
Living in Dose: Nuclear Work and the Politics of Permissible Exposure

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Testimony

Thursday evening, after dinner, workers bring their families. They find seats, or stand when there are no seats left, offering chairs to the elderly and infirm. They sign up to speak, printing names on index cards and placing them one on top of another. At the front of the room is a long table draped in royal blue cloth, with a slender microphone at its center and an American flag at its back. The air is silent and thick with the warmth of overcrowded bodies and the anticipation of long-held secrets.

The assistant secretary of energy walks to a podium and holds a microphone before his burgundy tie and bearded lips. He tells them that their government wants to know if it has hurt them. He tells them that “statistics are people with the tears washed off,” that there is more to the story than numbers can say. He tells them that he is there to listen.

The first to the table is an elderly man with parted white hair, glasses, and lung cancer. Second, a daughter speaks for her father, who died of bone marrow disease at age fifty-nine. Third, a middle-aged man wearing anger and a plaid shirt describes the tumors that grew on his hand, lung, and adrenal gland. He holds up a

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form he was required to sign allowing him to exceed his lifetime dose of radiation. Fourth: pancreatic, lung, and adrenal cancer. Fifth: prostate cancer and asbestosis. Sixth: lymphocytic leukemia. Seventh: asbestosis and beryllium disease.

The succession of stories continues for hours as hundreds of bodies sit before the microphone: “I’ve been diagnosed with cancer of the pancreas with six weeks to live, God save me.” Hundreds of workers lick lips and clear throats that catch with nerves and emotion: “They say the only thing they can do for me is a lung transplant. Any of you got a lung [you] want to get rid of?” Hundreds of hands unfold prepared statements to be read aloud: “I did my work and I did it proudly. What will you do for us?” Hundreds of people, indelibly marked by the bomb, take a deep breath. And speak.

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On February 3, 2000, more than five hundred Hanford Nuclear Reservation workers and their families crowded into the auditorium of the Federal Building in Richland, Washington.¹ At the request of the US Department of Energy (DOE), they came to the front of the room one by one and talked about their health problems. With voices that alternately vibrated with pride and cracked with anger and sorrow, workers testified to their shared history of exposure and its effect. For many, it was the first time they had spoken publicly about their illnesses, a subject long considered weak and unpatriotic in this company town (Gerber 2007). Their testimony continued for more than five straight hours, ending at almost midnight.²

This public airing of grievances in politically conservative, pro-nuclear Richland was historic. As the *Los Angeles Times* wrote the following Saturday: “No one ever thought they’d see it happen. Not in this town” (K. Murphy 2000). This town that gave birth to the bomb. This town that coaxed plutonium from uranium “slugs” for more than four decades to power the nation’s nuclear arsenal.³ This

1. The Hanford Nuclear Reservation sits on 586 square miles of land in southeastern Washington State. Built in 1943 as part of the Manhattan Project, Hanford produced weapons-grade plutonium for the US nuclear arsenal until 1987. Now home to more than two-thirds of the US high-level nuclear waste inventory, Hanford is currently undergoing the largest and most expensive environmental remediation project in human history—tasked with managing, mitigating, and containing “more than 50 million gallons of high-level waste in 177 underground storage tanks, 2,300 tons of spent nuclear fuel, 12 tons of plutonium in various forms, about 25 million cubic feet of buried or stored solid waste, about 270 billion gallons of groundwater contaminated above drinking water standards, spread out over about 80 square miles, more than 1,700 waste sites, and about 500 contaminated facilities” (Hanford Natural Resource Trustee Council 2013). The site currently employs about ten thousand workers in its remediation efforts.

2. To view these hearings, see DOE/OESH 2000.

3. Workers call uranium fuel rods “slugs” because of their long cylindrical shape.

town that shops at Atomic Foods and cheers for a high school football team called the Bombers, whose helmets are decorated with mushroom clouds. This town that held a candlelight vigil when Hanford's final reactor shut down, marking the end of Cold War weapons production. This town that now lives and works alongside the nation's largest nuclear dump.

Richland's evening of testimony came in response to a draft report by the National Economic Council. Released by the White House on January 29, 2000, the report found "credible evidence" that American nuclear weapons workers "may be at increased risk of illness" from exposure to ionizing radiation and chemical toxins (quoted in Warrick 2000). The report marked a significant reversal in the federal government's official telling of nuclear history. It stated publicly for the first time that workers' bodies had been sacrificed in the name of national security and economic expediency. Richland's *Tri-City Herald* wrote that the report "hit Hanford like a lightning bolt from one of the sudden summer storms that sweep over the nuclear reservation" (Cary 2000). Perhaps a more fitting analogy would be: the news hit Richland like a bomb.

