

Jacob Hamblin
Linda M. Richards *Editors*

Connecting to the Living History of Radiation Exposure

 Springer

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Previously published in *Journal of the History of Biology*
“Special Issue: Connecting to the Living History of
Radiation Exposure”, Volume 54, Issue 1, 2021

 Springer

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ISBN 978-3-031-18757-5 ISBN 978-3-031-18758-2 (eBook)
<https://doi.org/10.1007/978-3-031-18758-2>

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The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

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Connecting to the Living History of Radiation Exposure

Jacob Hamblin¹ · Linda M. Richards¹

Accepted: 1 February 2021 / Published online: 20 April 2021
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The largest radiation releases (I-131) studied by the government require the smallest health remedy. One tiny, inexpensive thyroid pill taken daily for the rest of your life; not life threatening. This is the most unimpactful radionuclide. It was chosen in order to show “it is not as bad as you think it is.” Not like the hundreds of other radionuclides released to the public that cause leukemia, cancer, spontaneous abortion, birth defects, and sterility. The things that are still happening to someone like me.

Patricia Hoover, Hanford Downwinder (2018)¹

The lived experience of contamination to our bodies, and the consequent generation of sickness and disease, is fraught with contested ideas about memory, science, authority, expertise, and the values we associate with life itself (Parry 2010; Steingraber 1997). In the latter half of the twentieth century, exposure to radiation created flourishing research fields in health physics and radiation biology, while also creating identities for some as “downwinders” who attributed their illnesses to living down-wind, down-river, or down-stream from a nuclear site (Fox 2014). The Hanford Nuclear Reservation Litigation, or the “Downwinders Case,” remains one of the most controversial legal struggles in the history of atomic energy. It raised scores of environmental, scientific, civil rights, health, and legal questions. It focused on the chemical separation plant at Hanford, Washington, built during the Second World War to extract plutonium from spent uranium. The facility is one of the earth’s most contaminated sites due to groundwater seepage, river pollution, and atmospheric discharges (Gerber 1992; Power 2008). The legal case, begun in 1990, consolidated thousands of plaintiffs who alleged that Hanford’s environmental contamination was responsible for health problems, specifically thyroid disease, over a wide area that included several US states (Pritikin 2020). As significant a site as Hanford was (and

¹ Patricia Hoover, remarks at research workshop, “Telling the Stories of Radiation Exposure,” Oregon State University, Corvallis, Oregon, June 21, 2018.

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is), the issues surrounding it were not unique. Similar scientific controversies, social justice concerns, and environmental consequences emerged in other contexts and other countries in the latter half of the twentieth century (Cianciolo 2015; Kushinskaya 2014; Shrader-Frechette 2013; Brown 2013; Brugge et al. 2006; Makhijani et al. 1995).

What is at stake when researching and narrating these histories of radiation exposure? On June 21–22, 2018, as part of a National Science Foundation grant, we convened a unique workshop at Oregon State University in Corvallis to draw a range of voices together to answer this question.² The workshop focused on historical research, and it invited collaboration from several different academic fields while also reaching out to advocacy organizations to engage them directly in historical work. The above broad question, posed in the workshop’s call for papers, was intended to provoke discussion among scholars, activists, and other citizens about the many challenges in researching, writing, or talking about past exposures to radiation. The histories of so-called “Downwinders” are contentious, in part because of the litigation and also due to continued scientific controversy. Yet the story must be told, and we must face the challenge. But how?

We initially prioritized inclusion of a diversity of voices and a range of narratives, believing that too intense a focus could blind us. With every narrowing on a focal point, essential pieces of other stories may be lost.³ What if, as Patricia Hoover warned us, the most pressing issues are unknowingly erased, even in the history of science, if we only look to science and the law for answers? She shared her painful experiences of sickness and long, drawn-out legal battles. She further noted the feeling of abandonment and betrayal felt by survivors who trusted their governments and academic experts. Many of the workshop participants were scholars, but some came keen to tell stories differently, as victim advocates or activists. They wondered whether their efforts would find respect among academics, or if we would defer instead to the hallowed process of peer review—the same process that many of them believe lent authority to published scientific work that allowed them to be exposed to harmful doses of radiation. They wondered whether we would deem them unscholarly, consider them biased activists rather than engaged witnesses, or listen to them at all.

We have begun to listen. And we also continue to care about the process of peer review in our scholarship. Not all workshop participants ended up writing essays for this special issue, but their voices carried us far in our discussions of unrepresented voices in extant historical narratives. For example, Desmond Doulatram, of the nonprofit REACH-MI (Radiation, Exposure, Awareness, Crusaders for Humanity—Marshall Islands), pointed out the history of exposure, betrayal, and empty promises experienced by people who lost their lands and lifeways due to trusting that their sacrifice would be “for the good of mankind.” Yet he also made clear that

² “Reconstructing Nuclear Environments and the Downwinders Case,” National Science Foundation Award #1734618.

³ We follow here the perspective pervasive among public historians and museum specialists that learning to listen to a range of actors is a way of sharing authority within historical narratives (McLean 2011).

such disproportionate health impacts run in parallel with the lack of representation of intergenerational harm to the Marshallese within academic discourse, a point that is pertinent to indigenous peoples in other parts of the world as well.⁴ Similarly, Lauren Nussbaum and Patricia Hoover recalled their experiences developing a scientific health survey that found an excess of illness, in direct conflict with government conclusions that thyroid cases were not in excess (Nussbaum et al. 2004). To Nussbaum and Hoover, their work validated victims' claims while demonstrating the need for large scale epidemiological studies that should be followed by remedial actions. Together they voiced their frustrations at the use of scientific work to minimize the appearance of harm to those living near Hanford Nuclear Reservation.

One of our workshop's lessons was that, however we tell the stories of radiation, we need to find ways to foster and sustain dialogue among those continually affected. Helen Jaccard, with the Veterans for Peace Golden Rule Project, shared her sobering and stunning interviews with Japanese mothers after the Fukushima disaster of 2011. In Japan, some mothers were shamed by health professionals and told their concerns were imagined. They were told they are overly "radiosensitive" and that their concerns created additional emotional strife. Those who suffered were told they were the agents of their own suffering.⁵ Historian Britt Dahlberg highlighted how art can be a window into discourse of repair, responsibility, and resiliency. Her presentation, "Engaging Toxicity in Context: Asbestos, Oral History, Theater, and the Grounds for Dialogue," highlighted ways that the asbestos story compared to radiation exposure, and she drew attention to a creative model of supporting action for cleanup and environmental justice using art in a community affected by industrial collapse and pollution.⁶

The essays in this peer-reviewed special issue highlight the multiple ways of telling stories of radiation exposure; they include stories about Japan, Australia, the United States, the Canadian Arctic, and more, and they probe the framing of major incidents such as Three Mile Island, Chernobyl, and Fukushima. All the essays included here are by authors who participated in our work at Oregon State University and have benefited from hearing not only from scientists but also from those whose lives were directly affected by the history of radiation exposure. The academic environment challenges the essential ethical question of how to stay true to the many needs of exposed populations. By linking these authors together in this special issue, we embrace a fuller perspective, but we are also keenly aware of what voices are absent. The lack of radiation-exposed populations in this special issue,

⁴ REACH-MI's work focuses not only on the continuing legacy of nuclear testing, but also a range of important issues such as climate change, ocean advocacy, and sustainable communities (<https://www.reach-mi.org>).

⁵ The Veterans For Peace Golden Rule Project's current advocacy work is tied to the historical era of nuclear testing but also includes peace activism (<https://www.vfpgoldenruleproject.org>). Related organizations, such as Beyond Nuclear, have broadened that activism to include criticism of civilian uses of nuclear energy as well (<http://www.beyondnuclear.org>).

⁶ Dahlberg's public history work was an example of efforts to reexamine the contested histories of chemical exposures while connecting to a variety of audiences. It was part of her work at the Science History Institute's Center for Applied History (<https://www.sciencehistory.org>).

beyond this brief introduction, is a testament to their ongoing suffering and disappointment. However, many of our authors have worked to portray how these communities' suffering came to be. It may be that, in the future, we will find a way to move from this seed of inclusion to a place where the radiation exposed can represent themselves and speak in their own voices.

Opening the special issue are two essays on contested interpretations of scientific data among victims of radiation exposure. Mary X. Mitchell shows how, in the aftermath of the Three Mile Island accident, citizen activists centered their scientific inquiry on the suffering, living world. In litigation, plaintiffs tried to make sense of their unexplained experiences and observations and substantiate radiation exposure with evidence from their own bodies. After failing to convince government agencies to launch serious studies of their cases, activists turned to citizen science in collaborative, expert scientific testimony in ongoing personal injury cases. Cynthia Folkers highlights inadequacies in extant scientific studies in an essay exploring the longstanding pattern of minimizing harm from radioactivity. Her provocative article suggests that risks to women, children, and pregnancy have been devalued through institutional silence and misapplication of science. She argues that correcting the narrative is not only important to understanding the history of biological effects, but also to future decision-making about a range of issues such as climate change mitigation and future energy sources.

We follow these with two essays that address perception and invisibility. Jonathan Luedee is concerned with perceptibility in science, specifically, assessments of radioactive contamination to human and non-human bodies. He draws from records of scientific institutions and health officials in Canada and the United States as they studied exposure levels in northern communities, often based on bioaccumulation in caribou. He tells the story of a series of bioenvironmental investigations in the 1950s and 1960s, showing how scientists mapped the spatial and temporal boundaries of radioactive exposures (or body burdens) in northern communities. Taking an approach that emphasizes visual culture, N. A. J. Taylor shows us multiple invisibilities in telling the stories of radiation in Oceania. One is that of biological life in settler colonial artistic representations, in response to the British nuclear tests at Maralinga. Another is the relative absence of Oceania generally in discussions of global nuclear history and culture. Taylor urges us to consider what the irradiation of biological life in Antipodean nuclear art can tell us about broader efforts of telling stories of radiation exposure.

We end with two essays focusing on depictions of radiation exposure in the scientific literature. Sumiko Hatakeyama offers an analysis of the role of atomic bomb survivors (*hibakusha*) as witnesses—not just as we typically understand the word, but as instruments of science. She shows us how survivors' inscribed bodies have, ever since the bombings of Hiroshima and Nagasaki, narrated what it means to be exposed to radiation. Focusing on two decades after the mid-1950s, Hatakeyama highlights how new methods, practices, and technologies allowed scientists to investigate chromosomal aberrations as a way to study radiation exposure and human risk. The decision to “let chromosomes speak” became not only a scientific approach but also an institutional strategy of engaging and publicizing contested science. David Hecht offers an essay on the treatment of radiation risks in public

discourse, particularly science writing in the early years of the Cold War. He shows us how literary forms—such as war reporting, travel memoir, and detective fiction—permeated accounts of radiation exposure. Hecht suggests that such forms provided tools for writers to overcome some of the inherent challenges of communicating radiation risks. These forms lent authority to the texts while also laying down narratives, showing us—uncomfortable as it may seem—just how much of science is storytelling.

The *Journal of the History of Biology* has been an important outlet for enriching the historiography of the twentieth-century history of radiobiology, health physics, dosimetry, and genetics (Lindee 1992; Bocking 1995; Creager 2006; de Chadarevian 2006; Gaudillière 2006; Rader 2006; Santesmases 2006; Hamblin 2007; Goldstein and Stawkowski 2015).⁷ We hope this special issue will aid us in thinking through what the stakes have been in the framing of historical narratives. We present a range of perspectives that draw attention to the ways nuclear narratives emerge—in forums as widely divergent as legal cases, activism, scientific institutions, literature, and art. The biological effects of radiation exposure are deeply contested, and this is likely to continue. Our goal is not to reinforce existing frameworks, such as legal decisions or government policies, but rather to highlight what narrative framings accomplish and commit once again to scrutinizing them with rigorous research, varied approaches, and, above all, listening to those whose lives were most affected by exposure.

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⁷ See especially the 2006 *Journal of the History of Biology* special issue “Radiobiology in the Atomic Age” edited by Angela N. H. Creager and María Jesús Santesmases.

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The Cosmology of Evidence: Suffering, Science, and Biological Witness After Three Mile Island

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Accepted: 30 January 2021 / Published online: 24 February 2021

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Abstract

The 1979 partial nuclear reactor meltdown at Three Mile Island was simultaneously hyper-visible and hidden from public view. It was the subject of non-stop media attention, but its causes and consequences required expert explanation. No fire or explosion marked the moment when insensible radionuclides escaped the facility. Yet, residents recalled a variety of troubling sights, sounds, odors, tastes, and sensations. Public distrust percolated in the interstices between government assertions that little radiation had escaped the facility and residents' sense memories of the incident. This article traces intertwined networks of activists from Japan and Pennsylvania as they mobilized legally, politically, and scientifically to develop evidence about the offsite effects of Three Mile Island. Exploring the distinct cosmology of evidence that activists marshaled, the article shows how they placed the messy, contingent, dynamic living world at the center of inquiries about the meltdown's consequences. Activists developed new practices of biological witness that reconfigured the interplay between scientific, legal, and moral authority, while concurrently reformulating sufferers' subjectivities and notions of scientific objectivity. In the process, they suggested that environmental justice entailed epistemic justice. Their cosmology of evidence served as an argument and a material proof that the beloved but suffering living world, and the sciences used to understand it, could and should frame the governance of industrial society's invisible harms.

Keywords Radiation · Biological witness · Three Mile Island · Citizen science · Epistemic justice · Evidence

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Introduction

In the pre-dawn hours of March 28, 1979, Marie Holowka and her brother Paul were milking cows on their family farm in Zions View, Pennsylvania, just a few miles away from the Three Mile Island Nuclear Generating Station (TMI). Marie remembered hearing a loud noise and feeling the ground shake at about the same time TMI Reactor Two began to meltdown. She later testified about what she had sensed and suffered: “When I came out of the barn to go to the house, the sky was blue, this deep blue. I couldn’t see. . . . The air was so heavy that it knocked me down three times. . . . It was a hot day—so blue, so muggy. . . . I got sick in the summer. It was my thyroid. I now have cancer. . . . We in this valley are all dying young and old alike.”¹

Following the TMI meltdown, activists sought to use residents’ embodied sense memories and observations to prove that the incident caused cancers in nearby communities.² After the chaotic early days of the incident had passed, government officials repeatedly assured residents that they were safe—that releases of radioactive materials had been too small to cause harm (see Walker 2004; Zaretsky 2018). Yet, by and large, regulators neither sought nor offered an explanation for residents’ experiences and maladies or even for the damage they observed in the natural world. Between 1979 and 2002, activists mobilized in search of new information about the meltdown’s offsite effects. This article traces the causes and consequences of activists’ work to transform suffering into science. I explore their efforts to develop evidence that revalued and reevaluated what happened—how exposure could be known, whose knowledge counted, who would bear responsibility, and why it all mattered.³

Activists’ efforts to produce evidence about TMI are revealing, even though they failed in narrow legal and scientific terms. Compared to other forms of pollution, exposures to ionizing radiation, as Kuchinskaya (2014) has noted, can be particularly difficult to make visible and easily made to disappear. Because ionizing radiation is generally imperceptible to human senses, knowledge about it is almost always mediated by technoscientific tools and experts. Its health effects, moreover, can take decades to emerge and may be tied to many other causes. These features have created difficulties for communities seeking to establish harmful levels of exposure (see Wynne 1982, 1996; Petryna 2002; Barker 2004; Masco 2006; Hecht 2012; Kuchinskaya 2014; Voyles 2015; Kimura 2016; Smith-Norris 2016; Brown 2013, 2017,

¹ Marie Holowka Affidavit, n.d. [ca. 1986], 003436, Volume V, Consolidated Appendix, In re Three Mile Island, Nos. 96-7623, 96-7624, 96-7625, 193 F.3d 613 (3d Cir. 1999), Federal Record Center, Philadelphia, PA (hereafter cited as Consolidated Appendix). Pinpoint citations are given to the unique *Bates stamp* identifiers used to organize the pages of voluminous trial records into a progressive, consecutively numbered series.

² I use the term *sense memories* to refer to residents’ recollections of what they saw, felt, heard, smelled, and tasted after TMI. As Joy Parr (2010) has established, embodied practices of sensing have been an important mode of knowledge-making about environments and technology.

³ TMI was the first major civilian nuclear reactor incident worldwide. Rich scholarly accounts chronicle its influence on nuclear regulation and political culture in the US and internationally (Walsh 1988; Walker 2004; Bösch 2017; Zaretsky 2018). Activists’ knowledge claims and legal claims, however, remain largely unexplored.

2019). After TMI, the development of an early and strong scientific consensus that little radioactive material had escaped the plant further complicated activists' work (Walker 2004). They ultimately failed to win compensation or to influence conventional scientific understandings about the meltdown's offsite effects. Their protracted efforts, however, created bountiful sources for the study of how evidence is produced and what makes it authoritative and trustworthy—both within and beyond scientific and legal institutions.⁴

My recounting of controversy over radiation exposure after TMI focuses on what one expert witness, Douglas Crawford-Brown, described as the “cosmology of evidence.”⁵ In using the term *cosmology*, he alluded to the broader frameworks of thought and action made material through the production of scientific evidence. Cosmologies are “an indispensable first order of relevance and relation which enable their adherents to make sense of and act within the world. . . . Cosmologies prescribe the visible and the invisible, the imaginable and the inconceivable” (Jewson 1976, p. 226). After TMI, much more was at stake than narrow conflicts over how much radioactive material escaped the plant (compare Wynne 1982). Controversies over exposure brought distinct world-making practices into view and materialized competing cosmologies of evidence.

Activists enacted a cosmology centered on the suffering, living world. Where scientists previously worked to transform exposed bodies and environments into biological truths about radiation (Lindee 1994, 2016; Hatakeyama 2021), activists turned this process back onto itself. They sought to transform residents' embodied experiences and environmental observations into scientifically authoritative evidence that they had been exposed. Their goal was not to supplant experts but to invite scientific study and collaboration centered on local communities and environments. They argued that biological evidence of radiation exposure could prove that TMI had caused them harm. The suffering they experienced and saw, they asserted, should serve as both *explanandum* and *explanans*—as the phenomenon to be explained and the key to explaining it.

This cosmology, I contend, centered on a form of *biological witness*. Forensic scientists have occasionally used this term to reference (uncritically) the capacity of biological evidence to establish truth (Kayser 2015). Science and technology studies scholars, by contrast, have mostly focused on the fraught epistemological and legal stakes of the entry of new forms of biological evidence into modern courtrooms (Smith and Wynne 1989; Jasanoff 1995, 2002; Cole 2001; Aronson 2007; Lynch et al. 2008). Like Hatakeyama (2021), I am interested in broader, modern configurations of witnessing (see Margalit 2002; Winter 2007; Dean 2019; Fassin and d'Halluin 2005; Fassin 2011a; Murphy 2012). I attend to the interplay and trade-offs

⁴ While sociological studies has a long tradition of examining the importance of legal mobilization outside the courtroom (see McCann 1994), scholars have often focused on the interplay between legal action, culture, and ideology (see generally McCann 2008). The production of evidence here also demonstrates interventions of, and intersections between, law and the material world (see generally Faulkner et al. 2012).

⁵ Testimony of Douglas Crawford-Brown, Transcript of Proceedings, In Limine Hearing, Volume 23, November 30, 1995, 003260, Volume V, Consolidated Appendix.

between moral, legal, and scientific authority at stake in activists' models of biological witness after TMI.

Starting with the birth of public distrust over dosimetry and tracing three episodes of mobilization, I explore how activists crafted a cosmology of evidence that rested on biological witness. Recasting people and plants as biological dosimeters, activists reconceptualized lay-persons' subjectivities and scientific objectivity.⁶ They sought to harness affectively and morally powerful *testimony* about embodied experience while transforming it into scientifically objective *proof* that radiation exposure had caused their suffering. Focusing solely on the biological effects of radiation, activists ultimately forged collaborations with experts in the life, earth, environmental, and biomedical sciences. These scientists used court proceedings to challenge both positivist, laboratory-based legal standards for the admission of expert evidence and traditional Comtean hierarchies of the sciences that placed physics and mathematics above biology (compare Jasanoff 2002, 2005, 2008; Cole 1983). In this cosmology of evidence, radionuclides moved unpredictably and accreted unevenly in a messy, dynamic, and contingent living world. The life, earth, environmental, and biomedical sciences, in this rendering, demonstrated important epistemic virtues because they offered more accurate, and therefore truthful, representations of nature (see Daston and Galison 2010).

The cosmology of evidence that emerged from activism after TMI was as much a political demonstration as an attempt to win legal redress. At several points, the legal process provided critical impetus, funding, and a culturally resonant stage for activists' reconfiguration of relationships between knowledge and justice (Reardon 2013). Legal victory was never the only goal, however. Drawing linkages between epistemic injustice and environmental injustice, activists' work served as argument and material proof that the suffering living world could structure interconnected efforts to know and govern the dangers of modern industrial societies.⁷

Uncertainty and Distrust

The TMI incident was both hyper-visible and frustratingly opaque. On the one hand, the internationally publicized disaster unfolded in real-time via extensive media coverage. On the other, its offsite effects were largely imperceptible. The massive concrete containment structure remained intact. There was no dramatic fire or large explosion. Evaluating the harm would require science and technology. TMI called into question the safety of nuclear energy while forcing the public to rely on

⁶ These activities included attempts to make knowledge through practices of health surveying. Brown (1992) has referred to this kind of work as "popular epidemiology." Numerous studies trace instances of popular epidemiology and citizen science, but few besides Kimura (2016) study in-depth citizen mobilization to detect radiological harm.

⁷ Scholars use the term *epistemic injustice* to describe many different kinds of inequity embedded in processes of knowledge-making, chiefly ones suffered by marginalized communities whose agency as knowers is limited (see Fricker 2007; Grasswick 2018).

regulators for answers about the risks and harms they faced. This central tension fueled public distrust (Zaretsky 2018).

A compounding series of technological failures and human errors caused a partial meltdown of Reactor Two at TMI. On March 28, 1979, around 4 a.m., the loss of coolant surrounding the radioactive core of the reactor caused it to begin to melt down. Radioactive water and gases collected in the containment and auxiliary buildings of the facility (Perrow 1984; Walker 2004; US Nuclear Regulatory Commission 2018). Utility and government spokespersons gave conflicting reports about risks to the public, wavering on whether radiation had escaped the facility and if there was ongoing danger of an explosion (Walker 2004; Zaretsky 2018). On April 9, regulators declared that the acute phase of the incident had passed—an explosion was unlikely—but public anxiety had only just begun (Walker 2004).

TMI called into question the competency and intentions of actors within the US nuclear complex. The utility and regulators ultimately acknowledged that radioactive noble gases had escaped the facility, mainly through a ventilation stack (Walker 2004), but there was little contemporaneously-produced data about the effluence. For instance, the facility's radiation sensor coverage had been scanty. A network of twenty instruments (Thermo-Luminescent Dosimeters, TLDs) used to measure radiation in the environment was too widely spaced to track precisely the course of radioactive gases (Beyea 1984). Even the principal radiation monitor within the plant's vent stack had gone off-scale. The instrument topped out and failed when it registered a reading higher than it could measure (Beyea 1984; Fabrikant 1979). Scientists and engineers had to reconstruct, model, and estimate the average radiation dose to persons in the communities surrounding the plant.

They worked from two different angles to calculate the *source term*—the kind and quantum of radionuclides that had escaped the facility. First, they used information about the fuel in the reactor and data from radiation monitors to estimate the amount of escaped material and to produce a computer model of where it might have settled. Second, they searched for radionuclides and their byproducts in the environment (Fabrikant 1979; Beyea 1984; Three Mile Island Public Health Fund 1985a, b; Walker 2004).

This work entailed judgment calls, on-the-spot decisions, and luck. Health physicist John Auxier recalled that scientists found an unaccounted-for radiation monitor near the vent stack and used its data as a part of source term calculations (Three Mile Island Public Health Fund 1985a). Where scientists and engineers encountered instrument readings that indicated extremely high levels of radiation, they simply scrubbed these datapoints from their estimates, concluding that the readings were likely the result of faulty or improperly calibrated devices (Three Mile Island Public Health Fund 1985a). Despite extensive study, scientists were transparent about the limitations of their work. They acknowledged that they could neither be completely certain about exposure to radionuclides having a short half-life nor pinpoint specific areas where a radioactive plume of noble gases may have touched down (Fabrikant 1979).

The overall approach, Department of Energy health physicist Andrew Hull later explained, had been “a sort of jigsaw puzzle approach in which an analyst has four or five pieces of information and tries to relate them to each other, and then to fill

in the missing pieces to describe the overall pattern” (Three Mile Island Public Health Fund 1985a, p. 100). In May 1979, a US interagency task force concluded that the maximum individual dose to offsite persons had been just 100 millirem (1 millisevert)—a level too low to cause observable symptoms or induce more than a handful of cancers (Walker 2004). This was, however, an estimate.

The incident, meanwhile, had left a bad taste in residents’ mouths—literally and figuratively. That spring, concerned community members across the region began to organize and file lawsuits (Walsh 1988). Some residents started to take notice of unexplained sensory phenomena and harm to the natural world around them. Pennsylvania Department of Health census-taker Larry Arnold noted that several residents mentioned experiencing a metallic taste following the meltdown. Thinking this odd, he compiled an informal preliminary report in June 1979.⁸

When Pennsylvania State Representative Stephen R. Reed asked the US Nuclear Regulatory Commission (NRC) to investigate residents’ reports, the agency dismissed the request. Relying on the government’s dose estimates, the NRC insisted that any exposure had been too small to cause the kinds of experiences reported in the community.⁹ The meltdown may have been largely contained within TMI’s massive concrete carapace, but distrust moved across the landscape alongside uncertain amounts of radionuclides.

Moral Witness

Residents’ bodies and emotions stood at the center of emerging efforts to make TMI visible and to raise awareness of the environmental and epistemic injustice it represented. Transnational Japanese environmental justice activism sparked action at TMI. In August 1979, Japanese visitors came to Pennsylvania to consider what the meltdown might indicate for mobilization against nuclear energy. They developed a model of moral witness centered on residents’ experiences as part of a broader gambit to frame scientific questions and invite further expert investigations.

Japanese activists found the TMI incident valuable for what it could teach about organizing around the imperceptible risks and harms of nuclear energy. Four Japanese antinuclear activists—lawyers Kazuyoshi Fujita and Katsuyuki Kumano, psychology teacher Mitsuru Katagiri, and student activist Fukiko Tomita—went to Pennsylvania to study TMI in August 1979. The lawyers hoped that “technical data and sociological facts” from TMI could be used to support ongoing litigation seeking to revoke the operating license of the Ikata Nuclear Power Plant in Hiroshima Prefecture, Japan. TMI was a particularly important site for this kind of work

⁸ Mitsuru Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Beverly Hess Papers, Dickinson College Archives and Special Collections, Carlisle, PA (hereafter cited as Hess Papers).

⁹ Stephen R. Reed to Joseph M. Hendrie, August 8, 1979; Joseph M. Hendrie to Stephen R. Reed, September 20, 1979, reproduced in Hajime Nakao (Mitsuru Katagiri), *Three Mile Island: The Language of Science and the People’s Reality*, Part Two, trans. Rebecca Jennison, *The Kyoto Review* 13, Spring 1981, in Folder 11, Box 5, Hess Papers (hereafter cited as Katagiri, *Three Mile Island*, Part Two).

because it was the first major civilian reactor disaster and since it occurred in a pressurized water reactor (PWR) with similarities to the US-designed Westinghouse PWR at Ikata.¹⁰

Drawing on prior activism over methylmercury pollution, the Japanese team began to evaluate how the moral and emotional resonance of TMI might be harnessed to challenge nuclear energy. Methylmercury is a byproduct of industrial processes. When polluters dump contaminated wastewater, it enters the food chain through fish and shellfish. Exposure to methylmercury causes a neurological syndrome called Minamata disease, named after the Japanese city where the disorder was first identified (George 2001). Although methylmercury, like radiation, is largely imperceptible, its effects are wrenching and visible. The “dancing cats” of Minamata—local felines whose jerky movements and painful deaths began during the early 1950s—became sentinels of a wider problem affecting the city’s people. In adult humans, exposures cause similar ailments, including disordered movement, muscle weakness, vision and speech problems, and even death. In utero exposure can cause growth deficits and atypical limb development. The effects of Minamata disease are written on the body (George 2001; Walker 2010).

During Japanese litigation over methylmercury pollution in the early 1970s, activists drew on the moral authority of nuclear survivorship in efforts to stop industrial pollution. Victims of nuclear fallout fit readily within developing conceptions of modern moral witness (Yoneyama 1999). In the broadest strokes, moral witnesses testify to the violence they have experienced in the hope of preventing similar atrocities in the future (Margalit 2002; Winter 2007; Dean 2019). In the *Watanabe* Minamata case, lawyers drew on the moral force of nuclear survivorship and legal arguments crafted in response to US nuclear fallout in the 1950s. They argued that corporate polluters, like nuclear nation-states, should be held responsible for the wrenching damage done to innocent victims. The court ruled in their favor in 1973, holding that corporations had a duty to prevent harm arising from industrial pollutants (George 2001; Taniguchi 1976).

On the heels of the *Watanabe* decision and several other pathbreaking Minamata precedents, in 1973 Fujita filed a lawsuit to revoke the operating license of the Ikata nuclear power plant. He and his colleagues argued that the plant, which was located near a major seismic fault, impermissibly placed the public at risk of radiation exposure (Cross Cultural Publishing Company 2014; Citizens’ Nuclear Information Center 2016).¹¹ This was the very first lawsuit against a nuclear power plant in Japan, and the litigation was ongoing when Fujita arrived in Pennsylvania in 1979 (Matsui 2017). The moral witness of nuclear bomb survivors had come full circle to bear on nuclear energy.

The TMI meltdown afforded the Japanese visitors a new opportunity to consider how experiences fighting methylmercury pollution could be reconfigured to challenge civilian nuclear power production. Visibly suffering bodies are a source of deep, if ambivalent, affective power and even of witness (Scarry 1987; Sontag 2003;

¹⁰ Mitsuru Katagiri, open letter, July 18, 1979, Folder 7, Box 1, Hess Papers.

¹¹ Mitsuru Katagiri, open letter, July 18, 1979, Folder 7, Box 1, Hess Papers.

Fassin 2011b; Dean 2019). Activists had used film and photography of Minamata sufferers to raise awareness of methylmercury pollution in Japan and among First Nations in Canada (George 2001; Avenell 2017). Aileen Mioko Smith had co-authored a high-profile 1975 photographic essay about Minamata with her former spouse, famed photojournalist W. Eugene Smith (Smith and Smith 1975).¹² In 1979 and 1980, she began collaborating with Mitsuru Katagiri on TMI. The TMI incident, however, left few lasting, visible marks on residents' bodies. Its primary traces were emotions, sense memories, and environmental observations. After attending social movement meetings and touring the area with local hosts Jane Lee and Beverly Hess, the Japanese visitors felt strongly that residents' experiences and observations were critically important.¹³ Fujita, the lawyer, explained that "what had the biggest impact on us was the terrible phenomena which we heard and saw near Three Mile Island . . . those data are the *most valuable ones in the world*" (emphasis added).¹⁴

Residents' testimony, in other words, appeared to the experienced Japanese visitors to be the central means of making TMI visible. The lawyers believed interviews could be useful in litigation in the US and elsewhere (though they were unsuccessful in a later bid to introduce TMI testimony into the Ikata plant case).¹⁵ Equally, the group believed that conducting interviews would help serve interests of epistemic justice. The whole Japanese team was troubled by what they saw as a lack of scientific attention to residents' experiences and observations.¹⁶ Katagiri and Smith likened it to how the Minamata sufferers' claims were brushed off until medical doctors and other experts became involved.¹⁷ To induce that kind of expert interest in TMI, the Japanese group believed that residents' experiences—the "tangible part of the incident"—needed to be captured before the "memory becomes vague and faded."¹⁸

¹² Today, Aileen Mioko Smith is a well-known antinuclear activist in Japan. She was married to Mitsuru Katagiri through much of her work on TMI. During that time, she often went by the name Aileen Smith Katagiri. I refer to her in the text as Aileen Mioko Smith because this is the name she uses today and by which she is best known.

¹³ Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers; Hajime Nakao (Mitsuru Katagiri), Three Mile Island: The Language of Science and the People's Reality, Part One, trans. Sara Acherman and Rebecca Jennison, *The Kyoto Review* 12, Spring 1980, in Folder 11, Box 5, Hess Papers (hereafter cited as Katagiri, Three Mile Island, Part One).

¹⁴ Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers.

¹⁵ Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers; Katsuyuki Kumano to Beverly and Richard Hess, April 27, 1980 and April 22, 1983, Folder 7, Box 1, Hess Papers.

¹⁶ Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers; Katsuyuki Kumano to Beverly and Richard Hess, April 27, 1980 and April 22, 1983, Folder 7, Box 1, Hess Papers; Mitsuru Katagiri to Beverly and Richard Hess, September 13, 1979, Folder 7, Box 1, Hess Papers.

¹⁷ Mitsuru Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Hess Papers.

¹⁸ Mitsuru Katagiri to Beverly and Richard Hess, Sept 23, 1979, Folder 7, Box 1, Hess Papers.

At the same time, the Japanese visitors insisted that the moral character of acts of witness could contribute something special to knowledge about TMI. The partial meltdown did not conjure the kind of atrocities with which moral witness is commonly associated, they knew, but perhaps some of its virtues could carry over. Modern configurations of both legal and moral witness embraced the subjective qualities and experiences of the sufferer as an authoritative source of truth (Winter 2007; Scott 1991). By contrast, conventional narratives about scientific witness typically rested the truth value of observation on observers' capacities to distance themselves from subjective, personal qualities like class background and emotions (Murphy 2012, chap. 2; Daston and Galison 2010). Katagiri and Smith, in particular, suggested that features associated with subjective knowledge and moral witness—interestedness, emotion, embodiment—were both moral *and* epistemic virtues. The love for community and local environments, for instance, enabled laypersons to detect and observe abnormalities and harm (Smith 1989). “Bodies” and “intuition” were therefore central to knowledge production—not only of oneself but also of nature.¹⁹

The chief power of residents' testimony, the Japan team advised, would be to frame scientific questions and induce expert studies of harm in the community. They suggested residents' experiences supported an inference that TMI had produced off-site effects.²⁰ The move from sense observation to common-sense inference was a form of abductive reasoning frequently employed both in everyday life and in legal reasoning about causation (Walton 2005). Since industry and government actors had polluted, engaged in cover-ups, and sought to silence members of the public in the past, they reasoned, it seemed logical to infer that the meltdown at TMI had caused residents' experiences.²¹ The Japanese visitors urged this inference to be adopted as a hypothesis and tested by scientists through further studies. “We feel that it's the scientists' responsibility,” Smith explained, “to find out the causes of these effects and be able to sort of ‘do homework’ and to find out: how-when-what-was.”²²

During the 1979 trip, the Japan team began the work of collecting witness testimony, using Arnold's informal report about metallic taste to locate interview subjects.²³ Katagiri conducted the early interviews, returning with Smith in 1980 and several more times throughout the decade to conduct hundreds of additional interviews.²⁴

¹⁹ Katagiri, Three Mile Island, Part Two.

²⁰ Mitsuru Katagiri, Purpose and Methods, November 20, 1980, Folder 7, Box 1, Hess Papers.

²¹ See, for example, Aileen Smith Katagiri and Mitsuru Katagiri, October 1982, Three Mile Island Revisited, Folder 6, Box 5; Mitsuru Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Hess Papers.

²² Mitsuru Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Hess Papers; see also Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers.

²³ Katagiri, Three Mile Island, Part One; Mitsuru Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Hess Papers.

²⁴ Katagiri, Three Mile Island, Part Two. These interviews were the only major source of in-depth interview data covering residents' experiences. See Jonathan Berger, Executive Secretary, Public Health Fund Advisory Board to Mitsuru Katagiri, May 31, 1984, Folder 12, Box 2, Hess Papers.

Across this testimony, residents remembered TMI as a visible, audible, palpable, odorous, and gustable event. The reactor had made a deep “brrup, brrup, brrup” noise, shaking the ground like an earthquake. The air tasted like a copper penny, a nail, a dental filling, a utensil. It smelled and tasted like the air around an iron foundry. It was hazy or filled with ash similar to that produced from burning paper. It felt thick in the throat, nauseating even, or prickly on human skin. The air was blue and the rain purple. The dog started acting funny and got sick. The farm animals would not eat. Plants looked different. People had diarrhea or headaches and felt unwell.²⁵ All of these recollections suggested that something troubling had happened as a result of the meltdown. In meetings, letters, and articles, the Japanese visitors urged local community members to take up the work of witness—to capture the traces of TMI as a central part of the interrelated work of making knowledge and seeking justice.²⁶

Biological Witness

By 1982, cancers had emerged in communities around TMI. Local activists began to transform the testimony that Katagiri and Smith had collected into a form of biological witness. Their model used testimony to structure the inquiry, map areas for sampling, and provide evidence of dose. It was an almost diagnostic, clinical model that took as its subject the suffering, living world around TMI, including the people residing there. These transformations altered the subjectivities of residents and community activists alike, reshaping moral witness into biological witness.

A local organization called the TMI Public Interest Research Center developed a Health Issues Committee as reports about local cancers began to emerge in 1982. Echoing broader, gendered trends in caring work associated with health social movements (Murphy 2006, 2015), this Committee was mostly comprised of women.²⁷

The Committee and other interested community members had initially hoped that the newly created Three Mile Island Public Health Fund might sponsor studies investigating links between residents’ experiences and what appeared to be an emerging cluster of cancer cases.²⁸ The Fund was part of a 1981 court-supervised settlement of a class-action lawsuit brought by persons and businesses within a 25-mile radius of the plant. It was tasked with distributing \$5 million to sponsor scientific studies on radiation and public health, both generally and concerning TMI (Gourley et al. 1984).²⁹ The Fund was institutionally independent, and its science

²⁵ For interviews from which this composite was drawn, see Smith (1989); Katagiri, Three Mile Island, Part One; Katagiri, Three Mile Island, Part Two.

²⁶ Kazuyoshi Fujita, Mitsuyuki Suga, N. Shibata, and K. Kumano to Richard and Beverly Hess, September 29, 1979, Folder 7, Box 1, Hess Papers; Katagiri, Three Mile Island, Part One, and Three Mile Island, Part Two.

²⁷ Linda Lotz to Dan Burnstein, July 9, 1984, Folder 12, Box 2, Hess Papers.

²⁸ Francine Z. Taylor to Daniel Berger, Esq. September 13, 1982, Folder 12, Box 2, Hess Papers.

²⁹ Stipulation of Settlement and Agreement, In re Three Mile Island Litigation, Civ. No. 79-0432, February 17, 1981, Folder 14, Box 91, Series IV, Ruth Patrick Papers, Philadelphia Academy of Natural Sciences, Philadelphia, PA (hereafter cited as Patrick Papers).

advisers were selected for their relative autonomy from US government agencies and industry interests.³⁰ In the words of its chief Science Advisor, Nobel-prize-winning medical doctor and biochemist Baruch S. Blumberg, the Fund “represent[ed] a decision in a civil settlement to use scientific process in arriving at the resolution of a problem.”³¹ In contrast to the legal world of adversarial advocacy, Blumberg hoped the Fund could be, in a word, objective.

