Colorado Central Cancer Registry from 1980 (the approximate date the entire metro area began to be counted within the registry) to date to determine whether a higher rate of thyroid cancer exists in residents living downwind of Rocky Flats versus the general population. In addition, since the incidence of "rare cancers" was also not studied within the 1998 Report, but abnormally high rates of "rare cancers" have been detected in the preliminary findings of the Rocky Flats Downwinders Health Survey, it is also demanded that the Public Health Department include an examination of such "rare cancers" in its new study.

It is not lost on us that the 1998 Report is now over 18 years old and has not been updated even though it is known that cancer caused from radiation exposure can take decades to appear. Any conclusions drawn from the study detailed in the 1998 Report are also questionable given that the use of the Cancer Registry relies on zip codes and thus by definition does not include anyone who moves before being diagnosed with cancer. Given that the United States Census Bureau reports that the average American moves 11.4 times in their lifetime, the average Rocky Flats resident is likely to have moved away before any cancer possibly caused by Rocky Flats manifests itself decades later.

The time is now for the state of Colorado to use its resources to assist Rocky Flats Downwinders with outreach to residents (wherever they currently live) to have them complete the health survey and to fund a controlled study regarding the health of residents living next to the plant during its operation compared to the general population. Until and unless it does so, Colorado is failing to protect its residents. If Coloradoans have been negatively affected by radiation exposure, lifesaving health monitoring programs and compensation arrangements under the Radiation Exposure and Compensation Act ("RECA") should be made available to them just like they are to citizens of other states negatively affected by radiation exposure.

Very truly yours,

Nicholas P. Hansen, Esq.
Co-Founder Rocky Flats Downwinders
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IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF COLORADO
Judge John L. Kane

Civil Action No. **90-cv-181-JLK**

MERILYN COOK, et al.,

Plaintiffs,

v.

ROCKWELL INTERNATIONAL CORPORATION AND THE DOW CHEMICAL COMPANY,

Defendants.

JURY VERDICT FORM

We the jury in the above entitled case, being first duly empaneled and sworn and having heard the evidence at trial and being instructed in the applicable law, present our Answers to the Questions submitted by the Court, to which we have agreed as provided in Instruction No. 4.5.

¶ A. <u>Trespass Claim Against Defendant Dow Chemical Company</u>

With regard to Plaintiffs' claim against Defendant Dow Chemical Company ("Dow") for trespass (*Instruction Nos. 3.2 through 3.5)*, we find as follows:

1. Do you find that plutonium from Rocky Flats is present on the Class Properties *(see Instruction No. 3.3)*?

ANSWER: __X__ Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ B.

2. Do you find that Dow intentionally undertook an activity or activities that in the usual course of events caused plutonium from Rocky Flats to be present on the Class Properties *(see Instruction No. 3.18)*?

ANSWER: X Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ B.

3. Do you find it appears that this plutonium will continue to be present on the Class Properties indefinitely *(see Instruction No. 3.4)*?

ANSWER: X Yes ______ No

IF YOU ANSWERED "YES" TO QUESTION NOS. 1- 3 IN THIS PARAGRAPH, THEN YOU HAVE FOUND FOR PLAINTIFFS AND AGAINST DOW ON THIS TRESPASS CLAIM.

PLEASE GO TO ¶ B.

¶ B. <u>Trespass Claim Against Rockwell International Corporation</u>

With regard to Plaintiffs' claim against Defendant Rockwell International Corporation ("Rockwell") for trespass (*Instruction Nos. 3.2 through 3.5)*, we find as follows:

1. Do you find that plutonium from Rocky Flats is present on the Class Properties *(see Instruction No. 3.3)*?

ANSWER: __X__ Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ C.

2. Do you find that Rockwell intentionally undertook an activity or activities that in the usual course of events caused plutonium from Rocky Flats to be present on the Class Properties *(see Instruction No. 3.18)*?

ANSWER: __X__ Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ C.

3. Do you find it appears that this plutonium will continue to be present on the Class Properties indefinitely *(see Instruction No. 3.4)*?

