1. BACKGROUND: RADIATION HEALTH EFFECTS AND EXPOSURE STANDARDS

Introduction: Soon after I learned about Rocky Flats I participated in a seminar on radiation convened by John (Jock) Cobb of the faculty of the University of Colorado medical school. He was a remarkable individual who gave freely of himself and his knowledge to anyone curious about Rocky Flats. In his seminar I was amazed at the technical complexity of radiation. I asked myself: What have you gotten into now? This chapter provides basic information about radiation, its health effects and standards for permissible exposure, information pertinent for everything that follows.

Ionizing radiation, the problem: The radiation encountered at Rocky Flats is ionizing radiation. It can alter the electrical charge of atoms and molecules within cells in the body, creating health problems. Do not confuse it with non-ionizing radiation, like that from a microwave oven or high voltage power lines. When radiation is mentioned in these pages, ionizing radiation is what is meant.

Main types of ionizing radiation: The four main type are distinguished by their penetrating ability, or alternately by the material that blocks them and prevents penetration (see Figure 1.1):

- *Neutron* radiation is the most penetrating of all forms of radiation. Neutrons are emitted in large numbers by nuclear fission or nuclear fusion (the splitting or fusing of atoms).
- *Gamma rays* and *x-rays* are strongly penetrating. They pass through most substances, including the body, but can be stopped by lead. A large dose of either can be harmful, even fatal, because it may kill enough cells to disrupt or destroy one's health. But because it passes through the body, at lower doses it may do little or no harm; it may kill cells directly hit, but they will be discarded. Americium-241, often in the Rocky Flats environment because it is a daughter product of plutonium-241, emits gamma radiation.
- *Beta particles* are less penetrating than gamma rays, more penetrating than alpha particles. A metal shield will prevent beta from penetrating an organism. Tritium is a beta emitter.
- Alpha particles, heavier and weaker than other forms of radiation, are the least penetrating. Because they cannot penetrate skin or a sheet of paper, they can be harmful only if inhaled or taken into the body through an open wound. Ingested alpha will likely be excreted. Alpha particles lodged in the body can be far more damaging than other types of radiation, because for as long as they remain in the body, which may be for the remainder of one's life, they continually irradiate surrounding tissue, damaging cells. A concentration of damaged cells may eventually lead to cancer or other ailments. Plutonium-239, the contaminant of principal concern at Rocky Flats, is an alpha emitter, as is radium (which appears in nature).



Figure 1.1: Types of radiation and what blocks each type. For example, the alpha radiation emitted by plutonium cannot penetrate human skin. It cannot enter the body from outside it, and it cannot leave the body from within. Image from Nuclear Waste Management Organization.

Isotopes: A given chemical element, such as plutonium, may have several forms, which are called isotopes. All isotopes of the element have an equal number of protons but a different number of neutrons in their nuclei; their chemical properties are identical but they differ in relative atomic mass. A specific isotope is identified by a number after the name, such as uranium-238 or plutonium-239. Since almost all plutonium used to make bombs at Rocky Flats is plutonium-239, when I refer to plutonium in this text the reference is to plutonium-239. When I refer to a different isotope, the number of that particular isotope will appear, an example being "plutonium-238."

Radioactivity and half-life: Radioactive materials are by nature unstable. The nucleus of the material breaks down, or disintegrates, in an attempt to reach a stable or non-radioactive state. As it disintegrates, energy is released in the form of radioactivity, and the material is transformed into other elements. The speed at which this radioactive decay or disintegration occurs is calculated in terms of "half-life." "Half-life" is the time required for a radioactive substance to decay to half its original radioactivity (see Figure 1.2).



Figure 1.2: Half-life is the time required for a specific radioactive material to become half as radioactive as at the beginning of the period. After passage of a second period of identical length the radioactivity of the material will have decreased by another half. The process continues until no more radiation is being released and the once-radioactive material has become stable. A radioactive material will pass through more than ten half-lives before it is stable or no longer radioactive.

Radionuclides found in nature generally have a very long half-life, and they are still decaying. Uranium-238, a natural element, has a half-life of 4.5 billion years. This means that after 4.5 million years, the uranium will be half as radioactive as it was at the beginning of the period. Plutonium exists in only minuscule amounts in nature; all plutonium at Rocky Flats was produced in reactors. The half-life of plutonium-239 is 24,110 years. After this long the alpha radiation being emitted is half what it was at the beginning. After another 24,110 years the radioactivity is reduced to 1/4; after passage of two half-lives 1/8 is still radioactive. And so on. After 241,100 years – 10 half-lives – the plutonium is still radioactive. It remains radioactive for almost half-a-million years. This is the principal contaminant in the environment on and off the Rocky Flats site.

Terminology for measurement of radiation: Terms used for the measurement of radiation vary, depending on whether one refers to a) the radiation emitted from a radioactive source, b) the radiation absorbed by an exposed person, c) adverse health effects that a person exposed to radiation

may suffer, or d) estimating harm from exposure to different types of radiation.¹ There are two main systems of terminology, the System Internationale (SI) that emerged from the metric system and the conventional system more widely used in the USA. The following provides terms from both.