The Fund, however, did not gravitate towards community members’ concerns, and its structure left little room for lay participation. On a number of occasions, community members sought to collaborate on study design, but many of them lived within the settlement’s geographical catchment zone and were, therefore, members of the plaintiff class.³² As parties to the litigation, their participation would compromise the settlement Fund’s independence.³³ Yet some residents suspected more ominous forces were at play in the rejection of their input. By 1983, there were rumors that the Fund and its science advisers were participating in a cover-up.³⁴ Even so, activists remained desperate for scientific attention to their concerns.

In the meantime, the Fund’s initial work on the TMI dose assessments further stoked activists’ fears. The Fund had commissioned an independent review of all published work on US government dose assessments. The resulting report publicized in clear language a number of problems with the dose estimates, such as reliance on an unscheduled radiation monitor, the scrubbing of high readings, mishandling of environmental samples, and failures to publish data or submit work to peer review (Beyea 1984). After attending a Fund-sponsored public meeting about the report, several women from the Health Issues Committee—Marjorie Aamodt, Mary Osborn, and Francine Taylor—became alarmed. They began working with physician Carl Johnson to devise and carry out studies of their own.³⁵

The activists argued that the circular sampling methodologies of government studies were unsuited to tracing the environmental effluence of radionuclides. Most prior scientific studies, even the settlement scheme creating the Fund, had relied on the superimposition of a series of concentric circles around the TMI plant, typically out to a fifty-mile radius. That it looked as if the plant had been the target of a nuclear bomb was no coincidence. NRC scientists had used this model because it had been employed in most earlier studies of human radiation exposure, many of which focused on Hiroshima (Three Mile Island Public Health Fund 1985a). Aamodt and her collaborators pointed out that radioactive effluents move in irregular

³⁰ The board members were Dean Abrahamson, John “Jock” Cobb, Thomas Cochran, Ian McHarg, Karl Z. Morgan, Edward P. Radford, Frank von Hippel, and George Woodwell (Three Mile Island Public Health Fund 1985, pp. xix–xxiv).

³¹ Journal of Scientific Advisor, May 25, 1981, Folder 2, Box 33, MS Coll. 144, Baruch S. Blumberg Papers, American Philosophical Society, Philadelphia, PA (hereafter cited as Blumberg Papers).

³² See, for example, Mary Osbakken, MD, PhD to Judge Sylvia Rambo, July 11, 1984, Folder 12, Box 2, Hess Papers.

³³ See Stipulation of Settlement and Agreement, In re Three Mile Island Litigation, Civ. No. 79-0432, February 17, 1981, Folder 14, Box 91, Series IV, Patrick Papers.

³⁴ Report of the TMI Public Health Fund on the December 15, 1983 Public Meeting, Folder: TMI Court Petition 1983, Box 93, Patrick Papers.

³⁵ Linda Lotz to Dan Burnstein, July 9, 1984, Folder 12, Box 2, Hess Papers.

patterns and accrete unevenly in the environment and in human bodies. They argued that a better sampling model would search for harm in areas where the plume of radioactive noble gases had traveled.³⁶

Given the paucity of contemporaneous physical sensing data from the early hours of the incident, the activists suggested that damage to people and environments should be used to establish the plume's path *and also* to prove and quantify exposure. Aamodt explained that living plants and human bodies “can serve as a more reliable measure of radiation dose. . . . Since the people and plants appear to have been the dosimeters, the amount and kinds of radiation released could be best determined from this information.”³⁷ Aamodt used Katagiri and Smith's unpublished interviews to identify the geographical areas the study would sample.

Aamodt and her collaborators then developed a survey to transform residents' experiences into health and environmental data. The survey form recorded symptoms the group associated with radiation exposure—erythema, gastrointestinal issues, bleeding gums, and metallic taste. It also inquired about cancers, miscarriages, and infant deaths. Surveying over 450 families, the group found an elevated rate of cancer, tumors, and deaths compared to baseline data from Pennsylvania.³⁸ One member of the group, Mary Osborn, concurrently catalogued abnormalities in flora and fauna with the help of radiation biologist James E. Gunckel, who had previously studied the effects of radiation on over 200 species of trees and plants at the Brookhaven National Laboratory during the 1950s.³⁹ The activists suggested that human and plant data substantiated absorbed doses of 5–100 rem—far higher than government dose assessments. To validate their sampling method, they collected new testimony in the form of affidavits provided by individuals suffering from cancer.⁴⁰ This inclusion also reminded readers that there were real people—often sick and suffering people—looking for answers.

On the surface, the activists' characterization of humans as dosimeters transformed testifying residents from moral witnesses into biological ones. Deprived, for the most part, of the opportunity to testify in the record, residents lost some of the moral authority associated with witness (compare Creager 2017). The power of residents in this configuration rested mainly on the bare, biological responses of living bodies to ionizing radiation rather than on any kind of intimate self- or local-knowledge (compare Murphy 2012; Wynne 1992, 1996). Residents, like the dancing cats in Minimata, became sentinels of harm, directing the activists toward geographical areas of interest. Activists, in turn, transformed newly collected information about

³⁶ Linda Lotz to Dan Burnstein, July 9, 1984, Folder 12, Box 2, Hess Papers; Statement of Carl C. Johnson, MD, MPH, in supplement to the Statement of the Aamodts to the Nuclear Regulatory Commission, May 22, 1985, Folder 6, Box 1, John H. Murdoch Papers, Dickinson College Archives and Special Collections, Carlisle, PA (hereafter cited as Murdoch Papers).

³⁷ Marjorie M. Aamodt, *The Three Mile Island Accident: An Investigation of the Effect of the Health of Residents and Flora in the Areas WNW and SW of TMI*, Folder 5, Box 4, Hess Papers (hereafter cited as Aamodt, *The Three Mile Island Accident*).

³⁸ Aamodt, *The Three Mile Island Accident*.

³⁹ Affidavit of James E. Gunckel, 003299–003303, Volume V, Consolidated Appendix.

⁴⁰ Aamodt, *The Three Mile Island Accident*.

health into a disaggregated list of symptoms and conditions recorded on documents intended to carry the epistemological power of a medical form that could support a particular, ostensibly neutral, enumeration of dose (compare Fassin and d'Halluin 2005; Murphy 2006). As one toxicologist sympathetic to the activists' cause observed, "unsophisticated" local people could be as reliable as animal models of radiation (Three Mile Island Public Health Fund 1985a). Emotions and words set to the side, residents' biological bodies would bear silent witness to TMI.

However, someone still had to interpret and present the data. Someone had to speak on behalf of plants and people. Though not a subject-matter expert in health or radiobiology, study author Marjorie Aamodt presented herself as a relatively reliable, objective, and knowledgeable lay expert (compare Epstein 1995; Wynne 1992). She cared deeply about residents, but in various filings with US regulators, she emphasized her disinterestedness and technical credentials. In earlier government filings, Aamodt highlighted her work history as a member of the technical staff at Bell Laboratories, describing herself as a pioneer of the "concept of human engineering in the telephone industry."⁴¹ In connection with the health study, she explained that she did not live in the survey area and did not personally know anyone there, implying that she would not be biased. The study had come about when she "suggested to area residents that we conduct a door-to-door survey rather than speculating about these occurrences."⁴²

Aamodt and others emphasized, moreover, that the group was *not* seeking to usurp the role of the expert, but rather to foster further scientific study. The activists reported they merely "used first-hand accounts to infer hypotheses which . . . they requested the Commission to test."⁴³ Medical doctor Johnson argued that the "anecdotal information" collected by the activists "is the same information that physicians value as medical history. . . . In this case, if an unusually high incidence or death rate from cancer is observed near . . . sources of extremely potent carcinogens, we had better believe it, and not strive tortuously to find some spurious but plausible explanation."⁴⁴ The report was both historical and diagnostic. It suggested that further scientific study was warranted.

Aamodt submitted the report in support of a legal petition asking the NRC to halt the restart of the TMI facility's undamaged reactor. She sent another copy to the NRC directly, asking the commission to conduct further scientific studies. Epidemiologists from the US Centers for Disease Control and Prevention (CDC), however, advised the NRC to take no further action. Among a litany of deficiencies, the CDC noted the suggestive nature of the survey and its reliance on unscientific, anecdotal reports. The survey, moreover, was not supported by bureaucratic evidence, like

⁴¹ Norman and Marjorie Aamodt to Chairman Nunzio J. Palladino, US NRC, Sept 10, 1981, Folder 6, Box 5, Hess Papers.

⁴² Aamodt Rebuttal of Pennsylvania Health Department Report on Cancer Mortality, 1985, Folder 6, Box 1, Murdoch Papers.

⁴³ Aamodt, The Three Mile Island Accident.

⁴⁴ Statement of Carl C. Johnson, MD, MPH, in supplement to the Statement of the Aamodts to the Nuclear Regulatory Commission, May 22, 1985, Folder 6, Box 1, Murdoch Papers.

medical records or death certificates. The report was thus not science, but rather “opinion” and “testimony.”⁴⁵

Of course, that was partially the point for Aamodt and her collaborators. They sought new and different ways for bodies and environments to matter, to be explained, and to speak within scientific discourses. Even though their study actually minimized some of the moral content of testimony in favor of producing biological witness, regulators *still* rejected activists’ methods as subjective and unworthy of investigation. In a bitter twist, if human bodies and plants could provide evidence sufficient to provoke scientific study, they would first need scientists to speak for them.

A New Cosmology of Evidence

The activists’ model of biological witness achieved its full realization through expert scientific evidence produced as a part of personal injury litigation. Relying solely on expert testimony about biological dosimetry showing effects in living beings, the plaintiffs crafted a version of scientific objectivity based on biological witness. In this cosmology of evidence, biological harm in the living world both directed inquiry *and* proved that TMI had caused these injuries. Against dominant hierarchies of the natural sciences, this model suggested that the life, earth, environmental, and biomedical sciences provided a messier, but more truthful and *just*, rendering of the world than mathematics and physical sciences.

Evidentiary disputes about the science of TMI dosimetry did not take center stage until the early 1990s. After years of preliminary legal wrangling over jurisdiction and governing law, more than 2,000 personal injury claims were administratively consolidated for trial in the Federal District Court in the Middle District of Pennsylvania.⁴⁶ The evidentiary disputes played out through a series of pre-trial motions to exclude expert evidence. The defendants sought to render plaintiffs’ expert evidence inadmissible and, subsequently, to have the entire action dismissed without a full trial. The presiding judge, Sylvia Rambo, who also supervised the Public Health Fund settlement, held that the plaintiffs needed to produce expert evidence of exposure to at least 10 rem of ionizing radiation—a relatively high dose—in order to show that TMI had more likely than not caused their injuries.⁴⁷ To do this, they needed to conform to legal rules governing the admission of expert evidence, which privileged a positivistic, laboratory-based vision of scientific objectivity (Jasanoff 2002; 2005; 2008). Guidelines developed in the US Supreme Court—known as *Daubert* factors—asked, for example, whether a theory was capable of being tested.⁴⁸ Controlling precedents in Pennsylvania federal courts added additional

⁴⁵ Glyn C. Caldwell to William A. Mills, Sept 7, 1984, Folder 4, Box 5, Hess Papers.

⁴⁶ See my forthcoming article, “Mapping Three Mile Island: Nuclear Liability & Compensation in the United States,” to appear in *Nuclear Disaster Compensation: A Call for Action*, ed. Hirokazu Miyazaki.

⁴⁷ In re TMI Litig. Consol., 927 F. Supp. 834, 865 (M.D. Pa. 1996).

⁴⁸ See also *Daubert v. Merrell Dow Pharmaceuticals*, 509 U.S. 579 (1993).

criteria, as did Judge Rambo. These included the Popperian criterion of whether a hypothesis was falsifiable.⁴⁹ The plaintiffs' chances of reaching a full trial turned on these court-made visions of how science worked.

Instead of hewing closely to these conventional legal discourses, however, the plaintiffs emphasized the value of both laboratory *and* field methods, especially those within the life, earth, environmental, and biomedical sciences. The plaintiffs' theory asserted that radioactive gases had escaped the plant in a series of larger puffs and concentrated into dense plumes, causing high radiation exposure in particular areas. To quantify dose, they developed new pilot studies showing evidence of purportedly radiobiological harm in plants and people.⁵⁰ They then reasoned backward from effects to causes, suggesting in a somewhat tautological fashion that biological harm around TMI could prove that the meltdown had caused the plaintiffs' injuries (mostly cancers). Studies focused on the damaged living world in all its contingencies and complexities, they argued, could help develop a more accurate, truthful, and just picture of TMI's offsite effects.

The litigation brought together a transnational group of scientists. A post-Soviet team led by radiobiologist Vladimir A. Shevchenko, for example, had been responsible for undertaking genetic and cytological studies on members of the Chernobyl clean up and rescue crews as well as for conducting extensive studies of flora and fauna near the meltdown. Shevchenko had also studied radiation effects on humans and environments emanating from the 1957 Kyshtym disaster in the Urals and weapons testing at Semipalatinsk in the Altai.⁵¹ Austrian meteorologist Ignaz Vergeiner had worked on the dispersion of Chernobyl's fallout in the Alps.⁵² Well-regarded experts from the US nuclear complex also joined in the plaintiffs' cause. Plant radiobiologist James Gunckel, who had consulted in the Aamodt report, came on board as a witness, as did University of North Carolina dose assessment expert Douglas Crawford-Brown, who had served as the Chief Dosimetrist on US Department of Energy studies of nuclear industry workers.⁵³ The group's profile as experts drew out the translocal and intertemporal nature of radiobiology. Each nuclear disaster, whenever it had happened and wherever located, influenced how others could be understood.

Some of the plaintiffs' experts saw the same epistemic injustice that activists had identified. University of North Carolina epidemiologist Steven Wing and his collaborators bristled at how regulators had dismissed TMI-area residents' concerns. They also noted that regulators and industry participants had vested interests in the

⁴⁹ For a full list of criteria, see *In re TMI Cases Consol. II*, 911 F. Supp. 775, 787 (M.D. Pa. 1996).

⁵⁰ *In re TMI Cases Consol. II*, 911 F. Supp. at 789–827. The plaintiffs' chief expert supporting this theory recanted during the course of the litigation, but it nevertheless remained the basis of the plaintiffs' claims.

⁵¹ Curriculum Vitae of Vladimir A. Shevchenko, 004159–004197, Volume VI, Consolidated Appendix.

⁵² Testimony of Ignaz Vergeiner, Transcript of *In Limine* Hearings, Volume 8, November 16, 1995, 003996–004003, Volume V, Consolidated Appendix.

⁵³ Affidavit of Douglas J. Crawford-Brown, May 26, 1994, 003027–003035, Volume V, Consolidated Appendix.

outcome of studies about TMI.⁵⁴ Wing was particularly attuned to the political pressures in play. The US Department of Energy had previously attempted unsuccessfully to prevent Wing from publishing studies that showed increased cancer rates among nuclear workers at the Oak Ridge National Laboratory.⁵⁵ Shevchenko was also aware of the political stakes of nuclear issues. He had been forced to keep his early work secret for decades. The Austrian meteorologist Vergeiner surmised that review by scientists not bound to industry or government agencies would serve “justice . . . and faith in democratic process.”⁵⁶

The plaintiffs’ experts agreed that remedying epistemic injustice involved taking the residents’ and activists’ experiences and observations seriously. The experts worked with Marjorie Aamodt and her team to focus inquiry on the damaged world around TMI. Gunckel and Shevchenko, for instance, reviewed Katagiri and Smith’s interviews and traveled the region with Aamodt and Osborn to consult with residents and local experts, such as veterinarians and medical doctors. Based on these discussions, the scientists conducted visual and dendrometric studies of damage in trees as well as cytogenetic and immunological studies on a sample of persons reporting abnormal physical sensations, including some who suffered from cancers.⁵⁷

Drawing on this wide range of biological pilot data, the plaintiffs contended that the maximum dose in some areas ranged much higher than the court-mandated threshold of 10 rem. They used Vergeiner’s meteorological studies to argue that prevailing weather conditions could have created densely concentrated plumes of effluent. Then, they used people and plants as biosensors to establish maximum possible doses. The observational and dendrometric studies, they explained, suggested a very high dose range between 60 and 1000 rem in some locales.⁵⁸ (By comparison, an acute dose of about 400 rem is widely considered to be fatal to fifty percent of exposed persons within thirty days of exposure.) Further bolstering the case, data showed that some people had abnormal immunological markers and signs of chromosomal damage.⁵⁹ Epidemiological studies recorded a slight increase in cancer incidence, and the testimony of treating physicians and pathologists helped link local

⁵⁴ Steve Wing, Rita Fellers, and Lucy Peipins, *Mortality Trends in Relation to the Accident at Three Mile Island*, January 1994, 006831–006832, Volume VIII, Consolidated Appendix.

⁵⁵ Summary of the TMI Public Health Fund Workshop, December 6–7, 1982, Folder 7, Box 328, Blumberg Papers; Victor Schoenbach, Interview of Steven Wing, July 15, 2015, available at: https://www.youtube.com/channel/UC8phyTICM4O8N7YJ_cwmtMg/videos.

⁵⁶ Affidavit of Ignaz Vergeiner, May 24, 1993, 003577, Volume V, Consolidated Appendix.

⁵⁷ Deposition of James E. Gunckel, June 7, 1995, 003377, 003400, Volume V, Consolidated Appendix; Galina Snigiryova, *Cytogenetic Analysis of the People Living in the Neighborhood of the TMI Nuclear Power Plant*, 005103–005117, Volume VI, Consolidated Appendix; Olga Tarasenko, *Immunological Analysis*, 005209–005212, Volume VI, Consolidated Appendix.

⁵⁸ Testimony of Gennady Kozubov, 005187, Transcript of In Limine Hearing, Volume 20, November 28, 1995, Volume VI, Consolidated Appendix; Deposition of James E. Gunckel, June 7, 1995, 003377, 003400, Volume V, Consolidated Appendix.

⁵⁹ Galina Snigiryova, *Cytogenetic Analysis of the People Living in the Neighborhood of the TMI Nuclear Power Plant*, 005103–005117, Volume VI, Consolidated Appendix; Olga Tarasenko, *Immunological Analysis*, 005209–005212, Volume VI, Consolidated Appendix.

cancers to the meltdown.⁶⁰ Risk assessment expert Douglas Crawford-Brown tied it all together, articulating a model of living things situated within dynamic environments and exposed to radiation doses far higher than government estimates.⁶¹

The court proceedings provided an opportunity to demonstrate and stage a way of doing science that activists had contemplated for years. The plaintiffs enacted a distinct cosmology of evidence that reimagined the subjectivities of sufferers, activists, and scientists and reframed what it meant for knowledge to be objective. In so doing, they took aim at both the defendants' case *and* the court's criteria for what knowledge could count as reliable. They argued that neither was representative of how scientific knowledge was made nor of the dynamic complexity of the living world. As Vergeiner explained: "The atmosphere and the oceans, and, by the way, the biosphere are not like a perfectly controlled physics or chemistry laboratory, where, in principle, you can fix all the parameters of an experiment at will." Since every scientist understood that the world was complicated and messy, he argued, they "should not be required to play dumb" for judges and juries.⁶²

The political value of the case as a pressure tactic and demonstration project was patently evident. The plaintiffs' experts ignored the typical legal conventions concerning the form and timing of expert evidence. Evidence trickled in in dribs and drabs, letters, and informal memos—many filed after court-mandated deadlines. Experts' explicit discussion of entrenched interests, the possibility of bias, and their attacks on the court's evidentiary criteria caused Judge Rambo to suggest that the plaintiffs' lawyers were using their scientific experts as mouthpieces for accusations and political positions the lawyers could not permissibly express as a part of the litigation.⁶³ To Judge Rambo, the case's broader political aims seemed clear.

The defendants, by contrast, shaped their evidence to fit the discursive form and epistemological assumptions favored in the legal process. The defendants rested their case on a version of what Daston and Galison have called mechanical objectivity—the capacity of scientific instruments to appear to speak for themselves (2010). The defendants' theory of the case emphasized the scientific agency and objectivity of instruments and computational models. Drawing on US government reports, presumptively admissible under the Federal Rules of Evidence,⁶⁴ the defendants suggested that a limited quantum of radioactive noble gases had entered the atmosphere and dissipated in an even, Gaussian distribution pattern. The defendants' experts testified the highest possible dose to be 75 millirem—far short of the 10 rem threshold set by the court (short even of earlier government estimates).⁶⁵ Of course, as the

⁶⁰ Deposition of Steven Bennett Wing, CV-88-1452, February 3, 1994, 006942–007196, Volume VIII, Consolidated Appendix.

⁶¹ Testimony of Douglas Crawford-Brown, Transcript of Proceedings, In Limine Hearing, Volume 23, November 30, 1995, 003260, Volume V, Consolidated Appendix.

⁶² Ignaz Vergeiner, Reply to In-limine challenge by Defendants, 003837, Volume V, Consolidated Appendix.

⁶³ Affidavit of Judicial Respondent, No. 96-7624, May 7, 1996, 009703, Volume X, Consolidated Appendix.

⁶⁴ Fed. R. Evid. 803(8).

⁶⁵ *In re TMI Litig. Consol.*, 927 F. Supp. at 850–856.

Fund's exposé had revealed, these dose assessments rested on a number of contingencies and assumptions. However, in the regimented world of courtroom procedures, the defendants made a neat, thorough case built on fuel calculations, physical sensors, and computer simulations.

Evaluating these two distinct models—one based heavily in the life sciences and one in the physical sciences; one based on the testimony of objects and algorithms and one on the testimony of living organisms—the court ruled to exclude almost all of the plaintiffs' expert evidence and grant summary judgment in favor of the defendants. Most of the plaintiffs' evidence was simply excluded as untimely filed—a procedural decision. The judge deemed most of the remaining evidence to be unreliable and inadmissible. The court gave a litany of reasons rooted in the factors governing admissibility—the legal shorthand for what counted as “scientific.” In the end, much of the court's conclusion rested on the common-sense judgment that the extremely high exposures suggested by the plaintiffs' experts would have caused more and worse instances of harm. Put simply, nobody died or showed clear signs of acute radiation sickness. The court also held that the plaintiffs had erred fatally in refusing to employ engineering studies and physical sciences methods to model the source term. Relying solely on biological evidence of effects of radiation without trying to quantify the radionuclides that escaped, Judge Rambo held, simply could not demonstrate exposure.⁶⁶ The Third Circuit Court of Appeals ultimately affirmed summary judgment in 2002, ending the dispute some twenty-three years after the TMI meltdown.⁶⁷

Other Worlds Are Possible

The seeds of activism sown by visitors from Japan had taken root and grown in Pennsylvania during more than twenty years of political, legal, and scientific mobilizations. Toward the end of the contentious litigation, Marjorie Aamodt's spouse, Norman Aamodt, used his presentation at a radiation genetics conference in Moscow to frame the plaintiffs' distinct cosmology of evidence: “Rarely, if ever, is the engineering equipment on scene to measure a radiation dose when it is accidentally absorbed. Conversely, the biological receptor is always there. The anecdotal information provided by those exposed is invaluable in identifying the exposed population as contrasted with geographical estimates made from engineering and meteorological data,” he wrote in the paper's abstract. “The biological scientific community must promote its role as the final authority in determining the extent and outcomes of radiation exposure. Without a resource to accurately assess the damage caused by radiation exposure, exposed individuals are denied their basic human right to

⁶⁶ *In re TMI Litig. Consol.*, 927 F. Supp. at 857–870; *In re TMI*, 193 F.2d 613, 666–722 (3d Cir. 1999).

⁶⁷ *In re TMI*, 193 F.2d 613; *In re TMI Cases Consol. II*, 53 Fed. Appx. 648 (3d Cir. 2002). The appeal was complicated procedurally. Although the circuit court affirmed summary judgment, it did not agree with all aspects of the lower court's evidentiary decision-making. The final disposition of the case, moreover, was a non-precedential opinion. It applied only to the TMI disputes.

compensation, and society at large is denied its human right to know the risks it faces from nuclear accidents” (Aamodt 2000). Calling on the purportedly universal vehicle of human rights, Aamodt suggested that the struggle over TMI was about much more than a solitary nuclear plant on the Susquehanna River.⁶⁸ Lessons about knowledge and justice learned at TMI might travel, just like radionuclides.

Activists had demonstrated that other worlds were possible, even as US courts and regulators rejected their cosmology. The world they envisioned was one in which suffering, living beings—human and nonhuman—were entitled to a voice, and science rested on a moral foundation of care. Love of community and nature framed scientific questions and informed scientific understanding. “We don’t do it because we’re going to win tomorrow or the next day,” expert witness Wing reflected on his environmental justice work in later years. “We do it because this is what we love, and we love each other” (Guidry 2017, pp. A1–A2). This was a world in which the causes of human and environmental suffering, wherever located, needed to be explained as a routine function of science and public health. Suffering not only underpinned scientific study but also served as proof that modern industry had caused harm. Working with community members, experts enabled the living world to bear biological witness to the dangers of industrial society. Here, the life, earth, biomedical, and environmental sciences were the pinnacle of knowledge-making because they could most accurately represent the causes and consequences of harm in a vibrant, dynamic, interconnected, living world.

Activists had re-conjugated relationships between science and justice (Reardon 2013). Placing the life sciences and field methods at the center of knowledge-making, activists suggested, could begin to remedy power disparities between the producers of industrial harm and those affected by it. Biological witness, though it diminished residents’ moral testimony in some ways, could serve as the basis of the bargain for a new scientific social contract. Knowing that scientists cared about, would listen to, and speak on behalf of suffering people and environments, activists suggested, could renew public trust tainted by the malfeasance of powerful interests and polluted by industrial production. Environmental justice entailed epistemic justice. Epistemic justice, in turn, required collaboration with, and care about, the people and places affected by pollution, seen and unseen.

The message still resonates today. Emerging biological knowledge surrounding TMI offers renewed hope for activists even as it demonstrates old tensions between how science is practiced and how it is described, between who frames the questions and how they are framed. In June 2017, shortly after the announcement that TMI’s reactors would be soon be decommissioned, medical doctor David Goldenberg and collaborators published the results of a novel study of thyroid tumors in the plant’s vicinity. Employing new techniques that use a mutational signal to identify thyroid neoplasms caused by radiation, the group has begun to find a correlation between thyroid tumors and presence near TMI in 1979 (Goldenberg et al. 2017; Sholtis 2017).

⁶⁸ Of course, as voluminous scholarship on both science and human rights teaches, claims to universality perform political work and are never truly universal.

This emerging biological knowledge opens up the possibility that activists might be vindicated in their view of TMI's offsite impact. In some ways, Goldenberg's work traces the path laid out in their years of mobilization. He conceived of his study after listening to patients' anecdotal accounts and fears about TMI. "I'm always wary," he explained, "when people say 'there's nothing to see, here'" (Sholtis 2017). But, in other ways, the project highlights the obduracy of conventional discourses about scientific objectivity and sufferers' subjectivities. Remarking on the possible impact of his work on activists' claims, Goldenberg stated, "I am not an advocate one way or another. I don't care. I am a scientist" (Sholtis 2017).

Funding Funding was provided by David R. Atkinson Center for a Sustainable Future, Cornell University.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Disproportionate Impacts of Radiation Exposure on Women, Children, and Pregnancy: Taking Back our Narrative

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Accepted: 2 February 2021 / Published online: 31 March 2021

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Abstract

Narratives surrounding ionizing radiation have often minimized radioactivity's impact on the health of human and non-human animals and the natural environment. Many Cold War research policies, practices, and interpretations drove nuclear technology forward by institutionally obscuring empirical evidence of radiation's disproportionate and low-dose harm—a legacy we still confront. Women, children, and pregnancy development are particularly sensitive to exposure from radioactivity, suffering more damage per dose than adult males, even down to small doses, making low doses a cornerstone of concern. Evidence of compounding generational damage could indicate increased sensitivity through heritable impact. This essay examines the existing empirical evidence demonstrating these sensitivities, and how research institutions and regulatory authorities have devalued them, willingly sacrificing health in the service of maintaining and expanding nuclear technology (Nadesan 2019). Radiation's disproportionate impacts should now be the research and policy focus, as society is poised to make crucial and long-lasting decisions regarding climate change mitigation and future energy sources (Brown 2019b).

Introduction: Women, Children and Pregnancy as Nuclear Sacrifices

Early in the atomic bomb age, nuclear weaponeers had evidence that pregnancy development and juveniles might be more susceptible to radiation than the healthy adult male workers regularly studied (Finkel and Biskis 1969).¹ Results of contemporary human research indicating disproportionate impacts during pregnancy were berated publicly and invisibilized along with the researchers (Stewart 1956; Russell

¹ Research conducted in 1945 and 1946 on pregnant dogs injected with radiostrontium resulted in offspring defects. Complete results were not made public until 1969 (Freeman 1981, p. 50, n. 1).

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and Russell 1952; Greene 2017). Privately, however, the US government tapped Dr. Shields Warren of Harvard University to help start *Project Sunshine*—one of a series of secret experiments to explore this susceptibility and to determine what doses had observable impacts (Moss and Eckhardt 1995; Fields 1953).²

In 1957, Jean Prichard, burying her stillborn daughter, was upset when the hospital forbade her the simple, intimate act of dressing her child for the funeral in her unused christening gown. Hospital personnel at Harwell, UK were hiding the fact that Jean's daughter's legs had been cut off to test the bones for radiostrontium. Decades would pass before Jean and the public at large would learn that her daughter's legs had been stolen and why (Goncalves 2001). Thousands of miles away, Dr. Willard Libby, a member of the United States Atomic Energy Commission (AEC) and one of *Sunshine's* architects, could have told Jean that hospital personnel had "sacrificed" the legs in a worldwide attempt to assess the impact of atomic bomb fallout on humans, mentioning in a secret meeting on January 18, 1955:

human samples are of prime importance ... particularly in the young age group.... [We need] large numbers of bodies—preferably stillborn or newly born babies ... and if anybody knows how to do a good job of body snatching, they will really be serving their country. (Roff 2002; see also Leary 1995)

This was not the first or last time nuclear proponents would be willing to sacrifice bodies, health, life, or individual rights for the promise of nuclear technology (Nadesan 2019).

Disproportionate impact is a chief concern of all work in environmental justice, revealing ways in which some groups are burdened more than others by their proximity to landfills, flood zones, industrial sites, or workplace risks, often paralleling racial discrimination or colonial relationships (Bullard 1996; Merchant 2006). In radiation studies, there are numerous examples of such impacts, particularly when considering the health impacts of uranium mining on indigenous peoples, the displacement and contamination of Marshallese Islanders or the political battles over radioactive waste disposal sites (Brugge and Goble 2002; Kuletz 2016; Barker 2013). In addition, institutional influences upon scientists—and unrecognized biases and methodological flaws within the scientific literature—have obscured disproportionate impacts on issues ranging from endangered species to the exposure of humans to pesticides and radiation (Shrader-Frechette 2014; Proctor 1996; Oreskes and Conway 2010).

In 1959, President Dwight D. Eisenhower established the Federal Radiation Council (FRC) by executive order to advise on health matters (Argonne Universities Association Conference 1969, pp. 59–60). Comprising heads of six federal agencies (Defense, Health, Atomic Energy, Commerce, Agriculture, and Labor), FRC

² Brigadier General K.E. Fields to J.C. Bugher, Director of the Division of Biology and Medicine, Atomic Energy Commission, March 9, 1953. Task Group Gabriel, Record Group 326. Box 1. Folder Title: Sunshine—Gabriel—1951–1953. See also Summary. Provisional Estimate of Long Term Effects of Fallout from High Yield Nuclear Weapons. Table 1. September 15, 1955. Record Group 326. Box 1. Folder Title: Sunshine—General—1955. National Archives, College Park, Maryland.

recognized “a need for a ... definition of ‘Standard Children’ ... in Radioactivity Concentration Guides” because of differing impact factors (1960, p. 7).³ Yet, despite decades of science supporting enhanced protection for women, children, and pregnancy, they have been left inadequately protected from radioactivity. Institutional influences favoring nuclear technology politicize or otherwise obscure research demonstrating disproportionate impacts. These influences have resulted in incomplete models of radiation damage, poor study design, and unwillingness to accommodate new methods and findings. In addition to shortcomings in research, nuclear advocates discourage proper health investigations through methods of denial (like “resilience”) and social shaming (such as accusations of “radiophobia”). These constructs result in characterizing women in particular as unscientific, especially in their role as protector of children (Heidi Hutner, PhD, personal communication, June 3, 2017).

Institutional focus on maintaining nuclear technology primacy has made accurate or meaningful health accounting difficult; this, in turn, not only makes providing health services to survivor communities problematic, but also complicates proper accounting of how radiation exposures have acted synergistically to compound individual and generational risk. Meanwhile, radioactive releases to the environment continue, as society makes world-altering energy decisions in the face of climate change.

Women, Children, and Pregnancy: Empirical Data Are Not Silent

Decades of studies exist demonstrating harm from ionizing radiation, and a portion of these studies demonstrate that *female* adults, children, and pregnancy, in particular, are more susceptible to this damage, making even low doses with supposedly low risk a greater concern (NAS 2006; Olson 2019; USEPA 2014).⁴ Women and children in underserved communities are at still greater risk because of unique exposure pathways and existing systemic inequities (Center for Native EH Equity 2016). Decades of studies also indicate that any dose of radiation—no matter how small—poses a risk and that radiation damage may be carried and compounded across generations (National Academy of Sciences 2006; Goncharova and Ryabokon 1998; Korsakov et al. 2020). This makes protection from low, protracted doses even more

³ Despite subsequent FRC reports recognizing children’s susceptibilities, the concept of “standard child” is no longer identified. “Standard man,” also mentioned in FRC’s 1960 report, became the focus of radiation regulation (see subsequent reports FRC 1961, 1962, 1963, 1964). FRC was later subsumed into the US Environmental Protection Agency.

⁴ While the term *radiation* can signify any wave or particle on the electromagnetic spectrum, this paper defines radiation as only that which emanates from the nucleus of an unstable atom and can “ionize” or rip off electrons from atoms. This essay does *not* explore the history and biological impacts of *non-ionizing* radiation, such as that given off by wireless technologies. Research does indicate potential biological impacts from non-ionizing radiation, and there are similarities in the research and regulatory history of both.

urgent; however, historically, recommendations have only *gradually* reduced allowable doses to workers and the public (Sutcliffe 2010).

Empirical findings are not silent, yet despite efforts of independent actors and researchers, *interpretation* of radiation's dangers has mainly been left to those who caused the dangers, specifically, those who wished to promote nuclear technology beyond the Second World War through a "mixture of state interests, elite science and technology, and corporate investments" (Lindee 2016b, p. 188; see also Kirsch 2004; Creager 2006). Decades of institutional, industry, and research practices favoring nuclear technology have compounded, not only obscuring low dose and disproportionate impacts, but also creating interpretations so influential that some scientists are loath to believe contradictory research, even their own (Davis et al. 2006).

One interpretation lingering from these practices—that low doses are harmless—was suspect from the earliest studies because heritable impacts seemed to lack a threshold dose (Parker 1948, p. 251). Proponents of nuclear technology voiced concern over heritability of radiation damage from a desire to ignore the problem rather than address it (Caufield 1985, p. 48). Uncertainty shrouded the survivability of atomic industry after World War II; consequently, scientific and governmental bodies wanted to foster non-weapon uses for nuclear technology, particularly energy uses, despite a disappointing start (Hamblin 2015; Creager 2006; Lindee 2016b). Since virtually all nuclear technology involves low dose exposures to workers and the public, obtaining support would be more difficult if all doses down to zero posed risk. To support a nascent civilian nuclear industry, AEC settled on a dose of radiation that was *practicable* instead of *protective* (Creager 2015). To accomplish this, nuclear technology proponents controlled basic research, regulation, and the social and political narratives that necessarily surrounded them.

AEC decided a permissible dose or "acceptable injury-limit" was needed to allow industry to proceed (Hamblin 2007; Parker 1948, p. 251). "Permissible dose" ensures legal compliance—not harmlessness—by establishing a dose below which nuclear technology proponents could claim existing effects were *nearly* impossible to see (Mangano 2012, p. 25; USNRC 2016). National and international institutions marshaled postwar secrecy and power over basic research to discourage amassing of "important data and materials that would have helped with dosimetry" (Lindee 2016b, p. 194; see also Kirsch 2004; Brown 2019a). The FRC would aid AEC by insisting that "[r]educing ... risk to zero would virtually eliminate any radiation use ... therefore ... the balancing of risk and benefit is a decision involving medical, social, economic, political, and other factors" (FRC 1960, p. 24, emphasis added). Despite FRC recognizing disproportionate impacts and being "virtually certain" of genetic harm at the lowest doses, FRC introduced *non-health* factors into exposure guidelines early on (FRC 1962). This tipped the balance toward radiation use, away from protection.

Evidence of harm discovered by some institutional scientists, such as calculations by Dr. Ernest Sternglass, a radiation physicist at the University of Pittsburgh, would run afoul of maintaining an *invisible* "acceptable injury-limit." Sternglass claimed that by 1969, 400,000 children had already died due to atomic weapons testing (1969). Even the much lower recalculation (4000 children) done by Drs.

John Gofman and Arthur Tamplin at Lawrence Livermore National Laboratory still greatly displeased AEC (Hefner and Gourley 1995).⁵ As Gofman stated: “If ... you ... find huge doses harmful ... [t]hat doesn’t worry [the] Commission.... But start to find that low doses are harmful and they’re going to fight you every step of the way... the bureaucrats cannot tolerate radiation to be harmful” (quoted in Hefner and Gourley 1995, p. 52). By 1969, AEC was actively undermining and censoring its own researchers’ work on low dose radiation (Hefner and Gourley 1995; Harrell and Fisher 1995). When Gofman pushed back, he was branded a “fiery nuclear critic” and at least one member of Congress—misled by AEC—threatened him (Semendeferi 2008; Hefner and Gourley 1995).⁶

In ensuing years, Gofman, Tamplin, physician Alice Stewart, and epidemiologist Steven Wing, to name only a few, continued to provide evidence countering FRC’s “balancing” and AEC’s “practicable” narratives on low dose and disproportionate impacts. The government confiscated research and defunded researchers (Mangano 2012, pp. 51–52). Their scientific work was often ridiculed, exacting a personal and professional toll on them and their colleagues who remained.⁷ Using uncertainty and accusations of bias, nuclear advocates would politicize some research—even research that was meritorious enough to influence exposure practices and recommendations (Semendeferi 2008; Stannard 1988; Freeman 1981; Greene 2017).