In the months that followed, the Clinton administration promised a new era of transparency. As Energy Secretary Bill Richardson told the *Washington Post*, "The Department of Energy is coming clean with its workers" (quoted in Warrick 2000). On April 13, Vice President Al Gore announced a new initiative for compensating the sick and injured, saying, "Today this administration begins the process of healing by admitting the government's mistakes, designing a process for compensating these workers for their suffering, and by becoming an advocate for Department of Energy workers throughout the nuclear weapons complex" (quoted in ENS 2000). True to its word, the federal government passed the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) on October 30, 2000, establishing a federal workers' compensation program for individuals who had been exposed to ionizing radiation in the course of their career.⁴ The act recognized workers at more than three hundred DOE facilities across the United States.

Today, more than fifteen years since Richland's historic hearing, many nuclear safety procedures within the DOE complex have been updated and more than sixty-six thousand compensation cases have been paid through the EEOICPA (DOL 2014). However, despite these notable efforts toward regulatory reform, the federal government has been unable to solve the fundamental paradox of nuclear

4. In 2004 Congress approved an expansion of the program to include illnesses associated with chemical exposure as well.

safety: that some level of exposure is unavoidable when working with nuclear materials and that any level of exposure comes with an associated biological risk. In short, *injury is an operational necessity of nuclear industry*. Thus nuclear safety can never mean total protection for workers—it can only ever be the level of exposure that has been deemed acceptable relative to the imagined benefits of radiation. Indeed, this notion of necessary wounding informs the most basic metrics for nuclear safety. Occupational dose rates are calculated using a specific definition of “reasonable” harm. For nuclear workers, this begs a very practical question: How do you stay safe in a system that requires your exposure in order for it to function?

In this article, I consider how nuclear workers, management, and policy makers negotiate the uncomfortable contradiction of safe injury. I begin with the federal policy directive that radiogenic exposure be “as low as reasonably achievable” (ALARA). Detailing the specific development and application of this concept, I discuss how ALARA uses reason to manage the inherent impossibilities of radiation protection. Next I explore how exposure standards are translated into the embodied practice of “dose”—a calculated dispensation of exposure over time that seeks to forestall the inevitability of harm. Finally, I consider how the cost-benefit calculus of acceptable risk frames exposure as critical to economic development and national security, normalizing nuclear injury as an unfortunate, yet necessary, part of modern life and work.

Making Exposure Reasonable

In late spring of 1960, the US Congress Special Subcommittee on Radiation of the Joint Committee on Atomic Energy held seven days of public hearings, published as *Radiation Protection Criteria and Standards: Their Basis and Use*. Focused specifically on the structural administration of nuclear safety, the hearings considered how best to regulate radiation protection through the auspices of government. Under debate was the question of who should develop radiation protection standards and how such criteria should then be applied in on-the-ground “atomic energy activities” (US Congress 1960: 1).⁵ Together these seven days of testimony

5. “Atomic energy activities” in this case refers to both nuclear energy and nuclear weapons facilities. However, it is important to note that federal standards for radiation protection are not applied universally across the US nuclear industrial complex. The Nuclear Regulatory Commission (NRC), for example, regulates civilian nuclear energy facilities, while the DOE regulates nuclear weapons facilities and their associated remediation projects. Meanwhile, the Environmental Protection Agency (EPA) maintains standards for nuclear exposure to the public, and these requirements have at times differed from NRC and DOE mandates. Finally, individual states often maintain their own

create a narrative picture of radiation protection as it emerged during the Cold War. They provide a window into the official making of nuclear safety, a series of cost-benefit calculations that later crystallized into the current policy of ALARA.

With few exceptions, both witnesses and congressional representatives spoke openly about the political and economic necessity of radioactive exposure, at times even framing injury as a measure of social progress. Indeed, the official hearing summary makes it clear that radiation protection is not designed to prevent harm altogether, stating bluntly: “None of this information contemplates absolute protection. Radioactive materials will be released into the environment. Occupational exposures will occur regularly. Accidents will occur” (ibid.: 25). Rather, the purpose of the radiation protection standard is to enforce a level of exposure that the “average individual” would be willing to accept (ibid.: 58). As the representative from the US Naval Radiological Defense Laboratory testified:

We cannot insist on . . . zero risk in the development of new industry which contributes immensely to man’s well-being, wealth, and power over his environment. Some degree of biological effect is associated with any exposure to ionizing radiation, and this effect must be accepted as inevitable. Since we don’t know that these effects can be completely recovered from, we have to fall back on an arbitrary decision about how much we will put up with; i.e., what is “acceptable” or “permissible”—*not a scientific finding, but an administrative decision*. (Ibid.: 6; italics added)

The point of the hearings, then, was to craft a bureaucratic definition of acceptability and to design frameworks for its implementation across a rapidly growing nuclear industrial complex. In general, speakers agreed that exposure should only be considered acceptable when the benefits outweighed the risks. However, translating this general philosophy into a specific numerical value presented significant challenges. As Hanford scientist Jack Healy put it:

We would like to strike a balance in which the maximum benefits are obtained through use of radiation with the minimum harm. [However], we cannot accurately define the risks nor can we accurately define the benefits to all people. Even if we could define these factors, there would still be controversy as to the proper level at which the balance should be taken. . . . Ultimately, our problem resolves itself into the broad area of

requirements for nuclear safety that may or may not coincide with those of the NRC, DOE, and EPA. This continued lack of interagency consensus produces an uneven and contested geography of permissible exposure across the United States.

overall social risk and progress. . . . How do we strike a proper balance between the interests of the individual and the interests of the Nation? (Ibid.: 21–22)

Healy was one of many at the hearings who raised this critical question of scale. At what point do the benefits of collective security outweigh the costs of individual sacrifice? How should the government formalize such a hierarchy of acceptability? Is the loss of one body too many? What about ten thousand?

These questions were especially urgent in the 1950s and 1960s, when above-ground weapons testing initiated fierce national debate surrounding the risks of nuclear fallout (Fradkin 2004; Masco 2008; Kopp 1979). Such debates positioned prominent scientists like Linus Pauling and Ralph Lapp against the Atomic Energy Commission (AEC) as each sought to define the appropriate boundaries of nuclear safety.⁶ While the AEC envisioned nuclear threat in the form of a Soviet attack, others like Pauling and Lapp emphasized the longer-term impacts of nuclear exposure on the general public.⁷ Like the 1960 hearings, these debates pointed to critical contradictions between national security strategy and public health. As Mike Wallace (1957) asked Lapp in a televised interview: “Let’s say for the sake of argument, say that we do run the risk of some physical harm from radiation. Now, which do you prefer . . . do you prefer the kind of risk to your body and that of your children . . . or the possible risk of moral and spiritual slavery that could result if we stopped the nuclear tests and thus lowered our guard against Russia?”

Calculating the official terms of nuclear safety was further complicated by the material realities of radiation itself. To begin with, the human body cannot sense ionizing radiation. It has no sound, smell, or taste; it imparts no pressure to the skin; the naked eye cannot see it. Furthermore, radiogenic injury often takes decades or even generations to manifest. This latency period removes the element of immediate causality, introducing doubt about the source of cancer, mutation, and birth defects.

6. The AEC preceded the DOE, which today manages US nuclear weapons production and stewardship.

7. In an effort to drive home the personal impact of nuclear fallout, Barry Commoner in cooperation with the Committee for Nuclear Information (CNI) initiated a multiyear study called the Baby Tooth Survey, which measured the level of strontium 90 in American children. By 1964 the CNI (1961) had collected almost 160,000 teeth and could demonstrate clear links between weapons testing and strontium 90 in St. Louis–area children. One 1964 analysis found that strontium 90 levels in the teeth of bottle-fed infants had risen to over thirty times what they had been in 1951 (Blumenthal 1964).

In addition, the physical act of measuring exposure is difficult and rife with uncertainty. First, guidelines for radiation protection permit a different level of dose for each part of the body. The skin, hands, forearms, feet, shins, and calves are allowed more exposure than the lenses of the eyes and still more than the critical organs. Second, there are four types of ionizing radiation associated with nuclear production, each with a different capacity for penetrating the body and therefore different requirements for monitoring and protection.⁸ Third, each radionuclide has its own unique biological signature. Some, like strontium 90, tend to deposit in bone, while others prefer thyroid tissue or muscle. So, too, radionuclides differ in the amount of time they remain active in the body, and they may behave differently when combined with the chemicals that are also associated with nuclear processing. Fourth, calculating exposure requires close attention to time—recording how long each body part was exposed to each type of ionizing radiation and then adjusting for relative risk accordingly. The result of all of this, Hanford’s chief radiation health scientist Herbert Parker testified, is that “man gets so subdivided between time, space, radiation types, and radionuclides *that the basic integrating sense of standards is lost*” (US Congress 1960b: 24; italics added).

Thus, though the hearings were convened to determine the administrative standards of radiation protection, much of the committee’s time was spent addressing the fundamental impossibility of such an endeavor. As the official summary stated, “Testimony presented at the hearings indicated that the major difficulty in translating [dose] recommendations into legal status apparently lies in the fact that such use of the recommendations is not compatible with the philosophy and rationale of the recommendations themselves” (ibid.: 40). Not only is it difficult from a material perspective to accurately calculate dose, but such a calculation would fail to incorporate the necessary political, economic, or technical context of each exposure event. In other words, such an explicit standard would be unable to account for the fact that “acceptable exposure” is a flexible and, more importantly, a *social* determination—one deeply informed by the entwined imperatives of war and industry. As Lauriston Taylor, chairman of the National Council on Radiation Protection, said:

8. Alpha particles will travel only short distances (about one to two inches) and can be stopped by a thin sheet of paper or skin, while beta particles can move up to twenty feet and require shielding made of plastic or glass. Gamma rays and neutrons can easily penetrate the body, traveling hundreds of feet from their source. Though lead, water, or concrete can shield the body from some gamma radiation, workers also manage their exposure by quota—counting how much they have received each day and doing their best not to exceed weekly and annual allowances.