ANSWER: __X__ Yes ______ No

IF YOU ANSWERED "YES" TO QUESTION NOS. 1- 3 IN THIS PARAGRAPH, THEN YOU HAVE FOUND FOR PLAINTIFFS AND AGAINST ROCKWELL ON THIS TRESPASS CLAIM.

PLEASE GO TO ¶ C.

¶ C. <u>Nuisance Claim Against Dow Chemical Company</u>

With regard to Plaintiffs' claim against Dow for nuisance (*Instruction Nos. 3.6 through 3.17)*, we find as follows:

1. Do you find Dow interfered with Class members' use and enjoyment of their properties in the Class Area in one or both of these ways: (A) by causing Class members to be exposed to plutonium and placing them at some increased risk of health problems as a result of this exposure *(see Instruction Nos. 3.7, 3.18)*; and/or (B) by causing objective conditions that pose a demonstrable risk of future harm to the Class Area *(see Instruction Nos. 3.7, 3.18)*?

ANSWER: __X__ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ D.

2. Do you find this interference with Class members' use and enjoyment of their properties was both "unreasonable" and "substantial" *(see Instruction Nos. 3.8 - 3.12)*?

ANSWER: __X__ Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ D.

3. Do you find the activity or activities causing the unreasonable and substantial interference by Dow were either "intentional" or "negligent" *(see Instruction Nos. 3.13 - 3.16)*?

ANSWER: X Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 3 IS "YES," THEN GO TO QUESTION NO. 4. IF YOUR ANSWER TO QUESTION NO. 3 IS "NO," THEN SKIP TO ¶ D.

4. Do you find it appears the unreasonable and substantial interference with the use and enjoyment of property caused by Dow's intentional or negligent conduct will continue indefinitely *(see Instruction No. 3.17)*?

ANSWER: X Yes ______ No

IF YOU ANSWERED "YES" TO QUESTION NOS. 1- 4 IN THIS PARAGRAPH, THEN YOU HAVE FOUND FOR PLAINTIFFS AND AGAINST DOW ON THIS NUISANCE CLAIM.

PLEASE GO TO ¶ D.

¶ D. <u>Nuisance Claim Against Rockwell International Corporation</u>

With regard to Plaintiffs' claim against Rockwell for nuisance (*Instruction Nos. 3.6 through 3.17)*, we find as follows:

1. Do you find Rockwell interfered with Class members' use and enjoyment of their properties in the Class Area in one or both of these ways: (A) by causing Class members to be exposed to plutonium and placing them at some increased risk of health problems as a result of this exposure *(see Instruction Nos. 3.7, 3.18)*; and/or (B) by

causing objective conditions that pose a demonstrable risk of future harm to the Class Area *(see Instruction Nos. 3.7, 3.18)*?

ANSWER: __X__ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ E.

2. Do you find this interference with Class members' use and enjoyment of their properties was both "unreasonable" and "substantial" *(see Instruction Nos. 3.8 - 3.12)*?

ANSWER: __X__ Yes ______ No.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ E.

3. Do you find the activity or activities causing the unreasonable and substantial interference by Rockwell were either "intentional" or "negligent" *(see Instruction Nos. 3.13 - 3.16)*?

ANSWER: __X__ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 3 IS "YES," THEN GO TO QUESTION NO. 4. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ E.

4. Do you find it appears the unreasonable and substantial interference with the use and enjoyment of property caused by Rockwell's intentional or negligent conduct will continue indefinitely *(see Instruction No. 3.17)*?

ANSWER: __X__ Yes ______ No

IF YOU ANSWERED "YES" TO QUESTION NOS. 1- 4 IN THIS PARAGRAPH, THEN YOU HAVE FOUND FOR PLAINTIFFS AND AGAINST ROCKWELL ON THIS NUISANCE CLAIM.

PLEASE GO TO ¶ E.

¶ E Actual Damages for Trespass

IF YOU DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ A (TRESPASS BY DOW) OR ¶ B (TRESPASS BY ROCKWELL), PLEASE SKIP TO ¶ F (ACTUAL DAMAGES FOR NUISANCE).

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ A (TRESPASS BY DOW), BUT DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ B (TRESPASS BY ROCKWELL), GO TO QUESTION NO. 1 IN THIS PARAGRAPH.