In Gofman’s case, critics would use his vocal stance against radiation exposure to claim his work was biased (Semendeferi 2008). However, historical records suggest that Gofman initially believed society should not stop nuclear progress simply because scientists were unsure of low dose harm.⁸ Only later, as his research progressed, would he recant this position, admitting that he had initially “got caught up in that mythology” (Freeman 1981, p. 88, n.10).

Nuclear proponents often use the *uncertainties* inherent in low dose research to politicize any science showing harm. Beginning in the early twentieth century, uncertainties flourished as researchers disagreed “on fundamental issues,” including dose, measurement, and impact time course (Nadesan 2019, p. 6). Researchers have contended—starting in the early twentieth century with H. J. Muller’s experiments on radiation-induced mutations in fruit flies, through mid- and late-twentieth-century research on low-dose radiation—that “[t]here never can be a direct experiment that can establish dose-effect relationships in these very low dose realms. Therefore, opinions can legitimately differ” (Stannard 1988, pp. 1082–1083; Crok 2011).

⁵ Later, Gofman told Freeman “new evidence coming out suggests to me that Sternglass may have been right” (Freeman 1981, p. 93).

⁶ Gofman told Hefner and Gourley that, as he prepared to testify before Congress on the dangers of radiation, Chester Hollifield (D-CA), Chairman of the Joint Committee on Atomic Energy, said “[t]here are people like you who have tried to hurt the Atomic Energy Commission program before. We got them, and we’ll get you” (Hefner and Gourley 1995, pp. 49–50).

⁷ In the OHRE interview, Gofman chronicled a pattern of berating scientists into silence for decades after he was forced out (Hefner and Gourley 1995). Gofman states that many government scientists told him that his research was solid, but *public* statements of support were not forthcoming and funding from non-AEC agencies dried up, despite need for the research (Freeman 1981, pp. 104–107).

⁸ Uncertainty of harm was used as a reason to delay protective action while nuclear technology proceeded apace.

Uncertainty and fundamental paradigmatic disagreements exist in low-dose radiation research; the question is *how* to advance these disagreements when presented with continually mounting evidence of disproportionate harm. Latour and Woolgar observed that science is “a fierce fight to construct reality” through social competition (1986, p. 243). For radiation, that “scientific reality”—constructed from the adversarial discussion—is then filtered through a regulatory body that considers more than just health outcomes. If a well-resourced system favors nuclear technology, then the reality this system constructs using science and regulation will probably benefit nuclear technology. Disputing the nuclear system’s constructed reality is challenging and costly, making it difficult to integrate new scientific evidence that fails to reinforce that reality (Boudia 2007; Latour and Woolgar 1986).

Because evidence early on indicated low dose harm, and because harm from radiation exposure was seeping into popular culture and public consciousness (often with scientific backing), nuclear proponents saw advantage in introducing measures of societal “benefit” to counterbalance risk (Lutts 1985; FRC 1960; BEAR 1954).⁹ Nuclear proponents could make the benefits more appealing by using uncertainties about harm to create doubt about radiation’s negative impacts. Creating doubt is easier, since low dose radiation damage can take decades or generations to manifest (Orient 1983). When data or methods promise to chip away at the uncertainties, nuclear primacy is threatened. As Gofman observed, “I don’t think they really want to know the hazards of radiation” (Freeman 1981, p. 88).

The institutional need for permissible doses continues to jeopardize impartial radiation science, even as foundational assumptions about internal and “low” doses are seriously questioned (Datesman 2019, 2020; Burgio et al. 2018; Wright 2010). Dose misconceptions borne of a system established to support nuclear development are still used to “adjudicate” empirical data from civilian nuclear power catastrophes, as are misconceptions about heritable impacts (Lindee 2016a, b). When Soviet scientists could no longer deny that disease rates were increasing among people exposed from the Chernobyl reactor explosion, they ignored their own science and turned to the West’s “much sunnier understanding of radiation’s effect on human health,” primarily based on the atomic bomb survivor study (Brown 2019a, p. 177). However, the data collected from survivors of the atomic bombings were never guaranteed to answer questions of chronic or low-dose exposures or heritability (Sutcliffe 2010; Cullings et al. 2006; Gofman 1998).¹⁰ As the committee appointed by the National Academy of Sciences-National Research Council to review the scientific options at Hiroshima and Nagasaki noted, “this material is too much influenced by extraneous variables and too little adapted to disclosing genetic effects” (Lindee 2016a, p. 47).

⁹ Lutts (1985) posits it may have been similarities Rachel Carson saw between atomic fallout dangers and pesticide poisoning that inspired her to write *Silent Spring* and use a public she knew was already familiar with radiation’s dangers to receive and act on her message about pesticides.

¹⁰ Research of atomic bomb survivors has spanned decades and is considered the “gold standard” for assessing how radiation will affect human health. The narrative of the atomic bomb survivors has dominated radiation science despite the controversy surrounding data, dose integrity, and applicability to impacts of chronic, low dose exposures (Sutcliffe 2010).

So, while primary research has consistently yielded data demonstrating disproportionate impacts, many studies are unable to link these adverse outcomes to radioactivity. This is because these studies *began* with the normative assumption that *doses were too low*—an assumption ensuring poor study design and sustained by invisibilizing or politicizing contrarian research. Instead, these studies did find disease increases, often among children exposed *in utero*, with no associated agent (Hatch et al. 1991; Talbott et al. 2000, 2003; Kaatsch et al. 2008a, b; Parkin et al. 1993). Improper hypothesis formation, based on assumed doses rather than disease cases, is one reason; problems establishing causality due to dose uncertainty and incorrect assumptions based on negative findings present additional barriers (Wing et al. 2010; Fairlie 2016).¹¹ Studies that can associate radiation exposure with more significant impacts on children and pregnancy have addressed these barriers.

At the same time that regulators and industry assert that doses are too low to cause health impacts, they also counsel that a link between disease occurrence (like childhood cancer) and radioactivity would need to be “*absolutely* establish[ed]” to carry credibility (USNRC 2017, emphasis added; Buongiorno et al. 2018).¹² However, meeting *absolute* standards of proof is hardly attainable, even with the best possible data. Absolute proof is also unnecessary for protecting health, and what constitutes scientific proof seems negotiable, the opposite of absolute (Kundi 2006; Latour and Woolgar 1986). Even well-designed studies, which often associate radiation exposure and disease, can fall victim to incorrect interpretations of *statistical significance* and an inability to detect disproportionate impacts, such as more female deaths *in utero* than male (Fairlie 2014, 2016; Amrhein et al. 2019; NAS 2006, App. C).¹³

The studies featured below encompass research on chronic or routine exposure to low or very low doses in real-life exposure circumstances; represent both external and incorporated exposures—that is, inhaled or ingested; examine cancer and non-cancer impacts; encompass every part of the nuclear fuel chain, including high-profile civilian reactor disasters as well as routine exposure from normally operating facilities; and reflect mostly impacts on human pregnancy development or

¹¹ According to Fairlie, “published studies with negative findings are generally unimportant unless the negative finding is very large: positive studies are what matter” (2016, p. 24).

¹² This is an example of NRC using known uncertainties to incorrectly inoculate radiation against culpability.

¹³ Radiation epidemiology relies heavily on the concept of “statistical non-significance” to claim a *lack* of association between radiation exposure and disease—a usage scientists in various disciplines, including statisticians, now call “ludicrous.” A review of radiation studies and proper use of statistical significance should correct the record on radiation’s association with disease.

children.¹⁴ Notably, some study authors operate under the normative interpretations that act to support nuclear technology, while others do not.

Radiation exposure during pregnancy is associated not only with impact during childhood but also causes the kind of *in utero* damage associated with diseases later in adult life, such as diabetes, early menopause, cardiovascular problems, and osteoporosis (Fernandez-Capetillo 2010). Enhanced sensitivity of women and pregnancy to radiation could, in part, be explained by the potential co-action of radiation and estrogen pathways. Estrogen and radioactivity have many cancer causation pathways in common, although the mechanism is not yet fully understood (Kutanzi and Kovalchuk 2013; Fucic and Gamulin 2011). In 1960, FRC No. 1 recognized hormones as radiation “cocarcinogens” along with chemicals and viruses, implying that decades have passed without proper study into suspected synergies (FRC 1960). Fucic argues that protective measures need to include radiation’s impact on estrogen despite mechanistic uncertainty (2011). After decades of neglect, any promise of future study on estrogen/radiation synergism still seems elusive.

All parts of the nuclear fuel chain are implicated in childhood disease and adverse pregnancy outcomes. In the 1950s and 1960s, atomic bomb detonations deposited fallout globally. Decades after these widespread exposures, radiostrontium from this fallout was associated with “about 80,000 excess early neonatal deaths in West Germany” (Körblein 2004, p. 608). This echoes Dr. Ernest Sternglass’s warnings about atomic bomb fallout (1969). Low-dose radiation from non-weapons technology can be just as detrimental.

Between 1970 and 1982, reproductive or gonadal cancer in New Mexico Native American children and teenagers was eight-fold greater than in non-Native Americans. While some traditional lifestyle cultural patterns can lead to increases in exposure, which has been multi-generational in this community, Duncan did not associate cancer increases with the uranium industry dotting the landscape (Center for Native EH Equity 2016; Duncan et al. 1986). Later, laboratory studies of animals associated uranium exposure with a host of reproductive problems (Raymond-Whish et al. 2007). Elevated leukemia rates in children and young adults were found around nuclear reprocessing facilities in the United Kingdom and France (Gardner et al. 1990; Pobel and Viel. 1997; Fairlie and Körblein 2015). Researchers were never able to determine a single mechanism implicating radiation—but neither have they been able to provide an alternative culprit (Dickinson and Parker 2002; Gardner et al.

¹⁴ Many radiation studies examine impacts on laboratory animals, special cell lines outside of the body, or those who have been medically exposed. These studies are not the focus of this article and are not included here. While such studies can indicate what *kind* of damage could be expected, a direct comparison between these studies and realistic exposure scenarios from routine or catastrophic releases of radioactivity is tenuous: (1) doses used in the laboratory or for medical purposes are often much higher than dose exposures expected from routine releases or from eating food contaminated with small amounts of radiation; (2) laboratory doses are rarely given over a large span of time, which would be needed for assessing whole life or cross-generational damage; likewise, medical exposures are discrete, finite, and do not replicate living in a contaminated area and/or eating contaminated food; and (3) research indicates that wildlife in nature could be *at least* eight times more sensitive to radiation than animals used in controlled experiments (Garnier-Laplace et al. 2013).

1990; Wakeford 2014; Committee Examining Radiation Risks of Internal Emitters [CERRIE] 2004; Pobel and Viel 1997).

Studies on anthropogenic and natural background radiation (0.8–3.0 millisieverts [mSv] per year) indicate an increase in childhood cancers, particularly leukemia and central nervous system cancers, beginning at very low doses—1–2 mSv per year (Kendall et al. 2013; Spycher et al. 2015).¹⁵ Such data highlight the risk from natural and manmade radiation to children and pregnancy and imply that increasing radiation dose from *any* source will increase risk.

Of over 60 epidemiological studies conducted worldwide, most reveal increases of childhood leukemia near normally-operating nuclear facilities (Fairlie 2014). In one particular study, childhood (and adult) leukemia increased after the startup of a nuclear power facility in Germany and remained elevated at least through 2005, although researchers did not implicate a cause (Schmitz-Feuerhake et al. 1997; Hoffmann et al. 2007). The official stance is radioactive emissions from normally operating reactors are too low to cause *discernible* health impacts (USNRC 2016). Empirical evidence shows a greater than the 10,000-fold discrepancy between increased risks for childhood leukemia and official dose estimates from nuclear power reactor emissions (Fairlie 2014). Researchers have theorized that lack of independent, reliable, and applicable monitoring; unreliable dose reconstruction; and averaging of doses is to blame (National Academy of Sciences 2014; Fairlie 2010). Timing of exposure matters during *in utero* development. Small exposures can damage developing cells that can then mutate, causing diseases (like leukemia) in childhood or later. Routine radioactive releases deliver doses in days that (despite common industry practice) should *not* be averaged out over months or over a whole body. Datesman's studies indicate that the current low dose models may fail to make valid damage predictions for internal beta doses, which could also explain the divergence between modeled outcomes and empirical data (2019, 2020).¹⁶ Pressing on, however, nuclear proponents now advocate establishing a dose limit based on “a dose below which [radiation's] health effects simply cannot be identified in the presence of other health risks” rather than on “a threshold below which no health effects occur” (Buongiorno et al. 2018, p. 146). Perhaps proponents are finally realizing once again that science does not demonstrate a threshold dose, especially as technology measuring radiation's impact on cells and genomes becomes more reliable and accessible. Their proposal evokes the historic phrase “acceptable injury-limit.”

Chernobyl and Fukushima Research

Civilian nuclear reactor catastrophes have spread large amounts of radioactive material widely, exposing large numbers of people and animals. Numerous

¹⁵ Natural background radiation is approximately 0.8–1 mSv per year. This excludes radon (2 mSv per year), which can be mitigated.

¹⁶ Understanding impacts of beta radiation, a focus of Datesman's research, is particularly important since beta's dose is most impactful if incorporated bodily and it is abundant in civilian nuclear contamination.

post-Chernobyl studies have suggested cancer, and non-cancer health effects, occur at doses that officials consider low. Dr. Yuri Bandazhevsky, former director of the Medical Institute in Gomel, Belarus, and Galina Bandazhevskaya, a pediatrician and his spouse, discovered cardiac disorders developed in children whose bodies contain an average of 10–30 becquerels (Bq) per kilogram (kg) of radioactive cesium (Bandajevski 2010; Bandazhevsky 1995; Bandazhevskaya 1994; Brown 2019a, p. 291). Post-Chernobyl protocols pinpoint 20 Bq per kg as safe (Brown 2019a, p. 265). Radioactive cesium depressed children’s immune systems. Tissue death developed at just over 50 Bq per kg. These doses have resulted in increased frequency of disease, death, and a decline in fertility (Bandajevski 2010). Consuming 1Bq per kg of radiocesium per day, every day, will reach these levels in less than six months (International Commission on Radiological Protection 2009b, p. 21, Fig. 2.2). However, research into radiation’s impact, particularly on children and across generations, is not exclusively about the science.

Dr. Bandazhevsky not only performed health research but also advocated for health study funding and protested when monies marked for Chernobyl research had vanished. His revelations jeopardized Belarus’s attempt to build a widely opposed nuclear power reactor, set to start in 2019. Bandazhevsky’s research was halted when he was arrested in 1999 on unsupported charges of treason, punishable by death if found guilty. Human rights and scientific groups protested vociferously, and he was freed. Bandazhevsky now lives in exile in Ukraine, where research into Chernobyl impacts seems a bit less perilous for both domestic and outside researchers (Brown 2019a, pp. 291–294).

Like Bandazhevsky’s work, research in Ukraine indicates several maladies have occurred that are not officially associated with radiation exposure during childhood or pregnancy. A National Academy of Medical Sciences, Ukraine report recognized that thyroid exposure can result in endocrine impacts—such as nodular goiter, autoimmune thyroiditis, obesity, type 2 diabetes, and hormone disorders—that are sometimes subclinical and may not appear until years after exposure (2016). These impacts are present in addition to cancer, which has received much more attention post-Chernobyl and post-Fukushima. Further, the Academy recognizes that children residing in areas contaminated with radionuclides had deficiencies in their immune systems.

Swendsen et al. associated decreased lung function with radiocesium contamination in soil and in children’s bodies. Two studies performed five years apart (2010 and 2015) showed respiratory health deficits persisted well below natural background radiation levels (that is, mean internal dose of 0.165 mSv per year). Further, Stepanova et al. (2008) showed that, in children 80 kilometers from Chernobyl, a decrease in blood components correlated with persistent radiocesium exposure from soil. Lindgren et al. found much the same for incorporated radiocesium; in all children born after the catastrophe, “[t]he mean internal effective dose was 0.14 mSv [per] year” (2013, p. 3).

While low blood count can result in subtle health impacts like excessive fatigue, other impacts on blood formation can be more devastating. A case-control study found significant increases in leukemia among children who were *in utero* or who were under six years of age at the time of the Chernobyl catastrophe.

Estimated doses were less than ten milligrays (mGy) (Davis et al. 2006). The original authors claimed their own study suffered from selection bias, but independent analysis of their data found no such bias (Noshchenko et al. 2010). The Davis and Noshchenko studies illustrate how radiation researchers often find disease increases that do not fit the normative hypotheses—particularly that of “mostly harmless low doses”—making the researchers suspect incorrect data collection or other problems in their own work. This often leaves no identified explanation for disease increases when, in reality, radiation could be responsible.

Wertelecki et al. (2014) finds significantly increased rates of conjoined twins, teratomas, neural tube defects, microcephaly, and microphthalmia among populations in Chernobyl-contaminated areas of Ukraine. The researchers characterize some of these effects as “blastopathies,” “anomalies that arise prior to embryonal implantation and organogenesis” (Wertelecki et al. 2014, p. 138). Therefore, these impacts would occur well before a woman would know she was pregnant. Nyagu et al. (2002) found prenatal irradiation from Chernobyl contributed to the deteriorated intelligence of children, as indicated by the reduction of full scale and verbal IQ. This study suggests that prenatal exposure to ionizing radiation at fetal doses starting at 11 mSv can result in detectable brain damage.

Post-Chernobyl studies of regions outside the former Soviet Union point to more subtle yet similar cognitive impact among children—subclinical outcomes not readily associated with radiation exposure. Students born in regions of Sweden with higher Chernobyl fallout performed worse in secondary school, particularly in math, and had more behavioral problems. The researchers estimate that the *highest* dose received was four mSv, and ponder what other subclinical negative health impacts might be caused at doses considered very low (Almond et al. 2009). Heiervang found similar results, associating *in utero* exposure to Chernobyl radiation deposited in Norway with significantly lower verbal IQ, verbal working memory, and executive functioning compared to controls. Researchers concluded that exposure might have had a subtle effect on cognitive function even if profound disability was not observed. Mean external doses were estimated to equal 0.935 mSv (Heiervang et al. 2010a, b).

Despite official claims that radiation levels from Chernobyl were too low to cause health impacts in central Europe, Hoffmann (2002) observed a statistically significant increase in childhood leukemias, with children *in utero* during the fallout being the most affected. Perinatal mortality increased in Germany, Poland, Belarus, and Ukraine after the Chernobyl catastrophe, which was observed in Belarus and Ukraine through the end of the study in 1998. The estimated dose was 1.1–1.4 microsievert (μSv) per year from radiostrontium (Körblein 2003). Increases in trisomy 21 were found in Berlin and Belarus in 1987/1988. The cases coincided with exposure to Chernobyl fallout (Sperling et al. 2012).

Echoing fallout and post-Chernobyl research findings, perinatal mortality rates increased significantly in Fukushima and six neighboring prefectures after the Fukushima nuclear disaster began, although researchers debate the magnitude of the increase and further study is needed to associate increases with radiation from the catastrophe (Scherb et al. 2016; Körblein and Küchenhoff 2017).

Monkeys in Fukushima-contaminated areas had significantly low white and red blood cell counts and other reduced blood components commensurate with their internal radiocesium contamination and mirroring post-Chernobyl results in humans. As of 2017, the monkeys had not recovered (Ochiai et al. 2014; Hayama et al. 2017).¹⁷ The median internal dose was considered low at 7.6 microgray (μGy) per day (Urushihara et al. 2018).

Heritable Impacts

For those who are exposed to radiation *directly* during early human life, associated effects (called somatic) can include cancer and other subtle or non-subtle diseases.¹⁸ However, decades of research implicate radiation in negative *heritable* consequences, which may only surface generations later.

As far back as 1927, Hermann Muller showed that x-rays could induce mutations in fruit flies and that some of these mutations were heritable (Gleason 2017).¹⁹ Gioacchino Failla, physicist and early radiobiologist, complained about consideration of genetic impact in radiation standards, noting that if genetic criteria were used to set exposure standards, then there would be no amount of radiation to which humans could be exposed (Caufield 1985, p. 48). Dr. Gofman, evoking two-time Nobel Prize winner Linus Pauling's concern over atomic bomb fallout expressed in 1958, contended that: "Irrevocable nuclear pollution inevitably increases humanity's rate of inherited afflictions" (1998, part 12e). Additional research confirmed the higher the dose, the greater the risk, with all doses down to zero harboring some risk (Creager 2015).

Naysayers persist, claiming no proof of heritable impact for *humans*, despite research signaling otherwise (Hamada and Fujimichi 2014). Even death has not prevented subsequent politicization of what is generally accepted research, as demonstrated by recent attacks on Muller's decades-old work. Muller was accused of lying about the presence of a threshold at low doses, a contention unsupported by the original research in question (Crok 2011; Caspari and Stern 1948, p. 81).²⁰ Scientists familiar with Muller's groundbreaking experiments reject these assertions (Crok 2011). In reality, Muller interpreted data based on his expertise, something all scientists do. The dispute, therefore, was over expert judgment, not the science itself.

Echoing Muller's findings, recent studies examined inhabitants (including humans) of high natural background radiation. They found significant adverse effects on immunology, mutation, and disease frequency, as well as reduced levels of

¹⁷ Studies of Fukushima monkeys suffer from poor sample size and no replication. Nevertheless, a similar result is seen in other species and other exposure scenarios.

¹⁸ Somatic damage, as opposed to heritable damage, comes from direct exposure to radiation.

¹⁹ A mutation is a change that occurs in the structure of DNA. Some mutations are repaired; some can be the beginning of disease. Not all mutations are heritable—defined as moving to the next generation.

²⁰ The study used by Muller's accuser (Caspari and Stern 1948) still exhibited an increase in mutations, although it was not statistically significant.

antioxidants across a wide range of species. Mutation effects, including but not limited to cancer, start at a few millisieverts per year of natural background radiation, indicating risk down to small doses (Møller and Mousseau 2013). These impacts also affect “future generations, with potentially significant population-level consequences, even beyond the area contaminated with radioactive material” (Møller and Mousseau 2015, p. 1). Importantly, well-conducted research showed no benefit of, or increased resistance to, radiation; or evidence of adaptation that meets the proper evolutionary definition (Møller and Mousseau 2013, 2016; Monosson 2014).

In the middle of the last century, in an attempt to make atomic weapons, atomic power, and radiologically-contaminated environments more palatable to the public, the AEC claimed that radiation could cure cancer (Creager 2015). At the same time, geneticists were insisting that scientific institutions recognize radiation’s mutational and heritable impacts, in addition to acute impacts (Creager 2015; Hamblin 2007). Today, as more areas become contaminated with radioactive elements and more people are exposed to higher radiation doses through the environment and food (doses still considered low by normative interpretation), questions of inherited versus somatic radiation damage have become difficult to answer. There is a minimal array of studies designed to examine this question, especially since laboratory research using historically accepted benchmarks is unable to replicate the magnitude or type of radiation damage that is occurring in nature (Timothy Mousseau, PhD, personal communication, January 16, 2019; Garnier-Laplace et al. 2013).

What Chernobyl Reveals about Heritable Damage

The nuclear explosion at Chernobyl contaminated a wide swath of land with man made radioactivity in both the post-Soviet states and areas of Europe. Studies of humans who live in contaminated areas show an increase of minisatellite mutations in children and more closely match the exposure circumstances of living in and eating from a contaminated environment, although implications for heritable impacts is unclear and more research is needed (Dubrova et al. 1996, 1997, 2002, 2006; Dubrova 2019; Little et al. 2013, p. 9). Heritable impacts from low doses may exist in children of Chernobyl liquidators, although liquidator exposures may not best represent chronic, low-dose exposure (Weinberg et al. 2001). Recent unpublished data also suggest radiation creates *de novo* germline mutations in humans and increased mutation rates, but human data are few and sparse. Much more research is needed, yet funding is paltry (T. Mousseau, personal communication, January 16, 2019). Importantly, Bandazhevsky contends that assessment of health damage using only radiation from a single contamination event is incomplete. He theorizes that researchers must account for past exposures to radioactivity contaminating the “European part of the former Soviet Union since the 1960-ies [sic]” and that the individuals exposed to Chernobyl radiation currently were more susceptible to low-dose damage because they were *already* genetically vulnerable due to previous exposures (Bandajevski 2010). Research by Korsakov et al. (2020, p. 1) indicates significantly higher birth defects—some *de novo*—“in newborns ... in regions with elevated radioactive, chemical and combined contamination” in the Chernobyl-contaminated

Bryansk region. Birth defects occurred at “cumulative doses [from Chernobyl radiation only] over an 18-year period (2000–2017) ... range[ing] from 12.1 to 37.9 mSv [67–210 mrem per year] (Korsakov et al. 2020, p. 3).” Birth defects could result both from direct radiation exposure during pregnancy and cumulative impact over a series of generations (genetic load). Projections indicate that certain birth defects will “exceed the average values” of the 18-year period in the next few years (A. Korsakov, personal communication, September 28, 2020). This potential genetic load component predicted by Bandazhevsky echoes other research results in multiple species (Bandajevski 2010; Goncharova and Ryabokon 1998; Møller and Mousseau 2013). Uniquely, Korsakov et al. (2020) also examined and demonstrated additive and potentially synergistic impacts in areas contaminated by Chernobyl radioactivity and industrial chemicals. These currently sparse yet growing data support long-held conclusions that humans do not differ significantly from every other plant and animal, suffering heritable damage from radiation (T. Mousseau, personal communication, January 16, 2019; National Academy of Sciences 2006; O’Connor 2010).

Chernobyl contamination has lingered for over thirty years, exposing animals that (unlike humans) often fail to avoid contaminated land and also reproduce much faster, providing a unique and horrible opportunity to examine heritable impacts of radiation exposure on wildlife. These stark implications could provide a window into future impacts on humans that reside in radioactive contamination zones—a future that current human research, like that of Korsakov, is only now beginning to reveal. Nuclear supporters claimed that after the Chernobyl nuclear catastrophe, the area is a wildlife “paradise,” thriving in the absence of humans (Kinley 2006). This false narrative persists, while research demonstrates the opposite. Rodent populations living in chronic low-dose Chernobyl radiation show an increase in radiosensitivity among descendants of exposed ancestors and an accelerated mutation rate in mitochondrial DNA 50 generations since Chernobyl began (Goncharova and Ryabokon 1998; Baker et al. 2017). The elevated mutation level is consistent with *harmful* mutagenic impacts of radiation exposure, as is the shorter telomere length found in bank voles (Kesäniemi et al. 2018, 2019). Research on birds concluded that damage from initial radioactive reactor deposition continues to play a role in causing mutations in birds 9 to 11 generations later through non-targeted effects (NTE), meaning that a dose of radiation to one generation should be included in calibrating risk to later offspring given that this risk carries across generations (Omar-Nazir et al. 2018, p. 60).

Institutional Silence on Disproportionate Impacts Continues

Nuclear technology proponents such as AEC have influenced institutions and committees since the National Academy of Sciences (NAS) convened the first Biological Effects of Atomic Radiation (BEAR) committee in 1954. AEC pressured BEAR to support a permissible dose that could “justify existing policies” benefiting nuclear technology, rather than allowing a simple survey of existing information. Despite this pressure, BEAR’s work remained reliable. However, nuclear proponents grossly misrepresented the report, engendering public rebuke by scientists who had served

on the committee (Hamblin 2007). To this day, national and international exposure recommendations, based on official reports like BEAR, minimize, ignore, or inappropriately average disproportionate impacts in service to a permissible exposure level, even as no safe dose is recognized.

In 2006, a National Academy of Sciences report presented data indicating gender sensitivity to radiation exposure (Table ES-1). However, this increased female susceptibility to solid cancer risk was not highlighted as a significant conclusion—either in the report itself or in the media—having only been emphasized by researchers outside committee ranks. These data, pulled from atomic bomb survivor studies, point to adult women suffering at least fifty percent more harm, and female children suffering nearly ten times more harm from radioactivity than adult males (Olson 2011, 2012). Particularly disturbing is that female baseline rates for most cancer types are lower than male, according to the International Commission on Radiological Protection's draft TG102 and supported by data in NAS's Table ES-1. This means exposure to radiation erases a woman's apparent natural cancer resistance while *also* increasing her risk relative to a man's. The calculated low-dose solid cancer risk to women and children is probably underestimated since it was additionally discounted by a factor of 1.5, a practice that has since garnered severe scrutiny (NAS 2006, p. 15; Rühm et al. 2016).

The US abandoned a nationwide study on childhood impacts. Although some smaller studies and citizen-led efforts continue, not all are singularly focused on women and children, nor are the studies tied to radiation exposure specifically. The United States Nuclear Regulatory Commission (NRC), a successor to AEC, asked NAS to examine cancer risks around nuclear facilities (National Academy of Sciences 2012). NAS recommended two study designs, one exclusively examining children, very similar to studies conducted in France and Germany that showed increases in childhood leukemia around nuclear power facilities (Sermage-Faure et al. 2012; Kaatsch et al. 2008a, b). NRC canceled the study, citing high cost; however, internal emails show that NRC employees had already pre-supposed a conclusion: the study would show no impact *because the doses were too low* (USNRC 2016; Sforza 2017). Importantly, NAS recommended new ways of addressing dose and measurement uncertainties that could have threatened decades of normative assumptions (Folkers 2018). There are no official plans to revive the study, even though it would help clarify and strengthen prior data.

The National Council on Radiation Protection and Measurements (NCRP) is used, primarily by US regulatory agencies like NRC, to advise on matters from nuclear medicine to environmental exposures. The NCRP says relaxation of cleanup standards is necessary in the face of nuclear power meltdowns since cleanup to levels the US government requires would be "impossible" (Guarino 2013). NCRP allows "collaborating organizations"—many from the nuclear industry—to view its reports and provide comments before the public has access (2015). Further, NCRP dismisses evidence of heritable disease in the offspring of humans and impacts to pregnancy development from low environmental doses (2013).

One Cumbrian community in Great Britain fought hard to uncover radiation's role in causing heritable mutations in humans, despite the historical dispute (Anonymous 1990; Hamada and Fujimichi 2014). Government practices and industry connections

clouded the outcome. People around the Windscale nuclear facility in Great Britain—later renamed Sellafield—became concerned that its radioactive releases were responsible for increases in childhood leukemia, a fear supported by a study linking paternal radiation exposure to leukemia risk (Gardner et al. 1990). Westlakes Research Institute (WRI)—founded and funded by the owner of Windscale: British Nuclear Fuels, a company owned by the British government—researched radiation exposure’s impact on heredity and pregnancy outcomes in the local region and unrelated exposures and outcomes in Denmark (Allis-Smith 2017; Stovall et al. 2004). These studies have been woven into the narrative of radiation, despite concerns voiced by the public about WRI’s conflicts of interest and improper collection and storage of human samples, a regular practice within the UK nuclear industry (Allis-Smith 2017; Walsh 2010). Study results were mixed, leaving a permanent mark on the science of heritability that served to confuse the topic and foster distrust rather than to clarify. The WRI debacle represents a perfect archetype for creating doubt and maintaining uncertainty.

The United States Environmental Protection Agency Office of Air and Radiation, responsible for regulating radiation exposure to the public, has never accounted for the higher susceptibility of children or women in its dose limits (USEPA 2014, p. 6516). Instead, EPA seems to follow BEIR VII conclusions, which average the cancer risk of more susceptible women and children with more resistant men (NAS 2006). USEPA completely fails to account for non-cancer impacts (unlike its regulations for toxics, which are based on a Hazard Index) or pregnancy impacts (2018b p. B-2).²¹

EPA seems to be abandoning its protective role even further, as some employees have begun to recognize the impossibility of complete decontamination: “US residents are used to having ‘cleanup to perfection,’ but will have to abandon their ‘not in my backyard’ mentality in such cases,” said Paul Kudarauskas of the EPA Consequence Management Advisory Team. “People are going to have to put their big boy pants on and suck it up” (cited in Guarino 2013). Such decisions are political—made to support nuclear technologies—not decisions based in science. The implication is that people must learn to live with radiation exposure and resulting illness because nuclear technology is more desirable than their health. Hence, the most recent exposure guidelines for radiological catastrophes encourage more exposure (USEPA 2017, p. 6).²²

Groups that focus on protecting women, children, and pregnancy are unwittingly prejudiced by normative interpretations favoring nuclear industry. The American Academy of Pediatrics recently released a policy paper recognizing that children’s short- and long-term health can be at particular risk from nuclear emergencies. However, on questions of chronic exposure to low doses, the paper claims “the

²¹ Radionuclides are not in the National Emissions Inventory or the National Air Toxics Assessment due to uncertainty of agency data and measurement units for this group of pollutants.

²² EPA divides a radiological “incident” into three phases: early, intermediate, and late. The intermediate phase allows the 5 mSv level, but there is no definitive exposure level for the “late phase,” possibly leaving the 5 mSv level as a *de facto* limit.

data ... tend toward no association” between childhood leukemia risk and living near operating nuclear power reactors, despite evidence of an association (Paulson 2018, p. 2). Further, the policy paper fails to address impacts on those forced to live in chronically contaminated environments, instead recommending that evacuees “[r]eturn home only when authorities say it is safe to do so” (Paulson 2018, p. 4). However, exposures that authorities deem “safe” for pregnant women and children are at levels associated with disease, as circumstances of post-nuclear catastrophes illustrate.

Fearing devastating consequences for their economy and global image, authorities in Japan increased allowable radiation doses by a factor of 20, abandoning ICRP-recommended standards that were already dismissive of disproportionate impacts (Mayama 2018). Japanese authorities claimed that no studies demonstrated health damage below 100 mSv; claimed that laughing could help defend against harm from radiation; and shamed and isolated women who asked questions about their children’s health (Meyer 2011; Kimura 2016). As of 2018, the government continued threatening to cut off aid to evacuees who refuse to live in contaminated areas (Mayama 2018).

Post-Chernobyl, Soviet scientists began conducting studies on health, not to treat disease but to assuage anxiety with “reassuring mistruths” about radiation’s impact (Brown 2019a, pp. 145–149). As the need for an international assessment of Chernobyl’s health impacts grew, institutional experts offered normative interpretations absolving radiation. They began with a reinterpretation of Chernobyl data using atomic bomb information and knowledge gleaned from Manhattan Project alumnus Clarence Lushbaugh. As Kate Brown noted, Lushbaugh well knew that “how a study was set up could easily determine the results” (Brown 2019a, p. 150). The International Atomic Energy Agency (IAEA) was chartered to support nuclear technology, and this was noted as a conflict even within the UN family, yet no entity curtailed its role in either health assessments or Chernobyl relief funding (IAEA 2000; Brown 2019a, p. 227).

IAEA came to Chernobyl-contaminated and exposed communities, incorrectly discounting local experiences such as disease increases and ingestion of contaminated local foods. IAEA decided to use much less relevant exposure assumptions that would result in lower dose estimates for Belarus (Brown 2019a, p. 234). Ignoring empirical evidence in favor of decades of normative assumptions obscured radiation’s possible health impacts, as *representations* of radiation’s hazards were misaligned with *real* health impacts (Kuchinskaya 2013). Years later, international scientists came up with dose numbers closer to those proffered by Belorussian experts (based on empirical data and showing doses three times higher due to internal exposures). However, by then, the normative interpretation forced by IAEA had become the official narrative (Brown 2019a, p. 235). The West wanted nuclear power, for which they were now losing public support. The Soviets wanted to end the costs of Chernobyl contamination by saying it posed no problem (Brown 2019a, pp. 150–151). Mutual denial of radiation’s impacts benefited both parties.

The International Commission on Radiological Protection (ICRP) recommends exposure amounts that, while not binding, are used by regulatory bodies worldwide (ICRP 2007, p. 3). ICRP discounts disproportionate impacts in subtle and non-subtle

ways that filter down into national radiation exposure standards for normal and catastrophic conditions. Contrary to contemporaneous evidence and conclusions, one of ICRP's founders, Lauriston Taylor, believed low doses were not harmful (Anonymous 2017). He established ICRP committees to set *permissible* doses, not doses based on precaution (ICRP 2009a, p. 79). Through the use of permissible dose, sacrifice of human health (as recognized by Nadesan 2019) was programmed into ICRP recommendations. Current evidence indicates harm at low doses; yet ICRP's task is still to optimize radiation exposure, not by minimizing dose, but rather by limiting "detrimental effects of radiation exposure *without unduly limiting ... desirable human actions* (Hamada and Fujimichi 2014, p. 629, emphasis added; ICRP 2007, p. 92 par. 219; Sutcliffe 2010). Like IAEA, the favored status ICRP has placed on nuclear technology will, by necessity, support interpretations that minimize disproportionate or low-dose impacts. Even definitions of "detrimental" can be open to varying interpretation and may not include subclinical impacts like impaired neural development.

Unsurprisingly, then, ICRP concludes that in emergency and existing exposure situations, "prenatal exposure would not be a specific protection case, i.e., would not require protective actions other than those aimed at the general population" (ICRP 2007, p. 115). Assumptions discounting prenatal exposure are woven throughout ICRP's recommendations. ICRP recognizes the many underlying uncertainties and claims they cannot be accounted for because they are too great.

ICRP *averages* risks based on sex and age for *pre-exposure* protection recommendations, obscuring disproportionate impacts on women, children, and pregnancy. For retrospective evaluation of risk, ICRP says using sex- and age-specific data is appropriate (ICRP 2007, pp. 42, 274). Therefore, ICRP only fully accounts for individual and disproportionate susceptibility *after* exposure has occurred and damage is done. However, if data are gleaned from such retrospective examinations, ICRP has historically not changed pre-exposure recommendations for susceptible individuals and life-stages in a timely fashion, despite known vulnerabilities and remaining uncertainties (Sutcliffe 2010).

ICRP recommends a post-catastrophe exposure level of 1 mSv per year, apparently in addition to natural background dose (ICRP 2007, pp. 96–97). For most locations, this effectively doubles *unavoidable* natural background. ICRP also encourages marketing, trade, and consumption of contaminated food in the wake of radiological catastrophes (ICRP 2009b, pp. 43–44). Risk from importing polluted food, however, is not theoretical. Contaminated tea has been exported from Japan. Wild blueberry spread, sourced from Bulgaria, was contaminated with radionuclides higher than Japan's limit (SimplyInfo.org 2015; Shukan Asahi 2013). The spread, currently sold in US markets, is labeled "organic." Ingestion of contaminated food constituted most of the post-Chernobyl doses, which could be underestimated (Brown 2019a, p. 234; Datesman 2020). Eating this food will increase risk. It will also make assessing radiation damage more difficult as untracked contaminated food is sold to unexposed and unaware populations outside of contaminated areas. Determining who is and is not exposed will become yet more problematic as those internally exposed could be placed in supposedly unexposed control groups of studies, threatening future low-dose research. Every time ICRP recommends increases in radiation exposure, those who are more susceptible will be at greater risk.

Despite data from atomic bomb survivor cohorts demonstrating that females are more sensitive to radiation exposure, ICRP does not attempt to have specific recommendations protecting *female* fetuses, which develop all their eggs during prenatal growth. Not only the developing fetus but also the fetus's future children could be at risk from radiation exposure. Some have promoted using the "reference embryo" or "reference fetus" as a model for radiation protection (Makhijani et al. 2006). Since the sex of a fetus is difficult to determine until the 18th week of pregnancy or later, this standard would protect all early pregnancy at the most protective level, as if the fetus were female.