I see no alternative but to assume that [an] operation is safe until it is proven to be unsafe. It is recognized that in order to demonstrate an unsafe condition you may have to sacrifice someone. This does not seem fair on one hand, and yet I see no alternative. You certainly cannot penalize research and industry . . . by assuming that all installations are unsafe until proven safe. I think that the worker should expect to take his share of the risk involved in such a philosophy. (Quoted in Caulfield 1990: 67)

Ultimately, in an effort to balance the contradictory demands of regulatory precision and socioeconomic reality, the federal government adopted the policy of ALARA in 1975. Still in practice today, ALARA requires that radiation releases from nuclear facilities be kept at the lowest reasonably achievable level, “taking into account the state of technology, and the economics of improvements in relation to benefits to public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest” (quoted in Walker 2000: 62). Though indemnified by this long list of contingencies, ALARA’s explicit objective is to expand the margin of safety for radiological workers. It requires nuclear facilities to find “reasonable” ways to lower their occupational dose rates below the maximum limits allowed by law. As such, it is designed to give workers additional protection in radioactive space, “an enhanced safety factor for what are already considered to be safe annual doses for radiation workers” (Environmental Health and Safety Center 2014).

In theory, ALARA provides a procedural framework for addressing the uncertainties of radiation protection. It recognizes that exposure produces a spectrum of hazard and acknowledges the embedded cost-benefit calculus of nuclear safety. In addition, ALARA translates these uncertainties into the more manageable language of risk, making the ambiguities of exposure concrete through statistical calculations of probability. Perhaps most importantly, it does this using the specific vocabulary of safety. It positions federal limits for permissible dose as the uppermost boundary of harm and then renders all exposures below that level safer by comparison. As such, it produces some exposures as more protective and thus *more reasonable* than others.

So, too, ALARA frames radiogenic exposure as a rational choice—the end result of thoughtful, informed, daily decisions made by workers and managers. It asks nuclear employees to adopt a questioning attitude, to be on constant lookout for ways to reduce their dose. As Caroline Schieber and Christian Thézé of France’s Centre d’étude sur l’Evaluation de la Protection dans le domaine Nucléaire (Center for the Study of Nuclear Protection) write, successful ALARA implementation means more than simply improving procedural controls. It means

engendering a “state of mind” among the workforce and creating “a shared radiological protection culture . . . [with a] common language and system of values” for understanding and managing nuclear risk (Schieber and Thézée 2000: 1). Only then, they argue, “will it be possible to achieve a socially acceptable compromise between the various risks and the resources and means allocated for their management” (ibid.: 3).

This shared culture of reasoned exposure is reproduced in the daily practice of nuclear work. Before each job, managers must complete documentation that calculates and justifies every minute of occupational exposure (CHPRC 2014). Workers then learn to stay within the boundaries of these calculations—donning personal monitoring devices on various parts of their bodies and cataloging their dose for each task. Critically, though it requires workers to obey procedural and managerial direction, ALARA also frames personal judgment as a natural basis for radiation protection. As the DOE’s (2014: 27) nuclear safety training manual states, “Acceptance of a risk is a personal matter [that] requires a good deal of informed judgment . . . the individual radiological worker is ultimately responsible for maintaining his/her dose ALARA.” As such, ALARA positions each individual as a liberal subject whose decision to engage in nuclear work is a critical part of making exposure reasonable. After all, nuclear safety is defined by an explicitly social regulatory standard: *an acceptable exposure is an accepted one*.

This logic is especially striking in personal injury cases, where the law requires a concrete definition of “unnecessary” or “excessive” exposure in order to determine culpability. Ironically, though it is a federal policy, ALARA is not considered a legal “standard of care” within the terms of toxic tort litigation.⁹ Indeed, as lawyers Donald Jose and David Wiedis write in *Radiation Safety Officer Magazine* (2003: 24): “If ALARA were the standard of care, every exposure, no matter how small, could potentially make the [nuclear] licensee liable for negligence since every exposure could be analyzed with the benefit of hindsight and in most instances it would be ‘possible’ to have reduced the exposure. This would undermine the very stability that the regulations were designed to provide because licensees would be held liable for allowing a dose that regulations specifically labeled as permissible.” As such, while injured workers can claim that doses above federal maximums have caused excessive harm, ALARA’s well-documented risk calculations do not hold the same legal weight. Instead, workers are expected to

9. The “standard of care” is defined as using reasonable judgment to prevent harm to oneself or others. The Judicial Council of California Civil Jury Instructions, for example, state that “a person is negligent if he or she does something that a reasonably careful person would not do in the same situation” (Judicial Council of California Civil Jury Instructions, June 2015 supp.).

have knowingly assumed the risks of permissible dose—by simply taking the job they have agreed to the terms of their exposure. As Jose and Wiedis argue: “All exposures are in a sense unnecessary to [the worker] because he could simply elect to not be a nuclear worker. Once he elects to be a nuclear worker, he consents to receive an exposure within the federal numerical limits, so that exposure cannot then be called unnecessary. It is a necessary part of the job he has chosen to pursue” (ibid.: 25).