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ B (TRESPASS BY ROCKWELL), BUT DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ A (TRESPASS BY DOW), SKIP TO QUESTION NO. 6 IN THIS PARAGRAPH.

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ A (TRESPASS BY DOW) AND IN ¶ B (TRESPASS BY ROCKWELL), SKIP TO QUESTION NO. 11 IN THIS PARAGRAPH.

With regard to actual damages resulting from trespass, (*Instruction Nos. 3.20 through 3.25)*, we find as follows:

Trespass Verdict Against Dow Only

1. Do you find the injurious situation resulting from the trespass by Dow became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

2. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the trespass committed by Dow *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

3. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the trespass by Dow? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the trespass; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the trespass.

For purposes of this answer, you should not consider Dow's affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties.

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	_______________%	$_______________
VACANT LAND	_______________%	$_______________
COMMERCIAL	_______________%	$_______________
	TOTAL:	$_______________

PLEASE GO TO QUESTION NO. 4.

With regard to Dow's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

4. Do you find that Dow proved that its trespass caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 4 IS "YES," THEN GO TO QUESTION NO. 5. IF YOUR ANSWER TO QUESTION NO. 4 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

5. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the average percentage by which Class Property values were diminished by Dow's trespass during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value
________________	____________	__________________________
________________	____________	__________________________
________________	____________	__________________________

PLEASE GO TO ¶ F (actual damages for nuisance).

Trespass Verdict Against Rockwell Only

6. Do you find the injurious situation resulting from the trespass by Rockwell became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 6 IS "YES," THEN GO TO QUESTION NO. 7. IF YOUR ANSWER TO QUESTION NO. 6 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

7. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the trespass committed by Rockwell *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 7 IS "YES," THEN GO TO QUESTION NO. 8. IF YOUR ANSWER TO QUESTION NO. 7 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

8. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the trespass by Rockwell? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the trespass; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the trespass.

For purposes of this answer, you should not consider Rockwell's affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties.

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	______________%	$______________
VACANT LAND	______________%	$______________
COMMERCIAL	______________%	$______________
	TOTAL:	$______________

PLEASE GO TO QUESTION NO. 9.

With regard to Rockwell's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

9. Do you find that Rockwell proved that its trespass caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 9 IS "YES," THEN GO TO QUESTION NO. 10. IF YOUR ANSWER TO QUESTION NO. 4 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

10. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the average percentage by which Class Property values were diminished by Rockwell's trespass during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value
______________	___________	______________________
______________	___________	______________________
______________	___________	______________________

PLEASE GO TO ¶ F (actual damages for nuisance).

Trespass Verdicts Against Both Dow and Rockwell

11. Do you find the injurious situation resulting from the trespass by Dow and Rockwell became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: X Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 11 IS "YES," THEN GO TO QUESTION NO. 12. IF YOUR ANSWER TO QUESTION NO. 11 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

12. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the trespass committed by Dow and Rockwell *(see Instruction No. 3.22)*?

ANSWER: X Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 12 IS "YES," THEN GO TO QUESTION NO. 13. IF YOUR ANSWER TO QUESTION NO. 12 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

13. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the trespass by Dow and Rockwell? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the trespass; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the trespass.

For purposes of this answer, you should not consider Defendants' affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties.

All numbers adjusted to 2005 CPI

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	7 %	$ 144,199,088.00
VACANT LAND	30 %	$ 27,000,000.00
COMMERCIAL	53.01 %	$ 5,651,252.00
	TOTAL:	$ 176,850,340.00

PLEASE GO TO QUESTION NO. 14.

14. Taking as 100 percent the combined trespass that caused the damages you have found, what percentage, if any, was caused by the trespass by Dow and the trespass by Rockwell *(see Instruction No. 3.19A)*:

ANSWER: Percentage, if any, charged to Dow: 90 %

Percentage, if any, charged to Rockwell 10 %

MUST TOTAL: 100%

PLEASE GO TO QUESTION NO. 15

With regard to Dow and Rockwell's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

15. Do you find that Dow and Rockwell proved that their trespass caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes X No

IF YOUR ANSWER TO QUESTION NO. 15 IS "YES," THEN GO TO QUESTION NO. 16. IF YOUR ANSWER TO QUESTION NO. 15 IS "NO," THEN SKIP TO ¶ F (actual damages for nuisance).

16. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the average percentage by which Class Property values were diminished by Dow and Rockwell's trespass during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value

PLEASE GO TO ¶ F (actual damages for nuisance).

¶ F Actual Damages for Nuisance

IF YOU DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ C (NUISANCE BY DOW) OR ¶ D (NUISANCE BY ROCKWELL), PLEASE SKIP TO ¶ G (PUNITIVE DAMAGES).

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ C (NUISANCE BY DOW), BUT DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ D (NUISANCE BY ROCKWELL), GO TO QUESTION NO. 1 IN THIS PARAGRAPH.

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ D (NUISANCE BY ROCKWELL), BUT DID NOT ANSWER "YES," TO ALL OF THE QUESTIONS IN ¶ C (NUISANCE BY DOW), SKIP TO QUESTION NO. 6 IN THIS PARAGRAPH.

IF YOU ANSWERED "YES," TO ALL OF THE QUESTIONS IN ¶ C (NUISANCE BY DOW) AND IN ¶ D (NUISANCE BY ROCKWELL), SKIP TO QUESTION NO. 11 IN THIS PARAGRAPH.

With regard to actual damages resulting from nuisance, (*Instruction Nos. 3.20 through 3.25)*, we find as follows:

Nuisance Verdict Against Dow Only

1. Do you find the injurious situation resulting from the nuisance by Dow became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO ¶ G (punitive damages).

2. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the nuisance committed by Dow *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 2 IS "YES," THEN GO TO QUESTION NO. 3. IF YOUR ANSWER TO QUESTION NO. 2 IS "NO," THEN SKIP TO ¶ G (punitive damages).

3. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the nuisance by Dow? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the trespass; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the trespass.

For purposes of this answer, you should not consider Dow's affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties.

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	____________%	$____________
VACANT LAND	____________%	$____________
COMMERCIAL	____________%	$____________
	TOTAL:	$____________

PLEASE GO TO QUESTION NO. 4.

With regard to Dow's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

4. Do you find that Dow proved that its nuisance caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 4 IS "YES," THEN GO TO QUESTION NO. 5. IF YOUR ANSWER TO QUESTION NO. 4 IS "NO," THEN SKIP TO ¶ G (punitive damages).

5. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the

average percentage by which Class Property values were diminished by Dow's nuisance during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value
______________	__________	______________________
______________	__________	______________________
______________	__________	______________________

PLEASE GO TO ¶ G (punitive damages).

Nuisance Verdict Against Rockwell Only

6. Do you find the injurious situation resulting from the nuisance by Rockwell became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 6 IS "YES," THEN GO TO QUESTION NO. 7. IF YOUR ANSWER TO QUESTION NO. 6 IS "NO," THEN SKIP TO ¶ G (punitive damages).

7. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the nuisance committed by Rockwell *(see Instruction No. 3.22)*?

ANSWER: ______ Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 7 IS "YES," THEN GO TO QUESTION NO. 8. IF YOUR ANSWER TO QUESTION NO. 7 IS "NO," THEN SKIP TO ¶ G (punitive damages).

8. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the nuisance by Rockwell? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the trespass; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the trespass.

For purposes of this answer, you should not consider defendants' affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties.

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	______________%	$______________
VACANT LAND	______________%	$______________
COMMERCIAL	______________%	$______________
	TOTAL:	$______________

PLEASE GO TO QUESTION NO. 9.

With regard to Rockwell's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

9. Do you find that Rockwell proved that its nuisance caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 9 IS "YES," THEN GO TO QUESTION NO. 10. IF YOUR ANSWER TO QUESTION NO. 4 IS "NO," THEN SKIP TO ¶ G (punitive damages).

10. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the average percentage by which Class Property values were diminished by Rockwell's nuisance during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value

PLEASE GO TO ¶ G (punitive damages).

Nuisance Verdicts Against Both Dow and Rockwell

11. Do you find the injurious situation resulting from the nuisance by Dow and Rockwell became "complete" and "comparatively enduring" some time between January 1, 1988 and December 31, 1995 *(see Instruction No. 3.22)*?