Stochastic health impacts (including cancer and other genetic damage) represent one major category of uncertainty in radiation exposure. Stochastic damage is random and, therefore, difficult to predict and protect against. ICRP tries to attain "reasonably achievable" protection against such impacts, the severity of which is ostensibly independent of dose and without threshold (Hamada and Fujimichi 2014, p. 630; HPS, n.d.). As population exposures increase through unrecognized contamination in food, water, air, and soil, the number of people affected will increase. Even decades later, the cesium 137 released from atomic bomb explosions and civilian nuclear routine releases and catastrophes is "impossible to avoid" (USEPA 2011), and radiostrontium and plutonium still appear in children's teeth (Mangano 2006; Barnett 2003). Protecting pregnancy development from stochastic damage—where one hit from radiation could damage or destroy the cell(s) meant to become an organ—will become more challenging, especially as fetal tissue collects some regularly-released radionuclides (like carbon 14 and tritium) at nearly twice the concentration of maternal tissue (ICRP 2001, pp. 24–25).

ICRP does not account for cumulative biological damage to an individual from continuing exposure to low doses, nor does it believe it has enough information to calculate cumulative heritable radiation damage past the second generation (Dr. Keith Eckerman, personal communication, November 7, 2016; ICRP 2007, p. 54). ICRP correctly reasons that the estimates used for the cumulative generational risk equation may not remain valid for hundreds of human generations (Hamada and Fujimichi 2014). Research indicates that ability to cope with low dose chronic radiation exposure will *decrease* over generations, supporting ICRP's modeled trajectory of increasing vulnerability to genetic disease over the two generations its model addresses (Goncharova and Ryabokon 1998). In the present, this offers a conundrum: how can we tell now how badly we may be damaging our descendants, and how do we act now to protect future generations?

ICRP recommendations fail to account for several significant developments during pregnancy, a fact ICRP often recognizes. ICRP claims that lifetime cancer risk following *in utero* exposure will be similar to exposure risk in early childhood. At the same time, it admits it fails to account for damage to all the highly sensitive proto-tissue or organ-forming sites and stem cells responsible for blood formation (Phipps et al. 2003). ICRP uses uterine dose to determine embryo dose while recognizing that averaging of dose over the uterus "hides the fact that the very early embryo, with a small number of cells, might receive doses significantly higher or lower than this average"; ICRP maintains that "future developments" can correct for this (ICRP 2001, pp. 53, 60–61). ICRP uses models made for postnatal exposures

to calculate radiation damage to prenatal tissues and organs and mentions the shortcomings of this approach, but claims there is a lack of data about damage at these early life stages and that using this method makes it more convenient for comparing dose data with adults (ICRP 2001, p. 27).

While ICRP at least admits shortcomings in other areas of pregnancy protection, it seems blind to the unique role of the placenta, recognizing it as a conduit for toxins and nutrients, but implying that only its mass matters (ICRP 2001, chap. 3; ICRP 2002, p. 231). The placenta, however, performs organ-like functions during pregnancy, and improper placental formation or function can result in negative impacts later in adult life (Gude et al. 2004; Yamauchi et al. 2009; Fowden et al. 2006).

Although universally relied upon for exposure recommendations, ICRP is not alone in interpreting radiation studies and writing reports steered by the primacy of nuclear technology's survival. Studies can be rejected for legitimate reasons such as faulty methodology, but many are rejected because their evidence would be too complex or uncertain to integrate into the current narrative (ICRP 2007, pp. 175–176). There are also *whole areas* of study, which promise to further clarify the uncertainties, that have, to date, enabled the obscuring and politicizing of disproportionate impact and low-dose research. Such clarification could undermine the normative interpretations supporting nuclear technology.

Decades of evidence implicate non-targeted effects (NTEs), historically unrecognized as conveyers of radiation damage, in disease causation, *even in unirradiated offspring*. Not always attributable to direct genetic damage, NTEs affect the functional processes of a cell. They may warrant the creation of new paradigms of health risk from radiation exposure since impacts of NTEs may not be accounted for in radiation damage models (Eccleston et al. 2007; Barber and Dubrova 2006; Baverstock 2010a, b; Mothersill and Seymour 2010; Wright 2010; Dubrova 2019). NTEs could also explain differences in modeled versus actual health impacts. Sociopolitical opposition to new discoveries has distracted from research into transgenerational effects, a category of NTEs; more work is “clearly warranted” and easier to accomplish as tools in molecular genetics continue to get better (Baverstock 2010a; Dubrova 2019). Failure to research NTEs puts in jeopardy a truthful narrative of how radiation affects life, who may be most susceptible to damage, and how society can protect its members, especially children.

Radiation exposure causes alterations in the cells of humans and animals in individuals and across generations. Measuring these biological or genetic changes that represent *empirical evidence* of radiation damage could help reduce uncertainties of radiation exposure. However, as a whole, conventional radiation dose reconstruction has failed to use genomic techniques. International recommendations remain largely silent on using bioindicators for radiation research, despite incorporation into health studies to help determine radiation exposure and to connect childhood leukemia increases with exposure to radiation (Wing et al. 1997; Schmitz-Feuerhake et al. 1997; Livingston et al. 1997; Hoffmann 2002). Conflicted interests, cherry-picked data, exposure recommendations based on convenience, and lack of public access and accountability have not only resulted in ignorance of disproportionate impacts, but also created nearly insurmountable credibility barriers for national and international institutions alike.

Nuclear Advocacy Silences Women's Voices, Concealing Disproportionate Impacts

Nuclear advocates have historically used interpretations, policies, and labels that deny anecdotal observations and concerns of laypersons—often women—willingly “tak[ing] enormous risks with people’s health and safety” (Sarathy et al. 2018, p. 11). Since the reactor explosions at Chernobyl and Fukushima contaminated their surrounding environs essentially permanently, nuclear technology advocates have added a new concept to their repertoire of denial: resilience.

Advocates have taken the concept of resilience, originally used in psychosocial contexts, and inappropriately applied it to a biological context. This “despotism of resilience” does not overcome the challenges of living in a radioactive environment; it succumbs to them by denying biological reality, ensuring “slow violence” is done to biological systems (Ribault 2019; Nixon 2011; Lindee 2016b). These are the hallmarks of so-called radiation resilience: eating and feeding your children contaminated food; living in a contaminated area while keeping the community’s *reputation* “safe” by not mentioning health concerns; labeling as *radiophobic* people who express such concerns; and returning to a new, abnormal, diminished, resource-starved life where you are responsible for your own safety while those responsible for the catastrophe walk away (Folkers 2020; Kimura 2016; Onozawa 2013). Eating contaminated food can deliver the most extensive radiation dose, and selling contaminated food can spread internal contamination to those who live in “clean” areas (Brown 2019a, p. 234). However, ICRP, as part of its economic and political function, encourages growing, marketing, selling, and consuming contaminated food as an economic imperative for those who would live in contaminated areas (ICRP 2009b, pp. 43–44).

In line with this concept, Project ETHOS, partly a French nuclear industry initiative, was launched after Chernobyl melted down. ETHOS encouraged Chernobyl-contaminated populations (particularly targeting mothers with small children) to monitor and consume locally grown food contaminated with radiation. Proponents of ETHOS claimed this initiative would help relieve mothers of the guilt of being unable to provide clean food for their children. Leaving contaminated areas was not provided as an option given that permanent relocation had proven expensive and publicly damaging to nuclear technology’s reputation, risking future investment (Topçu 2013). The ETHOS project promotes *individual* responsibility for maintaining safety from radioactivity (Topçu 2013; Kimura 2016). In this scenario, the industry that caused the contamination would not be held responsible. This individual responsibility trope shifts the blame and risk from government and industry to exposed people and contaminated communities (Topçu 2013; Nadesan 2013). ETHOS also appeared post-Fukushima through ICRP-arranged professional “dialogues” (Ando 2016). ETHOS has withdrawn from Chernobyl areas, but the Fukushima dialogues continue. The ETHOS concept of privatizing damage appears in ICRP’s latest draft recommendations, TG93, “Radiological Protection of People and the Environment in the Event of a Large Nuclear Accident” (June 17, 2019).

At the dawn of the atomic weapons age, nuclear technology proponents labeled as radiophobic people who questioned the safety of nuclear weapons, nuclear power, and nuclear fallout. The theory of radiophobia contends that if you are afraid of radioactivity, your fear—and not the radiation—will cause illness. Use of *radiophobia* as a derisive label appeared in a 1951 opinion piece in a medical journal. The author, a proponent of seeding clouds with radioactivity, blamed caretakers for inciting fear of nuclear weapons in US children (Piasecki 2008). In the piece, entitled “RADIOPHOBIA: A New Psychological Syndrome,” the author claims that “[a]nxiety-ridden parents or teachers who fear atomic bombs probably project the same fears to their children” and that this “conditioning ... amounts to psychological punishment” (DeMent 1951, p. 602). In essence, the author (who was not a mental health practitioner) accused these parents of abuse. Since contemporary teachers and other caretakers of children were most often women, and since the piece was published in a journal that considered female reproductive issues, the not-so-subtle implication was that radiophobia was a woman’s “disease” that she passed to any children she contacted.

The unscientific radiophobia label has persisted through the decades, beginning with above-ground bomb tests (“radiophobia” and “nuclear neurosis”) to the nuclear power catastrophes of Chernobyl and Fukushima (“Chernobyl syndrome” and “radiation brain mom”) and even has a Macmillan dictionary entry, where anyone opposed to nuclear power is defined as “radiophobic” (Novikau 2017; Onozawa 2013; Kimura 2016).²³ Disease increases among the children of Chernobyl liquidators has been attributed to “psychogenic stress,” among other factors (Koterov and Biryukov 2011). Women, concerned for their health and particularly that of their children, are often vocal and persistent—a protective role many societies demand that women fulfill. However, when women try to maintain that protective role post-nuclear disaster, they are accused of worrying needlessly. If they persist, they risk becoming social outcasts (Kimura 2016). In this warped context, radiophobia is not a scientific or medical diagnosis but rather a social label used to stigmatize and silence valid concerns about health damage.

Independent scientific research faces real danger when official parties use more subtle forms of the radiophobia argument to affect basic research into radiation’s impact on human health. Petryna posits that the chance to establish Chernobyl data as a touchstone for radiation exposure has “all but disintegrated,” in part because experts framed “Chernobyl’s health aftermath in abstract (mostly psychological) terms,” refusing to acknowledge all but a small cohort of victims (2013, pp. xiv–xvii). SHAMISEN, a project funded by the European Commission, has recommended against systematic thyroid screening after nuclear catastrophes, claiming over-diagnosis and psychosocial impact can result (SHAMISEN 2017). Children’s thyroids are particularly susceptible to radiation, with cancers often appearing as soon as one year after exposure (Howard 2012; Brown 2019a, p. 242, n. 11).

²³ Radiophobia: “an excessive fear of radiation, especially in relation to the health and environmental risks associated with nuclear energy resources” (<https://www.macmillandictionary.com/us/dictionary/american/radiophobia>).

Therefore, not recommending thyroid screenings will impact children the most. SHAMISEN's recommendation is based on a faulty premise, since knowing about risk or taking precautionary steps does not necessarily lead to negative psychological or psychosomatic (nocebo) effects (SHAMISEN 2017; Boehmert et al. 2018). Additionally, clinical details of thyroid examinations post-Fukushima showed most thyroid cancer cases were not innocuous—invading nearby tissues such as lymph nodes, lungs, trachea, and nerves—indicating that thyroid removal was recommended to avoid death by metastatic cancer and therefore not merely a result of overdiagnosis. Moreover, the ratio of female to male cancers was nearly two to one (Hiranuma 2016, 2018).

As a result of the SHAMISEN report, some academics have insinuated that investigating *any* health impacts may cause psychological distress. They pose questions such as “[d]oes the research we ask [nuclear accident victims] to participate in help them to recover from the accident—or does our thirst for knowledge make things worse?” and concluding with the quip, “nothing in life is risk-free” (Thomas and Symonds 2016, p. 5). The *reality* seems to be that mothers rather become stressed when *prevented from* confronting health problems (Onozawa 2013). Radiation risks for women, children, and pregnancy are higher and often preventable.

The ETHOS project, the SHAMISEN framework, and the ICRP support a so-called “practical radiation protection culture (PRPC),” whereby people are trained to measure radioactivity so they can make well-informed choices (ICRP 2018; SHAMISEN 2017). Claiming that PRPC is empowering, officials and nuclear supporters have used it to encourage people to live in contaminated areas and eat contaminated food rather than relocate to a clean environment—relocation being the safest scenario (Topçu 2013). If a family has no resources for relocation, their “well-informed choices” will be limited. If, as several studies suggest, small, chronic radiation doses are damaging to pregnancy, children, and future generations, PRPC is discriminatory and dangerous. Therefore, downplaying health risks is essential for community acceptance of PRPC.

When people advocate for moving affected populations to clean environments or for providing proper medical screening for those exposed, they are accused of fear-mongering (Ropeik 2012, 2016). Ultimately, the PRPC model shifts costs for relocating evacuees or repurposing contaminated lands—costs that would be borne by government and industry—to public health (Stawkowski 2017; Topçu 2013). Because some health impacts of radiation exposure are latent or subclinical, actual damage from exposure to radiation can remain difficult to attribute to a cause. During this time, governments have taken irreversible political, societal, and health decisions.

This speaks to a fundamental problem with PRPC and the “ethics” it supposedly relies upon—it begins in *medias res*. Beginning this conversation in the *middle* of the problem misses the most crucial point: society can, early on, decide that *preventing* the problem is desirable. What about the increased biological risk to women and children of contaminating where they live in the first place? What about the ethics of insisting that women and children live in contaminated areas *after* a nuclear catastrophe when they never agreed to live with contamination before construction of the nuclear facility (Topçu 2013)? Acting as if there were absolutely no way to *prevent*

radiation contamination and biological impact warps conversations around averting health damage once contamination occurs. Additionally, framing exposure as a *fait accompli* can also stifle basic research on how radiation affects health, obscuring disproportionate risks even further.

While the United Nations Human Rights Council (UNHRC) has yet to address violations of the Chernobyl nuclear explosion, it *has* done so with Fukushima (Grover 2013). Encouraging women and children to eat contaminated food appears to be in violation of Article 24 of the UN Convention of the Rights of the Child (CRC), particularly the principle of needed access to “adequate nutritious foods and clean drinking-water, taking into consideration the dangers and risks of environmental pollution” (UNOHCHR 1989, p. 7). In addition to unequal health impacts suffered by women and children, women have suffered domestic abuse, dissolution of families, and societal stigma post-Fukushima (Ulrich 2017). At least one evacuee reported Japan’s continuing violations to the UNHRC (McCurry 2017). Viewing radiological catastrophes through the right to human health is novel post-Fukushima, but will hopefully become normal.

International and US radiation recommendations have failed to fully account for disproportionate impacts, even when research indicates changes are needed. Primary research has yielded evidence that more protection is needed for women, children, and pregnancy. The drive for nuclear technology primacy has led to policy and research decisions that favor slow acceptance (delays of up to forty years) of new research findings and failure to fund appropriate and robust research. Novel ideas, methods, and models of assessing radiation damage are stifled (Sutcliffe 2010). Evidence that does not fit the nuclear narrative is ridiculed. As one study concludes: “it may be productive, constructive and useful to implement modern re-analyses to review initial findings that did not fit ‘conventional wisdom’” (Beaugelin-Seiller et al. 2020, p. 11). Scientific evidence warning of unnecessary risks intensifies year by year, despite obfuscation by institutional drivers that favor nuclear technology.

Conclusion

It is for solid reasons that “concerns about natality, thought of in terms of the vulnerabilities of youth and transgenerational genetic damage, have fueled resistance to the dominant paradigm of radiation protection since the 1950s” (Nadesan 2019, p. 12). Empirical evidence shows that radiation affects women, children, and pregnancy disproportionately; protecting those most susceptible to radiation will heighten protection for everyone. As manmade radioactivity continues to contaminate the environment, an increasingly radiosensitive population could likely suffer increased rates of disease. Experts say society should start assessing these implications without delay, despite others’ claims of needing more human data (Salomaa et al. 2010; Sutcliffe 2010). Several regulatory and research steps could be taken to overcome the historical primacy that has been afforded nuclear technology at the expense of fully accounting for disproportionate and low-dose impacts.

EPA should regulate radionuclides like every other contaminant: include radionuclides in its non-cancer Hazard Index; use its already existing regulatory and policy

frameworks to address disproportionate impacts and promote “reference embryo” as a baseline for radiation regulations; focus on relocating populations living on or near radiologically-contaminated sites; and estimate costs of health impacts from exposure to radioactivity based on cost estimates of *other* toxic exposures (USEPA 1992, 1997, 2005, 2018a; Makhijani et al. 2006; Attina et al. 2016).

Independently conducted research should use disease cases, biological indicators, and whole-genome sequencing—not just estimated dose reconstruction (T. Mousseau, personal communication, April 4, 2018; Hoffmann and Schmitz-Feuerhake 1999; Goodhead 2009; Schmitz-Feuerhake 2006). Proper funding of this research is essential in order to remove uncertainties that have long been used by nuclear proponents to politicize and undercut independent science. Given enough funding, whole-genome sequencing to examine radiation damage could produce definitive studies crucial to understanding future generations’ potential damage (T. Mousseau, personal communication, August 17, 2018).

The persistent focus from independent international entities on ongoing nuclear catastrophes is essential for understanding and publicizing such catastrophes’ actual damage. Enduring contamination and radiation refugee status require constant monitoring in order for the susceptible populations to be protected rather than abandoned to “resilience.” Beginning in 2012, the UNHRC has followed post-Fukushima conditions and concluded that experts should not disregard the effects of longterm low-dose radiation exposure and should be aware that risk-benefit analysis is not compatible with the Right to Health Framework, particularly concerning vulnerable populations (Grover 2013). Regarding susceptibility, “[t]he experts strongly urge the Government to lower the allowable dose of radiation to 1 mSv/year to protect children and women who may become pregnant” (UNOHCHR 2018).

The primacy placed on nuclear technology’s survival post-World War II has created a radiation exposure ideology that *discounts* disproportionate, low-dose, and, ultimately, heritable impacts. At the same time, it *promotes* the alleged benefits of nuclear technology. This ideology uses scientific uncertainties to politicize and starve the very research that would address these uncertainties (Oreskes and Conway 2010). Claiming that nuclear power is “necessary” for addressing the climate crisis is only this ideology’s most recent survival tactic. Since some world leaders are seriously considering tackling the climate crisis with nuclear power, civil society needs to expose how the drive for nuclear expansion creates conditions that society never agreed to, namely: (1) conscripting people worldwide (including inherently susceptible children) into living in and eating from contaminated environments; (2) foisting a more considerable health burden on women, children, pregnancy, and descendants; and (3) increasing the risk of heritable impacts, thereby jeopardizing biological viability. Concurrently, this ideological drive has discounted research inconvenient to the nuclear-friendly narrative that claims “no discernible harm.” The drive to expand nuclear technology resulted in consequences that need to be fully revealed. Movements at the national and international level are beginning to recognize that the official narrative on radiation’s disproportionate impacts harms us, and more must be done.

Acknowledgments I wish to thank Linda Richards and Jacob Hamblin, Oregon State University, for designing and guiding the workshop Telling the Stories of Radiation Exposure, June 21–22, 2018; for the invitation to participate; access to the remarkable Linus Pauling archive; and for preliminary help in guiding this essay. Thank you also to the other meeting participants for insightful presentations and discussion; to the *Journal of the History of Biology* for this special issue; and to the detailed and constructive comments of an anonymous reviewer whose help was indispensable in crafting this final essay.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Locating the Boundaries of the Nuclear North: Arctic Biology, Contaminated Caribou, and the Problem of the Threshold

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Accepted: 2 February 2021 / Published online: 5 March 2021

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Abstract

This essay is a historical–geographical account of how scientists and public health officials conceptualized and assessed northern radioactive exposures in the late 1950s and 1960s. The detection of radionuclides in caribou bodies in northern Canada both demonstrated the global reach of nuclear fallout and revealed the unevenness of toxic relations and radioactive exposures. Following the documentation of the lichen–caribou–human pathway of exposure, Canadian public health officials became increasingly concerned about the possibility of heightened radioactive exposures among Indigenous northerners. Between 1963 and 1969, scientists and officials with Canada’s Radiation Protection Division (RPD) coordinated an inter-departmental monitoring program through which they sought to determine whether the consumption of contaminated caribou meat had caused radioactive exposure levels in northern communities to exceed the officially recognized “safe limits.” In 1969, the northern monitoring program was suspended after officials determined that radionuclide body burdens had not exceeded the threshold for radioactive exposures. While the RPD emphasized its development of a technoscientific approach to measuring radioactive body burdens, the legitimacy of the monitoring program was linked directly to interdepartmental relations within Canada’s colonial northern administration. I situate the northern monitoring program within broader shifts in public health approaches to radiation protection and use Gabrielle Hecht’s concept of *nuclearity* to demonstrate how RPD officials employed the logic of the threshold in their assessment of radioactive exposures.

Keywords Radioactive exposures · Nuclearity · Caribou · Historical geography of northern science · Lichen · Contaminants · Nuclear history · Northern Canada

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Introduction: A New “Caribou Problem” in the North?

In 1962, William Pruitt, a “specialist in the ecology of northern mammals” and former associate professor of biology at the University of Alaska-Fairbanks (UAF), described what he viewed as the emergence of a *new* caribou problem in northern Canada (Pruitt 1962, p. 24). While biologists had struggled for years to determine the cause of ongoing population declines among Canada’s barren-ground caribou herds, he argued that the new problem was tied directly to the ecological transformations unleashed since the onset of the atomic age. After more than a decade of atmospheric nuclear testing, barren-ground caribou, he wrote, had been transformed into “hot spots” of radioactive contamination (1962, p. 24). For Pruitt, the discovery of radionuclides in caribou bodies represented a “neat demonstration of the interdependence of all living things” and signaled the vulnerability of northern communities to radioactive contamination (1962, p. 25). Since people consumed caribou throughout the Arctic, Pruitt suggested that the entire northern food chain might have been contaminated. “Behind all the reassuring announcements and news releases about nuclear explosions since the beginning of the Atomic Age,” Pruitt warned, “there has lurked the spectre of the time when the so-called ‘safe limits’ would be exceeded. It is clear that for a great area of the earth’s surface that time has now come” (1962, p. 25).

The question posed, however, was whether the emergence of this new caribou problem caused radioactive exposure levels to exceed the officially recognized “safe limits” in communities throughout northern Canada. Pruitt’s assertion, which was based mainly on the ecologist’s past research in northern Alaska, heightened concerns among federal bureaucrats and public health officials in Canada and revealed a significant geographical lacuna in the federal government’s knowledge of radioactive exposures. Although the government had initiated a nationwide fallout monitoring program in the mid-1950s, public health officials acknowledged that studies of radioactive contamination in the food chain had focused on more populated southern regions of the country (Bird 1964a, p. 1029).¹ To address this critical gap, the Radiation Protection Division (RPD) of the Department of National Health and Welfare (DNHW) initiated a northern monitoring program in 1963, which involved collaborative arrangements among multiple government agencies and members of the country’s northern administration. Over the next 6 years, participants in this monitoring program collected and analyzed biological samples from animal and human bodies, conducted experimental human radiation studies, and deployed specialized sensing technologies designed to detect and measure radionuclide “body burdens” (Bird 1964c; Tracy et al. 1997). Through the development and coordination of this monitoring program, the RPD sought to assess the geographic distribution of environmental radioactivity while determining if the resulting radioactive exposures had indeed exceeded the “so-called ‘safe limits.’”

¹ Library Archives Canada (hereafter cited as LAC), RG 109 (Canadian Wildlife Service), Vol. 475, File W1.U. 341. Peter Bird, “On the Problem of Radioactive Fallout Levels in Canada’s North,” February 1963.

The RPD's "Special Northern Study" (Bird 1964a) was bound up with official efforts to determine if the global dispersal of radioactive fallout had transformed northern Canada into a "nuclear" space. Throughout the circumpolar north, scientists had detected heightened levels of radioactive material in northern food chains. However, I suggest, following historian Gabrielle Hecht's (2012) assessment of the global uranium trade, that the presence of radionuclides in the flesh and bones of caribou did not mean that northern Canada would be treated as a nuclear space. Through its attempt to monitor environmental radioactivity and radioactive exposures in the region, the RPD became an active participant in the negotiation of northern "nuclearity" (Hecht 2012). Hecht defines *nuclearity* as the way in which specific nations, places, programs, or technologies are designated as nuclear or nonnuclear and argues that its spatial and temporal parameters are unevenly distributed and inherently unstable (2012, pp. 14–15). Rather than a fixed ontological category with rigid boundaries, nuclearity, Hecht argues, is a "technopolitical phenomenon that emerges from political and cultural configurations of technical and scientific things, from the social relations where knowledge is produced" (2012, p. 15). Indeed, the RPD's status as an arbiter of northern nuclearity was tied to its ability to develop the technological capacity and scientific methods required to detect, measure, and monitor radioactive exposures across the vast geographical expanse of northern Canada.

The official narrative of the northern monitoring program is indicative of the increasing belief that postwar Canadian governments held in the ability of scientific institutions to render northern environments legible through conceptual frameworks, scientific methods, and technologies developed elsewhere (Bocking 2013; Power and Keeling 2018; Coates 1994). As the northern monitoring program expanded, the RPD increasingly linked its "epistemic authority" (Gieryn 1999, p. 1) to a particular combination of scientific practice and technological development.² However, a reading of the archival records produced by scientists and officials involved in the northern monitoring program reveals the instability of the RPD's technoscientific framing of northern environmental radioactivity.³ As a southern research and public

² Sociologist of science Thomas Gieryn argues that epistemic authority refers to the "legitimate power to define, describe, and explain bounded domains of reality" (1999, p. 1). See Bocking (2009) for a specific examination of northern science.

³ My analysis of the northern monitoring program is based primarily on an examination of two archival collections that were produced through the RPD's interactions with officials, scientists, and field agents in the Canadian Wildlife Service (CWS) and the Department of Indian Affairs and Northern Development (DIAND). Library Archives Canada (LAC), RG 85 (Northern Affairs Program), Vol. 2081, File 1003-3-14 (1): Sub-Committee on Anthrax and Radiation; and LAC, RG 109 (Canadian Wildlife Service). Vol. 475 File W1.U 341: Radioactive Contamination. These documents cover the operations of RPD officials and scientists until 1967. This was a critical period in the RPD's northern monitoring program, which included the completion of the first major survey of exposures. The RPD's operational records, which are housed in Canada's federal archives, cover the entirety of the temporal period during which the northern monitoring program was in operation, including the results of the 1967–1969 survey discussed below (see LAC, RG 29, Operational Records of the Radiation Protection Bureau, 1950–1984; RG 29, Files of the Radiation and Protection Branch, 1959–1979). Although I have submitted formal requests to access these records through the federal Access to Information Act, closures and delays in processing due to Covid-19 will prevent me from accessing these materials before publication of this paper. In the absence of these documents, I draw on published scientific papers and government reports to piece together the final years of the RPD's Special Northern Study. For a relevant discussion of the

health institution based in Ottawa, the RPD relied on existing and emerging colonial infrastructures (Cowen 2020) to overcome the geographical challenges associated with monitoring radioactive exposures in northern Canada. Throughout the duration of the northern monitoring program, the RPD established institutional linkages with agencies in Canada's northern administration and sought to enroll northern residents, researchers, and wildlife managers as participants in the northern investigation. Connections forged through the establishment of this network were vital to the RPD's northern monitoring program's legitimacy.⁴

In Canada, government agencies, federal scientists, and public health officials emphasized the logic of the threshold as they sought to determine whether northern Canada had been transformed into a nuclear space. By asserting that exposure levels had already exceeded the "safe limits," Pruitt (1962) implied that northern Canada had been rendered nuclear by the particular way in which radionuclides moved through Arctic ecosystems. As officials in Canada moved to test Pruitt's claims, they based their assessment of northern radioactive exposures on threshold values established by international scientific committees and radiological health organizations (ICRP 1959a, b; Federal Radiation Council 1960). Intended to delineate a boundary between ostensibly safe and unsafe levels of radioactive exposure, the threshold, I suggest, represented a technopolitical apparatus (Burch 2019; Hecht 2009) that was developed in distant institutional contexts and used by RPD officials to interpret and frame dynamic socioecological relationships in northern Canada. For Canada's public health officials, the question of whether or not exposure levels had exceeded the "safe limits"—or threshold values—was fundamental to determining whether radioactive fallout had transformed northern Canada into a nuclear space. However, rather than a natural or stable boundary, the concept of a threshold for radiological hazards proved to be a site of contested knowledge claims, persistent debate, and scientific uncertainty (Hamblin 2008; Cram 2016; Walker 2000).

This essay is a historical–geographical account of the way in which scientists and public health officials conceptualized and assessed northern radioactive exposures in the late 1950s and 1960s. Drawing on Hecht's description of nuclearity's historical and geographical contingencies, the paper attends to the spaces in which scientists and public health officials negotiated the placement of the boundary between the nuclear and nonnuclear in northern Canada. Over the past two decades, historical geographers of science have paid increasing attention to the "situated nature of scientific knowledge production and reception and the migratory patterns of science on the move" (Finnegan 2008). Stephen Bocking argues that historical geographies

Footnote 3 (continued)

archival inclusions and exclusions engendered by the high degree of state involvement in nuclear projects, see Pitkanen and Farish 2018, p. 874.

⁴ Researchers and officials involved in the northern fallout studies used the terms *Eskimo* to refer to Inuit, Inupiat, Inuvialuit, and Yupik communities, and *Indian* to refer to First Nations. I have attempted to use specific and currently accepted terminology in cases where I am able to identify an individual's community or nation. When quoting officials and reports, however, I have maintained the language used in the reports if it reveals the racial and colonial aspects of the monitoring programs. For more on terminology and naming Indigenous communities and nations, see Kaplan (n.d.).

of science have demonstrated the importance of place and movement to the production of scientific knowledge about northern contaminants; “like contaminants themselves,” Bocking writes, “knowledge about them is located in specific places, and can move” (2017, p. 425). Like the global dispersal of nuclear fallout, northern nuclearity was not bound by political borders. Indeed, an examination of the RPD’s assessment of northern radioactive exposures highlights the limits of national approaches to nuclear histories (Abraham 2006). By following the movement of ideas about radioactive contamination in northern environments through an emergent transboundary scientific network, this paper examines the relationship between the spatiality of environmental radioactivity and the production of scientific knowledge about radioactive exposures in northern Canada.

In the first section, I outline how the global dispersal of nuclear fallout produced by atmospheric nuclear tests became a problem for Canadian public health officials in the mid-1950s. In this section, I demonstrate that increasing awareness of the fallout problem reshaped official understandings of radiation exposures and, ultimately, led to the emergence of the RPD as a critical institution in the state’s public health approach to radiation protection. The historical analysis then turns to northern Alaska, where a group of scientists involved in a series of bioenvironmental studies funded by the US Atomic Energy Commission (AEC) contributed to the documentation of the ecological mechanisms underpinning a distinct northern pathway of exposure. Due to the particular way that radioactive material moved through the lichen-caribou-human food chain, biologists and ecologists throughout the circum-polar north believed that northern animals and people were at risk of heightened radioactive exposures. The dissemination of AEC-funded research through unofficial channels heightened concerns about radioactive exposures in northern Canada. The third section examines the RPD’s attempt to assess the severity of radioactive exposures in northern Canada by developing a technoscientific monitoring program. In this section, I consider the scientific methods employed by RPD scientists and officials as they monitored radioactive exposure levels in communities across northern Canada. In the conclusion, I reflect on the way in which the RPD’s monitoring program was linked to the establishment of the boundary between the nuclear and nonnuclear in northern Canada.

Monitoring Fallout

In 1945, radioactive contamination was transformed into a global environmental problem. Since the mid-1920s, scientists had been aware of the somatic and genetic hazards posed by exposure to X-rays and radium (Boudia 2007). However, the 1945 detonation of the first atomic weapon at the Trinity test site in New Mexico, and the US bombing of Hiroshima and Nagasaki, transformed anthropogenic radioactive contamination into a planetary force (Martin and Harbinson 1979; Masco 2015). These first nuclear explosions released vast amounts of radioactive debris into the atmosphere, which was deposited as fallout across the earth’s surface over a period of several months (UNSCEAR 1958, p. 11). The subsequent development of national atmospheric nuclear testing programs radically altered the scale of the

“fallout problem” (Commoner 1958). Between 1953 and 1958, the US, UK, and the Soviet Union conducted more than 220 atmospheric nuclear tests, which caused widespread concern about radioactive contamination and exposures (Higuchi 2018; Pavlovski 1998, p. 219; Pochin 1983, p. 75).

As scientists and public health officials assessed radioactive exposures, they had to negotiate the unstable terrain of threshold values. In the postwar period, governments in North America adopted with only minor modifications the International Commission on Radiological Protection’s (ICRP) recommendations on safe levels of exposure to radioactive material (Bird 1964a; Hamblin 2008, p. 5; Stephens 2002, p. 96; Martin and Harbinson 1979, p. 59). However, the concept of a *safe* level of exposure changed over time. During the 1950s, biologists and geneticists increasingly questioned the existence of a threshold dose for certain forms of biological damage (Martin and Harbinson 1979, p. 59; Hamblin 2008, pp. 11–15; Cram 2016, pp. 522–524). As scientists produced new knowledge about radioactive exposures, the ICRP replaced the term *tolerance dose*, which implied a level of exposure below which somatic damage would not occur, with the concept of a *maximum permissible dose* (Martin and Harbinson 1979, p. 59), which was defined as the level of exposure that carried “a negligible probability of severe somatic or genetic injuries” (ICRP 1959a, p. 9). According to the ICRP, the effects that would likely be caused by a permissible dose “are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.” Severe somatic injuries, such as leukemia, the ICRP stated, “would be limited to an exceedingly small fraction of the exposed group; effects such as shortening the life span, which might be expected to occur more frequently, would be very slight and would likely be hidden by normal biological variations” (1959a, p. 9).

The establishment of threshold values was not a politically neutral project. The ICRP and the governments that adopted its recommendations viewed a permissible dose as one that would “produce effects that could be detectable only by statistical methods applied to large groups” (ICRP 1959a, p. 9). However, as sociologist of science Soraya Boudia argues, international regulatory frameworks, such as the ICRP’s recommendations, served to increase the social acceptability of controversial nuclear technologies by promoting the idea that governments and the nuclear industry were managing and regulating the attendant radiological risks and hazards (Boudia 2007, p. 402; see also Higuchi 2018, p. 102). Ultimately, the adoption of the “maximum permissible dose” concept indicated a broader shift in the practice of radiation protection, in which governments decided that a certain level of human radiation exposure was both inevitable and acceptable (Cram 2016, p. 522).

In the late 1950s, amid the political and scientific debate about radioactive fallout’s environmental and health effects, nuclear powers began negotiations to curb or end atmospheric test programs (Higuchi 2018). A voluntary moratorium on atmospheric nuclear detonations, initiated in 1958, resulted in a dramatic reduction in short-lived fission materials in the atmosphere and lower elevations (Higuchi 2018; Wilson 1967, p. 4). However, the moratorium, which ended in 1961, was also short-lived. In the three months following the resumption of tests, the Soviet Union conducted more than 50 nuclear detonations over the Arctic (Wilson 1967, p. 4). In 1963, the US, UK, and Soviet Union signed the Limited Test Ban Treaty (LTBT),

which placed a moratorium on nuclear detonations in the atmosphere, ocean, and outer space and restricted signatories to underground nuclear tests (US Department of State 1963; Masco 2015, p. 143). By the time the LTBT came into effect, however, radioactive fallout represented a “planetary industrial signature” that was inscribed at multiple scales and different levels into every being living on Earth (Masco 2015, p. 151).

The global dispersal of radioactive fallout precipitated a series of transformations in the Canadian government’s approach to radiation protection. In 1949, the federal government assigned the Department of National Health and Welfare (DNHW) to manage radiation protection programs in the country. As J.W. Monteith, Minister of DNHW, explained, the department’s initial responsibility involved “advising the Atomic Energy Control Board on the health aspects of the use of atomic energy and its by-products” (Monteith 1959, p. 356). Due to the complexity of monitoring and maintaining the health of “radioisotope workers,” the DNHW established the Radiation Protection Division (RPD), a separate unit within the department that employed “highly trained” medical professionals and public health officials with expertise in the radiological sciences (Monteith 1959; DNHW 1955, p. 56). Initially, the RPD focused on occupational radiation hazards and had three related functions: in addition to advising the Atomic Energy Control Board, the RPD undertook physical measurements of radiation exposures and conducted clinical studies of the somatic and genetic effects of radiation on humans (Monteith 1959, pp. 356–359).

By the mid-1950s, however, Canadian public health officials were growing increasingly aware of radiation hazards outside of occupational settings. In particular, the initiation of nuclear testing programs led officials in the RPD to conclude that the “widespread distribution of radioactive fallout ... would result in some degree of radiation exposure for members of the general public” (Bird 1964a, p. 1029). As the scale of nuclear testing increased, so too did concern about environmental radioactivity (Bird 1964c, p. 1115). Following developments in the international public health and radiation protection communities, the RPD expanded its investigations beyond occupational settings and focused more broadly on radiation sources that contributed to the general population’s exposure levels. This shift in priorities was supported by changes in the division’s allocation of funds and resources. By the beginning of the 1960s, approximately fifty percent of the RPD’s resources were devoted to the “assessment of the radiation exposure of members of the public from radioactive fallout, effluents from nuclear reactors, natural background radiations and x-rays used for medical purposes” (Bird 1964c, p. 1115).

To address concerns about radioactive fallout in Canada, the RPD initiated a “special study” in 1955 (DNHW 1955, p. 127). Over the next eight years, the RPD’s investigation grew into a nationwide fallout monitoring program. Although the program was administered and coordinated by the RPD, it depended to a large extent on the support and infrastructural capacities of the Department of Agriculture, the Meteorological Services Branch of the Department of Transport, and the participation of pathologists at multiple hospitals throughout the country. As Peter Bird, Chief of the RPD, explained, “[b]ecause of the large number of factors that affect the distribution and deposition of radioactive fallout and its subsequent passage through the food-chain and into man, the program is made up of several separate but

interrelated studies” (1964c, p. 1115). By 1963, the RPD collected milk, wheat, soil, precipitation, and air samples from 96 locations across the country. In support of the RPD’s efforts, pathologists at multiple Canadian hospitals provided the division with human bone samples for testing and analysis (1964c, p. 1115).