Thus ALARA successfully performs a type of regulatory magic—it formalizes a flexible notion of risk while avoiding the legal liability of such a determination. By identifying federal dose limits as the upper boundaries of acceptability, ALARA lends authority to what remains an uncertain metric for safe exposure. Amazingly, it does this using the language of reason, creating spreadsheets, compiling data, and asking workers to make informed decisions about their own potential for injury. As such, ALARA has achieved what the 1960 Special Subcommittee on Radiation thought impossible: it has transformed an inherently imprecise and uncertain definition of nuclear safety into a broadly accepted regulatory imperative.

Living in Dose

For nuclear workers, exposure is translated from theory to practice using specific calculations of “dose”—numerical values that represent the biological impact of radiation.¹⁰ Dose provides a common language for articulating exposure, for measuring the amount of radioactivity each body has received, and for expressing the relative probability that it will result in injury. The DOE, for example, uses dose to instruct workers in risk interpretation. In its radiological worker training handbook, the DOE (2013: 26) states:

The risk of cancer induction from radiation exposure can be put into perspective . . . the current rate of cancer death among Americans is about 20 percent. Taken from a personal perspective, each of us has about 20 chances in 100 of dying of cancer. A radiological worker who receives 25,000 mrem over a working life increases his/her chance of dying of cancer by 1 percent, or has about 21 chances in 100 of dying of cancer.¹¹ A 25,000 mrem dose is a fairly large dose over the course of a working

10. The most common unit of measurement for radiogenic exposure is the rem—a calculation of biological impact from radioactivity that adjusts for the penetrative capacity of each type of ionizing radiation.

11. An mrem (or millirem) is one-thousandth of a rem.

lifetime. The average annual dose to DOE workers is less than 100 mrem, which leads to a working lifetime dose (40 years assumed) of no more than 4,000 mrem.¹²

This passage is accompanied by a table designed to help workers “put the potential risk of radiation into perspective when compared to other occupations and daily activities” (ibid.). Juxtaposing a range of industries and personal practices, the table allows workers to compare the relative decrease in life expectancy from things like smoking cigarettes, working in agriculture, or being struck by lightning (see fig. 1).

Estimated Loss of Life Expectancy from Health Risks	
Health Risk	Estimated Loss of Life Expectancy
Smoking 20 cigarettes a day	6 years
Overweight (by 15%)	2 years
Alcohol consumption (U.S. average)	1 year
Agricultural accidents	320 days
Construction accidents	227 days
Auto accidents	207 days
Home accidents	74 days
Occupational radiation dose (1 rem/y) from age 18-65 (47 rem total) (Note: the average DOE radiation worker receives less than 0.1 rem/yr)	51 days
All natural hazards (earthquakes, lightning, flood)	7 days
Medical radiation	6 days

Figure 1 “Instructor’s Guide” of the *DOE Handbook: Radiological Worker Training* (DOE 2013)

At a decreased life expectancy of only fifty-one days, the table positions occupational exposure to radiation as safer than simply spending time at home, where accidents decrease the average lifespan by seventy-four days. Asking workers to therefore consider the big picture, the training handbook elaborates:

12. What this statement fails to acknowledge is that the federal limits for permissible dose to nuclear workers is actually five thousand millirem *per year*—meaning a worker could receive a lifetime dose of two hundred thousand millirem (using the DOE’s forty-year estimate) and still be considered safe within the terms of the law.

The estimated risk associated with occupation radiation dose is similar to other routine occupational risks and much less than some risks widely accepted in society. The risk of work in a radiation environment is considered within the normal occupational risk tolerance by national and international scientific groups. However, acceptance of risk is an individual matter and is best made with accurate information. . . . It is hoped that understanding radiation risk and risk in general will help you to develop an informed and healthy respect for radiation, and that your understanding will eliminate excessive fear. (Ibid.: 27–28)

This table not only has the effect of normalizing exposure, but it also assigns concrete numbers to what are fundamentally uncertain metrics for radiogenic injury. So, too, it erases the structure in which nuclear work is done by assuming that workers can simply choose to accept or decline the risks of exposure at will.