ANSWER: __X__ Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 11 IS "YES," THEN GO TO QUESTION NO. 12. IF YOUR ANSWER TO QUESTION NO. 11 IS "NO," THEN SKIP TO ¶ G (punitive damages).

12. As of the time you find the injurious situation became "complete" and "comparatively enduring," do you find the actual value of the Class Properties was less than the value these Properties would have had but for the nuisance committed by Dow and Rockwell *(see Instruction No. 3.22)*?

ANSWER: __X__ Yes ______ No, and so we award nominal damages of $1 per class member on this claim.

IF YOUR ANSWER TO QUESTION NO. 12 IS "YES," THEN GO TO QUESTION NO. 13. IF YOUR ANSWER TO QUESTION NO. 12 IS "NO," THEN SKIP TO ¶ G (punitive damages).

13. As of the time you find the injurious situation became "complete" and "comparatively enduring," what is the amount of the difference between the actual value of Class Properties and what their value would have been but for the nuisance by Dow and Rockwell? For each of the three types of property below, please state your answer as follows *(see Instruction No. 3.23)*:

(a) in the first column, state the average percentage by which Class Properties were diminished or depressed in value, relative to what their value would have been, without the nuisance; and

(b) in the second column, the corresponding total dollar amount by which Class Properties, as a whole, were diminished or depressed in value, relative to what their value would have been, without the nuisance.

For purposes of this answer, you should not consider Defendants' affirmative defense of setoff or any "prior market discount" at which Class Members may have purchased their properties. Adjusted to 2005 CPI

	Percentage Undervaluation	Aggregate Damages (Entire Class)
RESIDENTIAL	7 %	$ 144,199,088.00
VACANT LAND	30 %	$ 27,000,000.00
COMMERCIAL	53.03 %	$ 5,651,252.00
		TOTAL: $ 176,850,340.00

PLEASE GO TO QUESTION NO. 14.

14. Taking as 100 percent the combined nuisance that caused the damages you have found, what percentage, if any, was caused by the nuisance by Dow and the nuisance by Rockwell *(see Instruction No. 3.19A)*:

ANSWER: Percentage, if any, charged to Dow: 30 %

Percentage, if any, charged to Rockwell 70 %

MUST TOTAL: 100%

PLEASE GO TO QUESTION NO. 15

With regard to Dow and Rockwell's affirmative defense of setoff *(see Instruction No. 3.25)*, we find as follows:

15. Do you find that Dow and Rockwell proved that their nuisance caused a diminution in the value of Class Properties in one or more specific time periods before June 7, 1989?

ANSWER: ______ Yes X No

IF YOUR ANSWER TO QUESTION NO. 15 IS "YES," THEN GO TO QUESTION NO. 16. IF YOUR ANSWER TO QUESTION NO. 15 IS "NO," THEN SKIP TO ¶ G (punitive damages).

16. For each time period in which you found there was a pre-existing diminution in Class Property values, state when the period began, when it ended and the average percentage by which Class Property values were diminished by Dow and Rockwell's nuisance during this period. (Add more lines if necessary.)

Beginning of Period	End of Period	Percentage Diminution in Value

PLEASE GO TO ¶ G (punitive damages ¶).

¶ G Punitive Damages

Punitive Damages Against Dow

ANSWER THIS SECTION ONLY IF YOU AWARDED ACTUAL DAMAGES AGAINST DOW IN ¶ E (ACTUAL DAMAGES FOR TRESPASS) AND/OR ¶ F (ACTUAL DAMAGES FOR NUISANCE). IF YOU DID NOT AWARD ACTUAL DAMAGES AGAINST DOW, SKIP TO NEXT SECTION IN THIS PARAGRAPH, "PUNITIVE DAMAGES AGAINST ROCKWELL."

With regard to punitive damages against Dow, we find as follows:

1. Do you find beyond a reasonable doubt that Dow's conduct in committing the trespass and/or nuisance was "willful and wanton" as defined in Instruction No. 3.27? In deciding this question, you may only consider Dow's conduct up to August 20, 1988, including conduct that resulted in harm on or after this date.