While the RPD drew on interdepartmental linkages to compile a body of scientific evidence from across the country, officials aimed to develop the infrastructural capacity required to administer the fallout monitoring program from the division’s headquarters in Canada’s National Capital Region. In 1964, the RPD opened its new headquarters in Ottawa, which housed the division’s laboratories where scientists tested and analyzed samples received from sites across the country (DNHW 1966a, b, p. 81; Bird 1964c). A significant development in the early 1960s was the RPD’s construction of a whole-body counting system located at its headquarters. The system, which used “large scintillation detectors in a heavily shielded enclosure,” was developed to measure the radioactivity content of living individuals (Bird 1964c, p. 1115). The tests and measurements made at the RPD’s laboratories in Ottawa were a critical aspect of the division’s attempt to determine the geographical distribution of fallout in Canada. Through these developments, and with the support of Canada’s federal bureaucracy, the RPD became firmly entrenched as a critical institution in the government’s attempt to monitor and manage radioactive exposures resulting from the dispersal of fallout throughout Canada.⁵

Although nuclear fallout had transformed radioactive contamination into a global environmental problem, scientific investigations demonstrated that its impacts were not distributed evenly across the earth’s surface. Like Canada, other state-based scientific institutions established monitoring programs in the late 1950s and early 1960s to investigate the spatial and temporal dimensions of fallout dispersal. In a review of fallout data produced by global monitoring programs, climatologist Cynthia Wilson (1967, pp. 1–4) noted that the highest concentrations of radioactive fallout at the earth’s surface were located at sites between 40° and 60° North, slightly to the south of the Arctic. However, despite the detection of relatively lower levels of fallout throughout the circumpolar north, many scientists believed that there were still considerable radiological hazards associated with the accumulation of radioactive material in Arctic environments. Indeed, as scientific investigations demonstrated, the risk of radioactive exposure was not determined solely by the amount of radioactive material in the environment. Instead, the environmental effects and health consequences of radioactive fallout were shaped profoundly by local ecological conditions (Bocking 2017, p. 428).

⁵ From 1963 to 1968, the Department of National Health and Welfare released reports containing data and findings from its ongoing investigations in *Data from Radiation Protection Programs*, a periodical published in English and French.

Mapping a Northern Pathway of Exposure

Before the signing of the LTBT, several scientists and members of northern Indigenous communities began to voice their concern about radioactive contamination in Arctic environments (Kirsch 2005, pp. 86–88). Their worries were exacerbated by the amount of radioactive debris released by Soviet tests above the Arctic and the accretion of scientific evidence regarding the existence of a distinct northern pathway of exposure for radionuclides. One of the first indications that northern environments were vulnerable to radioactive material bioaccumulation came from northern Scandinavia where scientists determined that reindeer had considerably higher exposure levels than other grazing animals, including groups of animals located closer to nuclear test sites (Bocking 2017; Liden 1961).⁶ Further, in 1959, Canadian botanist Eville Gorham documented the capacity of lichens to accumulate higher concentrations of radioactive contamination than flowering plants (Gorham 1959; Bocking 2017, pp. 428–429). Although Gorham was unable to explain the ecological mechanisms underlying this phenomenon, his research did suggest broader implications for people and animals throughout the circumpolar north: “The chief practical conclusion to be drawn from this work,” Gorham stated, “is that animals feeding on mosses and lichens may well exhibit high intakes of radioactive fall-out” (1959, p. 329).

Following the publication of Gorham’s findings, the US Atomic Energy Commission (AEC) played a vital role in the development of an ecological understanding of the relationship between northern environmental radioactivity and radioactive exposures. In 1957, the AEC established Project Plowshare, a research and development program that was intended to use nuclear weapons for “geographical engineering” (Masco 2015; Kirsch 2005). The following year, the AEC selected Cape Thompson in northwestern Alaska as the future site of Project Chariot, which involved the planned nuclear excavation of an experimental harbor north of the Bering Strait (Cittadino 2018; O’Neill 2007; Kirsch 2005; Coates 1989). Partly in response to political opposition and scientific concern about Project Chariot’s potential environmental impacts, the AEC funded a series of bioenvironmental studies for the region (Millar and Mitchell 1998). John Kelly, director of Project Plowshare, later wrote that the bioenvironmental studies were intended to develop an understanding of Arctic ecological systems so that the AEC could estimate the “biological cost” of the excavation, establish environmental baselines that could be used in post-detonation research, and “determine radiation levels and the distribution of radioisotopes in the biota and physical environment in pre- and post detonation time” (Wilimovsky and Wolfe 1966, p. iv). The planned nuclear excavation, however, did not take place. In 1962, the Project Chariot proposal, which had been met with staunch opposition from Alaskan Iñupiat communities and American environmental organizations, was withdrawn by the AEC.

⁶ Scientists classify caribou and reindeer as subspecies of species *Rangifer tarandus*. While caribou evolved in North America, reindeer evolved in northern Europe. AWF Banfield, *A Revision of the Reindeer and Caribou Genus Rangifer* (Ottawa: Queen’s Printer, 1961).

Although Project Chariot was canceled, the research funded through the bioenvironmental program transformed scientific understandings of northern environmental radioactivity. An essential aspect of the bioenvironmental program was the production of baseline data concerning environmental radioactivity in the Cape Thompson region (Kirsch 2005, p. 95). By analyzing the stomach contents and droppings of animal species located in the region, investigators produced visual representations of northern food webs, which they used to model the flow of energy through local ecosystems (Kirsch 2005, p. 95). Further, a group of scientists affiliated with the University of Alaska-Fairbanks (UAF) claimed to have verified Gorham's findings by demonstrating that lichens found in the study area had significantly higher levels of strontium-90 than other Arctic plants (Alaska Conservation Society 1961, p. 23). Several investigations involved the intentional release of radioactive material into the northern environment (ACHRE 1995, chap. 11). In these studies, scientists placed "mixed fission material" into bounded sample plots and small pits, and monitored the movement of radioactive material to determine transportation and absorption rates (ACHRE 1995, chap. 11). An investigation led by Wayne Hanson, a biologist working for the AEC at the Battelle Memorial Institute in Washington State, established a direct correlation between caribou consumption and heightened Cesium-137 exposure levels (Hanson et al. 1966). These studies represented a critical step in the development of an ecological understanding of the lichen-caribou-human pathway of exposure.

During the early years of the Cold War, the relationship between the AEC and the ecological sciences proved to be a "double-edged sword" (Hagen 1992, p. 100). While the AEC provided ecologists with critical sources of funding and new research tools and opportunities, it also created many of the environmental problems that ecologists were investigating (Kirsch 2005, p. 57; see also Hagen 1992; Bocking 1995; Martin 2018). The tensions engendered by the multiple and competing interests at play in this relationship shaped the content and conduct of the AEC's bioenvironmental studies. One particularly salient controversy involved William Pruitt, who had been hired by the Department of Biology at UAF to conduct a study of terrestrial mammals for the bioenvironmental program. During his research, Pruitt became increasingly interested in understanding the ecological mechanisms underlying the bioaccumulation of radioactive material in caribou bodies. The AEC, however, reduced funding for the costly caribou studies and rejected Pruitt's proposal to study the relationship between caribou and Arctic vegetation (Millar and Mitchell 1998, pp. 293–294).

Concerned about AEC censorship, Pruitt and his colleagues developed a strategy that involved disseminating their concerns and research findings outside of officially approved channels (Millar and Mitchell 1998, p. 294; Kirsch 2005, p. 98). The fallout from their decision to publicly oppose Project Chariot was immediate and severe. Pruitt's involvement in this public controversy "earned him the enmity" of both AEC officials and UAF administration, and, ultimately, led to the termination

of his position in the Department of Biology (Millar and Mitchell 1998, p. 295).⁷ Despite significant personal and professional consequences, the strategy adopted by the dissenting UAF scientists was, in many ways, a “contested success” (Millar and Mitchell 1998). As geographer Scott Kirsch argues, Pruitt and his colleagues effectively challenged the authority of the AEC’s claims over the Cape Thompson region’s environmental future by shifting the boundaries of dissent and enrolling new actors and groups in the local opposition movement (Kirsch 2005, pp. 78, 98).

In the early 1960s, UAF scientists established a transboundary network of communication that involved experts, activists, and government agencies that extended beyond the US and included officials in the Canadian government. In publications and correspondence with members of this emergent network, the dissenting scientists suggested that the threat of heightened radioactive exposure levels in the North was not merely a hypothetical future scenario that depended on project Chariot proposal’s success. Drawing on research from Alaska and Scandinavia, they insisted that current levels of environmental radioactivity represented a profound threat to people living in northern communities due to the movement of radionuclides through the lichen-caribou-human food chain (see Alaska Conservation Society 1961).

By disseminating their findings through unsanctioned channels, Pruitt and his former colleagues at UAF contributed to the development of terms by which the northern environment—including northern Canada—could be understood as a nuclear space. In 1962, Les Viereck, a former employee of UAF and participant in the AEC’s bioenvironmental research program, provided officials in the Canadian Wildlife Service (CWS) with a “restricted” report on movement of radioactive materials through the lichen-caribou-human food chain in northern Alaska. Following this document’s receipt, E.H. McEwan, a mammologist with the CWS, prepared a report on the dangers of northern environmental radioactivity. McEwan’s report was subsequently tabled and discussed at a meeting of the Administrative Committee for Caribou Preservation. This joint federal-provincial body developed policy recommendations for senior levels of government.⁸ Following this meeting, officials with the CWS prepared and submitted a memorandum to the Department of Northern Affairs and National Resources (DNANR), which outlined the confidential report’s findings and commented on its implications for northern Canada. Acknowledging the “distinct probability of transmissiion” of Strontium-90 and Cesium-137 to humans “through the food chain mechanism,” the CWS recommended the immediate establishment of an “intensive” program of research.⁹

However, it was William Pruitt’s 1962 essay on radioactive fallout and caribou that garnered the most interest among Canadian wildlife managers, public health

⁷ A full consideration of the scientific controversies engendered by the AEC’s involvement in the bioenvironmental studies is beyond the scope of this essay. For more on this important episode in northern nuclear history, see Millar and Mitchell (1998); Kirsch (2005); O’Neill ([1994] 2007).

⁸ This restricted report is now open for public access in Canada’s federal archives. See LAC, RG 109, Vol 475, File W1.U. 341. For more on the caribou committee, see Sandlos (2007, p. 206).

⁹ LAC, RG 109, Vol 475, File W1.U. 341, 20 December 1962, “Memorandum for the Deputy Minister.”

officials, and members of the country's northern administration.¹⁰ Shortly after his contract at UAF was terminated, Pruitt published an article in *The Beaver*, a Canadian historical magazine, in which he articulated the ecological mechanisms underlying the lichen-caribou-human pathway of exposure. Drawing on emergent understandings of Arctic ecology and research from northern Alaska, Pruitt emphasized the important role that lichen played in facilitating the movement of radioactive material through the northern environment. This slow growing plant, he explained, was a combination of an alga and a fungus that had evolved extremely efficient mechanisms for acquiring nutrients from air-borne particles. Pruitt noted that lichen, which were common throughout Arctic tundra ecosystems, were capable of retaining "virtually 100% of the radioactive particles which fall onto them" (1962, p. 25). Due to its "peculiar physiology," the lichens upon which migratory caribou grazed tended to be highly contaminated with fallout from atmospheric nuclear tests. The implications for people in northern Canada, Alaska, and Scandinavia, Pruitt suggested, were clear: "Since the caribou is the base of the food chain in the North, turning vegetation into a form that other animals, including man, can utilize," he wrote, "one would expect the entire food chain to be contaminated" (1962, p. 25).

Pruitt's article heightened concerns about environmental radioactivity in northern Canada. It also exposed a considerable lacuna in scientific and public health understandings of radioactive exposures throughout the country. In December 1962, E.A. Côté, the Deputy Minister of DNANR, sent a memorandum to the CWS requesting information about the relationship between nuclear fallout and caribou. In the memo, Côté noted that he had recently read Pruitt's article in *The Beaver* and expressed some concern about the biologist's hypotheses regarding radioactive exposures in northern Canada.¹¹ Although CWS officials stated that there was "no factual basis" to support Pruitt's assertions, their response revealed that the federal government had not yet undertaken a systematic investigation of radioactive exposures in the North. However, CWS officials noted that they were aware of the situation and were in the process of preparing a joint investigation with the DNHW that would focus on radioactive exposures in locations where Indigenous peoples consumed caribou meat.¹² In his response, Côté asserted that the investigation should not be limited to the CWS and the DNHW due to the connection between caribou and northern Indigenous peoples' health.¹³ Côté immediately sought to establish connections between the CWS and members of the Northern Administration Branch to ensure that the appropriate agencies could proceed with the necessary studies as quickly and efficiently as possible. In closing, he stated: "I think this matter should not be looked at in the narrow context of wildlife. In view of the potential explosiveness of a nuclear

¹⁰ In 1963, Peter Bird, Chief of the Radiation Protection Division, claimed that much of the "recent interest" in fallout and caribou was related to Pruitt's article in *The Beaver*. See LAC, RG 109, Vol 475, File W1.U. 341, February 1963, "On the Problem of Radioactive Fallout Levels in Canada's North."

¹¹ LAC, RG 109, Vol 475, File W1.U. 341, 28 December 1962, "Memorandum for Parks Branch."

¹² LAC, RG 109, Vol 475, File W1.U. 341, 16 January 1963, "Memorandum for Mr. E.A. Côté."

¹³ LAC, RG 109, Vol 475, File W1.U. 341, 22 January 1963, "Memorandum for National Parks Branch."

debate in the House of Commons, I think this matter should be considered in the light of all factors.”¹⁴

Body Burden: Mapping the Uneven Geographies of Northern Exposures

By early 1963, negotiations were underway to establish the terms and administrative parameters of a joint investigation of radioactive exposures in northern Canada. As Peter Bird, Chief of the RPD, explained, the “special features” of the northern food chain, particularly the lichen-caribou-human pathway of exposure, made it “desirable” to investigate radioactive exposures in the North through a separate program (Bird 1964c, p. 1116). From its inception, officials agreed that the investigation’s scale, and the complications associated with conducting scientific research in northern Canada, necessitated a cooperative agreement that involved multiple government agencies. As the project’s parameters took shape, members of Northern Health Services, RPD, DNHWS, Northern Administration Branch, and the Northern Co-ordination and Research Center of the DNANR became key participants in the investigation.¹⁵ Due to the RPD’s position within the federal government’s public health approach to radiation protection and its development of specific nuclear technological capacities, the division was well positioned to lead the “Special Northern Study.”¹⁶ By the end of the year, the RPD had assumed responsibility for coordinating the activities of the program’s multiple participating agencies, and determining whether radioactive exposure levels in northern Canada had indeed exceeded the “safe limits.”

For the RPD, radioactive exposures in northern Canada represented a geographical problem that was complicated by the multiscalar dimensions of environmental radioactivity. Global monitoring programs had demonstrated that radioactive fallout was distributed unevenly across the earth’s surface, and scientific investigations had revealed how local ecological conditions—such as vegetation diversity, precipitation rates, and the presence of grazing animals—regulated the movement of radionuclides through northern food webs. Based on a review of literature from Alaska and Scandinavia, Canadian officials determined that Cesium-137 and Strontium-90 represented the most significant fallout radionuclides present in the northern environment.¹⁷ With half-lives of approximately thirty years, these two radionuclides posed long-term radiological hazards for caribou herds and human communities throughout the region (Hanson 1966). However, each posed different radiological risks and uncertainties due to the particular ways that they accumulated in caribou

¹⁴ LAC, RG 109, Vol 475, File W1.U. 341, 22 January 1963, “Memorandum for National Parks Branch.”

¹⁵ LAC, RG 109, Vol 475, File W1.U. 341, N.D., “Draft Letter,” Peter Bird to Regional Superintendents of National Health Services.

¹⁶ LAC, RG 109, Vol 475, File W1.U. 341, 20 December 1962, “Memorandum for the Deputy Minister”.

¹⁷ LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, “On the Problem of Radioactive Fallout Levels in Canada’s North.”

bodies (Palmer et al. 1963; Hanson 1965a, b; Pochin 1983). Whereas Strontium-90 concentrated in caribou bones, Cesium-137 accumulated in the animal's flesh and muscle. Because it accumulated in the parts of caribou bodies consumed most commonly by people, RPD officials expected to find "that the ratio of caesium-137 in eskimos and indians (sic) to 'southern' Canadians will be higher than the same ratio for strontium-90."¹⁸ At this early stage in the research program, however, there was considerable uncertainty about the biophysical determinants of human exposure levels: it was entirely possible, Bird wrote, that the ingestion of Cesium-137 through the consumption of caribou meat was being offset by the "rapid elimination" of the radionuclide from the body.¹⁹

A critical step in assessing the spatial distribution of risk was determining if there was a relationship between nuclear fallout and the accumulation of radionuclides in caribou bodies. Although the RPD operated a nationwide fallout monitoring program, which included data from six locations in northern Canada, the "[e]mphasis on the food chain-human side of the program," Bird noted, "has been directed to the more heavily populated areas of Canada."²⁰ Before the establishment of a formal agreement among the participating agencies, the RPD initiated a "preliminary investigation" of Strontium-90 in caribou bones. In the early 1960s, the CWS, recognizing that there may be a future need to study the relationship between fallout and caribou, had built up an inventory of caribou bones, which it made available to the RPD for the Strontium-90 assay. In a report shared with participating agencies, Peter Bird explained that caribou bone samples selected from locations across northern Canada would be tested for radioactive content. The results would be compared with the RPD's soil data to determine if "differences in caribou bone levels can be associated with the differences in a deposition" of radioactive fallout.²¹ The decision to begin with a preliminary investigation of Strontium-90 was also indicative of the RPD's inchoate monitoring and infrastructural capacity. At the beginning of 1963, the RPD's whole-body counter, which was designed to detect Cesium-137 concentrations in humans, was still under construction at its new headquarters in Ottawa. Bird stated that if the results of the Strontium-90 tests revealed the need for further investigation, the RPD would use the whole-body counter to conduct Cesium-137 body burden measurements following its completion.²²

By the beginning of 1964, the federal bureaucracy had finalized the administrative details for the Special Northern Study, and the RPD was in the process of

¹⁸ LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, "On the Problem of Radioactive Fallout Levels in Canada's North."

¹⁹ LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, "On the Problem of Radioactive Fallout Levels in Canada's North."

²⁰ LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, "On the Problem of Radioactive Fallout Levels in Canada's North."

²¹ LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, "On the Problem of Radioactive Fallout Levels in Canada's North."

²² LAC, RG 109, Vol 475, File W1.U. 341, February 1963, Peter Bird, "On the Problem of Radioactive Fallout Levels in Canada's North."

coordinating the various components of the research program.²³ In a draft letter to the Regional Superintendents of the Northern Health Service, Peter Bird provided a detailed overview of the proposed studies, all of which, he argued, “must be undertaken if we are to be able to make an assessment of the fallout problem in Canada’s North.”²⁴ The RPD’s investigation of radioactive exposures among people and animals in northern Canada comprised five separate though interrelated studies: analysis of Cesium-137 in caribou, reindeer, and moose samples; analysis of urine specimens for Cesium-137 content, with accompanying information on dietary habits; whole-body counting for Cesium-137 in northern residents (measurements to be conducted at RPD headquarters in Ottawa); and a study of northern dietary habits (Bird 1964c, p. 1116). In correspondence with officials in the federal government’s northern administration, wildlife managers, and members of the northern health services, Bird delivered guidelines for the collection of biological samples that he expected field agents to follow. Failure to adhere to the guidelines and instructions, Bird explained, would render biological samples useless to the research program’s scientists.²⁵

Because of the role that caribou were believed to play in the transmission of radionuclides to humans, the RPD based its spatial division of the sampling program on migratory caribou herds’ movements in northern Canada. To collect samples and map the geographical distribution of radioactive exposures, the RPD divided the northern research area into five discrete regions. Officials later added a sixth region in the eastern Arctic, centered on Baffin Island (see Fig. 1). As Peter Bird explained, each area’s boundaries corresponded with the ranges of major barren ground caribou herds, among which there was thought to be little interchange of animals.²⁶

The RPD’s biogeographical division of the North revealed the confidence that the state placed in the ability of scientific wildlife managers to render northern landscapes legible and accessible through the application of scientific methods and visualization technologies developed elsewhere (Bocking 2009). By the beginning of the 1960s, wildlife biologists, armed with aerial surveillance technologies, had established firm boundaries around the major caribou herds in the North American Arctic. These boundaries were accepted by government agencies and employed within emergent herd-based management for caribou (Banfield 1961; Kelsall 1957, 1968). Indeed, the belief that radioactive exposures could be understood and ultimately controlled by managing the relationship between migratory caribou and Indigenous peoples was informed by a long history of colonial conservation and knowledge production in northern Canada. Since the beginning of the twentieth century, caribou conservation had been linked inextricably with the colonial administration of

²³ LAC, RG 109, Vol 475, File W1.U. 341, 10 June 1964, Correspondence: Peter Bird (RPD) to V.F. Valentine (Chief, Northern Co-ordination and Research Centre).

²⁴ LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

²⁵ LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

²⁶ LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

the North; through the management of caribou, the state sought to manage northern Indigenous peoples and their relationship with northern environments (Sandlos 2007; Kulchyski and Tester 2007).

Despite the establishment of clearly delineated boundaries and explicit instructions, the rigors of northern field research complicated the task of collecting biological samples from each of the designated areas. From the perspective of southern scientists and bureaucrats, the five original research areas—charted neatly on hand-drawn maps and corresponding with caribou herds' ostensibly tidy movements—seemed to make sense. On the ground, however, the reality was much less orderly. As G.F. Parsons, an official with the Northern Co-ordination Research Centre, reminded RPD officials, each of the five areas represented a vast geographical region that was sparsely populated and mostly inaccessible to state-based researchers and field agents. When officers and game wardens did secure a caribou carcass, they often experienced difficulties following the RPD's instructions for preserving and transporting biological samples.²⁷ By the end of 1964, Bird was concerned that inconsistencies in field preservation techniques had rendered many of the biological samples unusable.

To preserve the sampling program's integrity, Bird and his colleagues implemented a series of measures intended to "systematize" biological material collection. According to this new system, caribou meat would have to be dried before being shipped to the RPD laboratories. Bird requested that scientists at the Inuvik Research Laboratory—an important site of scientific knowledge production in northern Canada—develop an effective method of drying caribou meat for transportation and scientific analysis.²⁸ By 1965, the RPD had compiled a substantial inventory of caribou samples from sites throughout the North (Mohindra et al. 1966). There was, however, significant geographical disparity among the samples being sent to the RPD's headquarters for testing. More than seventy percent of the 220 samples came from just two designated research areas (Area II and Area IV). Although northern administrators placed pressure on field agents to supply samples from all research areas, the RPD's attempts to address the increasing disparity in samples' geographical distribution were mostly ineffective.²⁹

By testing and analyzing the samples received in Ottawa, the RPD documented significant spatial and temporal variances in radioactive exposures among migratory caribou. After exposure levels peaked in 1964, tests indicated that Cesium-137 concentrations in caribou decreased by approximately 20%—from 18,000 to 14,000 picocuries per pound—over the next 12 months (Mohindra et al. 1966, pp. 3–4). For the sake of comparison, the RPD measured the radioactivity content of poultry

²⁷ LAC, RG 109, Vol 475, File W1.U. 341, 20 November 1964, Correspondence: G.F. Parsons (NCRC) to Peter Bird (RPD).

²⁸ LAC, RG 109, Vol 475, File W1.U. 341, 21 December 1964: Peter Bird, "Memorandum: Meeting with representatives from Dept. Northern Affairs and National Resources re Special Northern Fallout Studies."

²⁹ LAC, RG 109, Vol 475, File W1.U. 341, Correspondence: G.F. Parsons (NCRC) to Peter Bird (RPD); LAC, RG 109, Vol 475, File W1.U. 341, 30 July 1965, Correspondence: Peter Bird (RPD) to J.S. Tener (CWS).

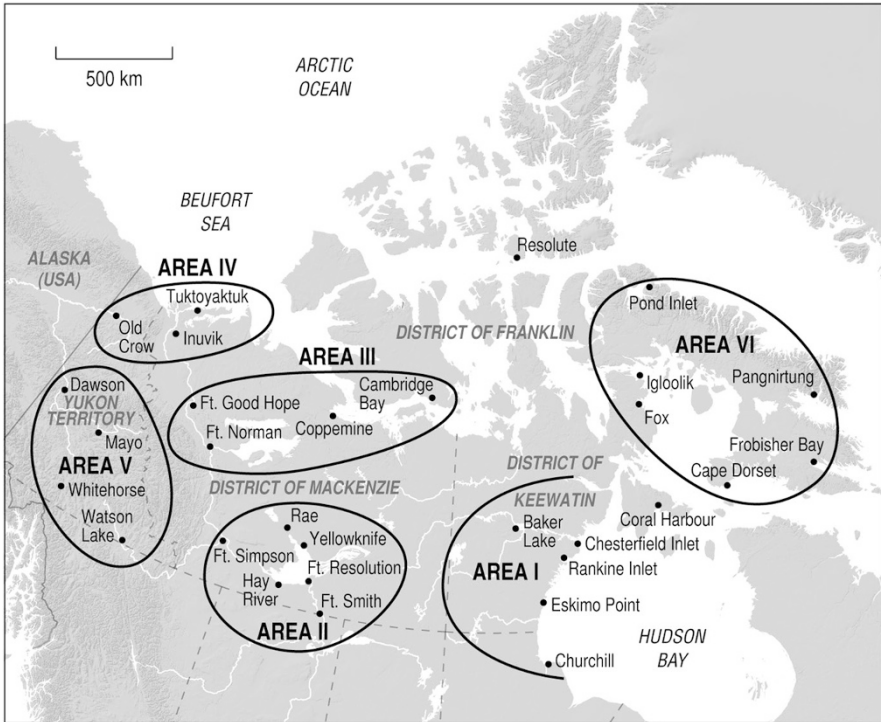


Fig. 1 Map by Eric Leinberger. Originally published in: V.K. Mohindra, Cesium 137 Body Burdens in the Canadian North, *Acta Radiologica: Therapy, Physics, Biology* 6 (1967): 481–490. See also: LAC, RG 85, Vol. 2018, File 1009-3-13 (1): Sub-Committee on Anthrax and Radiation

samples acquired at a market in Ottawa. For this decidedly southern food source, tests indicated a Cesium-137 concentration of just 24 picocuries per pound of meat (Mohindra et al. 1966, p. 13). Even at 1965 levels, the amount of Cesium-137 detected in caribou meat was more than 580 times greater than that found in Ottawa’s poultry sample. Further, the RPD’s analysis demonstrated that radioactivity levels among caribou were not uniform across northern Canada. Tests indicated that caribou from Areas I and II (see Fig. 1) had significantly higher body burdens of radioactivity than the herds located within the other four research areas’ boundaries.³⁰

For the RPD, these tests demonstrated that caribou in northern Canada were still vulnerable to the bioaccumulation of radioactive material, even two years after the LTBT came into force. The question remained, however, whether officials believed that contaminated caribou meat consumption had caused human exposure levels

³⁰ LAC, RG 85, Vol. 2081, File 1003-3-14 (1), 28 December 1965, Correspondence: G.F. Parsons to Director Northern Administration Branch.

to exceed the “so-called ‘safe limits,’” as Pruitt had argued in 1962. To assess the severity of radioactive exposures and the attendant risk to public health, the RPD developed a series of human studies, which involved direct and indirect methods of quantifying Cesium-137 body burdens among northern residents.³¹ Because Cesium-137 accumulated in the parts of caribou bodies most frequently eaten by northerners, RPD officials viewed it as the most significant radionuclide in the northern food web (Bird 1964c; Bird 1968b, p. 631). Although the RPD developed an ancillary study that examined Strontium-90 exposures, the human studies focused primarily on the bioaccumulation of Cesium-137 in human bodies.³²

By the beginning of 1964, the RPD had established two interrelated human studies through which officials sought to assess the severity and distribution of Cesium-137 body burdens in northern Canada (Bird 1964c). While the first study involved the direct measurement of Cesium-137 body burdens at the RPD’s laboratories in Ottawa, the second developed an indirect method of quantifying radioactive exposure levels based on the analysis of urine samples (Bird 1964c, 1968b). Like the caribou studies, however, this approach was challenged by the problem of numbers. Between 1964 and 1967, RPD officials not only struggled to recruit representative numbers of research subjects from the designated research areas, but also had to contend with scientific uncertainty concerning how to quantify body burdens through indirect methods of measurement.³³ The RPD sought technoscientific fixes to address these issues and continued to draw on official linkages within Canada’s northern administration to recruit research subjects.

From the perspective of RPD officials, the whole-body counting system offered the most direct and efficient method of measuring Cesium-137 body burdens (Bird 1968b). In this study, northern residents who had traveled to southern Canada would be recruited by the RPD to undergo testing in the whole-body counting system, which was located at the division’s headquarters in Ottawa. In a 1967 presentation at the “Symposium on Circumpolar Health Related Problems,” which was held at the University of Alaska, Peter Bird explained how the whole-body counting system operated (Bird 1968b). His discussion emphasized the facility’s technical aspects and outlined how its various components operated to ensure the accuracy of recorded measurements (Bird 1968b, pp. 636–637).

However, Bird’s presentation also hinted at the limitations of this approach. Because the whole-body counter was located at the RPD’s headquarters, he explained, this part of the investigation relied on the “movement of healthy Eskimos into the Ottawa region” (Bird 1968b, p. 637). During the first year of the study, the RPD recruited only 14 Inuit participants from the eastern Arctic to undergo

³¹ LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

³² For a discussion of the methods employed to determine Strontium-90 concentrations in human bones, see Samuels 1967, 1968. For an overview of the collection of human bones, see LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

³³ LAC, RG 85, Vol. 2081, File 1003-3-14 (1), 28 December 1965, Correspondence: G.F. Parsons to Director, Northern Administration Branch.

whole-body counting at the RPD's headquarters in Ottawa. Bird continued to rely on the state's existing colonial administration infrastructures as the RPD sought to increase the number of research subjects. In response to pressure from officials in the DNANR, local administrators across northern Canada agreed to assist in recruiting research subjects by notifying the RPD when Indigenous northerners traveled south to Ottawa.³⁴ To "increase and systematize" the flow of subjects for the body burden studies, officials with the Northern Co-ordination and Research Centre agreed to select and make travel arrangements for potential research subjects.³⁵ Despite the assistance of local officials, the RPD's efforts were largely ineffective, and the division failed to recruit a representative number of research subjects for its Ottawa-based whole-body counting study.

The RPD also sought a technoscientific fix to the problem of numbers. In an effort to increase the number of people undergoing direct body burden measurements, the RPD initiated the construction of a portable whole-body counter. The Canadian institution based its model on a system created by technicians at the AEC's Hanford Laboratory and adopted by scientists and public health officials investigating radioactive exposures in northern Alaska (Bird 1968b; Hanson 1965). Bird argued that access to this device would facilitate the geographical expansion of the monitoring program and enable the RPD to increase the number of people undergoing direct measurements for Cesium-137 body burdens. Although trials began in 1966, this technology was not fully operational and available for extensive testing until 1967 (Bird 1968b; Tracy et al. 1997).

In the absence of this specialized sensing technology, the RPD relied greatly on an indirect method of quantifying Cesium-137 body burdens, which was based on the analysis of urine samples (Mohindra 1967). Unlike the RPD's massive and immobile whole-body counting system, this method offered a geographically expansive approach to monitoring radioactive exposures across northern Canada. Rather than depending on the recruitment of northern research subjects who had traveled south to Ottawa, the RPD asked participating agencies and health practitioners to collect urine samples from people living in communities across northern Canada. Following collection, the samples were transported to the RPD's headquarters in Ottawa, where they were subject to testing and analysis to determine Cesium-137 levels. Between 1964 and 1967, the RPD conducted tests on 562 urine samples collected from people living in 24 northern communities (Tracy et al. 1997, p. 432). In the RPD's laboratories, scientists and technicians employed gamma spectrometric techniques to measure the Cesium-137 content of the urine samples (Mohindra 1967, p. 484).

The RPD categorized urine samples according to the consumption of caribou meat, which officials viewed as a primary risk factor for heightened radioactive exposures. Northern health officials were asked to determine and document the

³⁴ LAC, RG 85, Vol. 2081, File 1003-3-14 (1), 4 March 1965, Correspondence: G.F. Parsons to Director, Northern Administration Branch.

³⁵ LAC, RG 85, Vol. 2081, File 1003-3-14 (1), 25 February 1965, Correspondence: G.F. Parsons to Director, Northern Administration Branch.

“dietary habits” of the individuals who provided urine samples for the research program. In its initial proposal, RPD officials established three “classes of diet,” which they believed to be characteristic of northern Canada. In an outline of the urine sampling program sent to health officials in northern Canada, Peter Bird provided details on the three dietary classifications. They were: “Native (principally caribou, reindeer, moose, etc.); Native (other foods e.g. fish and sea mammal); ‘White’ (principally imported store foods).”³⁶ As the sampling program progressed, the RPD dispensed with the racial division of dietary classes and instead adopted an alphabetical system of classification. In this organization system, diet class A indicated the consumption of relatively large amounts of caribou and reindeer meat, diet class B represented relatively small amounts of caribou, and diet class C represented a “northern diet” that did not include caribou or reindeer meat. For comparative purposes, the RPD included diet class D, which represented an “urban diet in Ottawa, Canada” (Mohindra 1967, p. 483).

Although this method facilitated the spatial expansion of the RPD’s monitoring program, its effectiveness was compromised by scientific uncertainty regarding the relationship between the urinary content of Cesium-137 and radioactive exposure levels. When the RPD adopted this method, scientists and officials believed they could calculate an individual’s radioactive body burden based on the amount of Cesium-137 present in their urine. Underpinning this method of measurement was the assumption that Cesium-137 was excreted in proportion to the amount that was present in the body (Bird 1968b, p. 636). As the study progressed, however, RPD scientists learned that a broad range of poorly understood physiological mechanisms regulated the rate at which individuals metabolized and excreted Cesium-137 (Overton and Quastel 1967; Bird 1968b).

In 1965, the RPD initiated an experimental human radiation study that aimed to clarify the mathematical relationship between urinary Cesium-137 concentrations and radioactive body burdens (Bird 1968b; Overton and Quastel 1967).³⁷ Participants in the experimental study voluntarily ate caribou meat that contained “a relatively high concentration” of Cesium-137, and were then monitored to determine the rate at which the radionuclide was excreted in urine (Overton and Quastel 1967, p. 540). The experimental research program was challenged by the RPD’s inability to recruit study participants. After two years, only two Indigenous northerners and a small number of other volunteers had participated in the experimental study (Bird 1968b, p. 636; Overton and Quastel 1967). Nonetheless, RPD scientists claimed the experimental findings demonstrated that the relationship between urinary excretion and body burdens was not a simple or linear proportionality. Instead, they stated that as Cesium-137 moved through the human body, kidney functions caused daily variations in excretion levels (Overton and Quastel 1967, p. 540).

³⁶ LAC, RG 109, Vol 475, File W1.U. 341, 10 September 1963, Draft Letter: Peter Bird to Regional Superintendents, Northern Health Services.

³⁷ For more on the history of the use of radioactive tracers in health and medical experiments, see Creager (2014); for a specific northern example from Alaska, see Farish (2013).

As officials moved to calculate individual and average body burdens, they cautiously adopted a mathematical formula based on the ICRP's biological data and mathematical models. The formula was based on the assumption that "the amount of cesium 137 in the urine can be taken as a measure of the amount in the body" (Mohindra 1967, p. 486). However, as RPD physicist V.K. Mohindra noted, "precise evaluations cannot be expected" due to the "many factors" that affect the relationship between urinary Cesium-137 concentrations and radioactive body burdens (1967, p. 486).

By 1967, RPD scientists had completed the urine sampling program. Their findings indicated that human exposure levels in northern Canada had peaked in 1965 (Mohindra 1967). Like their counterparts throughout the circumpolar north, Canadian officials observed a correlation between caribou consumption and heightened exposure levels (Mohindra 1967, p. 486). Further, tests indicated that human exposure levels generally followed increases in Cesium-137 concentrations in caribou meat. There was, however, a distinct temporal lag of approximately one year between spikes in caribou and human exposure levels, which scientists attributed to the time that it took for radioactive material to move through the northern food chain (Mohindra et al. 1967). While RPD officials drew a strong connection between caribou consumption and cesium-137 body burdens, they documented geographical variations in radioactive exposure levels. The sampling program's results revealed that body burdens were much higher in the central and eastern Arctic than the western Arctic, where caribou formed an essential part of the local diet. As they had recorded similar levels of fallout at monitoring stations across the region, scientists attributed seasonal and geographic variations in body burdens to fluctuations in the availability of caribou meat and ecological mechanisms they were unable to explain at that time (Mohindra et al. 1967, p. 485).

Did the RPD believe that human exposure levels in communities across northern Canada exceeded the "safe limits," as Pruitt had argued in *The Beaver*? As RPD scientists and officials analyzed urine samples and calculated radioactive exposure levels, they documented only one case in which an individual's recorded Cesium-137 body burden appeared to exceed the threshold values established by the ICRP (Mohindra 1967, p. 488). Based on an observed urinary Cesium-137 concentration of 19,500 picocuries per liter, the RPD estimated that this individual's body burden was 3.2 microcuries (Mohindra 1967, p. 489). This level of exposure, stated V.K. Mohindra, was only "slightly higher" than the ICRP's maximum permissible dose of 3.0 microcuries for any individual member of the population (1967, p. 489). As RPD scientists outlined the results of the urine sampling program, they emphasized that this case represented an outlier: "It is evident," wrote Mohindra, "that the body burdens of the northern residents referred to in this study are generally well below the acceptable level" (1967, p. 489). Based on an examination of the aggregated results, which were classified according to the established dietary classes, the RPD suggested that caribou eaters "can be much more significantly exposed than the average for the rest of the population" (Bird 1968b, p. 638). Nevertheless, officials were confident in their determination that, on average, northern body burdens "correspond to radiation doses well within the dose limit" recommended by the ICRP (Bird 1968b, p. 638). Although Bird (1968b) emphasized the need for further studies, by 1967,

RPD officials had concluded, “[t]here will be no expectation of a significant effect on the health of the population and no necessity to consider restricting the normal consumption of caribou meat” (Mohindra 1967, p. 489).

In 1966, RPD technicians completed the construction of the portable whole-body counting system (Bird 1968b). This specialized sensing technology’s availability enabled the RPD to expand the geographical scale and reach of its direct body burden measurements in northern Canada. Following field trials and calibration tests, a team of scientists from the RPD used a chartered aircraft to transport the counter to communities across the North. Once on the ground, however, the RPD scientists relied on the local availability of snowmobiles, dogsleds, jeeps, and tractors to move the portable system between the plane and community (Tracy et al. 1997, p. 432). During an initial 1966 field survey, the RPD visited nine communities in the eastern Arctic and measured the Cesium-137 body burdens of 260 Inuit (Bird 1968b, p. 637). The following year, the RPD expanded the survey to include communities in the central and western Arctic. By 1969, RPD technicians and scientists had traveled to 41 northern communities and used the portable whole-body counter to measure the Cesium-137 body burdens of approximately 3000 northern residents (Tracy et al. 1997, p. 431). Through the 1967–1969 surveys, the RPD added important geographic detail to its assessment of northern radioactive exposures. The results, however, seemed to confirm the findings produced through the urine sampling program. Although exposure levels recorded for some individuals exceeded or approached the maximum permissible dose for Cesium-137, RPD officials concluded that average body burdens in northern Canada had not exceeded the safe limits (Tracy et al. 1997). Based on these surveys’ results, the RPD suspended the northern monitoring program in 1969 (Tracy et al. 1997).