- **Measuring emitted radiation**: Emitted radiation is measured in terms of its activity (radioactivity) rather than the mass of the emitting material. The activity is the number of disintegrations the material undergoes in a given period of time. The conventional term for measuring this activity for any radioactive material is a **curie (Ci)**, named for Marie Curie. One curie is the amount of any radioactive material that undergoes 37 billion disintegrations per second, which is the intensity of the radioactivity of one gram of radium. There are numerous subdivisions of a curie, such as nanocurie (1/billionth of a curie) and picocurie (1/trillionth of a curie). The SI term is **becquerel (Bq)**. One becquerel is the amount of any radioactive element that undergoes one disintegration per second. Clearly a curie is a large quantity of material, while a becquerel of the same material is a small amount. Regarding plutonium-239, 16.3 grams (0.57 lbs.) produces one curie of radiation. One Bq of plutonium is equal to 27 picocuries (one picocurie = 1/trillionth of a curie, or 0.027 disintegrations per second).
- **Measuring absorbed radiation**: When a person is exposed to radiation, energy is deposited in tissues of the body. The amount of energy deposited per unit of weight of human tissue is called the absorbed dose. Absorbed dose is measured using the conventional term **rad (radiation absorbed dose)** or the SI term **Gray (Gy).** One Gy = 100 rad. Gy is now often used instead of rad.
- Measuring possible adverse health effects of radiation exposure: The risk that a person may suffer adverse health effects from radiation exposure is measured using the conventional unit **rem (roentgen equivalent man)** or the SI unit **Sv (sievert).** Roentgen, a German physicist, discovered X-rays. His name was attached to an imprecise unit indicative of radiation health effects, imprecise because radiation health effects cannot be accurately measured; they can at most be estimated.
- Measuring harm (relative biological effect or RBE) due to different types of radiation: To account for the large range of uncertainty regarding possible harm from exposure to different types of radiation, specialists use the concept of relative biological effect (RBE) or Quality factor (Q) also called the radiation weighting factor (W_R). There is a difference between the amount of energy absorbed by the radiated organism (rad) and the damage that may result (rem). To determine a person's biological risk, scientists have assigned a number to each type of ionizing radiation (alpha particles, beta particles, gamma rays, and x-rays) depending on that type's ability to transfer damaging energy to the cells of the body. This number is the RBE or Q. To estimate one's risk in rems, the dose in rads is multiplied by the RBE or Q. Thus, rems = rads x RBE. The RBE for plutonium will be discussed more fully below.

All this is a bit overwhelming. I tell myself not be cowed or discouraged by these terms. Only one constantly immersed in this language is likely to become conversant in its use. I try to use the terms accurately. Generally, I avoid this level of detail unless it is essential. Some of these terms, such as RBE and picocuries, show up in the following pages because they figure prominently in discussions of plutonium at Rocky Flats. They'll be explained.

Standards for permissible exposure to radiation: A U.S. body of technical specialists, now called the National Committee on Radiation Protection and Measurements (NCRP), proposed the first radiation exposure standards in 1934. According to Catherine Caufield, who has examined the history, these first standards "rested on scientifically shaky ground – on studies too short to detect long-term effects; on inadequate samples; on ill defined and inconsistent units of measurement; on untested assumptions" – problems that, she says, have continued to characterize most efforts to set

¹ For clear explanations of these technical topics, see www.rense.com/general93/uner.htm and www.bt.cdc.gov/radiation/measurement.asp

exposure limits.² Standards did not become legally binding until 1957, when the Atomic Energy Commission (AEC), which was responsible for both the nuclear weapons and nuclear power programs in the U.S., wanted officially established standards, so they couldn't be changed at the whim of the NCRP.³ Today the NCRP continues to produce studies on radiation health effects and to make recommendations for exposure standards. The International Commission on Radiological Protection (ICRP) does similar work at the international level. Also working at the global level is the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

A variety of U.S. agencies currently establish and enforce radiation standards. For the nuclear weapons industry, two sets of standards apply, one for employees in the plants and another for the general public. Standards for the latter are enforced by the EPA and state agencies, such as the Colorado Department of Public Health and the Environment (CDPHE). The DOE enforces standards for workers. All these agencies rely on recommendations from NCRP, ICRP and other bodies, such as the National Academy of Sciences (especially its *BEIR* studies [Biological Effect of Ionizing Radiation]).

The following shows how official radiation standards have changed over time, generally in the direction of being more protective as more is learned about radiation health effects.⁴

<u>Workers</u>	Permitted maximum exposure
1934	30 rem per year
1950	15 rem per year
1956	5 rem per year
1987	1.5 rem per year (adopted for Britain, not the U.S.)
1990	2 rem per year (60% reduction from the 1956 standard, recommended
	by ICRP but not adopted for U.S. by DOE as of January 2015)
<u>Public</u>	
1949	0.3 rem per year (1% of worker limit)
1953	1.5 rem per year (10% of worker limit)
1956	0.5 rem per year (10% of worker limit)
1990	0.1 rem per year (5% of worker limit; recommended by
	ICRP and adopted in the U.S.)