ANSWER: X Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 1 IS "YES," THEN GO TO QUESTION NO. 2. IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," THEN SKIP TO NEXT SECTION IN THIS PARAGRAPH, "PUNITIVE DAMAGES AGAINST ROCKWELL."

2. What amount of punitive damages do you find should be awarded against Dow? This amount may not exceed the total amount of actual damages you found against Dow in ¶ E and ¶ F.

ANSWER: $ 110,800,000.00

PLEASE GO TO NEXT SECTION IN THIS PARAGRAPH, "PUNITIVE DAMAGES AGAINST ROCKWELL."

Punitive Damages Against Rockwell

ANSWER THIS SECTION ONLY IF YOU AWARDED ACTUAL DAMAGES AGAINST ROCKWELL IN ¶ E (ACTUAL DAMAGES FOR TRESPASS) AND/OR ¶ F (ACTUAL DAMAGES FOR NUISANCE). IF YOU DID NOT AWARD ACTUAL DAMAGES AGAINST ROCKWELL, SKIP TO ¶ H (ADDITIONAL QUESTIONS).

With regard to punitive damages against Rockwell, we find as follows:

3. Do you find beyond a reasonable doubt that Rockwell's conduct in committing the trespass and/or nuisance was "willful and wanton" as defined in Instruction No. 3.27? In deciding this question, you may only consider Rockwell's conduct up to August 20, 1988, including conduct that resulted in harm on or after this date.

ANSWER: X Yes ______ No

IF YOUR ANSWER TO QUESTION NO. 3 IS "YES," THEN GO TO QUESTION NO. 4. IF YOUR ANSWER TO QUESTION NO. 3 IS "NO," THEN SKIP TO ¶ H.

4. What amount of punitive damages do you find should be awarded against Rockwell? This amount may not exceed the total amount of actual damages you found against Rockwell in ¶ E and ¶ F.

ANSWER: $89,400,000.00

PLEASE GO TO ¶ H.

¶ H Additional Questions

1. Do you find it appeared on or before January 30, 1990, which is the date this case was filed, that any trespass or nuisance by Dow would continue indefinitely *(see Instruction No. 3.28)*?

_X_ YES as to any trespass or nuisance by Dow

_____ NO as to any trespass or nuisance by Dow

_____ NOT APPLICABLE because we did not find any trespass or nuisance by Dow

IF YOUR ANSWER TO QUESTION NO. 1 IS "NO," GO TO QUESTION NO. 2. IF YOUR ANSWER IS "YES" OR "NOT APPLICABLE," SKIP TO QUESTION NO. 3.

2. When do you find it became apparent that the trespass or nuisance by Dow would continue indefinitely? If you found against Dow on both claims, please state the date for each claim separately.

____

PLEASE GO TO QUESTION NO. 3.

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3. Do you find it appeared on or before January 30, 1990, which is the date this case was filed, that any trespass or nuisance by Rockwell would continue indefinitely *(see Instruction No. 3.28)*?

X YES as to any trespass or nuisance by Rockwell

_____ NO as to any trespass or nuisance by Rockwell

_____ NOT APPLICABLE because we did not find any trespass or nuisance by Rockwell

IF YOUR ANSWER TO QUESTION NO. 3 IS "NO," GO TO QUESTION NO. 4. IF YOUR ANSWER IS "YES" OR "NOT APPLICABLE," SKIP TO QUESTION NO. 5.

4. When do you find it became apparent that the trespass or nuisance by Rockwell would continue indefinitely? If you found against Rockwell on both claims, please state the date for each claim separately.

____

PLEASE GO TO QUESTION NO. 5.

5. Do you find that any intentional or negligent conduct by Dow or Rockwell or both of them at Rocky Flats, and/or actual or threatened harms caused by such conduct, created a situation that is capable of causing fear, anxiety, or mental discomfort in individual Class Members *(see Instruction No. 3.28)*?

	DOW	ROCKWELL
YES	X	X
NO	____	____

PLEASE SIGN AND DATE THIS VERDICT FORM.

Dated this 13 day of February, 2006.

JUROR NAMES REDACTED