Conclusion: Locating the Boundaries of the Nuclear North

The detection of radionuclides in the bodies of caribou in northern Canada both demonstrated the global reach of nuclear fallout and revealed the unevenness of toxic relations and radioactive exposures (Masco 2015; Martin 2018; Bocking 2017; Liboiron et al. 2018). Although global monitoring programs indicated that the Arctic environments were subject to lower levels of nuclear fallout, migratory caribou herds throughout northern Canada exhibited significantly higher radioactive contamination levels than grazing animals in more southerly regions. In the early 1960s, a group of Alaskan scientists involved in the US Atomic Energy Commission’s Cape Thompson bioenvironmental studies helped clarify the ecological mechanisms that facilitated radionuclides’ movement through the lichen-caribou-human food chain. In doing so, their work highlighted how local ecological conditions shaped radioactive exposures. The scientific documentation of a distinct northern pathway of exposure heightened concerns among Canadian public health officials about the potential impact that nuclear fallout was having on migratory caribou and Indigenous northerners who consumed contaminated caribou meat. Between 1963 and 1969, Canada’s Radiation Protection Division coordinated a “Special Northern Study,” through

which officials aimed to measure, monitor, and map radioactive exposures across the North. While the RPD emphasized its technoscientific approach to measuring radioactive exposures, the monitoring program's legitimacy was tied to establishing interdepartmental linkages within the federal bureaucracy and connections with members of the country's northern administration. In 1969, the RPD's northern monitoring program was suspended after officials determined that radioactive exposure levels had not exceeded internationally accepted threshold values.

Through its investigation of northern radioactive exposures, the RPD contributed to the production of terms by which northern Canada could be understood as a nonnuclear space. Despite increasing evidence suggesting that the lichen–caribou–human pathway of exposure amplified the bioaccumulation of radionuclides, scientists and public health officials in Canada believed that the resulting body burdens still fell within acceptable levels of exposure to radioactive material. Although average body burdens in northern communities were higher than those documented in southern Canada, the RPD believed that the threshold for radioactive exposures had not been exceeded. During the 1960s, Canada's emerging public health approach to radiation protection was influenced strongly by the increasing importance of nuclear technologies in national and international political and economic systems. In his review of Canada's radiation protection services, Peter Bird claimed that radiation exposure and the possible effects on health "is a subject the discussion of which often generates an emotional rather than an objective response" (1964a, p. 1024). After outlining steps taken by the government to protect the health of radiation workers, Bird argued that the "imposition of unnecessary and unrealistic control measures based on emotional concern about radiation effects could have a serious effect on the medical and technical development of the country" (1964a, p. 1029).

The view that radiological hazards—including those linked to environmental radioactivity—had to be measured against the ostensible social, political, and economic benefits offered by nuclear technological development was echoed in Canada's emergent federal health policy framework. In 1961, the federal government initiated a Royal Commission on Health Services, intended to report on existing facilities and Canadians' future health requirements. In a study prepared for the Royal Commission, Robert Kohn (1967, pp. 75–76) situated radiation exposures among an increasing number of health hazards that stemmed from the anthropogenic alteration of the physical environment. Although Kohn acknowledged scientific uncertainty surrounding the biological and genetic effects of low-dose radioactive exposures, he was careful to interpret the risks in relation to the benefits derived from nuclear technologies: "Here, as with other advances of the human race, it may be unrealistic to expect that the vast benefits of nuclear energy and radiology can be reaped entirely without sacrifice, but such sacrifice must be kept to the minimum which our knowledge permits us to reach" (1967, p. 95). For Kohn, the ICRP's development of threshold values and the RPD's efforts to mitigate radioactive exposures in Canada were essential developments in national and international efforts to assess and control radiation hazards (1967, p. 93). However, as suggested by my examination of northern nuclearity's contested boundaries, the radiological risks engendered by the onset of the atomic age were distributed unevenly and shaped profoundly by local ecological relationships.

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The Visual Politics of Maralinga: Experiences, (Re)presentations, and Vulnerabilities

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Accepted: 4 February 2021 / Published online: 31 March 2021

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Abstract

Visual cultures are being increasingly discussed in the history of science literature, although relatively very little of that work concerns the nuclear age. In addition, within the discrete yet burgeoning literature on global nuclear art and culture, Oceania is often overlooked despite its central role in the development of the American, British, and French nuclear weapon capabilities, as well as their associated colonial legacies. This article serves to redress both concerns by examining the visual politics of Maralinga in relation to settler-colonial and Aboriginal experiences, vulnerabilities and (re)presentations. I do so by surveying artworks with a connection to the Australian experience of nuclear colonialism and find that the figure of biological life has been conspicuously left absent from contemporary non-Indigenous Australian depictions of British nuclear testing in Australia.

Keywords Nuclear harm · Visual nuclear politics · Oceania · Antipodean nuclear art · Nuclear humanities

Introduction

The first foreign journalist to visit Hiroshima following the nuclear attack of August 6, 1945 was an Australian. Writing from Ground Zero, Burchett (1945) described a city that “looks as if a monster steamroller had passed over it and squashed it out of existence.” Published in *The Daily Express* of London on September 5, Burchett’s dispatch was syndicated internationally, eleven months before Hersey’s (1946) classic essay was published in *The New Yorker*. However, Burchett’s critical insight derives not from its speed of circulation (coming as it did a month after the attacks)

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but its enduring incisiveness. In it, Burchett described how the nuclear attack left “nothing standing,” such that, if “you look around ... for 25, perhaps 30, square miles you can hardly see a building.” To introduce nuclear harms as different-in-kind to his audience, Burchett made special mention of the “uncanny after-effects” of nuclear weapons on the human body, whereby “people are still dying—mysteriously and horribly—from an unknown something which I can only describe as atomic plague.”¹ Thus, for Burchett, the problem of nuclear harm was such that “[t]he damage is far greater than photographs can show.” Burchett’s insight derives not merely from the fact that irradiation is a process that humans have no sense of—we cannot see it, smell it, feel it, or touch it. Rather, it is because Burchett intuitively understood that Hiroshima’s aftermath was itself an event that had yet to unfurl fully. Burchett’s account was widely influential in constructing the nuclear narrative in the immediate term—not only on the Australian continent, but also internationally (see Burchett 1983).

Despite the invisibility of radiation, as first popularised by Burchett, the nuclear age has yielded a vibrant visual culture. The visual arts are particularly rich sources of how observers conceived of radiation exposure. They explicitly portrayed the violation of biological life—namely, the human body—thus making visible the otherwise invisibility of irradiation processes. Indeed, soon after the first report filtered in from Hiroshima, artists living and working in Australia began visualizing the problem of nuclear harm. Initially, these artistic representations responded exclusively to world news media dispatches from Ground Zero. However, by 1946, Australian artists, such as Reginald Rowed and Albert Tucker, were traveling to Hiroshima to witness Burchett’s “atomic plague” for themselves. While those early artistic representations of Hiroshima visualized a city devoid of biotic life, as Burchett and others had described, as artists began visiting Hiroshima, they began profiling individual human suffering of atomic survivors (*hibakusha*). However, when Britain began nuclear testing in Australia on the Monte Bello Islands off the coast in Western Australia in 1952—and later at Emu Field and Maralinga in central South Australia through 1963—many of these very same artists retreated instead to the landscape to capture the spectacle of the mushroom cloud, albeit removed at a distance. Maralinga, with all the harm and damage inflicted there, was reduced to a mere motif.

In this article, I argue that, while depictions of Hiroshima and Nagasaki revealed artists’ willingness to confront the violation of biological life, white-settler representations of British nuclear colonialism in Australia tended to render invisible the figure of biological life, in contrast to various Aboriginal representations that emerged in 1990. Oceania, however, remains largely neglected within global nuclear art history, as it is in broader environmental histories (see McNeill 1994; Rapaport 1999; Garden 2005; D’Arcy 2012; Lobban et al. 2014). Perspectives from Oceania have been relatively underexplored in the nuclear culture literature, despite occupying a central role in the development of the American, British, and French nuclear

¹ Burchett’s is, without question, the earliest use of the term *uncanny* in relation to the emergence of nuclear harms, although it is Joseph Masco’s more thoroughgoing theorization of the term that has subsequently gained greater currency in the literature (2006, pp. 27–34).

capability between 1945 and 1992. Oceania is both a platform and site of nuclear violation, yet its unique perspective seldom circulates in the nuclear literature. To redress this neglect, I have developed the notion of *Antipodean* nuclear art as vehemently oppositional to the dominant Anglo-American narratives (Taylor 2017a, b, 2018), of which artistic representations of British nuclear colonialism at Maralinga, as well as on the Monte Bello Islands and at Emu Fields, are merely a part. For instance, it might be said that such depictions are consistent with the critique of the white-settler colonial narrative, which tends to position the Australian landscape as untrammelled, wild, or uncivilized rather than shaped and in active kinship with first-nations cultures. In short, my proposal for an *Antipodean* nuclear art derives from the related claim that people from the Antipodes—by which I mean Australia as well as Melanesia, Micronesia, and Polynesia—offer a unique perspective on the relationship between human and nonhuman beings, and the earth they inhabit, due in large part to their geographical location in the Southern Hemisphere.²

This essay is structured as follows. First, in arguing for the importance of Australian experiences of radiation exposure, I offer a political framework for understanding the processes of (in)visibility and (re)presentation. Second, I retrace how the emergence of nuclear harms after Hiroshima was (re)presented by Australian settler-colonial artists as foregrounding the figure of biological life. In the third—and final—section, I turn to (re)presentations of British nuclear colonialism at Monte Bello, Emu Fields, and Maralinga in Australia. I suggest that settler-colonial artists tended to background nuclear harms as a mere motif, whereas Aboriginal artists from 1990 more directly addressed the impact of British nuclear colonialism on Aboriginal people, lands, and waters. In so doing, in the conclusion, I come to speculate about what examining the irradiation of biological life in Antipodean nuclear art might mean for broader efforts of story(telling) about the exposure of nuclear radiation internationally.

Experiences: Oceania in the Nuclear Age

The first nuclear weapon test “in peacetime” occurred when the Americans conducted a series of tests as part of Operation Crossroads at Bikini Atoll in 1946. Over a fifty-year period, Oceania was subjected to three hundred and fifteen nuclear weapon tests and other forms of radiological experimentation by the Americans, British, and French, including the world’s first thermonuclear test. Despite the enduring legacy of American, British, and French nuclear colonialism in the Pacific, it is common to frame such nuclear weapons testing as mere “non-use.” For instance, in 2008, Thomas C. Schelling, a theorist of nuclear strategy and co-recipient of the 2005 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, remarked that it was “sixty-two and a half years since the second, and last, nuclear weapon exploded in anger, above a Japanese city” (2008, p. xv). In this way, the

² For a partial exposition of this argument within the context of a broader nuclear art history, see Taylor (2018).

appellation of “use” appears to be confined to cases where hostilities between enemies provide the context to nuclear events and that the harm inflicted is conceived in purely human-centered terms. That is to say, that nuclear testing is anthropocentrically framed as “non-use.”

This article problematizes this notion of “non-use” by exploring the violation, not only to the human body and the biosphere on which all life depends, but also to the very cultures with which meaning between each is transmitted. In this way, the task is to open up what is considered violated to the more broad category of Oceanic cultures. Oceania is particularly interesting and important as a study site since it remains home to the world’s oldest continuous cultures within the world’s largest Ocean, which spans one-third of the planet. While many of the tests had the full consent of local governments, as in Australia’s case, in no instance had any nuclear weapons state entered into respectful dialogue with the Indigenous custodians whose peoples and ancestors maintain both ancient yet continuous connections to its now irradiated lands and waters.

As a direct response to this nuclear colonial history, Oceania was one of the first regions to denuclearize comprehensively in 1986 and is home to the world’s first state-level nuclear-free zone, New Zealand, in 1987. Oceania is thus singularly important in that it has both forgone nuclear weapons (through its regional treaty obligations) and nuclear energy (both unilaterally and voluntarily). Specifically, I want to argue that the hyper-separation of humans from nature that underpins the nefarious non-use claim I outlined earlier is increasingly being broken down by Oceanic visual cultures, specifically through Indigenous representations and more broadly via immersive technologies.

However, the problem of nuclear harm is notoriously challenging to visualize. Vexingly, nuclear radiation is a form of energy for which people have no sense. Until, that is, the aftermath explicates a violation. Indeed, as Masco states in *The Nuclear Borderlands* (2006, p. 28): “The nuclear uncanny exists in the material effects, psychic tension, and sensory confusion produced by nuclear weapons and radioactive materials.” Drawing this idea of the (in)visibility of nuclear harms into dialogue with contemporary fine and community arts, the leading contemporary curators of nuclear culture, Ele Carpenter, has pointed out that “the ‘invisibility’ of radiation is a political project as well as an optical deficit” (2017, p. 15; see also Decamous 2018). Despite this, in the major global survey of documentary and creative photography on the nuclear age, art curator and theorist John O’Brian provocatively claims:

Wherever nuclear events occur, photographers are present. They are there notably to record what happens, but also to assist in the production of what happens. ... The camera’s prosthetic eye possesses the power of deferred sight, the uncanny ability to make visible after an event what could not be seen at the time. (O’Brian 2014, p. 11)

In this way, the imperceptible and invisible can be made perceptible and therefore visible, or at least what Akira Mizuta Lippit (2005) terms *avisual*, by which he means “the profoundly unseen.” That is to say, outside of our ordinary senses, radiation and nuclear harms can be rendered visible very precisely and accurately

through the mediated technology of Geiger counters and other instruments. Indeed, while the nuclear Anthropocene concept may appear abstract at the biospheric spatial scale and in geological units of time, creative works offer additional material evidence of radiation; namely, of how it has been internalized in our individual and collective consciousness.

Focusing on the ways nuclear harms are differentially experienced, (re)presented, and made vulnerable informs the broader field of visual global politics. For instance, many of the leading proponents of "the visual turn" in international relations (IR), such as Roland Bleiker, tend to amplify the role of "speed" and "circulation"—and the resultant "democratization" of global politics—in laying bare their arguments for why images and visual artifacts should and do matter. Building upon this work, what is essential concerning the problem of nuclear harm is instead the "slowness, not speed" and "stickiness, not circulation." By slowness (as opposed to speed), I mean that, while, certainly, images continue to proliferate via the Internet and other networks, as Bleiker and others describe, to perform a study into nuclear visuality I need something more like Rob Nixon's notion of "slow violence" or Derrida's muddled notion of "nuclear speed" to account for how nuclear harms unfurl and tangle humans with multitudes of non-human others over long periods. By stickiness (rather than circulation), I mean that, rather than images serving to democratize politics as Bleiker and others reasonably claim, the nuclear imaginary has proven largely immovable, if not diminished, in the public consciousness. In particular, the content of American, British, and French visual cultures has mainly remained unchanged on the question of Oceanic nuclear testing. That is to say, the mushroom cloud motif lingers on the horizon as a specter of human life's fragility, just as it did from the very first moment nuclear weapons were tested in the Pacific in 1946.

(Re)presentations: Foregrounding the Human at Hiroshima

Australian artists were among the first to confront the violation of biological life that took place at Hiroshima and Nagasaki, including the possibility of nuclear ends to human life on earth.³ However, the figure of biological life was not always present in Australian artistic representations of the nuclear attacks on Japan. Notably, the earliest known nuclear artwork by an Australian, James Cant's *The Bomb* (1945), depicted the human artifice of a city empty of all life. Cant's nuclear

³ The literature is analyzed most fully by James (1993), Mittmann (2016), and myself (Taylor 2018). While the emphasis of James's exhibition concerns the universal question of nuclear vulnerability in the post-Hiroshima world up until 1990, Mittmann's curatorial focus is loosely focused on British nuclear colonialism at Monte Bello, Emu, and Maralinga produced up until 2017. Earlier shows include exhibitions of nuclear art that have appeared in many forums—from curated exhibitions, items held in private and public collections, to solo shows by artists exploring nuclear themes. For instance, in 1976 there was an exhibition of nuclear works at the Sydney Opera House, followed by the anti-nuclear activist shows *Uranium—Artists Speak* in 1978, and the *Artists for Peace* exhibition in 1982. More recently, Linda Williams curated a group show entitled *Japanese Art After Fukushima: Return of Godzilla* at the RMIT Gallery in 2015, and Kate Downhill was the subject of a retrospective exhibition, *Chain Reaction*, at Macquarie University Art Gallery in 2013.

imaginary contrasts markedly with reports filtering out of post-war Hiroshima by Burchett and others, which described a completely decimated city.

The first Australian artist to visit Ground Zero was the official war artist Reginald Rowed, who arrived in Japan in 1946 to paint the city of Hiroshima being rebuilt, yet devoid of organic life. Rowed's *Rebuilding Hiroshima* afforded a prominence to the now-familiar silhouette of the "dome," or Hiroshima Exhibition Hall, which has come to stand-in as a symbol of defiant peace (1946a, b). The modernist painter Albert Tucker was the first to confront the subject of individual suffering in Hiroshima by foregrounding an orphaned child survivor—or *hibakusha*—amidst the now-familiar image of a leveled city (1947). Although situating the human at the center of the painting, it is arguably the charred tree, foreboding sky, and green and brown hues of the Earth that take center stage. Through this image, organic and human life in postwar Hiroshima are depicted for the first time by an Australian artist. Perhaps it is worth noting that Tucker intended to fund his trip by selling prints to the world news media, but also planned to produce a series of larger, modernist compositions (Heathcote 2012, p. 78). Tucker failed to deliver on either aim and instead turned to the medium of (and mediation afforded by) photography. Heathcote alleges that he was commissioned to deliver "publishable illustrations" of subjects such as Ground Zero, the bodies and suffering of various *hibakusha*, and the many able-bodied who were returning to their ruined city. The idea has circulated that Tucker experienced something altogether different at Hiroshima, or somewhat exhausted the subject of human suffering that was at the heart of his earlier series, *Images of Modern Evil*, and so confronted instead the damage done to (inanimate) objects such as buildings and machines, as well as a barren landscape.

More obliquely, both John Perceval and Sidney Nolan exhibited works that confronted the violation of biological life in Hiroshima. John Perceval's *Homage for Lawrence Hargrave* (1960) reconstructs post-Hiroshima existence. At the center is the "splitting of the atom" by way of strewn faces and limbs. Flight—into space—is seen as one of the only hopes for survival, yet at the top left is a baby severed of the umbilical cord from its mother, in the top right. Overlooking all this is the man-of-flight, Sir Lawrence Hargrave, one of Australia's most eminent men—astronomer, inventor, and aviator. Out of sight here is the sun—in peace—in stark opposition to the violence surrounding Earth. Breaking out of the confines of the modernist movement, Sidney Nolan returned to his earlier *Boy and Moon* (1940) series by (re) configuring the mushroom cloud of an atomic test with the human head reminiscent of Dali's *Three Sphinxes for Bikini Atoll* (1947). In Nolan's *Untitled (Moonboy and Atom Blast)* (1974), however, the human figure is depicted as an earthen mushroom cloud with two figures on horseback—perhaps the ill-fated explorers white-settler colonialists, Robert O'Hara Burke and William John Wills—in harm's way.

Vulnerabilities: Maralinga as Motif and Embodied

When the subject of British nuclear testing did first appear in Australian art, several of these same male modernist painters consigned the notion of nuclear colonialism to the background as a mere motif. In part, this is explained by a combination of

ignorance, apathy, and poor media reporting that withheld news of what has transpired at Monte Bello, Emu, and Maralinga until a series of investigative reports and revelations from whistleblowers in the 1970s. Most notably in this regard, Sidney Nolan completed his lauded *Central Desert* series (1952) in Melbourne, Australia, although later added a mushroom cloud in the background of one painting in 1957 after he had attended one of the earliest Campaign for Nuclear Disarmament rallies in London.⁴ To extend the irony of importing a nuclear imaginary into the Australian landscape further, Mittmann contends that the work was not publicly shown until almost by accident in 2001 (2016, p. 41).

Arthur Boyd similarly incorporated the mushroom cloud into two works from his *Shoalhaven* series. However, both James and Mittmann make no more than a passing reference to the way(s) in which Boyd conceives of the nuclear. Boyd's first painting, *Jonah Outside the City* (1976), imposes Biblical themes onto the Australian landscape, as if British nuclear testing has wreaked evil on Earth. Whereas Boyd's later work, *Picture on the Wall, Shoalhaven* (1979), juxtaposes two images side-by-side: a painting on a wall of an almost identical scene framed through a doorway. The juxtaposition arises from Boyd's inclusion of a mushroom cloud in the painting absent from the representation of the landscape outside. From an Antipodean point of view, two readings of Boyd's work are possible. On one reading, the painting on the wall—and the viewer—is positioned internally to what may only be glimpsed externally. In this way, what is positioned outside affirms a distance between the external world and the painter and the imagined scene and the actual one. Alternatively, another reading points to the invisibility of past nuclear harms, but also their arrival in new, previously unimagined contexts. In this view, the inference of importing a nuclear imaginary into his *Shoalhaven* series for Boyd's largely non-indigenous audience was that nuclear harm could be inflicted here too—to non-indigenous Australians! Thus, despite the apparent need to intrude Oceanic perspectives into the literatures of global nuclear culture, the central theme of both James's and Mittmann's formalization of the category of Australian nuclear art is an introspection towards other worlds—and knowledges—of nuclear culture.⁵

More recently, we have seen the emergence of experiential and immersive nuclear knowledges, including developing increasingly accessible augmented and virtual reality technologies that foreground the human. Two Aboriginal artists, Lin Onus and Jonathan Kumintjarra Brown, are among the precursors to this experiential and immersive approach to nuclear representations of the problem of nuclear harm. The first known aboriginal work to appear in the public domain on British nuclear colonialism also marks a critical juncture in Antipodean nuclear art. Lin Onus's *Maralinga* (1990) sculpture does not portray a mother and child in the moment of incineration, but, rather, the enduring harm inflicted upon them by the blast wave that

⁴ It must be noted that, at the same time, Nolan painted *The Galaxy* (1957), which has variously been said either to represent the inside of an atom or the threat of nuclear war.

⁵ Additionally, almost all of the major works conceptualize themselves around the Cold War, and with this comes an emphasis on certain states and peoples at the exclusion or marginalization of others (see Taylor and Jacobs eds. 2017).

reaches out for kilometers after a nuclear device is detonated on their lands.⁶ Thus, the explosion itself is absent from Onus's experiential sculpture, replaced instead by the trefoil radiation warning standard, which dances in front of the pair, in the British colors of red, white, and blue, as if in a double-torment. In this way, Onus's character suffers because of forces carried on the wind, such that the human cost of nuclear weapons—whether in warfare or testing—is entwined with ecological ones. In my view, such artworks present a critical juncture in nuclear art history, whereby the mutual implication and co-constitution of humans and nature are affirmed.

Onus's sculpture is also a political statement against the suffering inflicted upon indigenous Australians under British (nuclear) colonial rule. It renders visible the invisibility of nuclear harm and reiterates the irrevocable connection between people and the land violated at Maralinga. Kumintjarra Brown (1992, 1995, 1996) was mentored by Lin Onus and inspired by his family history. Brown, a victim of the Stolen Generation—whereby babies and children were forcibly removed from their families and communities, thereby (and mortally) severing their connections to the country—painted Maralinga as someone divorced from connection to his people and land. He was later to learn that they were themselves violated by the British atomic tests at Maralinga (see Brown 1992). Brown's is, therefore, a double tragedy. In *Black Mist* (1995), Brown recalls the tragic story of the Milpuddie family, who were found to be camping at a contaminated above-ground nuclear test site at Maralinga and suffered horrific health issues, including the death and disfigurement of several children and the inter-generational trauma produced by the forced removal from their land, as a result (see McLelland 1985, vol. 1, pp. 302, 319–322, vol. 2, p. 613; Yalata and Oak Valley Communities with Mattingley 2009, pp. 44–45). Following the work of Onus and Brown, the Nuclear Future Partnership Initiative and Mittmann's *Black Mist Burnt Country* touring exhibition evidence a vibrant contemporary interest by aboriginal artists in the subject of British nuclear colonialism.

Two of the most ambitious recent works have been carried out by the aboriginal artist Scarce (2015) and senior men from across the Anangu Pitjantjatjara Yankunytjatjara lands (Baker et al. 2017). Both immersive installations have appeared at the biannual Tarnanthi Festival in Adelaide, Australia, curated since 2015 by Nici Cumpston.⁷ Although Scarce's artist practice has long employed the medium of glass to explore the impact of colonialization on Aboriginal people in some way, the relevance of firing sand to produce her work is heightened concerning British nuclear weapons testing on her grandfather's country at Maralinga. Scarce's *Thunder Raining Poison* (2015) consists of 2000 hand-blown glass yams (a vital food stuff for desert peoples) suspended from the gallery ceiling.

Similarly, a group led by senior men from the Anangu Pitjantjatjara Yankunytjatjara Lands have transformed a crucial link to their country—this time the cultural

⁶ Critically, there is also a gender narrative at play in Onus's work too, which led Ariel Salleh to deploy a photograph of Onus's *Maralinga* sculpture on the front cover of her classic eco-feminist monograph (1997). Nowhere in that volume does Salleh unpack the meaning behind the pairing, however, nor the (in)compatibility of aboriginal and settler-colonial worldviews.

⁷ *Tarnanthi* means to come forth or appear.

practice of spear making—into an immersive artwork (see Baker et al. 2017). Also suspended from the gallery ceiling, *Kulata Tjuta* (meaning many spears) is made up of 550 spears, representing the moment of detonation of one of the nuclear weapons tests inflicted upon the ancestors of the group and their land at Emu Junction and Maralinga. By inserting a light inside the installation, pointed shadows spill out onto the gallery walls, floor, and ceiling, thereby expanding the work ever outwards—not as “an explosion frozen in time,” as many have said, but rather the representation of a past nuclear event that has forever violated what was once whole. In this way, the light serves a double purpose: first, to activate the spears as a detonation and, second, to afford a temporal quality to the work. Positioned on the floor are several dozen hand-carved piti (wooden bowls) carved by local women in an act of intra-group cooperation as well as an offering of life-giving stuff in the face of otherwise hopeless adversity. *Kulata Tjuta* derives out of a larger, ongoing project of cultural maintenance in which individual members of the Anangu community learn the craft of spear making through workshops.

Among the significant outputs of the Nuclear Futures Partnership Initiative, a three-year community arts project sponsored by the Australia Council for the Arts, are two immersive films, *10 Minutes to Midnight* (2015) and *Ngurini (Searching)* (2015), which were designed as 360° projection installations intended to be screened on 8-m diameter cylindrical screens to immerse the viewer (see Barkley et al. 2018). Doing so has the effect of implicating the viewer in the film, centrally positioned within the storyscape of sound and moving image, and—by way of the shadows cast by other participants all around you—you are left asking, “in what ways might I be implicated in this story too?” Both films follow in a tradition of community arts projects with nuclear survivors in Australia, starting with Lance Atkinson’s efforts in the late 1990s, culminating in an exhibition at the 2002 Adelaide Festival. The films deal with themes of forced migration and intergenerational impact for indigenous communities and the grotesque experimentation and exposure of service personnel and civilians during British testing.

10 Minutes to Midnight was developed with the nuclear veteran and service personnel communities who are also among the victims of British nuclear colonialism. The Nuclear Futures project sought to document the nuclear knowledge of the Australian veteran-turned-whistleblower Avon Hudson and his family (see Cross and Hudson 2006). It arose from the eighteen-month Nuclear Futures Partnership Initiative residency at Balaklava, in South Australia. Also involved were the British veterans involved in Charles Stewart’s documentary film, *Nobody Told Us Anything* (2014). Therefore, Nuclear Futures sits on a trajectory of work dating back to the 2002 Adelaide Festival that included Alphaville’s *Half a Life* project (2003–2007), which involved forty-five nuclear veteran families in Britain and Australia (see P. Brown 2006a, b). As a companion piece to *10 minutes to Midnight*, the film *Ngurini (Searching)* tells the Anangu story of forced migration in South Australia’s Far West. It is another immersive output of the Nuclear Futures Partnership Initiative. *Ngurini (Searching)* demanded sustained dialogue with the aboriginal atomic survivor community that continues to experience impacts of nuclear testing at Maralinga by way of intergenerational health effects as well as the continued dislocation from their ancestral land. Produced in consultation with Yalata community elders, including

Russell Bryant, Mima Smart, and Keith Peters, *Ngurini (Searching)* serves to resituate the audience, not in the moment of the blast as James and Mittmann have read Onus's work to have done, but in the contemporary aftermath.

The explanatory value of these two immersive installations, *10 Minutes to Midnight* and *Ngurini (Searching)*, is perhaps best illustrated in relation to another contemporary work produced outside of the Nuclear Futures program, Wallworth's (2016) virtual reality film *Collisions*. In *Collisions*, the reviewer is transformed by mobile phone technology into an autonomous participant in what Wallworth terms an "encounter" with not only an indigenous survivor of British nuclear testing, the Martu man Nyarri Nyarri Morgan, but also with the aboriginal connection to place.⁸ For instance, when Morgan is shown "painting with fire" in an effort to tend to his people's land for the next 100 generations to come, we are reminded not only of the irresponsibility of British nuclear testing and Australia's championing of it, but also of the possibility of intergenerational responsibility. However, the virtual reality medium—which requires goggles and headphones to be worn by each participant—renders the viewer wholly isolated in their experience, or encounter, with the work. Only after the film is over, and the goggles and headphones are removed, does the audience become one. Although based on older technology, the immersive installations *10 Minutes to Midnight* and *Ngurini (Searching)* position the audience together within the work such that at any one point in time, the silhouettes of several members of the audience obstruct another viewer's experience of the film. In this way, the three immersive artworks employ technology—not to stage mere "encounters," but rather to explicate the mutual implication and connectedness of atomic survivors' experience in our own lived experience.

Conclusion

This article set out to do two things. First, it sought to highlight the (in)visibility of biological life—both human and non-human—in works of nuclear art originating from Australia. The experience of nuclear colonialism in Australia was as differentiated as it was far-reaching. Just as the scientific effect of nuclear weapons is distinct from other forms of explosions by way of radiation, the radiation that results from nuclear weapons detonations—whether in warfare or peacetime—follows two distinct pathways: first, *external* radiation from direct exposure to gamma rays (in the blast zone) and, second, *internal* radiation, from indirect exposure to radioactive particulates, including beta and alpha emitters (through air and water intake). Aboriginal peoples at Maralinga, for instance, were exposed both to external and internal radiation. In contrast, at least some attempt was made to protect Australian and British service personnel from such exposures.

Meanwhile, thousands of kilometers away from Maralinga, the vast proportion of white-settler colonial society, living on the East Coast of the Australian

⁸ *Collisions* is one among a series of films that Wallworth has made with the Martu people, which is well documented and analyzed by Rey (2016).

continent, were neither significantly vulnerable nor sufficiently aware of either. This scientific fact points to the production of distinct vulnerabilities to, and experiences of, nuclear harm. Because these vulnerabilities and experiences differ most starkly between atomic survivors and communities and those who are not, this paper intended to shine some light on the contrast between the (re)presentations that arise from these two particular sites of nuclear knowledge. Therefore, the task is not to perform a comprehensive nuclear art history of the Antipodes, but rather, more specifically, to examine how biological life featured in the nuclear imaginaries of artists from the time of the nuclear attacks on Hiroshima and Nagasaki. Second, the article sought to remedy the (in)visibility of Oceanic nuclear art. I argue that the need for such a move arose because the clear majority of the nuclear literature was written from either a superpower or else a Eurocentric perspective. Although an Antipodean stance—by which I mean perspectives from Oceania, consisting of Micronesia, Melanesia, and Polynesia—should have no bearing on the morality of the matter, in this paper, I make the case that such Antipodean perspectives on the nuclear age are highly politically relevant.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Let Chromosomes Speak: The Cytogenetics Project at the Atomic Bomb Casualty Commission (ABCC)

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Accepted: 30 January 2021 / Published online: 31 March 2021

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Abstract

Hibakusha (atomic bomb survivors) are “witnesses” of the atomic bombings, not just in a standard sense but also in the instrumental sense. For medical and scientific experts, *hibakusha* are biological resources of unparalleled scientific value. Over the past seventy years, the *hibakusha* bodies have narrated what it means to be exposed to radiation. In this paper, I explore studies at the Atomic Bomb Casualty Commission (ABCC) that examined *hibakusha* bodies as sites where risk could be read. I focus on a period from the mid-1950s to 1975, during which new methods, practices, and technologies allowed ABCC scientists to investigate chromosomes as a way to study radiation exposure and human risk. By focusing on chromosomal aberrations, ABCC scientists connected their work directly to the emerging infrastructure for radiobiology at the time. ABCC administrators actively sought out such prestige, especially given their relationship with the Atomic Energy Commission (AEC). The shift in approach would also alleviate some public relations problems with which the institution was struggling. Launching a cytogenetics program required some older practices that had assumed American privilege and dominance to be abandoned. Eventually, the decision to let chromosomes speak of radiation exposure brought about fundamental changes in ABCC, which came to symbolize the model for future studies at the organization, especially as ABCC was transitioning to a US-Japan binational organization. More broadly, this case highlights the intricate scientific negotiation of radiation risk where uncertainties necessarily prevail.

Keywords Atomic Bomb Casualty Commission (ABCC) · *Hibakusha* · Cytogenetics · Chromosomes · Radiation risk

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Introduction: *Hibakusha* as “Witnesses”

On August 6, 1945, the United States dropped an atomic bomb on Hiroshima. The uranium gun-type bomb, nicknamed Little Boy, exploded with approximately 15 kilotons of force above the city of 350,000. The bomb caused a shockwave of destruction and a fireball with temperatures as hot as the sun. Three days later, the United States dropped another bomb, a plutonium-implosion bomb referred to as Fat Man, on Nagasaki, home to an estimated 250,000 at the time. The bombs devastated the areas. Anything that remained was burned to ashes. The two cities “disappeared,” as some survivors recall, together with tens of thousands of people. It is estimated that, due to these bombings, 140,000 people in Hiroshima and 70,000 in Nagasaki died by the end of 1945.

These numbers, and the breathtaking destruction they represent, often obscure the existence of survivors, known as *hibakusha*.¹ Contrary to the assumptions made by American scientists prior to the bombings, hundreds of thousands of people survived the atomic explosion. They became the first and the largest population to survive radiation exposure of an unprecedented scale and intensity.

In the words of a *hibakusha*, they are witnesses to “hell on earth.”² As Robert Lifton powerfully described, the voices of these sufferers elucidate “an extraordinary immersion in death, lasting imagery of fear surrounding the possibility of radiation aftereffects, and lifelong struggle to integrate the event and its elaborate web of psychic consequences” (1967, p. 6). *Hibakusha* therefore serve as “moral witnesses” (Margalit 2002, p. 182). Their experiences speak to the human costs of what Nobel Laureate Joseph Rotblat (1995) referred to as “a mortal danger to humanity created by science.” Indeed, in the peace and anti-nuclear movement since 1945, and particularly since the *Lucky Dragon* incident in 1954, *hibakusha* as witnesses have served as powerful tools of emotional mobilization (Zwigenberg 2014, pp. 64–93; Braw 1991; Yoneyama 1999).

For scientists and medical experts, *hibakusha* are not only witnesses in the standard sense—as human subjects who speak—but also in the instrumental sense. Over the past seventy years, *hibakusha* bodies have narrated what it means to be exposed to radiation (Hiroiwa 2018, pp. 29–156). Many *hibakusha* developed acute radiation syndromes immediately following the atomic bombings. A leukemia epidemic followed a decade later. Several doctors in Hiroshima and Nagasaki have likened these bodies to “time bombs,” suggesting the unknown and precarious nature of radiation effects on human biology (NHK 2013). Instances of cancer continued to

¹ Literally “bomb-affected people.” The term *atomic-bomb survivors* is often employed as the English translation for *hibakusha*. However, the original term *hibakusha* does not carry the connotation of heroism that may be implied in the term *survivor*. As such, *hibakusha* will be used throughout this paper to refer to those who experienced and were exposed to radiation through the atomic bombings of Hiroshima and Nagasaki.

² Testimony by Fujimori Toshiki, Assistant Secretary General of Nihon Hidankyo (Japan Confederation of Atomic and Hydrogen Bomb Sufferers Organizations) at the United Nations conference to negotiate a legally binding instrument to prohibit nuclear weapons, leading towards their total elimination, New York, 27 March 2017. <https://futureoflife.org/2017/03/29/testimony-fujimori-toshiki-hiroshima-survivor/>

increase after the 1960s. Most recently, myelodysplastic syndromes (MDS) induced by atomic radiation have been found among *hibakusha*, whose average age is now over 83. These are all stories of radiation exposure that bodies of *hibakusha* have revealed and continue to reveal. *Hibakusha* are biological resources of unparalleled scientific value.

The United States was quick to seize this unique scientific opportunity in the immediate aftermath of the bombs. With their own ambitious plan to further expand their nuclear arsenal, the US military was convinced that knowledge gained from *hibakusha* would be relevant to any radiation risk situation in the atomic age. After the Presidential Directive of November 26, 1946, the National Academy of Sciences (NAS), via its operating arm, the National Research Council (NRC), established the Atomic Bomb Casualty Commission (ABCC) in Hiroshima. ABCC's aim was to study the biological and medical effects of radiation, using *hibakusha* as subjects. The very first laboratory was set up in retired train coaches until ABCC rented a portion of the Hiroshima Red Cross Hospital to more formally establish the institution (Lindee 1994; Beatty 1993; Nagasawa 2015).³ Since then, ABCC scientists and physicians have worked to extract, interpret, read, and analyze the stories of radiation exposure that these witnesses reveal.⁴

In this article, I focus on a specific period in the history of ABCC, from the mid-1950s to 1975. During this period, specific biological materials—chromosomes—became an important focus of radiation research at the institution. Centering its analysis on chromosomes had the advantage of shifting ABCC's work from a strictly clinical endeavor to one focused on laboratory science. This move to the lab held promises that no earlier efforts at ABCC could realize. As chromosome aberrations increasingly gained prominence as the *lingua franca* of the atomic age, introducing cytogenetics at ABCC had the potential to connect the work of ABCC scientists directly to cutting-edge research in radiation genetics and human cytogenetics. Those who administered ABCC actively sought out such prestige, especially given the institution's strained relationship with its sponsor, the Atomic Energy Commission (AEC); the AEC was raising questions about the value of ABCC and seeking ways to lessen its financial contribution (Putnam 1998; Lindee 1998). Meanwhile, the shift in approach would also alleviate some of ABCC's public relations problems in Japan.