The standard for permissible radiation exposure for U.S. nuclear workers (enforced by the DOE and its predecessor agencies) was set at 5 rem per year in 1956. As of March 2015 it has not been changed. In adhering to this standard, DOE rejects ICRP's 1990 recommendation of a 60% reduction from 5 to 2 rem per year. Just how much radioactive substance will result in a 5-rem dose varies drastically. The radiation emitted, the retention time, the material's RBE as well as its tendency to accumulate in certain parts of the body are all important factors.

Controversy: Can "hormesis" save money? In the mid-1990s then-Senator Peter Dominici from New Mexico, a powerful supporter of the nuclear enterprise, wanted proof that exposure to radiation at low doses is <u>not</u> harmful. He evidently believed in "hormesis," the idea that low-dose radiation exposure, far from being harmful, is in fact beneficial – that a little radiation will actually make you healthier. He thought the U.S. was spending too much needlessly protecting people from harmless low-dose exposure and that the cost of the impending cleanup of DOE sites (like Rocky Flats at the time) could be greatly reduced if existing radiation exposure standards were relaxed. Over a period of several years he supported three major efforts that together should achieve what he sought. First,

² Caufield, Multiple Exposures: Chronicles of the Radiation Age (NY: Harper & Row, 1989), p. 21.

³ Ibid., p. 73.

⁴ Ibid., p. 249.

he asked the Government Accountability Office (GAO) to produce a report on radiation exposure standards, expecting it to demonstrate that present standards should be relaxed. Second, in 1997 he got Congress to create and fund the ten-year DOE Low Dose Radiation Research Program. He believed scientists funded by research grants from the program would show that low-dose radiation exposure is not harmful. Third, he wanted the National Academy of Sciences (NAS) to do another in its series of highly influential *BEIR* (Biological Effects of Ionizing Radiation) studies, this one on low-dose exposure, expecting it to confirm hormesis. Once he had results from these three endeavors, Domenici thought getting current radiation exposure standards relaxed would be simple. His effort was ambitious, but it was also controversial. And in the end he failed.

I played an active role in trying to make sure each of these three endeavors included a broad enough representation of points of view that Domenici's very one-sided approach to radiation standards would not prevail. But there was no way to get the GAO, which produces reports for Congress, to produce a balanced report when it was requested by a prominent senator, so Domenici got from the GAO essentially what he wanted. Actually, the body of their report showed a lack of agreement among radiation health specialists, while its conclusion claimed a consensus for the view that existing standards were overly protective and that relaxing them would do no harm and would save money in cleaning up DOE sites.⁵ The report displays a division of consciousness not unusual in official circles, especially regarding protection from radiation exposure -a division between the view that any exposure is harmful and, alternately, that a little exposure can't hurt. Oddly, though the GAO claimed consensus for its conclusion, it provided no references to studies that supposedly supported its view. I asked GAO for a list of the studies they had reviewed. When I finally received a long list I corresponded with key individuals to find out if they really agreed with the GAO "consensus." Across the board, the people I contacted said two things: first, GAO never asked for their views, and, second, they were not part of the GAO "consensus." I later published an article in the Bulletin of the Atomic Scientists on the range of efforts to relax radiation exposure standards, including an extensive account of the GAO report. I suggest that people curious about this issue read the article, because it provides a readable primer on the complex issue of setting standards. It is available on line.⁶

Regarding the DOE low-dose research program, I attended a report session in Washington. S Scientists whose research was paid for by DOE grants did not meet Domenici's expectation. Many of them criticized current radiation standards not for being overly protective but for being not protective enough. And of the two dozen or so research projects reported on, the one researcher who sought explicitly to prove hormesis admitted in public that his effort failed.

Finally, the *BEIR* study sought by Domenici was delayed for a couple of years, because the committee named by the NAS to produce the report at first included individuals who favored hormesis or displayed a conflict of interest. Activists, including myself, visited the NAS office in Washington two or three times in our eventually successful effort to persuade NAS officials to remove several biased individuals from the committee and to appoint in their places other more neutral parties. When finally released in 2006 the report, called *BEIR VII*, was a ringing affirmation that any exposure to ionizing radiation is potentially harmful⁷ Or, in other words, there is no such thing as a safe dose of ionizing radiation. Official standards for permissible exposure at best limit the radiation to which people can be exposed. They do not guarantee protection. Though *BEIR VII* says that any dose of radiation is potentially harmful, existing standards allow some exposure and thus

⁵ Radiation Protection Standards: Scientific Basis Inconclusive (GAO, 2000).

⁶ "Lowering the Bar," *Bulletin of the Atomic Scientists* (May-June 2002), pp. 28-37. On line at <u>http://www.rockyflatsnuclearguardianship.org/wp-content/uploads/2013/07/Lowering-the-Bar_Bulletin-May-02.pdf</u>

⁷ National Academy of Sciences, *Health Risks from Exposure to Low Levels of Ionizing Radiation*, *BEIR VII*, (Washington: National Research Council, 2006).

also some harm. This permits a harmful industry to operate. Though official standards do limit risk they also perpetuate and even sponsor it. The permissive nature of this practice at Rocky Flats has given to Denver-area people a tradition of risk. Where there is risk, there will be harm.