What does it mean to embody such an ambiguous standard? How do nuclear workers negotiate the uneven terrain of risk, reason, and relativity? Being a nuclear worker often means accepting the notion that safety can coexist with risk—that the presence of one does not necessarily negate the other. As one Hanford worker (2012) told me:

We know how to protect ourselves, how to be safe. Now, we still do things, you have to take risks. Yes, we do have contaminations, we do have people get dose, but we try to limit that. We're out there monitoring our exposure, monitoring our dose, but to do this you have to have a certain buy-in of understanding. I do work in the nuclear industry, and there are some times that we're going to have proceed forth with a certain amount of risk. And that's just life. That's just how it goes. We do that every single day anyway. And I realize that the catastrophes can be enormous, I fully understand that, but we have a pretty good handle on it.¹³

It also means learning to embody the specific parameters of radiation protection—calibrating physical movements according to strict procedure in order to avoid unnecessary dose. “It’s not just cutting up cheese and turkey, for crying out loud!” the worker continued. “If I’m going into some nasty crap, I gotta have a decent work plan, we gotta know what we’re doing. If not, your risk is going to shoot up astronomically and you’re going to have a lot more uh-ohs out there” (2012). “We have to be in constant control,” another Hanford worker (2013) told me.

13. Interviews for this article were conducted in confidence during 2011, 2012, and 2013. The names of interviewees have been withheld by mutual agreement and reflect the terms of the human subjects compliance protocol.

Because radiation is insensible to the human body, protecting oneself means developing a working knowledge of the invisible, using procedural directives and radiation sensors to mediate the relationship between one's body and environment. As retired Hanford worker Wakefield "Wakie" Wright described it: "The radiation danger was always with us. We were taught to obey our instrumentation, like flying an airplane. If your instrument says you are flying straight and you think you are flying upside down, you better think you are flying straight" (Sanger 1995: 189).

Historian Joy Parr (2010) examines this distinctive pedagogy of radiation protection, a theoretical and practical training in what she calls "embodying the insensible." She describes how workers learn to understand sensory perception through technological proxy, educating their bodies to experience instrumental readings "as sensation, as a form of tacit knowledge with the same credibility as touch, taste, or smell" (ibid.: 68). In addition, embodying the insensible means developing a somatic awareness of occupational exposure limits, understanding radiation through bodily quotas, and calculating and cataloging one's accumulated dose. It requires learning to *live* federal regulations for radiation protection, fine-tuning *oneself* to the statistical reasoning of nuclear industrial risk. As one retired Hanford worker (2012) told me, "You're regulated by the procedure . . . it just gets into your head, how you do your work and how you live your life. It has to get into your head."

This embodied practice is something one learns over time. It requires years of experience working with nuclear materials, developing an instinct for how radiation travels through space, and forming habits of movement that minimize exposure. "You have to do the work to really understand what it's like," one worker told me. "New people don't understand how the systems interact, don't understand what specific things mean, and don't understand the interactions" (Hanford worker 2012). Another worker echoed her by saying: "This is stuff you learn over time, over years of knowing history and knowing what you're dealing with. These new kids think they know everything, and it's like, yeah, you're twenty-two years old, you're not really trained. You just spent six months in a classroom doing calculations. Well, this is a high-rad area, stuff you don't have any clue about" (Hanford worker 2013). As a legal advocate for Hanford whistleblowers (2013) told me:

There's been a deliberate shift to get younger, less experienced workers that are cheaper into the workforce. No pension, not complaining as much, but they don't know what they're dealing with. They're ARRA [American

Recovery and Reinvestment Act] hires off the street¹⁴—very little training and boom you're a Hanford worker. They are deliberately given skilled jobs like operators used to do, taking over a lot of that work, and the operators are like, no you can't have them do that, they're not trained, and you're putting them all at risk, but they are losing those fights. That's how Hanford is being run now. And it scares the hell out of a lot of people who are retiring out of there, saying "I don't even want to go to work anymore. I'm worried about what's going to happen." If someone doesn't know what they're doing, it can be dangerous. I'm not saying that's the way it is all over the place, but I think those incidents happen on a regular enough basis that people are concerned. (Hanford worker 2013)

Workers argue that an embodied knowledge about place and practice comes with an increased measure of safety. As the same longtime Hanford worker (2013) said: "We have procedures. We have a certain way that we work around here and we do it for a reason: to keep people safe. I want to go home safe. I want to go home to my kids at the end of the day." At the same time, this worker and others she works with recognize that this safety is not absolute. Many acknowledge that even safe practices cannot prevent eventual radiogenic impact (Hanford workers 2011, 2012, 2013). She continued,

Well, you know, with radioactivity, you get a chronic exposure to that eventually. I mean, it's a cancer-causing agent. The scary part is I've been [here] a long time. And you know, I'm at that point, that latency period, you know. About twenty years. You know, where stuff starts happening or people start getting sick or things just aren't right. And so that worries me, it's like, gosh. But you know, the damage has already been done. I mean, I suppose I could quit now and there would be no more damage for me from this day forward, but . . . (Hanford worker 2013)