Launching a cytogenetics program required that some older practices, which presumed American privilege and dominance, be abandoned. As the cytogenetics program crystallized, ABCC administrators reconsidered the ad hoc nature of American staff, while also seeking more cooperation with Japanese institutions. Eventually, the decision to let chromosomes speak of radiation exposure created fundamental

³ For a broader and more extensive exploration of how postwar radiobiology came to serve the interests of the Cold War state, see Kraft (2009), especially pp.183–189.

⁴ This article is part of a larger dissertation project on ABCC's work on dosimetry, tentatively entitled "Reconstructing the 60s: The Development of Atomic-bomb Dosimetry Systems, 1945–2002." In my project, I examine the role of *hibakusha* as witnesses from different angles.

changes in ABCC.⁵ As chromosomes gained more prominence, so did Japanese scientists. These changes ultimately came to symbolize the model for future studies at the organization, especially as ABCC was transitioning to a US-Japan binational organization in 1975.

Susan Lindee has demonstrated that bodies and body parts were highly managed at ABCC, like many other bodily materials in twentieth-century biomedicine. *Hibakusha* bodies were made into “natural objects”—“a particular kind of nature, of that subset of nature that can serve as legitimate evidence in a specialized formal text, a scientific paper” (Lindee 1998, pp. 377–378). I build on her work to argue that chromosomes became perfect biological materials to function as “natural data points” for radiation research, especially given the changed scale of radiation hazards in the atomic era. Further, Joanna Radin has examined how human geneticists and biological anthropologists in the 1960s and 1970s studied and preserved indigenous body parts, believing that the bodies contained a latent or untapped archive of human evolution. Following Radin’s work, I attend to the many ways in which ABCC scientists used *hibakusha* bodies as “portals to the past” and illustrate how *hibakusha* chromosomes, in particular, came to symbolize a static, unchanging archive of radiation history (2013, p. 487).

At the same time, it is important to recognize the capacity of bodies and bodily materials to affect and to be affected, and resist the temptation to reify the archival nature of the *hibakusha* body in analysis (Seigworth and Gregg 2010). *Hibakusha* bodies not only represent the past but also play an active role in shaping our understanding of the past, present, and future. In fact, shifting scientific and geopolitical contexts are constantly defining and re-defining the meanings of *hibakusha* bodies. Thus, in this article I follow Maria Santesmases (2017) and carefully delineate how the rise of chromosomes as evidence of radiation damage silenced some types of evidence—such as spoken testimonies—while simultaneously giving voice to other previously suppressed entities, particularly those of Japanese geneticists.

The 1950s and Early 1960s as the Moment of Truth for Human Radiation Cytogenetics

The first decade of ABCC’s existence was a period of uncertainty. Accomplishments were marred by financial problems and lack of a clear scientific direction. Desirable studies were primarily epidemiological and biostatistical, while ABCC was directed and its programs organized primarily by scientists from the medical and pathological fields. Clinical studies at ABCC had begun without clear objectives. With a few exceptions, physicians from the US came for two-year “tours,” each with

⁵ Unlike how Timothy Mitchell analyzed the role of mosquitoes in the history of Egypt in “Can the Mosquito Speak?” (2002), I use the expression “chromosomes speak” more as a rhetorical than an analytical device.

his or her own idea about what might be useful.⁶ Plans for how to observe *hibakusha* changed, and the idea of establishing a fixed population to be studied over time had not yet taken root (Jablon 1988; Lindee 1994; Niwa 2006). Ironically, the situation was worsened by the fact that none of the early genetic programs at ABCC provided any positive evidence of genetic effects of atomic bomb radiation (Neel and Schull 1956). Among the Japanese population, suspicion of ABCC was heightening. With the end of the US Occupation in 1952, Japanese journalists began to criticize openly the controversial no-treatment policy at ABCC. The privileges the “foreigners” enjoyed at ABCC were beginning to crumble (Beatty 1993, pp. 217–219; Lindee 1994, pp. 117–143, 151–152). Despite initial determination and enthusiasm, the NAS-NRC and the AEC were now raising serious questions concerning the feasibility of continuing ABCC’s research program. Attempts to make the “most important people living” and their bodies tell the stories of radiation exposure seemed too laborious, too politically controversial, too costly, and with too few positive results (Lindee 1994, p. 5). Some went so far as to claim that “the ABCC had lost its way” (Jablon 1988, p. 36).

In the mid-1950s, three American figures collaborated on a series of much-needed interventions to reinvigorate ABCC: R. Keith Cannan, chairman of the NRC’s Division of Medical Sciences since 1953; Thomas Francis Jr., head of the University of Michigan’s Department of Epidemiology; and George B. Darling, who succeeded Robert Holmes as ABCC director in 1957.⁷ Cannan’s and Francis’s initial contributions to planning, organizing, and staffing were of strategic importance. In October 1955, Cannan convened a meeting of NAS-NRC consultants to review the research design of ABCC. This meeting led to the recommendation that a Unified Study Program based on a fixed population be created. An Ad Hoc Committee for Reappraisal of the ABCC Program was thus created, headed by Francis. The Francis Committee’s report, released in 1955, emphasized the critical importance of continuity. One of its central recommendations to further this goal was the establishment of fixed, well-defined groups of exposed and non-exposed persons that would permit observation of disease rates and change over time (Francis et al. 1955). Darling took the Francis Committee’s recommendations seriously. He was adamant that the program not change to suit the ideas of each new chief of medicine or pathology. Based on the Francis Committee’s recommendations, Darling directed the launch of one of the major studies at ABCC, the Adult Health Study (AHS), in 1958.⁸

⁶ The scheme was such that these physicians would be recruited by the NAS and commissioned by the Public Health Services (PHS), which provided two years’ credit toward the physician’s draft.

⁷ Seymour Jablon, who was a member of the Francis Committee, spoke of Cannan in less positive terms. He thought that Cannan formulated the Francis Committee because he was unwilling to concede that “the [ABCC] program was a failure” (1988, p. 36).

⁸ AHS, which still continues to date, is a clinical research program based on biennial health examinations of approximately 20,000 subjects. These subjects are selected from the Life Span Study (LSS), which is a research program investigating life-long health effects based on epidemiologic (cohort and case-control) studies. About 120,000 subjects selected from residents of Hiroshima and Nagasaki identified through the national census in 1950 have been followed since that time, including 94,000 atomic bomb survivors and 27,000 unexposed individuals. In 1977, an additional 2400 LSS participants and 1000 in utero-exposed persons were added to the AHS.

By the early 1960s, with the firm establishment of longitudinal studies, such as the Life Span, Adult Health, and Pathology programs, it seemed appropriate for ABCC scientists to consider reviving a broad medical genetics program.⁹ ABCC was thus ready for a new endeavor to let chromosomes speak.

The broader scientific landscape, which was characterized by new methods and techniques for studying chromosomes, provided the perfect setting for ABCC scientists with ambitions for a new genetics program (de Chadarevian 2020). The period between 1952 and 1956 marked a new development in twentieth-century biology. In April 1953, James Watson and Francis Crick first identified the famous double-helix structure of DNA and published a short but path-breaking paper in *Nature* (1953). In 1956, two papers reported conclusive counts for the chromosomes in the human cell for the first time. The first was by Indonesian cytologist Joe-Hin Tijo and Swedish plant cytologist Albert Levan. The second, which confirmed Tijo and Levan's report, was by cytogeneticists C. E. Ford and John L. Hamerton, both at the radiobiological research unit of the British Atomic Energy Research Establishment at Harwell. These two papers inaugurated a new era of modern human cytogenetics (Hsu 1979, pp. 8–14, 25–30; Kevles 1995, pp. 238–240; Lindee 2005, p. 98; de Chadarevian 2020, pp. 39–76).

The development of simple, reliable methods of tissue culture in the 1950s made it easy to grow mammalian cells for genetic and cytological studies. Crucially, Hsu and Pomerat discovered an improved method of tissue-culture cell preparation in 1953. This offered the possibility of making cytological studies on radiation damage to human chromosomes through direct examination for aberrations, as had been done with classical plant materials (Bender 1957, p. 974). Besides tissue culture techniques, other technological improvements such as air-dried preparations and photomicrographs expanded knowledge of human chromosomes during this period (Santesmases 2017; Ferguson-Smith 2015). Particularly noteworthy was the development of peripheral blood culture by Moorhead and his colleagues in 1960 (Moorhead et al. 1960). Fresh human specimens for subsequent culture were easily obtained aseptically by vein puncture. For chromosome analysis, it required only a few millimeters of peripheral blood. Two days of cultivation *in vitro* was all the time required to yield a sufficient number of mitotic cells.

Finally, and most centrally for ABCC, preliminary studies out of the Medical Research Council (MRC) in Edinburgh reported that radiation can cause chromosome damage that remains in a cell for a long period of time. Led by William Michael Court Brown, MRC's 1960 study showed the persistence of gross chromosome damage in the peripheral blood lymphocytes of patients who had previously received therapeutic X-ray treatment for ankylosing spondylitis (Tough et al. 1960; Harper 2006, pp. 119–120). Two years later, the team confirmed that radiation-induced structural rearrangements of chromosomes were able to persist in circulating blood lymphocyte populations for several years after the relevant exposure:

⁹ Draft Report, "A Proposed Medical Genetics Program," prepared by T.S. Edgington, dated March 31, 1962. ABCC Collection, Series 3, National Academy of Sciences Archives, Washington, DC; hereafter: **NAS Archives**.

some patients' treatments had occurred as far back as 1943. The team suggested that some chromosomal aberrations—fragments, dicentrics and triscentric, rings, and other structural abnormalities—linger for up to twenty years and “may well persist for the rest of the patient’s life” (Buckton et al. 1962, p. 680). This was, in the words of Brookhaven National Laboratory scientist Eugene Cronkite, “a quite extraordinary state of affairs” and, if true, would be thrilling news for those studying the atomic bomb survivors at ABCC.¹⁰ It meant that *hibakusha* chromosomes too might be able to speak of radiation exposure.

The news about the latest chromosome studies soon reached Cannan at NRC. On November 29, 1961, he received a letter from Shields Warren of the Cancer Research Institute in Boston, who had served as the director of the Division of Biology and Medicine at the AEC between 1947 and 1952. Warren found the ongoing cytogenetic work of Court Brown and his colleagues in Edinburgh promising and suggested that such an approach “would be very worthwhile for ABCC to think of.” Quickly grasping the potential importance of this project, Cannan took a pencil to the upper right corner of the letter and scribbled a note to Francis J. Weber, the Executive Secretary for ABCC: “Dr. Weber – please look into recent Court Brown studies.”¹¹

Weber wasted no time; he immediately began reading up on the subject and sought advice from NAS-affiliated experts, including William Schull and Randy Brill, seeking “as much information as possible on what would be involved in such efforts.”¹² Following Cannan’s later advice, Weber also reached out to William Moloney in the Hematology Lab at the Boston City Hospital. Moloney was developing a protocol in the field of cytogenetics to investigate the Marshallese population, another key irradiated population in the atomic age.¹³ In the meantime, James V. Neel at the University of Michigan and Hardin B. Jones at the University of California both wrote to Cannan, suggesting that a study of chromosome changes be undertaken at ABCC. Neel was convinced that “this area looks to be a potentially very important facet of the ABCC effort,” and suggested that ABCC consider embarking on chromosome studies on adults undergoing periodic medical examinations. He further advised re-examining the children registered with the old genetics program he had led at ABCC in the 1950s.¹⁴ Jones likewise highlighted the readiness of appropriate techniques and the need for chromosome studies of the survivors. He especially emphasized the potential relevance of the newest approach developed by

¹⁰ Eugene P. Cronkite to R. Keith Cannan, January 4, 1962, ABCC Collection, Series 3, NAS Archives.

¹¹ Shields Warren to R. Keith Cannan, November 27, 1961, ABCC Collection, Series 3, NAS Archives. The letter, as the stamp indicates, was received by Cannan on November 29.

¹² Francis Weber to Hardin B. Jones, December 28, 1961, ABCC Collection, Series 3, NAS Archives. In this letter Weber also talks about the difficulty of tracking down relevant work being done, since it is “only now coming to a fuller description in scientific literature.”

¹³ Inter-Office Memorandum “Chromosome Aberrations and Radiation” from R. Keith Cannan to Francis J. Weber. December 14, 1961, ABCC Collection. Series 3, NAS Archives; From Francis J. Weber to William C. Moloney. (carbon copy), December 27, 1961, ABCC Collection. Series 3, NAS Archives. For the Marshallese population and their experience of radiation exposure, also see Nagasawa (2015) and Mitchell (2016).

¹⁴ James V. Neel to R. Keith Cannan, December 11, 1961, ABCC Collection, Series 3, NAS Archives.

Theodore Puck in Denver of using electron microscopy to observe minute chromosome deletions following radiation exposure.¹⁵

Within about a month, Washington was ready for ABCC scientists to begin working with chromosomes. Weber had efficiently and systematically canvassed expert opinions on practicability of the various techniques then in use, the special facilities and amount of expertise called for, and the man-days investment needed to survey an adequate sample.¹⁶ On January 4, 1962, Weber sent Cannan a three-page memo titled “Progress on Possible Cytogenetics Study in the ABCC Population.” His conclusion was clearly stated: “ABCC should attempt to enter this field,” or if any efforts had already been made, “expand it sufficiently to a point enabling an evaluation in terms of radiation-induced changes in human chromosomes.”¹⁷

The Promises of Broken Chromosomes

Chromosome aberrations appeared as the common language of atomic age studies of harm. As more discussions took place between NAS-NRC, ABCC, and other affiliated institutions in preparation for the establishment of the new cytogenetic laboratory, it became clear that chromosomes—or, rather, broken chromosomes—held crucial promises for ABCC.

One of the most alluring prospects of this new cytogenetic project for the scientists involved was its ability to connect the work of ABCC to the cutting-edge global radiobiological research agenda. Earlier programs at ABCC had focused on the somatic effects of radiation, which included the direct consequences of exposure on bodily health, such as leukemia, cancer, and early death.¹⁸ While valuable, the narrow research focus allowed for limited comparability of the data gleaned from *hibakusha*, since only those who were exposed to a comparatively high dose of radiation would manifest such symptoms. In terms of somatic effects, then, *hibakusha* were too unique as an irradiated population to be compared with other populations (Kraft 2009, pp. 186–187). By contrast, human karyotyping—the counting and examining of chromosomes—provided the tool to track the effects of even lower levels

¹⁵ Hardin B. Jones to George B. Darling at ABCC (Cannan’s carbon copy), December 15, 1961, ABCC Collection, Series 3, NAS Archives.

¹⁶ Francis J. Weber to James V. Neel, December 28, 1961, ABCC Collection, Series 3, NAS Archives; R. Keith Cannan to Stuart C. Finch (Chief, Department of Medicine, ABCC), December 29, 1961, ABCC Collection, Series 3, NAS Archives.

¹⁷ Memo “Progress on Possible Cytogenetics Study in the ABCC Population” from Francis J. Weber to R. Keith Cannan, January 4, 1962, ABCC Collection, Series 3, NAS Archives.

¹⁸ The genetic study had existed in ABCC as mentioned above, and in fact had had extensive resources invested in it. However, it was based on the study of human inheritance (Lindee 1994, pp. 57–79). The exception was the work attempted by cytogeneticist Masuo Kodani. One of his assignments was a study of testicular materials for evidence of chromosome damage. However, as Neel explained, the technical problems proved insurmountable, and it was not possible to get satisfactory data on chromosome aberrations in this material. James V. Neel to R. Keith Cannan, December 11, 1961, ABCC Collection, Series 3, NAS Archives. For more about Kodani’s scientific work, see Smocovitis (2011). Also see Comfort (2012) for the so-called “medical turn” in human genetics.

of radiation in each individual cell, often before the potentially damaging effects became apparent. Moreover, at an international conference in Denver in 1960, the so-called “Denver System” of classifying chromosomal configurations and changes was adopted by common consent of major researchers in the field. Nomenclature for normal chromosomes and those called “aberrations” was agreed upon, giving biologists a common language to talk about human cytogenetics.¹⁹

For the AEC (ABCC’s sponsor), the fact that ABCC would be part of this “new infrastructure for radiobiology” held further promises (Kraft 2009, p. 186; see also Barahona 2016). As Creager (2015) has demonstrated, the debates in the 1950s about the connections between radiation, mutation, and cancer facilitated acceptance of the somatic mutation theory of carcinogenesis. This led to increasing interest in the ways in which chromosomal abnormalities could be linked to somatic effects. It was imperative to determine whether heritable chromosomal changes could be introduced into human populations subjected to appreciable doses of ionizing radiation.²⁰ Alongside greater acceptance of the somatic mutation theory of carcinogenesis came a transition to the linear, no-threshold model for low-dose radiation effects (Institute of Medicine 1996, pp. 284–289; also see JCAE 1960; UNSCEAR 1962). Yet, uncertainties persisted about the shape the dose–response curve would take for low ionizing radiation levels. AEC officials hoped that the ABCC research population, which included subjects with all ranges of exposure levels, would offer insights.²¹ Hence, AEC encouraged, or even put “very active pressure” on, ABCC to swiftly begin the work on cytogenetics.²²

By letting *hibakusha* chromosomes speak, ABCC scientists would be able to engage with similar studies on a wide range of population groups exposed to ionizing radiation, from battlefields and industrial settings to test grounds and clinics. In the 1960s, chromosomal aberrations detected through human karyotyping had become the “new disseminated meaning of mutation” (de Chadarevian 2010, p. 180; Kraft 2009). In addition to Court Brown’s study of patients during and after radiotherapy for ankylosing spondylitis, others were finding chromosomal aberrations in patients who underwent radiotherapy for malignant tumors (Warren and Meisner 1956; Millard 1965) or in persons exposed to radiation in diagnostic procedures (Bloom and Tijo 1964). To investigate the effects of nuclear testing in the Pacific population, Hermann Lisco, at the Cancer Research Institute of New England Deaconess Hospital, had completed studies on chromosome abnormalities in the

¹⁹ Memo “Summary of Visit with Dr. Theodore Puck and Associates at University of Colorado Medical Center” from Francis J. Weber to R. Keith Cannan, January 16, 1962. ABCC Collection, Series 3, NAS Archives. Also see Santesmases (2017, pp. 408–415). Human karyotyping also had the advantage of visualizing the effects of radiation (de Chadarevian 2015; Santesmases 2017). This is another aspect that Neel emphasized as potentially having “particular appeal to the staff in Japan.” James V. Neel to Francis J. Weber, January 8, 1962. ABCC Collection, Series 3, NAS Archives.

²⁰ From Theodore T. Puck to Hardin B. Jones, October 27, 1961, ABCC Collection, Series 3, NAS Archives.

²¹ ABCC Interoffice Memorandum, “Statement on Cytogenetic Studies,” from Seymour Jablon to George B. Darling, June 18, 1962, ABCC Collection, Series 3, NAS Archives.

²² R. Keith Cannan to George B. Darling, June 20, 1963, ABCC Collection, Series 3, NAS Archives.

Marshallese people exposed to fallout in 1954 (Lisco and Conard 1967). In Japan, Ishihara and Kuratori, at the National Institute of Radiological Sciences, affirmed Lisco's conclusions through further studies on the Japanese fishermen exposed to the same fallout.²³ Consistent chromosomal abnormalities were reported in individuals involved in radiation accidents as well.²⁴ At Oak Ridge National Laboratory, M. A. Bender had comparable findings from the Y-12 accident cases of 1958. Bender (1964) also studied the Hanford cases and got proportional results. In the US, the UK, New Zealand, Denmark, Austria, and even in Czechoslovakia, scientists were using chromosome breakages as a shared code to advance the new field of human radiation cytogenetics (Evans et al. 1967).

The abstraction of *hibakusha* into broadly relevant research subjects also offered political advantages for ABCC leaders and scientists who believed that cytogenetics research should be the crown jewel of the exhilarating scientific momentum of the mid-twentieth century. With Japan fully onboard with the Atoms for Peace campaign, the new cytogenetics program seemed globally relevant (Westwick 2003). The cytogenetic work gave ABCC scientists the confidence that they were contributing to much-needed advancement in science and, by extension, to the future of mankind more generally.

Arthur Bloom, a cytogeneticist assigned to ABCC in 1966 to work on the pilot program on cytogenetics, presented the program to the Japan Advisory Council as profoundly meaningful:

This [cytogenetics program] has meaning not only for the survivors themselves. It also has meaning for mankind in the future. The Asahi Evening News of 12 April 1967 reported that fifteen nuclear power stations are planned for Japan by 1975. Inevitably, nuclear radiation workers will be accidentally exposed, as they have been in the United States and elsewhere. Conceivably, inhabitants of surrounding areas could also be accidentally irradiated. Chromosome abnormalities will be useful as an index of the patient's dose in the acute radiation exposure. But it will also be critical for us to know what significance the persisting aberrations might have for the long-term health of the patient.²⁵

By the late 1960s, the prospect of broken chromosomes thus shaped a conviction among ABCC scientists that they had a scientific "obligation" to conduct their research.²⁶ Such grandiose interpretations of their work became integral to ABCC's rhetoric vis-à-vis the Japanese. Intriguingly, in 1967 Darling agreed for the first time to an interview with one of the Japanese national newspapers, Sankei Newspaper, to talk about ABCC's work. In the interview, he explained "the humanitarian purpose"

²³ Arthur Bloom to Herbert N. Gardner, July 11, 1967, ABCC Collection, Series 3, NAS Archives.

²⁴ Charles L. Dunham to George B. Darling, May 25, 1962, ABCC Collection, Series 3, NAS Archives.

²⁵ Report, "Implications of Recent Cytogenetic Studies at ABCC," by Arthur D. Bloom. To be presented to the Japan Advisory Council, Tokyo, Japan, 28 April 1967, ABCC Collection, Series 3, NAS Archives.

²⁶ Report, "Implications of Recent Cytogenetic Studies at ABCC," by Arthur D. Bloom. To be presented to the Japan Advisory Council, Tokyo, Japan, 28 April 1967, ABCC Collection, Series 3, NAS Archives.

of ABCC's work as collecting insights that were useful for any radiation risk situations. Darling stated that such work would be key to the setting of safety regulations for the peaceful use of atomic power. "In other words," he continued, "we wish that ABCC's work ... would contribute to the future of humanity in areas where no other institutions can compete with us."²⁷

A focus on chromosomes implied a move to the lab, which was particularly attractive for ABCC scientists as ABCC had been heavily criticized for the humiliating ways physicians and scientists interacted with the *hibakusha*. The ABCC staff often took *hibakusha* to ABCC during school hours, usually without prior notice. During clinical examinations, *hibakusha* "had to become almost naked so that they [the doctors] can take many photographs." The doctors "also took so much blood" (Hayashi Yuriko, quoted in NNN 2017). Those at ABCC were keenly aware that "painful or unpleasant techniques" were currently "out of the question," since they might have "the effect of damaging ABCC's rapport with the populations." This could not be underestimated, since the ABCC program was entirely dependent on "voluntary cooperation by the subjects over an indefinite period." In contrast, the technique for the new cytogenetic program would be "perfectly acceptable to the subjects," requiring only 1–2 ml of blood per person.²⁸ Theoretically, at least, the new endeavor to let chromosomes speak seemed to promise a way out of the messy public relations problem surrounding ABCC at the time.²⁹

In practice, however, the on-the-ground reality was more difficult than was hoped. In the initial phase of the program, Leland Stoddard in the Pathology Department mentioned to Cannan that the quantity of blood available was limited and only one culture per patient could be done. This was because of the "circumstances you know about," Stoddard explained, referring to the deep-seated distrust *hibakusha* and the locals in general held towards ABCC.³⁰ Later, workers at ABCC felt compelled to visit patients' homes to obtain agreement to conduct the research despite the move to the lab and to fully explain to the *hibakusha* as well as their parents or close relatives, if any, the purpose of the research. However, as soon as the researchers revealed their affiliation with ABCC, the door was often literally shut in their face. To get the families to at least listen to the purpose of the study, researchers would put their shoe in the doorway and continue to explain through the partially open

²⁷ Newspaper article, "ABCC wo torimaku mondai [Issues surrounding the ABCC]," *Sankei Shimbun*, August 5, 1967. Awa Akio Personal Collection. Translation by the author.

²⁸ ABCC Interoffice Memorandum, "Statement on Cytogenetic Studies," from Seymour Jablon to George B. Darling, June 18, 1962, ABCC Collection, Series 3, NAS Archives. Talking generally about the techniques involved in human karyotyping, Santemeses also described the shift to blood samples as a displacement of "invasive biopsy as an easily accessible source for human cytological analysis" (2017, pp. 404–405).

²⁹ In his work on the history of human experiments, Chamayou (2018) has an interesting discussion of how introduction of experimental medicine may be linked to doctors and scientists becoming less concerned with the political and cultural embeddedness of the very work they engage with. See also Kay (1996).

³⁰ Leland D. Stoddard to R. Keith Cannan, February 1, 1962, ABCC Collection, Series 3, NAS Archives.

door (Nakamura 2019, p. 4). Whether the promises the Americans envisioned to address the public relations problems were real requires further investigations.

Who Will Let Chromosomes Speak?

The importance of the cytogenetics program appeared unequivocal. While no one raised objections, it is striking that the program did not fully begin until 1967. ABCC needed five years to consolidate the plan and form a reliable team of scientists that could carry out its cytogenetics program. The biggest challenge turned out to be the question of who was to work on that cytogenetics program.

Within ABCC, the initial discussion was whether to make the new cytogenetics laboratory part of the Pathology Department rather than establishing it as an entirely new department. In fact, some work with chromosomes had already begun at Pathology, albeit limited and small in scale.³¹ Even so, it was evidently infeasible for the Pathology Department to lead the new, much larger project. The department was already overwhelmed by autopsies and other research programs.³² At the same time, dividing work across departments was not realistic. Weber's visit to Hiroshima in May 1962 and the roundtable discussion he held with department heads had revealed the "inter-departmental sensitivity," which would hinder any substantial cross-departmental collaborations.³³

Another option Cannan considered was to send a team of experienced scientists from the US to help set up a new laboratory and train Japanese scientists. But this turned out to be significantly more difficult than he envisioned. After endless correspondence with several American scientists, he wrote to Gardner, a new Executive Secretary who replaced Weber, in frustration: "Some offered to train people we might send them. As far as I know no one offered to come himself. Nor was any specific American nomination made even if we could have found the money."³⁴

There was a structural cause underlying the reluctance of American cytogeneticists to join ABCC. A new cytogenetics study at ABCC would require a long and substantial commitment by experienced experts, beyond the usual "two-year tour" arranged by PHS. Yet, a tour at ABCC was not part of a standard faculty track. It did not necessarily lead anywhere. In other words, the building momentum of cytogenetics, with American institutions being the key players, made it difficult for ABCC to secure any credible persons to come and work for them in Japan. A post-trip analysis by Michael Bender of Oak Ridge National Laboratory, who visited Japan in March of 1963 on a consulting visit, illuminates this point. As he noted:

³¹ Stuart C. Finch to R. Keith Cannan, January 12, 1962, ABCC Collection, Series 3, NAS Archives.

³² Leland D. Stoddard to Dr. Sidney C. Madden, January 29, 1962, ABCC Collection, Series 3, NAS Archives; Table, "Total Number of Autopsies Performed, ABCC 1948 – 1 September 1967," September 28, 1967, ABCC Collection, Series 3, NAS Archives; Table, "Table 1. Autopsy Rate in the JNIIH-ABCC Mortality Sample by Year of Death and by City," no date, ABCC Collection, Series 3, NAS Archives.

³³ George B. Darling to R. Keith Cannan, May 7, 1962, ABCC Collection, Series 3, NAS Archives.

³⁴ George B. Darling to Herbert N. Gardner, November 8, 1966. ABCC Collection, Series 3, NAS Archives.

it is clear that, while short term studies may successfully be carried out by investigators visiting Japan for periods of up to one or even two years, any large or long range efforts must have permanent staff members....[However] it would certainly be very difficult to obtain competent non-Japanese scientists who would be willing to work in Japan on a permanent basis, particularly in the field of human cytogenetics, in which there are now far more jobs than people to fill them in most countries.³⁵

While the final alternative was to employ Japanese scientists from outside ABCC, Bender believed that many were “extremely reluctant” to join ABCC for ideological, political, or sentimental reasons: they felt that ABCC, as an American institution, viewed the atomic bombings and *hibakusha* merely as research opportunities. Based on his visits to various institutions in Japan, Bender concluded that many powerful Japanese scientists were “openly critical and mistrustful of the ABCC in particular, and of American motives in general.” He speculated as well that the Japanese would also find it “a loss of face” to have to be supervised by Americans. Such supervision, however, was essential, because any operation of such magnitude would have had to be financed by the US and, Bender went on, because the work needed to be done “properly, economically, and with reasonable speed.” Many at the ABCC concurred with Bender.³⁶

It is also possible to see a structural cause—just as was the case for American scientists—why working for ABCC was not palatable for Japanese scientists. Masanori Nakaidzumi, a retired professor of radiology from Tokyo University and an associate director of ABCC since 1956, challenged Bender’s view with a more nuanced interpretation. While he agreed with Bender’s analysis to some extent, Nakaidzumi argued that the fundamental problem was that ABCC was not scientifically attractive enough for young Japanese scientists. University professors who were deeply invested in the future success and happiness of their pupils, Nakaidzumi contended, “[would] be discreet in sending his pupil out to ABCC in its present state.” His detailed analysis deserves attention for what it reveals about the reluctance of Japanese scientists to consider permanent employment at ABCC:

The ABCC handles as much as or even more cases of autopsy than any first-class Japanese university. Therefore, up to the stage of handling autopsies one may learn as much or more of excellent American technique there than at a first-class Japanese university ... [and] the department heads of ABCC are professors of fine American universities and eminent figures in their respective fields. However, they change after one or two years, and with them change the fields of interest. A young Japanese doctor cannot possibly receive sufficient training even in one field in a period of one or two years.... [Furthermore,] an ABCC department is staffed with people from several universities, which is

³⁵ Report, “Cytogenetic Studies at Hiroshima and Nagasaki, Japan,” prepared by M. A. Bender, April 22, 1963, ABCC Collection, Series 3, NAS Archives.

³⁶ Report, “Cytogenetic Studies at Hiroshima and Nagasaki, Japan,” prepared by M. A. Bender, April 22, 1963, ABCC Collection, Series 3, NAS Archives.

unfavorable as compared with a Japanese university where scientific education is received not only from one's professor but also from one's seniors.... Under such circumstances it would be to the disadvantage of a Japanese doctor scientifically to join the staff of the ABCC.³⁷

There were many strengths ABCC could leverage, according to Nakaidzumi, if the Commission were to become more scientifically attractive. For instance, the application of statistics to biological studies at ABCC could not be seen elsewhere in Japan. However, he saw the conditions at ABCC as "unfair" when considered from the perspective of Japanese scientists.³⁸ Nakaidzumi argued that this be treated as an opportunity to rethink the way ABCC engaged with Japanese scientists. ABCC leadership had to take seriously, for example, the fact that Japanese scientists had professional aspirations and ambitions. If ABCC were to undertake important long-term research projects involving Japanese scientists, it would entail reviewing and rethinking how American staff were assigned. Programs had to be restructured so that Japanese scientists were given opportunities for high quality training and career advancement, which also included access to leadership positions.

Eventually the solution of how to staff the new cytogenetics laboratory came from two directions: one from the American side and the other from the Japanese side. Arthur Bloom, realizing the importance of the study, decided to extend his two-year assignment. Having published the preliminary results from the cytogenetics program and presented them in key international conferences, Bloom was convinced that ABCC must commit "more funds, more personnel, and more space to the Cytogenetic Program." It was clear to him that there was worldwide interest in ABCC's work, especially since they could now state confidently that "cytogenetic effects are an established index of radiation exposure."³⁹ Darling, knowing the importance of continuity more than anyone else, made tireless efforts to persuade Bloom to stay. He emphasized the unique opportunity the ABCC population provided, as well as the kind of leadership role Bloom was assigned at ABCC, which he might not enjoy elsewhere.⁴⁰ He even promised a salary raise. "If you could give us one more year," Darling pleaded to Bloom, "I think your research baby here, now so healthy but still unable to help himself, would have a chance to grow into an astonishingly precocious child."⁴¹ Finally, Bloom made up his mind and extended his term until the summer of 1968. Together, Darling and Bloom committed to ensuring the continuity of the program.

³⁷ Memorandum (translation) "Impression of Dr. Bender's Letter" from Masanori Nakaidzumi to George B. Darling, July 9, 1963, ABCC Collection, Series 3, NAS Archives.

³⁸ Memorandum (translation), "Impression of Dr. Bender's Letter," from Masanori Nakaidzumi to George B. Darling, July 9, 1963, ABCC Collection, Series 3, NAS Archives.

³⁹ ABCC Interoffice Memorandum, "International Symposium on Radiation-Induced Chromosome Aberrations in Man, Scotland, October 12–15, 1966," from Arthur D. Bloom to George B. Darling, October 24, 1966, ABCC Collection, Series 3, NAS Archives.

⁴⁰ Darling himself had extended his term which was originally only for two years like others. Eventually, he stayed at the ABCC for fifteen years, until 1972.

⁴¹ George B. Darling to Arthur D. Bloom, November 8, 1966, ABCC Collection, Series 3, NAS Archives.

Another, more substantial breakthrough had come in December 1966 when, after a series of negotiations, Sajiro Makino of Hokkaido University agreed to ABCC's request for collaboration.⁴² Makino was a pioneer of human cytogenetics in Japan, and his name was widely known both nationally and internationally as an authority on human and mammalian cytogenetics (Santesmases 2017, pp. 401–403, 408–415). His influence in Japan was so great that virtually everyone who had any cytogenetic competence were graduates of his laboratory.⁴³ The precise reason for Makino's decision is unknown. Akio Awa, his disciple and a cytogeneticist who was later recruited by ABCC, believes that it was a combination of the pay scale at ABCC, his ambition to build the first cytogenetics laboratory in Japan, and the retirement age he was approaching that made him agree to a collaboration with ABCC.⁴⁴ In any case, Makino decided during the meeting held at ABCC that he would fully support ABCC's proposed research collaboration, and, to start, he would recommend his recent graduate Takeo Honda for employment at ABCC. On his way home, Makino decided that he would also send another one of his graduate students, Akio Awa.

Once the agreement was made, Makino's lab provided a stable flow of Japanese researchers to ABCC. In January of 1967, Awa and Honda were assigned to ABCC as permanent research associates.⁴⁵ In the same year, two more of Makino's graduates also joined ABCC: Michihiro Yoshida to the Nagasaki labs and Toshio Sofuni to Hiroshima. In subsequent years, many others from Hokkaido followed suit: Hachiro Shimba and Kazuo Ohtaki joined the team in Hiroshima, and Masahiro Itoh in Nagasaki (Awa 2002). The arrival and permanent position of Japanese scientists fundamentally changed the research capacities of the ABCC cytogenetics program.

Unlike other ABCC programs, the cytogenetics program welcomed Japanese experts to play leading roles. With the team strengthened by the "Hokkaido boys," the official work on cytogenetics at ABCC began.⁴⁶ From the beginning, Honda and

⁴² In March of 1963, Michael Bender of Oak Ridge National Laboratory (ORNL) visited Makino at Hokkaido University in Sapporo. In October 1964, Ernest Chu, also from ORNL, visited Makino again to ask for his support for ABCC's cytogenetic work. During the summer of 1966, Bloom visited Hokkaido University from ABCC and asked for research collaboration. Makino declined. Bloom did not give up, and in September of the same year, he invited Makino to present at ABCC's annual Program Review. Michael A. Bender to Akio Awa, April 5, 1963; Akio Awa to Michael A. Bender, April 23, 1963; Michael A. Bender to Akio Awa, May 4, 1963; "I Quit!" 1995, Awa Personal Collection.

⁴³ Makino's lab was well connected to the laboratory of Charles Pomerat. Many of his students were trained at Pomerat's lab, including Akio Awa, who stayed there for two years, 1960–1962. It is also noteworthy that cytogenetics was an area in postwar biomedicine in which Japanese scientists were making prominent contributions. As Santesmases describes, this is linked to Japan's cultural heritage of plants and animals (2017, p. 412).

⁴⁴ Makino was nearing his retirement age, and the issue of where to place his students was becoming a serious source of concern. He may have thought that ABCC could be a good option, especially given the much higher pay they could offer compared to other Japanese institutions (for a postdoctoral level position, the salary was about 60% higher). Awa believes that Makino also had a plan to take this as an opportunity to establish the first independent cytogenetics laboratory in Japan with the help of funding from the US. However, this did not turn out to be the case. See "I Quit!" 1995, Awa Personal Collection, and also the author's interviews with Awa Akio in Hiroshima, conducted on 17 and 18 May 2018.

⁴⁵ "Employment Agreement" between M.E. Rappaport, ABCC Business Administrator and Awa Akio, on January 16, 1967, Awa Akio Personal Collection.

⁴⁶ "I Quit!" 1995, Awa Personal Collection.

Awa were given a large amount of responsibility and worked closely with Bloom as colleagues. Bloom returned to the United States after three years with ABCC and joined Neel's group at the University of Michigan Medical School in Ann Arbor. After Bloom's departure, Awa took over the management of the laboratory.

The staffing issue for the cytogenetics program reveals how an asymmetrical power relation between the US and Japan underpinned the operation of ABCC well into the 1960s. On one hand, American scientists saw little advantage in investing in ABCC research, including spending time in Japan, despite the unique opportunities available as part of a nascent cytogenetics study. As Nagasawa (2015) pointed out in his study of the work of Wataru Walter Sutow, ABCC was a mere local research commission with little independent governance. It was structured so that all key decisions were made in Washington at NAS-NRC, in conjunction with the will of the US government and the US Army. On the other hand, those who directed ABCC had almost no consideration about how work at ABCC would or would not appeal to Japanese scientists professionally. To them, Japanese scientists were of a lower caliber—overly emotional and too easily influenced by the local political and ideological climate.

The initiation of the cytogenetic program marked ABCC's partial departure from some visible forms of power imbalance at the institution. Practical realities in the late 1960s required that more substantial leadership roles be given to Japanese scientists. It was necessary for capable cytogeneticists who were willing to stay for an extended period of time to be involved in the project and even to lead it. American ABCC leaders had to recognize Japanese contributions and make their expertise visible. Without reconsidering at least some of the practices at ABCC that presupposed an American superiority, a new project on cytogenetics would have remained impossible.

Conclusion: A Model for Future Japanese Leadership

For some five years, from the spring of 1969 (the beginning of the official project) to 1974, Awa and his team cytogenetically examined approximately 4000 patients in two cities—about 2300 in Hiroshima and 1700 in Nagasaki. The work was exhausting: 100 cells per *hibakusha* and 10 cells per F1-generation subject had to be examined (Crow et al. 1975; Awa et al. 1987). Despite the demanding workload, Awa led the team with great dedication. He standardized the procedures to analyze radiation-induced chromosome aberrations and prepared a minutely detailed protocol on how to classify them.⁴⁷ He also made efforts to smooth relationships with other departments to facilitate collaboration.