Karl Morgan: Which approach to low-dose radiation exposure is most protective? Here I will include one small portion of my above-mentioned article because it makes clear that how you view low-dose radiation exposure affects your whole understanding of radiation and its health effects. In 1943, as part of the Manhattan Project, Karl Z. Morgan accepted the task of determining how much ionizing radiation nuclear weapons workers could be exposed to without danger to their health. He was dubbed the "father of health physics," a wholly new discipline of specialists who knew radiation was dangerous and sought to protect the health of workers. At the time, he said, "We all had, all of us, a serious misconception, in that we adhered universally . . . to the so-called 'threshold hypothesis,' meaning that if a dose were low enough, cell repair would take place . . . and there would be no resultant damage. In other words, we believed there was a safe level of radiation." By 1949, however, "The majority of us realized that there really wasn't a so-called safe level of exposure." Convinced that risk increased in exact proportion to dose, those responsible for radiation safety rejected the threshold model in favor of the "linear no-threshold" or "LNT" hypothesis.

Morgan headed the newly conceived Health Physics Division at the Oak Ridge National Laboratory from its creation in 1943 until his retirement in 1972. He was very influential in both the ICRP and the U.S. NCRP (see pp. 11-12), the principal bodies that study radiation health effects and recommend standards for permissible exposure to radiation. Both bodies adopted the LNT approach for calculating risk, making it the orthodoxy of the nuclear establishment. It simplifies the range of exceedingly diverse and complex data regarding radiation effects long-term malignancy, in utero processes, effects among different sub-populations, genetic change, repair actions, and so on. The LNT approach was first applied to radiation exposure standards as a result of Hermann Muller's discovery in the 1920s of genetic mutations in fruit flies exposed to radiation, work for which he received the 1946 Nobel Prize in medicine.

Morgan eventually rejected the LNT in favor of the more stringent "supralinear" approach, because he had become convinced that it "fits the data more appropriately." He explained: "Down at the very low doses you actually get more cancers per person-rem than you do at the high doses. Now, I'm not saying that you get more cancers at these low doses than at high doses. I'm saying that damage per unit dose is greater at these levels. And that's true in part because the high levels will more often kill cells outright, whereas low levels of exposure tend to injure cells rather than kill them, and it is the surviving, injured cells that are the cause for concern." Over time, a damaged cell may become cancerous: "It divides, it divides again and again, and, on the average, if it's leading to a solid tumor, after 30 years it will be large enough that it will be recognized as a malignancy"⁸ (see Figure 1.3).

Morgan understood that if low-dose exposure was more dangerous than previously realized, more stringent protective measures were needed. But once he rejected the LNT orthodoxy in favor of the supralinear approach, he had moved beyond the establishment paradigm, and the industry ostracized him. Recognized as the "father of health physics" until his death in 1999 he led an active campaign against exposure to low-dose radiation, testifying as an expert witness in various lawsuits, helping win key cases. One case he deemed significant, *Silkwood v. Kerr-McGee Corporation* in 1979, about the death of Karen Silkwood, showed that "there is no such thing as a 'safe dose' of radiation."⁹

⁸ Morgan, quoted in Robert Del Tredici, *At Work in the Fields of the Bomb* (NY: Harper & Row, 1987), pp. 133–34.

⁹ Karl Z. Morgan and Ken M. Peterson, *The Angry Genie: One Man's Walk through the Nuclear Age* (Norman: University of Oklahoma Press, 1999), p. 145.



Figure 1. Development of cancer from mutation produced by ionizing radiation.

Figure 1.3: Low-dose Radiation Exposure and Cancer. This image shows what Morgan described, that a low dose of radiation attacks cells in the body, severing the DNA and resulting in a damaged cell that over time is multiplied until there are enough damaged cells to form a cancerous tumor. A higher dose of radiation would kill cells rather than damaging them, and it is replication of damaged cells that leads to a cancer.

The favored *Linear No-Threshold (LNT)* approach of the nuclear establishment, with its recognition that any exposure to radiation is potentially harmful, is a middling way between the *threshold* view that there is a level of exposure below which harm does not occur and the *supralinear* view that low dose radiation is more harmful per unit dose than higher levels of exposure. *Hormesis*, a close cousin of the threshold view, assumes that a little radiation below the threshold is good for you. Each of these views has supporters. The key question is what is best for the public health, including offspring and future generations. The answer is simple: That is best which is most protective. Obviously, this is the supralinear approach, with its recognition that any exposure can be harmful and its concern to protect people from harmful effects from low-dose exposure. If people are protected at this level, they are protected at all levels of exposure (see Figure 1.4)

The "Petkau Effect," another way of explaining greater harm from very low-dose

exposure: In 1972 Canadian researcher Abram Petkau showed that repeated exposure to very low doses of radiation wreaks far more harm than one-time exposure to higher doses allowed by official standards. Karl Morgan explained that cancer could result from low doses injuring rather than killing cells. Petkau gave another explanation, namely, that prolonged low-dose exposure destroys the protective membrane of cells, producing multitudes of "free radicals" that themselves create havoc among cells, destroying health in the process. His explanation is called "Petkau effect."¹⁰

¹⁰ Ralph Graeub, *The Petkau Effect: The Devastating Effect of Nuclear Radiation on Human Health and the Environment* (NY: Four Walls Eight Windows, 1994). See also <u>http://www.nuclearreader.info/chapter3.html</u>



Figure 1.4: Approaches to Radiation Protection. This diagram shows the major approaches to understanding the relation between dose and risk of harm. A) The *linear* approach, favored within the nuclear establishment, assumes an equivalence between dose and health effect. B) The *threshold* approach assumes there is a level of exposure below which harm will not occur; harm begins at the threshold and increases as the dose increases. C) *Hormesis* is a threshold approach with the addition that exposure below the threshold has a beneficial effect. D) The *supralinear* approach assumes that very low-dose exposure is more harmful per unit dose than higher levels of exposure.