So, too, the logic of safety as administered through dose is often undermined in the recording process. The same worker remembers receiving a dose of six hundred millirem in one day while she was pregnant—one hundred millirem more than the total amount allowed for her entire nine-month gestation period. "They never assigned me the dose because then I would have been overexposed for a pregnant worker," she told me. "They said that there was probably just something wrong with my dosimeter, that there was a pinhole—a microscopic pinhole in my dosimeter that nobody could see—that would cause it to malfunction. I said, well that's crap. I'm not buying that. And I've gone back and said, hey, you know,

14. The ARRA, signed into law in 2009, is also known as Barack Obama's stimulus package.

I'm curious about this. You know, I was pregnant! And they said, no, they have no record of it. None whatsoever" (ibid.). Another recent retiree told me: "When I would dress out, I was told that my [dosimetry] badge went on the inside of my coveralls.¹⁵ My pencil dosimeter, if it was issued, was in my pocket on the outside. But my badge that had the secondary dose on it was inside my coveralls.¹⁶ . . . That was the way you dressed out because they didn't want you crapping up your badge.¹⁷ 'Don't crap up your badge,' they said. What's more important here, a two-dollar badge or your life? The badge! [*Laughs sarcastically.*]" (Hanford worker [retired] 2012). As workers, these individuals have to continually negotiate the difficult cognitive territory of safe exposure. They have to obey strict procedural direction and comply with dose limits in the name of their protection, while also knowing that these structural requirements ultimately fail to prevent the eventual injury of nuclear work. As such, they have to learn to embody both the logics of nuclear safety and its embedded contradictions.

This complex relationship with exposure is, in part, a consequence of conceptualizing threat through the lens of risk. As Langdon Winner has argued, there is a subtle yet critical difference between using words like *danger* and *peril* to describe an issue versus using *risk*. The word *risk* "carries a certain baggage, a set of ready associations," Winner contends (1986: 145). Risk is something one can choose to "take" based on the relative probability of cost and benefit. It evokes a liberal subject whose decisions are informed by rational calculation (Porter 1986). In addition, risk affords statistical comparison between incongruous activities like driving a car and working in a radioactive environment. If one is willing to accept the relatively higher risk of an automobile accident, for example, how can one argue that the relatively lower risks of nuclear work are unacceptable? As such, risk discourse creates its own conditions of possibility for rational decision making (Clarke 1999). Choices that do not reflect these terms are considered suspect, the result of fear, misinformation, or both.

Of course, the clean statistical distributions that inform risk frameworks are underwritten by a broader social and political reckoning. In this sense, risk can be understood not simply as a series of cost-benefit calculations but also as a set of social relations that give such parameters meaning (Beck 2009; Douglas and Wildavsky 1982; Slovic 1987). Like the low-hanging overpasses and the tomato

15. "Dress out" is slang for getting suited up for radioactive work.

16. Placing the dosimetry badge on the inside of one's coveralls would make it difficult (if not impossible) to detect radiogenic exposure.

17. "Crap up" is slang for getting contamination on something or someone.

harvesters that Winner (1986) famously describes, the nuclear safety standard is a social technology that retains the politics of its creation. Thus Cold War understandings of nuclear threat continue to inform the contemporary boundaries of radiation protection.

In formalizing limits for permissible exposure during the Cold War, the US government sought to manage the social and environmental consequences of nuclear industrial development. Indeed, the 1960 hearings of the Special Subcommittee on Radiation are explicit in this regard, asking, “How can the Nation (and the world) deal with . . . constantly rising levels of potential radiation exposure to the human population?” (US Congress 1960a: 32). Unfortunately, the committee found it was unable to answer its own critical question. Instead, it offered the vague proposal that if contamination or exposure “became excessive,” then “reactor development might have to be curtailed” (ibid.). However, in arriving at the ambiguous conclusion that production should stop at the moment its social and environmental costs became “excessive,” committee members were again met with their original dilemma: the need to transform a complex and contingent understanding of harm into a concrete numerical value. Thus risk-based calculations for nuclear safety were used to manufacture certainty from a set of uncertain conditions, to assert discursive control where material control was not possible.

Conclusion

When hundreds of Hanford workers and their families gathered and gave testimony in Richland’s Federal Building auditorium, their stories revealed more than a shared history of illness and injury. For many, exposure was a violation not just of their bodies but also of their rights as American citizens. At stake was the meaning and value of their sacrifice, whether their wounds carried social, political, or economic weight. As one worker told the secretary of energy: “There’s a lot of us who worked hard for a lot of years. We’re not looking for a free lunch. We’re not interested in a big money claim. But you don’t want to be left with nothing, with no health to go get another job. We just want enough to get by and to live a dignified life for what’s left of it” (DOE/OESH 2000). Another worker echoed him angrily, saying: “The Department of Energy is spending over \$6 billion to clean up [its] contaminated waste. A billion of that is coming to the Hanford Site.¹⁸ We’re only asking that the Hanford workers get treated just half as well as the dirt” (ibid.).