Affected populations excluded from the standard-setting process: Nuclear workers and people who live or work in the vicinity of a nuclear plant are excluded from the task of setting standards for radiation exposure likely to affect them. All such standards are developed by a self-selected scientific elite without any direct input from affected populations, much less their consent. When I was serving on an NCRP committee, two colleagues and I urged the NCRP at their 2004 annual meeting in Washington to include affected parties in the task of studying radiation health effects and setting standards.¹¹ They rejected our appeal. In the realm of standards for permissible exposure to radiation, the earthly fate of people continues to be decided not by those affected but by a group that functions like a self-appointed medieval priesthood.¹²

Protecting those who least need to be protected: The whole edifice of standards for permissible exposure to radiation rests on the dubious foundation of cancer incidence among survivors of the Hiroshima and Nagasaki bombings. There are several problems with relying on this data. First, the data used in the study was compiled not immediately after the bombing but five years later. Second, U.S. medical personnel who were part of the military occupiers from the country that had dropped the bombs did the initial work; only later were Japanese specialists directly involved. Third, the data is full of uncertainty because much of it relies on interviews of survivors rather than direct medical observation; also, by the time interviews were first done many survivors had died. Fourth, exposure from the bombs was mainly to external gamma rays rather then the far more dangerous internal alpha particles (see p. 9); to this day, standards for internal radiation are not based directly on data from alpha exposure but are extrapolated from standards set for external

¹¹ Lisa Ledwidge, LeRoy Moore and Lisa Crawford, "Stakeholder Perspectives on Radiation Protection," *Health Physics*, vol. 87, no. 3 (Sept. 2004).

¹² See Rosalie Bertell,"Critique of ICRP structure and membership" (1993), http://www.ratical.org/radiation/inetSeries/wwc2 10.txt

radiation exposure. Finally, perhaps most important, survivors, whose data provides the foundation for the study, belong to the strongest, healthiest, most robust part of the population; those who died first from the exposure included the ill, the old, the very young and those with a genetic susceptibility. Basing exposure standards on what happens to survivors protects the strong more than the weak.¹³ A better foundation for setting standards would be data on nuclear workers.¹⁴

Protecting "reference man": Existing radiation standards, including those applicable for the Rocky Flats "cleanup," were calculated to protect "reference man," that is, a Caucasian male age 20 to 30, 5 feet 7 inches tall, weighing about 154 pounds and living in a moderate climate.¹⁵ Clearly, protecting "reference man" does not protect the most vulnerable.

Women and infants, the most vulnerable, the least protected: Standards for radiation exposure ignore the disproportionately greater harm to both women and infants. Mary Olson, who has written an essay that highlights this issue, points out that the *BEIR VII* study of 2006 recognized the problem but did not highlight it.¹⁶

Scientific uncertainty: A National Academy of Sciences report in December 2008 harshly criticized the EPA for the way it deals with scientific uncertainty in calculating risk. Too often the EPA treats uncertainty as indicating a problem that can be ignored rather than dealt with. "There's almost an incentive to having scientific uncertainty," observed one scientist.¹⁷ Too little is known, the report says, about variability in human susceptibility as well as cumulative effects of exposure to radioactive and chemical toxins in combination. The report calls for greater transparency and stakeholder involvement in the risk assessment process.¹⁸ Because cleanup standards for Rocky Flats were established with the public playing more a spectator role than the role of genuine participants, affected populations near Rocky Flats must live with the results of approaches the scientific establishment now criticizes. For more details on this, see chapter 7.

Genetic specialist warns about the long-term effect of radiation exposure: Herman Muller received the 1946 Nobel Prize in medicine for his discovery of genetic mutations in fruit flies exposed to radiation. Toward the end of his life he published an article on the genetic effect to humans of radiation exposure. Though birth defects may occur, far more serious is the cumulative effect "over a virtually unlimited period." The damaged gene will "be passed along in inheritance . . . before it happens to turn the scales against the individual carrying it. When it does so, it will cause the extinction of its own line of descent," because some person in the chain of the harmed gene burden will lose the ability to reproduce, resulting in "genetic death . . . The losses are spread out over centuries, even millennia, with only a few thousand genetic deaths resulting from them in any one generation." The total damage to posterity will be massive. "Therefore the hereditary damage should be the chief touchstone in the setting of 'permissible' or 'acceptable' dose limits . . . We must learn, through experience, to tackle our problems of today that affect tomorrow in a truly responsible way –

¹³ David Richardson, "Lessons from Hiroshima and Nagasaki: The most exposed and most vulnerable," *Bulletin of the Atomic Scientists*, vol. 68, no. 3 (May-June 2012), pp. 29-35. http://bos.sagepub.com/content/68/3/10.full.pdf+html

¹⁴ Steve Wing, David Richardson and Alice Stewart, "The Relevance of Occupational Epidemiology to Radiation Protection Standards," *New Solutions*, vol. 9, no. 2 (1999).

¹⁵ Arjun Makhijani et al., "Healthy from the Start," *Science for Democratic Action*, vol. 14, no.4 (Feb. 2007). <u>http://ieer.org/projects/healthy-from-the-start/</u>

¹⁶ Mary Olson, "Atomic radiation is more harmful to women," Nuclear Information and Resource Service, October 2011. <u>http://www.nirs.org/radiation/radhealth/radiationwomen.pdf</u>

¹⁷ Cornelia Dean, "Panel Seeks Changes in EPA Reviews," New York Times, December 3, 2008.

¹⁸ Board on Environmental Studies and Toxicology, National Academy of Sciences, *Science and Decisions: Advancing Risk Assessment* (Washington, DC: National Research Council, 2008). See http://www.nap.edu/catalog.php?record_id=12209.

one that our successors will thank us for."19

"Genetic uncertainty problem" for wildlife: Reminiscent of Muller, genetic specialist Diethard Tautz says that effects of radiation exposure on a given species of wildlife may not be readily apparent in the individuals of that species until the passage of several generations. He calls this a "genetic uncertainty problem."²⁰ His work suggests that wildlife at Rocky Flats could in the long term be hurt by conditions at the site. Such harm would not be confined to the site. Some observers have taken a very sanguine approach to reports that plutonium has been found in the bodies of deer killed near Rocky Flats. Ecologist K. Shawn Smallwood, who in 1996 studied wildlife at Rocky Flats, "found it remarkable that no genetic studies" had been done there or at other nuclear sites.²¹

Concerns to remember regarding radiation exposure standards:

- Don't deny the adverse effect of radiation exposure because you can't see, feel, hear, taste, or smell radioactivity.
- Remember that "there is no way of inactivating radioactivity or shortening its active period. There is no practical method of preventing its spread in the atmosphere . . . once it has escaped from containment."²²
- Ask regarding "permissible" radiation exposure standards, who gives permission?
- Remember that the government and industry brought radiation to you, not the reverse. The people are not the source of such exposure.
- Remember that the only justification for standards for radiation exposure is to protect you and others, secondarily to protect the industry.
- Do what you can to protect the most vulnerable from the lowest exposure to human-produced radiation; doing this protects all.

Radiation standards: A prediction

Standards for permissible exposure to radiation fail to protect sufficiently. They are a dam that holds back a flood of illness and death but lets pass an "insignificant" trickle of the diseased and damned. These standards are a damn dam that lets a harmful enterprise thrive. Today's trickle is a warning: In time, the dam will break in a flood of illness and death.

¹⁹ Herman J. Muller, "Radiation and Heredity," *American Journal of Public Health Nations Health*, vol. 54, January 1964. <u>http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1254569/?page=9</u>

 ²⁰ Tautz, "Genetic Uncertainty Problem," *Trends in Genetics*, vol. 16, November 2000, pp. 475-477.
²¹ Smallwood et al., "Animal Burrowing Attributes Affecting Hazardous Waste Management," *Environmental Management*, vol. 22, no. 6, 1998, p. 834.

²² John F. Loutit, Irradiation of Mice and Men (Chicago: University of Chicago Press, 1967), p. vii.

2. THE PECULIAR DANGER OF PLUTONIUM

Toxic: Physicist Glenn T. Seaborg at the University of California in Berkeley discovered plutonium in 1940. He called it "fiendishly toxic, even in small amounts."²³ The fact that plutonium could fission (its atoms would divide) and also had a long half-life, made it suitable for building bombs. Plutonium is exceedingly rare in nature. In 1956 a small quantity that was the byproduct of the natural fissioning of uranium was discovered in the central African state of Gabon. The plutonium used at Rocky Flats was produced in reactors at either DOE's Hanford facility in Washington State or its Savannah River Site in South Carolina. We humans have brought large quantities of plutonium into the world and we are now responsible for it.

Long-term danger: Plutonium-239, the principal material used at Rocky Flats to produce the fissile "pit" (actually a bomb) at the core of nuclear warheads, has a half-life of 24,110 years. Physicist Fritjof Capra of the University of California in Berkeley says this material should be isolated from the environment for half-a-million years (see Figure 2.1). At Rocky Flats plutonium was not isolated from the environment but was repeatedly deposited there. Those responsible for the Superfund "cleanup" knowingly left behind an unknown amount, the main source of problems today. Tiny particles left in the environment make Rocky Flats a local hazard forever.



Figure 2.1: Fritjof Capra's timescale for plutonium in the environment. His diagram provides a look at the nuclear age and plutonium in relation to time.