18. The Hanford Site now receives about \$2 billion annually in cleanup funding.

In telling their stories, workers raised broader questions about the nature of citizenship in the nuclear state.¹⁹ Until Congress passed the EEOICPA in 2000, nuclear weapons workers within the DOE complex did not receive special benefits for their role in wartime activities.²⁰ Though they produced the technologies of war and were exposed to its by-products, they were not afforded veteran status. As a result, they lacked the political recognition and access to social and economic programs promised their Department of Defense counterparts. The EEOICPA, therefore, is an attempt to expand the legal geography of the nuclear battlefield. Its passage created a new bureaucratic subject: the “atomic weapons employee,” an individual whose sacrifice in the service of the nuclear arsenal now officially merits compensation (Energy Employees Occupational Illness Compensation Program Act, 42, U.S.C. § 7384).

The EEOICPA renders injury legible through a complex valuation of pain and suffering. As a compensatory system, it seeks to “ensure fairness and equity” (*ibid.*) for injured workers within the socioeconomic terms of progress, profit, and national security. As such, the EEOICPA is framed as a rational mechanism for remedying the unequal social relations of nuclear production. As legal subjects, atomic weapons employees submit their wounded bodies as evidence that they have not received adequate protection from workplace hazards. Subsequent compensation is then distributed (or not) according to the logic of the marketplace that gives their labor value—where injury is imagined to be “undone” through the monetary award that will in a rough sense ‘buy back’ what it has taken” (Jain 2006: 12).

However, as Elaine Scarry (1985: 300) argues, “Compensation . . . [is] only a mimetic rather than an actual undoing.” While the financial and medical assistance that the EEOICPA offers may prolong and improve workers’ lives, it does little to address the uncomfortable reality that injury is necessary to nuclear production. Instead, compensation rearticulates the broader social logic of acceptable exposure. By determining the point at which injury becomes compensable, the

19. In *Life Exposed*, Adriana Petryna describes how radiogenic injuries following the Chernobyl disaster became the currency through which exposed individuals negotiated survival in the post-Soviet era. Identifying the legal boundaries of health and suffering, she argues, produced new forms of “biological citizenship,” where injury and illness became “the basis for staking citizenship claims” (Petryna 2002: 5). Likewise, Hanford workers called attention to their injuries as a means of renegotiating their citizenly rights and privileges. Evoking liberal ideals as old as the nation, workers contested what they saw as an unequal relationship between their individual bodies and the body politic.

20. Uranium miners are the exception; they have been eligible for compensation through the Radiation Exposure Compensation Act (RECA) since 1990.

EEOICPA authorizes the terms of permissible dose. So, too, it masks the state's complicity in creating the conditions for worker injury. Asking the federal government to determine the basis for compensation fails to acknowledge the ways that it is profoundly invested in *producing* the injuries it adjudicates (Brown 1995).

How, then, can we attend to the unequal social relations of worker health and safety? If compensation simply reproduces the structural inequalities it purports to address, what possibilities are there for social justice? I suggest that critical engagement should begin by investigating the complex politics of permissibility. As I have argued in this article, permissible exposure forms the basis for measuring and evaluating the impacts of nuclear development.²¹ Translated from an administrative category into an embodied practice through the probabilistic language of risk, this cost-benefit calculus informs radiation protection standards and compensation structures. Permissibility teaches workers how to move through radioactive space and how to interpret their damaged bodies. It frames exposure as integral to progress and security and positions wounding as a social good (Jain 2006).

Thus structural change requires closer attention to the deeply political ways that injury facilitates nuclear production. It calls for critical scholarship that explores how permissibility plays to power and asks questions like, permissible for whom? Finally, it demands better analytics for understanding how permissible exposure has been made intelligible and legally actionable. Rather than taking the standards and structures that govern nuclear production for granted, we need to interrogate their conditions of permissibility. We need to consider what it means to live, work, and design environmental regulations in an increasingly contaminated world and to think critically about how “safe” has become synonymous with “safe enough.”

21. Permissible exposure extends beyond nuclear safety as well. Exposure has been rationalized and regulated for pesticides (Nash 2006), industrial chemicals (M. Murphy 2006), hormones in industrial meat (Langston 2010), bisphenol A (BPA) in plastics (Jain 2013), and many other parts of industrialized life. In each of these cases, exposure is made reasonable through a series of cost-benefit calculations that reference a privileged understanding of the common good—the notion that even if pesticides, industrial chemicals, and radioactive particles injure some, overall they improve our collective quality of life (Jain 2006).

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