Potentially lethal if internalized: The alpha radiation emitted by plutonium cannot penetrate skin like x-rays or gamma radiation (see p. 9). But tiny particles inhaled, ingested, or 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, typically for the rest of one's life (see Figure 2.2). The result may be cancer, genetic harm, or a compromised immune system, making one vulnerable to other illnesses. The latent period for cancer is likely to be 20 to 30 years.

²³ Jeremy Bernstein, *Plutonium* (2007), p. 105.



Figure 2.2: Plutonium in lung. "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."²⁴

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.²⁵ Particles too small to see are not too small to do harm.

More harmful than other forms of radiation: Plutonium's RBE: Exposure to internal alpha emitters like plutonium is much more harmful than exposure to an equivalent dose from penetrating gamma or x-ray radiation. In an attempt to account for the difference, those who set standards for permissible exposure refer to the "relative biological effect" (RBE) – or "weighting factor" – for alpha emitters (see p. 11). Plutonium's RBE is important for two reasons. First, plutonium is harmful only if taken inside the body, but once lodged there it continually irradiates nearby tissue, probably for the rest of one's life, making it far more dangerous than larger doses of radiation that enter the body and pass through. Second, plutonium's tendency to concentrate in certain organs (predominantly lung, bone and liver) and then to cluster within these organs makes it far more damaging than if it were evenly distributed throughout an organ. It sometimes concentrates in the brain or the gonads. In the gonads, it may affect offspring, as reported by Muller (see pp. 17-18). There are no known circumstances in which plutonium is distributed uniformly in a particular organ or throughout the body (see Figures 2.3 and 2.4).

²⁴ Robert Del Tredici, At Work in the Fields of the Bomb (NY: Harper & Row, 1987), plate 39.

²⁵ Biggs, "Airborne Emissions and Monitoring of Plutonium from Rocky Flats," March 17, 2011 http://www.rockyflatsnuclearguardianship.org/#!academic-information/zoom/c1arf/image_17gh



Figure 2.3: Where plutonium is likely to settle in the body if inhaled.



Figure 2.4: Where plutonium may settle in the body if ingested. If ingested, the plutonium is likely to be excreted and thus to be far less harmful than inhaled plutonium.

Though the ICRP said in 1980 that the RBE for plutonium should be 85,²⁶ to calculate radiation exposure standards it uses 20 as the plutonium RBE, because 20 is the average RBE. This means that those doing calculations to set radiation exposure standards assume the damage caused

²⁶ ICRP, *Biological Effects of Inhaled Radionuclides, Publication No. 31* (Oxford, England: Permagon Press, 1980).

by plutonium exposure is 20 times as severe as the damage caused by external exposure to uranium, a radionuclide where rads equals rems and the RBE is 0. 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. For example, a 1979 study concluded that for chromosomal (genetic) changes induced by plutonium exposure, the RBE should be 278.²⁷ And the RBE for bone cancer ranges as high as 320.²⁸ The agencies responsible for the Rocky Flats "cleanup" followed the ICRP in using an RBE of 20 to establish the radiation exposure standards for the cleanup. The averaging approach customarily employed by those who set exposure standards disregards the enormous variations in human susceptibility. Further, British researchers concluded in 1997 that the RBE for genetic effects from plutonium exposure is essentially "infinite," because the extent of potential harm to the gene pool is incalculable.²⁹ This review shows that the prevailing way of using the average RBE for plutonium in setting standards for permissible exposure fails by design to protect the most vulnerable. Look again at the dire predictions of Herman Muller, foremost student of genetic effects of exposure to ionizing radiation (see pp. 17-18).

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 or bystander] cells that received no direct radiation but harmed anyway.

Hot particles: The previous paragraph deals with what others call a "hot particle," that is, a tiny (10 or less microns) particle of plutonium or other alpha emitter that is highly radioactive and can be inhaled or otherwise internalized. Lodged within the body, it constantly irradiates a small area of nearby tissue for an indeterminate period, very likely for all of one's life after the initial exposure. As noted above (pp. 16-17), official radiation protection standards are based on external radiation that hits the whole body once, distributes radiation more or less evenly and is then gone. A hot particle, even one giving off much less radiation, can be far more harmful because of its concentrated irradiation of a small area long-term. The concept, while demonstrated often, is controversial. Efforts to get hot particles considered in establishment of radiation exposure standards have not succeeded.³¹

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

²⁷ R. J. DuFrain et al., "Human Cyclogenetic Dosimetry: A Dose-Response Relationship for Alpha Particle Radiation from 241 Am," *Health Physics*, vol. 37 (1979), pp. 279-289.

²⁸ Helen A. Grogan et al, *Assessing Risk of Exposure to Plutonium* (Risk Assessment Corp., Feb. 2000), pp. 6.27-6.39.

²⁹ M. A. Khadim et al, *Nature*, vol. 355, no. 20 (Feb. 1992), pp. 738-740.

 ³⁰ Hei et al., Proceedings of the National Academy of Sciences, vol. 94 (Apr. 1997), pp. 3765-3770; and vol. 98 (4 Dec. 2001), pp. 14410-14415. They reinforced what Karl Morgan had said (see above, p. 14).
³¹ Thomas B. Cochran and Arthur R. Tamplin, 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 (Washington, DC: Natural Resources Defense Council, February 14, 1974). For this and other writings on hot particles, see http://www.nrdc.org/nuclear/cochran/cochranpubs.asp

workers who had not been exposed.³² Prior to publication, Wilkinson was told to change his results "to please the customer," that is, the DOE. When he published his findings without change he was isolated, deprived of work and soon forced out of his job. I have yet to meet a Rocky Flats worker familiar with thus study. Officials at the plant did not inform the workers, though the study was about them. For a fuller account of his work and the treatment he received, see Appendix C.

The entire 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. Soil sampling done at predominantly upwind locations by Harvey Nichols, retired biology professor of the University of Colorado,³³ supports this conclusion. His work will be discussed in more detail later.

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. 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. There is no guarantee that plutonium left behind will remain safely in place or even on the site. This topic will be addressed more fully in chapter 7.

Concluding words about plutonium: The trouble with plutonium begins if it enters one's body, most likely by inhalation. You probably won't know it happened. But if you get a bit of plutonium inside – not much, just a bit – you may be forever changed, no longer the person you were, because now you're being constantly irradiated somewhere in the recesses of your being – in one of your lungs, in the marrow of a bone or on its surface, in your liver, maybe even in your brain or gonads. It's working on you, and you're not the same. The plutonium is dangerous not briefly, not for a few weeks or a number of years, but for the rest of your life and perhaps in your offspring. Your health may later be ruined. Future generations may be affected. We humans have brought this about.

The DOE, the EPA, the CDPHE – they and all the corporations that ever operated the Rocky Flats plant – tell us: It's OK. They're infected with the twin conceits of denial and risk – risk from a teasing permissible exposure, and denial backed by a pile of reports and records.

 ³² Wilkinson et al., "Mortality among Plutonium and Other Radiation Workers at a Plutonium Weapons Facility," *American Journal of Epidemiology* (1987), vol. 125, no. 2, pp. 231-250.
³³ <u>http://wwwrockyflatsnuclearguardianship.org/#!presentation-by-harvey-nichols/c1m2k</u>

3. Fateful Mistake: Locating a Nuclear Bomb Plant at Rocky Flats

After the end of World War II and, as a crucial step in beginning the Cold War, President Harry Truman decided that the U.S. would mass-produce nuclear weapons. Manhattan Project veteran Danish physicist Niels Bohr said that doing this would require turning the whole country into one vast factory. This is exactly what happened. Rocky Flats, to be located 16 miles northwest of central Denver (see Figure 3.1), would be one of a dozen large plants deployed across the country, each focused on producing either material for the bomb or specific parts.



Figure 3.1: Location of the Rocky Flats plant. From *Summary of Findings: Historical Pubic Exposure Studies on Rocky Flats*, Colorado Department of Public Health and Environment (August 1999). Plutonium released from Rocky Flats was carried by the wind well beyond the "study area" outlined on this map.

The Atomic Energy Commission (AEC), predecessor to the Department of Energy (DOE), assigned Cleveland-based Austin Company the task of choosing a site for "Project Apple" (AEC's name for what became the Rocky Flats plant).³⁴ The selection process included only negligible study of dangers at the Rocky Flats site, nothing, for instance, about earthquake danger. Austin's crucial mistake was to locate the plant where it should never have been located, a blunder that would prove fateful for the public. The company took wind readings not at Rocky Flats but 20 miles away on the east side of Denver at the now closed Stapleton Airport, where prevailing winds are from the south. By contrast, at Rocky Flats prevailing winds blow steadily, sometimes severely, from the mountains toward the east and southeast, across the suburbs of Arvada, Westminster, Broomfield and others toward central Denver (see Figure 3.2). Seasonal Chinook winds, clocked in excess of 140 mph, are

³⁴ For more detail on Project Apple and the decision to locate the plant at Rocky Flats, see Len Ackland, *Making a Real Killing: Rocky Flats and the Nuclear West* (Albuquerque: University of New Mexico Press, 1999), chap. 3; *Citizen's Guide to Rocky Flats* (1992), p. 3, on line at http://www.rockyflatsnuclearguardianship.org/#!citizens-guide-to-rocky-flats/c1hm8; and Kristen Iversen, *Full Body Burden: Growing Up in the Nuclear Shadow of Rocky Flats* (New York: Crown Publishing Group, 2012), pp. 4-8.



Figure 3.2: Wind Rose at the Rocky Flats plant, showing force and direction of the wind that at the site blows half of the time toward the east, southeast, and northeast. Strongest winds are also in these directions. From P. W. Krey and E. P. Hardy, "Plutonium in Soil Around the Rocky Flats Plant," HASL 235 Report (NY: AEC Health and Safety Laboratory, 1970), p. 5.

known to snap telephone poles and overturn vehicles in the Rocky Flats area (see Figure 3.3). With Rocky Flats as the site, radioactive contaminants released from the plant, most notably plutonium, would be distributed by the wind across heavily populated parts of the Denver metro area.



Figure 3.3: A windy day along Colo. Hwy. 93 near the West Gate (main entrance) of Rocky Flats, December 14, 1990. Photo by Jay Koetzer, *Rocky Mountain News*.