Positive assessments of the cytogenetics program appeared as early as the 1970s. In the message that accompanied the ABCC Annual Report, 1971–1972, Seiji Kaya, the president of the Japan Society for the Promotion of Science (JSPS), congratulated ABCC on the latest findings that came out of the cytogenetics program. He

⁴⁷ Masahiro Ito. 1998. "Awa Sensei to no Deai [Dr Awa and I]," in *I Quit*. Awa Personal Collection.

noted that such a discovery should be recognized as “a gratifying indication of success in the cooperative research by a Japanese university with ABCC and the Japanese National Institute of Health (JNIH).”⁴⁸

In February 1975, before the reorganization of ABCC as the Radiation Effects Research Foundation (RERF), a special scientific committee meeting was held at ABCC chaired by James F. Crow of the University of Wisconsin-Madison. The charge of the Crow Committee was to carefully review each item of the ABCC scientific programs to determine which should be taken over by the new US-Japan bilateral foundation. The committee’s remarks on the cytogenetics program are noteworthy:

We note that this program has become one of the most active in the ABCC and that it is entirely under Japanese leadership. As the ABCC is replaced by the new Foundation, this is a model for future Japanese leadership in the joint venture. We recommend that the highly successful cytogenetics study be continued, with increased scientific personnel as needed. (Crow et al. 1975)

The report also included the issue of “cytogenetic outliers” and recommended pursuing this line of research even more vigorously. The Crow Committee judged that chromosomes had much more to reveal about *hibakusha* stories of radiation exposure.

ABCC’s decision to direct their research attention and efforts to chromosomal abnormalities was deeply embedded in the institutional, scientific, and political landscapes of the 1950s and 1960s. Letting chromosomes speak of radiation was attractive to ABCC because of the many promises it held for scientific knowledge more broadly, as well as its capacity to allow researchers to overcome the more practical issues they faced. At the same time, their decision also unraveled some long-standing elements of presumed American prestige and dominance that had guided operations. The launch of the cytogenetics project, perhaps unexpectedly, became a turning point for ABCC. The project necessitated substantial changes in the way ABCC programs were managed and staffed. Consequently, Japanese scientists were given much more responsibility in the cytogenetics project, serving as the model for future work at RERF when the assessment was done in 1975.

The new techniques of human cytogenetics, bubbling up all over the world, created a dialogue between the local context responding to national needs and concerns—of both Japan and the US—and a global approach to studying human biological diversity. Simultaneously, adopting these techniques brought about a shift in the meaning of *hibakusha* bodies. By letting chromosomes speak, *hibakusha* bodies became much more generally relevant to radiation risk. Thus, with the rise of cytogenetics, *hibakusha* chromosomes entered into a “transnational material culture” (Barahona 2016, p. 17). This, though perhaps controversial, provided ABCC scientists with scientific promises and obligations, the AEC with a rationale to continue supporting the work of ABCC, and Japanese scientists with more leadership opportunities within ABCC. All in all, cytogenetics and chromosomes

⁴⁸ ABCC Annual Report, 1971–1972. Awa Personal Collection.

were embraced on multiple levels, as ABCC aspired to be more and more relevant in worldwide efforts to estimate and counter radiation risk. However, while giving voice to some, the new techniques may have silenced others. With its “humanitarian purpose,” less humiliating and painful methods of investigation, and relocation of research into the safe space of a laboratory, the cytogenetics program offered ABCC some ways to soothe its critics. While paving ways for the future work at RERF, chromosomes permitted ABCC/RERF scientists to escape politics, at least superficially on a day-to-day level. What chromosomes reveal, then, are the stories of radiation exposure, and much more.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Embracing Mystery: Radiation Risks and Popular Science Writing in the Early Cold War

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Accepted: 30 January 2021 / Published online: 23 February 2021
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Abstract

Narrative form is crucial to the understanding of science in popular culture. This is particularly true with subjects such as radiation, in which the technical details at hand are often remote from everyday experience—as well as contested or uncertain among experts. This article examines the narrative choices made by three popular texts that publicized radiation risks to the public during the Cold War: John Hersey’s *Hiroshima*, David Bradley’s *No Place to Hide*, and Ralph Lapp’s *The Voyage of the Lucky Dragon*. It contends that each author borrowed from well-established literary genres and that this borrowing was crucial to coherence and effective messaging of the argument. At the same time, placing the arguments in such a familiar form served to blunt some of the radical potential in those same messages.

Keywords Radiation · Nuclear · Risk · Narrative · Popular culture

In the spring of 1955, the midpoint of the decade that saw nuclear arsenals grow from a theoretical threat to a tangible one, director Robert Aldrich released an adaption of Mickey Spillane’s novel *Kiss Me, Deadly*. A film noir classic, *Kiss Me Deadly* unfolds slowly as an atomic story. The protagonist is Mike Hammer, a hard-nosed detective with a considerable anti-authoritarian streak. In the movie’s opening scene, he picks up a hitchhiker who has barely begun to relate her mysterious past when the pair is stopped by unnamed men who capture them, kill her, and leave him for dead. Hammer recovers but is unable to let the matter go. He repeatedly refers to the fact that his now-deceased hitchhiker must have been connected to “something big.” This imprecision is vital to the plot, as both detective and audience are kept in the dark as to the nature of the trouble until quite close to the end of the film. A trail of clues leads Hammer to a mysterious box, the contents of which are never precisely explained. However, the glowing substance inside makes radioactive burns on Hammer’s hand, and one of his police contacts confirms to him that he has stumbled

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upon some kind of nuclear secret. The story ends when Hammer and his partner are held captive in a beachside house, from which they narrowly escape seconds before the box and its contents explode. There remains something unsettling about this resolution, as neither the protagonists nor the viewers learn the full story of the events that nearly resulted in a nuclear-fueled demise (Aldrich [1955] 2001).

The challenge of understanding nuclear things is not unique to *Kiss Me Deadly*. Of the many rhetorical tropes associated with nuclear energy, few are more prominent than the notion of mystery. Early atomic age journalists frequently explained the new science to their readers with reference to the “secrets of nature”—in fact, as Luis Campos and others have shown, such rhetoric significantly predates World War II and was rooted in the history of biology as much as in physics (Campos 2015; Lavine 2013). From movies to music to comics, popular culture texts highlighted the mystery of the new science, both reveling in and recoiling from the power of this unfamiliar energy (Boyer 1985; Weart 1988). At the same time as such rhetoric was filling the pages and airwaves of postwar media, government and military officials were creating a national security state premised on the notion of secrecy, feeling that much of the technical information newly vital to the maintenance of the nation must be obscured from public view. Scientists were wrestling with the difficulty of how best to measure and communicate radioactive risks; this was a challenging intellectual endeavor, even apart from the highly charged political context in which such assessment took place. Mystery, secrecy, and uncertainty were defining elements of Cold War encounters with nuclear energy.

Yet we can—and should—do more than simply note the presence of mystery in the rhetoric of the early atomic age. In this essay, I argue that mystery influences the form as well as the content of nuclear stories. Many key texts about radiation in the postwar era—such as John Hersey’s *Hiroshima*, David Bradley’s *No Place to Hide*, and Ralph Lapp’s *The Voyage of the Lucky Dragon*—need to be seen as experiments in literary form as much as straightforward attempts to communicate scientific information. In this respect, all three works of non-fiction join a long tradition of blurred lines between science and literature. Such connections have been explored most thoroughly in the context of nineteenth-century Britain, particularly evolutionary biology. James Secord, for example, writes of Robert Chambers’ debt to the novelist Walter Scott in the very structure of *Vestiges of the Natural History of Creation*; from the literary side of the aisle, Gillian Beer’s groundbreaking work on Darwin explores the appropriation of evolution in Victorian literature (Secord 2000, pp. 78–92; Beer [1983] 2009). Scholars of twentieth-century history have long noted the interplay between science fiction and technological advance, and David A. Kirby has explored the importance of “forensic fictions” in contemporary cinema (Weart 1988; Kirby 2013, pp. 92–102). All three works under consideration here are non-fiction, but they still evince a dependence on narrative form that parallels these examples. The way that authors communicated radiation risks to audiences cannot be understood without an appreciation of how literary genres—particularly, but not exclusively, the detective story—work.

This essay argues, first, that accounts of radiation danger in the early Cold War were heavily indebted to particular literary forms—such as war reporting, travel memoir, and detective fiction. All of these forms provided ways that authors could

overcome some of the inherent challenges of communicating radiation risks. However, communication can be a messy process, and there are many ways in which information changes in transit (Secord 2004). Megan Barnhart Sethi's work on the activism of the Federation of American Scientists (FAS) in the mid-1940s provides a particularly apt reminder of this; she chronicles the ways that the very success of that organization in publicizing nuclear dangers led to policy outcomes quite different from what many of its members wanted (2012). Similarly—and this is the second major argument of the article—dissemination of radiation risks via conventional literary forms did not guarantee how the reading public would react to these risks. In fact, I contend that the same rhetorical strategies that succeeded in making radiation legible to a Cold War public also served to downplay its risks. This is rooted in the elements of mystery with which all three literary forms engage. Ronald R. Thomas has suggested that detective fiction is of interest for “the ways it produces the truth and reinterprets a dark deed from the past” (1999, p. 6). Such interpretation, Thomas suggests, sometimes enforces existing cultural authority and sometimes resists it. Similarly, the works of Hersey, Bradley, and Lapp sounded an alarm about radiation dangers, but they also offered (perhaps unexpected) reasons for reassurance.

The War Report

Of the many nuclear texts that have circulated in the United States since 1945, John Hersey's *Hiroshima* might well be the most influential. In fact, journalism scholar Kathy Roberts Forde suggests that it may be the most widely circulated and respected *publication* of the twentieth century (2011, p. 562). Over 600,000 copies of the book were sold in the first year (Forde 2011, p. 572), not including the extensive circulation of the original *New Yorker* version, its extended life in many reprints and school classrooms, or the voluminous discussions in other media forums. The book follows the lives of six survivors of the atomic bombing of Hiroshima, which allowed readers to get a sense of the human suffering involved. The particular individuals chosen included two doctors, two clergy, and a widowed mother—relatable figures who allowed Americans to reimagine the citizens of a recent wartime adversary in a more sympathetic light. Though it bears witness to considerable suffering, *Hiroshima* is not a radical text. “Hersey's work,” writes Michael Yavenditti, “aroused many readers but incited few of them.” It carefully avoided criticism of the United States or its leaders, focusing instead on dramatizing and humanizing the effects of the bomb. “Hersey struck precisely the right note,” Yavenditti suggests, “by inviting readers to view the bomb victims as objectively as sympathetically as he had” (1974, p. 48). *Hiroshima* is not science journalism, nor does it claim to be. It is a human interest story that presents evidence of nuclear harm to its readers—and therefore helps shape public perception about the nature of that harm.

Yet there is something curiously nonnuclear about the text as well. As much as it anticipates some of the public discourse of the Cold War, it is also deeply rooted in narrative traditions that predate the atomic age. Fundamentally, *Hiroshima* is war reporting. By the time he embarked on the research for what would become his most famous book, Hersey was already a veteran journalist well-known for war stories;

his *A Bell for Adano* had gone through fifteen printings during World War II (Boyer 1985, p. 204). The pages of *Hiroshima* vividly bring to life not just the landscape of a bombed city, but also the lived experience of the citizens who inhabited it during the war's final days. In one passage, for example, Hersey writes:

The street was cluttered with parts of houses that had slid into it, and with fallen telephone poles and wires. From every second or third house came the voices of people buried and abandoned, who invariably screamed, with formal politeness, “*Tasukete kure!* Help, if you please!” The priests recognized several ruins from which these cries came as the homes of friends, but because of the fire it was too late to help. ([1946] 1985, p. 37)

Passages such as these make clear why one critic called the book “the best reporting to come out of this war”—seeming to assume the text was most relevant for the military conflict just past rather than the atomic age recently begun (Forde 2011, p. 567). Everything about this passage is geared toward recreating a wartime experience: the physical description of the changed street, the scattered voices, the sense of despair in describing people as “buried and abandoned,” and the touches of authenticity created by the Japanese language and the cultural detail—possibly apocryphal and certainly paternalistic—of the “formal politeness” of their cries for help. There is also a sense of irreversible change. “Because of the fire it was too late to help,” Hersey writes, thereby indicating how altered both the physical landscape and the social world had become. Almost every page of *Hiroshima* contains some similar re-creation of wartime devastation, and there is nothing particularly nuclear about the details included.

The same holds true when Hersey turns from landscapes and structures to individual bodies. In the first three-quarters of the narrative, there are occasional references to vomiting and other signs of radiation sickness. Until the final section, his focus is on the sorts of injuries that might have resulted from any kind of bombing: burns, broken limbs, and deep cuts. Like a street “cluttered with parts of houses,” Hersey’s account of the bodily suffering of bomb victims makes for powerful and disturbing reading. However, there is nothing necessarily nuclear about the details offered. One of the few reviewers to criticize *Hiroshima* focused on precisely this point. Mary McCarthy complained that Hersey had trivialized the atomic bomb by likening it to natural disasters—a “familiar order of catastrophes.” His chosen format, she writes, is simply incapable of communicating existential threat; the journalistic staple of interviewing survivors “is an insipid falsification of the truth of atomic warfare” (McCarthy 1946, p. 367). Not everyone has read Hersey’s choices in the same way. Patrick Sharp, for example, saw subversive potential in Hersey’s move to place the experience of survivors center stage. Nevertheless, he also affirms Hersey’s debts to established literary forms and authors—citing a narrative structure borrowed from Thornton Wilder, sparse prose reminiscent of Ernest Hemingway, and imagery from T.S. Eliot’s *The Waste Land* (Sharp 2004). Like many authors in the early nuclear age, Hersey was compelled to use preexisting literary forms in an attempt to communicate novel dangers.

In the fourth section, Hersey turns to one of the most indisputably new parts of the nuclear story: radiation sickness. To convey this experience over the weeks and

months after the Japanese surrender, he emphasizes mystery. In his rendition, there are not just confused individuals but an entire country trying to understand a baffling phenomenon (as well as a reporter experimenting with ways to represent it). Hersey opens the section by returning to the experiences of several of his main characters, providing details that the reader recognizes as symptoms of radiation sickness before the protagonists do. One survivor thought little of the fact “that the minor cuts he had received had not healed in three or four days,” and another “began fixing her hair and noticed, after one stroke, that her comb carried with it a whole handful of hair” (Hersey [1946] 1985, pp. 85, 87). The precipitous onset of symptoms was common: another “fell suddenly ill with a general malaise, weariness, and feverishness.” Hersey makes it clear that these victims did not understand the nature of their affliction, as the opening section of part four ends with his claim that they “did not realize it, but they were coming down with the strange, capricious disease which came later to be known as radiation sickness” ([1946] 1985, p. 88). Everything about this final sentence works to create mystery. The sufferers do not realize the cause of their illness, and since it only “came later to be known as radiation sickness,” they could not have known. Uncertainty was a necessary part of the experience of a “strange, capricious disease.”

Throughout the section, Hersey emphasizes uncertainty. Radiation sickness is described as an “unprecedented disease” about which “doctors could not be certain” ([1946] 1985, pp. 97, 98). Some people had “died so mysteriously” and others’ “wounds were unusually slow in healing” (Hersey [1946] 1985, p. 98). Such words and phrases evoke both uncertainty and unsettling novelty. Because Hersey’s approach prioritizes lived experience, readers get a sense of what his characters thought and felt, thus enabling the sense of mystery that pervades its final section. “Whatever its source,” Hersey writes, “the disease had some baffling quirks” ([1946] 1985, p. 100). Such uncertainty is, among other things, a challenge of representation. War journalism lends itself to depictions of broken bodies and buildings more easily than to radiation sickness. And so Hersey’s tone shifted. Whereas in the first three parts, he rarely deviated from his focus on the main characters, even for a single paragraph, in the final section, he does this consistently. There are descriptions of the efforts of Japanese physicists to understand radiation, the scope of the public health problem facing hospitals, and the beginning of the United States’ occupation. Nothing of the sort appears earlier in the book; consciously or not, Hersey must have realized that a different narrative strategy was necessary. As Gillian Beer points out in her work on evolution and literature, scientific discoveries often “call on evidence beyond the reach of our senses and overturn the observable world” ([1983] 2009, p. 1). The parallel is not exact, as our senses can certainly detect radiation sickness. However, it cannot be understood without the theory and apparatus of modern science. Therefore, Hersey’s story changes from a story of survival amid ruins to one of the quest to understand radiation.

This narrative choice succeeds in depicting risks, but Hersey ultimately does not follow through on the point. He certainly emphasizes the mysterious nature of radiation sickness. “As the symptoms revealed themselves,” Hersey narrates at one point, “it became clear that many of them resembled the effects of overdoses of X-ray, and the doctors based their therapy on that likeness” ([1946] 1985, p. 99). In this

rendering, the illness itself has agency; the baffled doctors are only able to prescribe treatment after “the symptoms revealed themselves.” However, the overall message is one of a threat contained. Hersey describes the efforts of Japanese physicists to determine if Hiroshima was still dangerously radioactive; this short narrative digression is a kind of scientific detective story that ended with the reassuring message that the city could be safely entered. The (eventual) presence of American doctors, along with the gradual recovery of the medical sector in Hiroshima, helped to alleviate the immediate crisis. Perhaps the most interesting resolution in the text is a non-resolution: Hersey simply changes the subject. Roughly halfway through part four, he starts talking about the rebuilding of the city, as within three months after the bombing, “citizens who had recovered from various degrees of radiation sickness” returned to the city and were quickly put to work in the reconstruction effort (Hersey [1946] 1985, p. 102). The transition is abrupt, and its narrative effect is that recovery from radiation sickness fuses with the recovery of the city. We have the beginnings of a detective story, but not the end. This leaves radioactive exposure in a kind of limbo—it is neither resolved in Hersey’s text, nor elevated to the level of true crisis.

Travel Diary

David Bradley’s *No Place to Hide* is a physician’s account of the 1946 Bikini tests, Able and Baker. Therefore, it reflects events from before the publication of *Hiroshima*, though the book itself did not appear until after Hersey’s account had entered popular discourse. Owing to his job as a radiological monitor, Bradley focuses much more squarely on radiation dangers than Hersey had; the prologue introduces readers to the *Independence*, one of the ships in the target area of the tests. He describes the visible damage it took during the two bomb blasts, but quickly changes to a “more impressive” consequence: “the disease of radioactivity lingers on her decks and sides and along her dingy corridors.” He then repeats this comparison, emphasizing that the ship had survived the air blast of Able and the tidal wave of Baker. “But the invisible poison of radioactivity,” Bradley writes, “she could not throw off” (1948, p. xi). Such comparisons highlight his primary focus and attempt to elevate this “invisible poison” to the level of atomic threats that had already received much publicity. *No Place to Hide* is not exclusively concerned with radioactivity; it also gives a detailed account of the preparations and events of the Bikini tests. However, its message focused on this lingering threat.

No Place to Hide highlights radiation dangers in a clear and compelling manner. In a log entry completed shortly after the first test, Bradley identifies “the real threat of atomic weapons” not as the blast itself, but instead “the lingering poison of radioactivity” (1948, p. 62). He also writes of the “rain of radioactive fission particles,” the lethality of which makes one “inclined to turn from calculus to Christianity for comfort” (Bradley 1948, pp. 87–88). Later, he notes that “these ships are fouled up with radioactivity to a degree far greater than anticipated” and that “this coat of radioactive paint cannot be scrubbed off or removed by any of the ordinary measures” (Bradley 1948, p. 116). The difficulty of effective decontamination is a major theme of the book; at one point, Bradley noted the persistence of even small amounts of

radioactivity by saying that “even the great Pacific itself cannot wash out a roentgen of it” (1948, p. 73). Even methods that demonstrated some efficacy, like sandblasting, pointed to problems as well as solutions. “You can’t sandblast a whole ship under battle conditions,” Bradley points out. “You can’t sandblast, Pearl Harbor, or Bremerton Shipyards, or Chicago” (1948, p. 131). The implication is clear: even escaping an atomic blast’s direct effects still presents civilian and military audiences alike with an insidious and perhaps intractable problem. Radioactive dangers were secondary (if still visible) in *Hiroshima*. However, no reader of *No Place to Hide* could have missed them.

Contemporary reviewers were quick to point this out. Writing in *The Washington Post*, Sterling North accepted Bradley’s “authoritative and quietly terrifying report” and worried openly that the atomic age might well threaten the “narrow margin” that makes the planet’s environment habitable to human beings (1948, p. B4). William Laurence—a reporter whose long association with atomic energy was marked by considerable enthusiasm for it—gave the book a similarly positive review. Laurence felt that *No Place to Hide* “will take its place as an outstanding human document of our times” and quoted approvingly Bradley’s assessment that:

Bikini is not some far-away little atoll pin-pointed on an out-of-the-way chart. Bikini is San Francisco Bay, Puget Sound, East River. It is the Thames, the Adriatic, the Hellespont, and misty Baikal. It isn’t just King Juda and his displaced native subjects about whom we have to think—or to forget. (1948, p. BR 1, 36)

The passage Laurence chose to cite was not the only time that Bradley tried to collapse the distance between the (perceived) remoteness of Bikini and the contemporary concerns of his readers. The literary scholar Molly Wallace uses *No Place to Hide* as an early example of an author recognizing the “global reach” of technology-induced risk; she is particularly intrigued by his claim that “‘Bikini is our world.’” Wallace notes the tense that Bradley employed. “This is not the move of so many commentators,” she writes, “to make nuclear events of the past into speculative models of the future” (2016, pp. 64–65). Instead, it is a rethinking of time and space. If Hersey’s world in *Hiroshima* was defined by discrete—if terrifying—local events, Bradley imagines the global environment changing into a world of shared risk.

Despite the similarities between *Hiroshima* and *No Place to Hide*—parallels that Bradley’s publisher did its best to point out—the books are oriented quite differently.¹ Hersey’s task was to make an undeniably spectacular event relatable. (Mary McCarthy’s critique was rooted in a feeling that he accomplished this too well.) There is no visibility problem with an atomic blast; the representational challenge is that it has a kind of overwhelming reality that makes it hard to process. Radioactivity is the opposite; it is simply hard to make legible. Bradley makes this clear early in the book. In his log for June 11, 1946—before even reaching Bikini—he

¹ The book jacket for *No Place to Hide* concludes with the assertion that “just as John Hersey’s HIROSHIMA made the fate of that city clear to millions of readers, so NO PLACE TO HIDE interprets these controlled explosions in terms of the whole world.”

notes that “it will be difficult to convince people of the dangers of radiation, dangers which are evident only upon the dial of some ‘Geiger machine,’ especially when you consider what minute amounts of radioactive materials are significant” (1948, p. 9). The predictive nature of this sentence is important; Bradley already knew from experience that it *will be difficult* to make a case for radioactive danger. Throughout *No Place to Hide*, this claim takes on a double meaning; it informs the context in which Bradley (in his role as physician) interacts with others at Bikini and how (in his role as author) he interacts with his readers.

The key to both interactions is the narrative form Bradley chooses. *No Place to Hide* is structured as a traveler’s log; the story unfolds entirely in chronological journal entries, in the roughly four and a half months from “Wednesday, May 29, 1946” to “Wednesday and Thursday, October 9 and 10.” The reader has no way of knowing the editorial process that transformed Bradley’s notes into his book, but its arrangement in diary form gives it a sense of objectivity and transparency. The entries provide numerous examples of the difficulty of understanding and measuring radioactivity. Part of this inheres in the available techniques. At one moment, Bradley acknowledges a difficult question: “are we getting evidence of radioactivity, or are we merely recording the statistical variation possible in the instrument?” (1948, p. 118). He is quite forthright about such difficulties and uncertainties throughout the book, although the reader is never left to doubt the ultimate authority of science. The various Navy officers and crewmen who populate the pages of *No Place to Hide* quickly learn to accept the methods and expertise of their new scientific colleagues; Bradley details the constant updates he and his fellow monitors provide to crews hungry for their reassurance. This is also reminiscent of detective fiction: Thomas writes that “the conventions of the form generally require the detective to explain what seems to be his uncanny act of second sight as the simple application of a technique, or even a technology, to the variables of the present occasion” (1999, p. 3). In this case, it is technology rather than technique, as Bradley’s use of the Geiger counter endows him with the authority to interpret the mysteries of radiation.

Some of the book’s most memorable moments relate Bradley’s interactions with Navy personnel baffled by the nature of the risks the scientists claim exist. Consider, among many examples, his recollection of one particular attempt at decontamination after the Baker test:

When the survey was complete the Chief turned his booted, sweating, profane, and laughing crew loose with brushes, water, and a barrel of lye. Yet when the hydraulics were done and the deck rinsed clean again, another survey showed the invisible emanations to be present doing business as usual. The portly Chief stood watching the dial of my Geiger counter, completely bewildered. The deck was clean, anybody could see that, clean enough for the Admiral himself to eat his breakfast off of. So what was all this goddam radioactivity? (Bradley 1948, pp. 109–110)

In this passage—and many others like it—Bradley’s two audiences merge. There is the immediate audience of the Navy crew, whom he must convince of the invisible danger—one knowable only through the clicks of a scientist’s tool. There is also the implied audience of his readership, who must undergo a similar

process of learning to trust a scientific account of a threat that cannot be detected by the senses. In both cases, Bradley depicts a deployment of technology that has strong echoes of detective fiction. Lawrence Frank has noted that, in the hands of authors such as Edgar Allen Poe, Charles Dickens, and Arthur Conan Doyle, such stories promoted “a new version of common sense that seemed to defy the everyday experiences of their readers” (2003, p. 4). This is precisely the narrative challenge that Bradley faced.

However, the significance of the log format does not end with the way it walks readers through the process of discovery. *No Place to Hide* is also a travel journal, as Bradley provides a record of his experiences that goes well beyond his work as a radiological monitor. Shortly after his arrival at the test site, for example, he notes some early impressions of the area: “the sun was rich with its tropical intensity, and the sky full of the clustering thunderheads. The beauty of this Bikini setting seems to belong to another world entirely, having no relation to the strange mission which brings us here” (Bradley 1948, p. 21). The added detail that he and his colleagues observed this while drinking beer on the shore makes it sound more like a tropical vacation than work done in the shadow of a pending nuclear test. This is far from an exceptional moment. Bradley writes of “the soft breezes and strange sounds of a Pacific night,” “a spectrum of greens and blues of marvelous intensity,” and “another sparkling day, with the ecstatic brilliance which heralds the end of summer” (Bradley 1948, pp. 8, 23, 136). These are not mere rhetorical flourishes; they are a persistent and integral part of how Bradley describes his life at Bikini—months that included reef exploration, fishing, and a dicey encounter with a shark. Such passages are quite prominent in the book, but appear only indirectly in book reviews and other contemporary discourse. There is at least some evidence that this narrative approach may have shaped its likely audience. The science fiction author Judith Merrill wrote to Bradley about his book: “few women have read it or will, because the technique you used for relief from strain, the tropical isle stuff, fishing, etc., is men’s reading exclusively” (Newell and Lamont 2005, p. 426).

Merrill’s suggestion has important implications for understanding *No Place to Hide*. Bradley’s work, in many respects, is more far-reaching than Hersey’s. As Molly Wallace suggested, his attempts to universalize Bikini anticipate several aspects of late twentieth and early twenty-first-century commentary on ecology and risk. Merrill’s critique reminds us that the book’s narrative structure also locates it in a more traditional genre. There is a long history of association between scientific achievement and the romance of expedition (Oreskes 1996). Bradley himself provides ample indication of how deeply the two are mixed in his narrative. “Our work out on the reef,” he writes, “was not far removed from youth’s ecstasy of exploration” (Bradley 1948, p. 106). This connection is central to what makes the book work. Other reviewers may not have felt the need to single out the travelogue qualities of the book because, in the context of late 1940s American science journalism, this was simply a quite natural move to make. Just as the apparent detachment of Hersey’s war reporting enabled audiences to accept his argument, so too did a familiar blend of adventure, danger, and science resonate with the readers of *No Place to Hide*.

Detective Work

Ralph Lapp's 1958 *The Voyage of the Lucky Dragon* entered a very different context than had greeted either *Hiroshima* or *No Place to Hide*. All three books appeared during decades in which popular science books commanded significant readership (Gormley 2016). However, they appeared at different moments in an evolving nuclear culture. Hersey's and Bradley's books were published during (or just after) what Paul Boyer has identified as the first of three major cycles of Cold War nuclear activism: the very early years, when scientists and others still hoped that an arms race might be avoided (1985). *The Voyage of the Lucky Dragon* was published near the beginning of the second wave, as fear of fallout prompted a new round of concerns in the latter half of the 1950s. Those years saw vigorous debate, both political and scientific, over the dangers of fallout from nuclear tests (Divine 1978). Lapp's chosen subject—the 1954 exposure of a Japanese fishing boat to fallout from a nuclear test—had perhaps inaugurated this era; Lapp himself wrote that the incident would “mark a turning point in history” (1958, p. 40). It dramatized the much greater risks of testing hydrogen bombs (as opposed to atomic ones), and it turned into a public relations nightmare for the Atomic Energy Commission (AEC). The AEC made the situation considerably worse by providing dismissive and misleading information (Hacker 1994, pp. 147–148). Therefore, Lapp did not have to introduce new arguments in the way that Hersey and Bradley did. Instead, *The Voyage of the Lucky Dragon* contains a full narrative arc, tracing the lives of the crewmen from before the ill-fated trip until significantly afterward. Lapp's extensive research (including interviews) allows him to paint sympathetic and informative portraits of not merely the individual protagonists but also the social, cultural, professional, and medical contexts central to the story. Part history, part journalism, and part popular science writing, *The Voyage of the Lucky Dragon* contains a novelistic form and sensibility despite being a work of non-fiction.

The book is structured as a detective story—in fact, as three overlapping such stories. The first takes place on the decks of the *Lucky Dragon* itself, as the crew tries to piece together what happened. When “the skies in the west lighted up and a great flare of whitish yellow light splashed against the clouds and illuminated the water,” some of the crew immediately thought that they had seen an atomic test (Lapp 1958, p. 28). Others pointed out that there was no mushroom cloud in the sky, and no reconnaissance planes were visible (Lapp 1958, pp. 29, 32). Lapp effectively details their process of discovery, showing their steady accumulation of clues from the nature of the falling dust, the variety of physiological symptoms, and the limited amount of research that the radio operator (Kuboyama Aikichi) was able to do as he “dug through his stack of books looking for one which he recalled described Hiroshima” (Lapp 1958, p. 49). The second piece of detective work was begun by a local high school student who had learned from two visiting relatives about the strange symptoms they had seen in the crew of the *Lucky Dragon*. He tipped off a local reporter, who doggedly pursued the story and ultimately earned a scoop for his paper and a promotion and raise for himself. As

with the events onboard the ship, Lapp tells this part of the story with dramatic flair and a sense of high stakes. Once the news broke and “a swarm of reporters, photographers, television cameramen and their assistants descended upon the pier,” it had become clear that the crew’s private mystery was now a national event (Lapp 1958, p. 80).

The third and final subplot involved Japanese scientists, who diligently pieced together the available clues to discover facts about the test that the AEC had hoped to keep secret. At this point, Lapp explicitly made the connection between doing science and solving cases: “like detectives studying fingerprints, the scientists used their Geiger counters to probe into the mystery of the ashes” (1958, p. 151). They eventually discovered the presence of uranium-237, and with it the ability “to make the very important calculations concerning the amount of radiation to which the fishermen were exposed” (Lapp 1958, p. 156). At least one reviewer noted the importance of form to this part of Lapp’s story; the physicist Arnold Kramish wrote of the “nuclear detective work” that was “effectively woven into the fabric of the tale” (1958, p. 808). Lapp tells each of these three smaller narratives in the style of a detective writer, moving from initial questions through subsequent clues, false turns, cooperative witnesses, and recalcitrant authorities. This lends both thematic continuity and narrative cohesion as the drama moves from sea to land to laboratory. As Lapp’s story develops, he focuses increasingly on the United States’ role in exacerbating the situation. On at least six separate occasions, he held his country accountable for not having warned the Japanese of the larger-than-expected test, as well as for failing to be transparent about the nature of the explosion. Writing in the *Washington Post*, book reviewer Warren Unna emphasized the serious but very limited nature of this critique. “Lapp has no quarrel,” he writes, “with the fact that unexpected winds in the stratosphere caused the fallout dust to spew off in a strange direction. His quarrel is with the AEC and Defense Department, which knew within an hour of the test explosion that something had gone wrong” (Unna 1958, p. E6). If the United States is the villain of the story, it is in this partial sense.

However, the villain is important to the narrative. In Lapp’s rendition, official recalcitrance serves to heighten the degree to which science is seen as heroic. Different decisions by those with insider knowledge shaped how people in the various affected venues—ship, media, fish market, hospital, and laboratory—dealt with the consequences of the Castle Bravo test. From the technically astute radio operator aboard the *Lucky Dragon* to the knowledgeable and talented scientists who unraveled the mysteries of exposure, scientific know-how plays the role of hero. As in a good detective story, there is little doubt that the investigators will triumph; Lapp writes that “it was inevitable that Japanese scientists would discover the truth once they started analyzing the ashes” (1958, p. 156). In his view, this only underscores the absurdity of the U.S. insistence on secrecy. It also highlights the way that narrative structures shape the transmission of information. Writing of a different science in an earlier time, Thomas suggests that “the detective narrative, in its deployment of these forensic technologies, and in its resemblance to them, helped to make nineteenth-century persons legible for a modern technological culture” (1999, p. 17). Much of what Thomas says about forensics in the nineteenth century holds true for radiological monitoring in the twentieth;

it is particularly apt when looking at the role of a new science in reading the subtle evidence that individual bodies can provide. A large portion of the evidence in Lapp's story—as well as Hersey's and Bradley's—concerns either the analysis of physical symptoms or the search for such signs. Radioactivity, of course, complicates the process by which science makes “persons legible”; it broadens the stakes to include collectives, not simply individuals. However, the importance of demonstrating causality from the evidence of individual bodies remains, making detective stories a natural literary model.

Lapp's work also shows the limits of this form. After establishing the successful detective work of Japanese scientists, he turns to one of the most controversial issues surrounding the *Lucky Dragon* incident. Lapp considers the question of what killed Kuboyama Aikichi—whose death six months after returning to shore made him the lone causality among the many sick crew. As Aya Homei explains, there were two plausible culprits. The first, widely assumed to be true in Japan, is that “he died as a consequence of radiation exposure” (2013, p. 221). The second, issued in a statement by a U.S. defense official, is that Kuboyama died due to “infectious jaundice” as a result of many blood transfusions (Homei 2013, p. 222). At issue is who (or what) should be blamed: the U.S. bomb test or the Japanese doctors? This matters for a host of reasons, as Homei points out, including the question of responsibility (legal and otherwise). Lapp leaves little doubt as to his position. Though he acknowledges the same uncertainty that Homei identifies, he argues that “if he had not been dusted with the radioactive ash he would never have needed a blood transfusion” (Lapp 1958, p. 176). In other words, even if one judges the proximate cause of death to be the transfusions, the ultimate origin lay with radioactive fallout. This is not an issue that can be fully resolved through detective work. At the intersection of radioactivity and international politics, simply determining what happened does not answer the question of blame as fully as it might in a mystery novel.

Importantly, however, such judgment is not the major point of the book. Lapp's critique is a limited one; he writes of the futility of U.S. secrecy in this one instance, but does not use that story to make a broader argument about nuclear testing. Form matters here as well. In much the same way that the formats of *Hiroshima* and *No Place to Hide* served to mute some of their potentially radical implications, so too did the narrative structure of *The Voyage of the Lucky Dragon* serve to narrow its applicability. Detective stories have resolutions. Criminals are caught, and mysterious situations are made explicable. Even in the somewhat more expansive story that Lapp tells, a broader critique of U.S. nuclear policy emerges only in the sub-text—if at all. Moreover, the scientist-detectives who solve the mysteries at hand provide reassurance that such understanding is possible, that order can be restored, and that reforms might be implemented. Lapp's world is not the messy one of which Rob Nixon writes in *Slow Violence*, where the “unstable, complex procedures—and hierarchies—of toxic recognition” resist definitive resolution (2011, p. 47). Nixon writes of the uncertainties, contingencies, and power relations that make just adjudication of responsibility an exceptionally tricky task. For all his pointed critique, Lapp writes of a world that is more ordered and more susceptible to reasoned intervention. The conventions of detective fiction help him do that.

(Non) Fiction

Fallout, as Joseph Masco has suggested, is not just a material consequence of nuclear tests but a way to view American modernity. This is a rich and multifaceted notion; among its many uses is to help us think through the way people have understood radiation. “Fallout,” Masco writes, “is therefore understood primarily retrospectively, but it is lived in the future anterior, becoming a form of history made visible in negative outcomes” (2015, p. 138). This highlights one of the key similarities between detective fiction and (some) science: both involve an attempt to reconstruct past events. Fallout, he argues, retains this historical nature even when projected into the future; assessing radiation risk is relevant, not simply because of what has already transpired. It is also a question of what has not yet occurred but *what will have happened* looking back from some future date. This is an even more daunting representational task than conveying the potential harm of an invisible and highly mobile threat like fallout, as challenging as that is. Telling the stories of radiation exposure involves constructing new ways of understanding not only sight and space, but also time.

John Hersey, David Bradley, and Ralph Lapp—among many others—recognized that facts alone are not sufficient for this task. That holds true whether the facts in question are uncovered by journalists, detectives, memoirists, or scientists. In a fascinating discussion on the role of literature in making sense of science, Tina Young Choi and Barbara Leckie write of “the potential of the novel to make evidence persuasive in the absence of empirical certainty” (2018, p. 575). This is precisely the situation confronting many popularizers—and defenders—of radiation exposure in the 1950s; the available facts often permitted a wide range of interpretations. Choi and Leckie suggest that fiction may well be more powerful than non-fiction in such a context, and there is much evidence to support this proposition. Nevil Shute’s *On the Beach* provides an excellent illustration of their theory. Of this influential book, Robert A. Divine writes simply that “more than any of the protests in 1957, *On the Beach* revealed the real anxiety of the American people over fallout.” He also highlights the tension between narrative and evidence. “Reviewers recognized,” he writes, “that Shute had written a potboiler that stretched available scientific evidence beyond the limits of credibility, yet they dealt with his work sympathetically” (1978, p. 162) This is a clear illustration of Choi and Leckie’s suggestion about what fiction can do—make evidence convincing despite the lack of clear proof.

The books under consideration here are non-fiction; none of them are as fully dependent on literary effects as is a novel like *On the Beach*. (In fact, this may be a critical factor in why they did not push political or cultural norms more than they did.) Nevertheless, all three authors did borrow from particular genres, which was key to the cohesion and appeal of their texts. It was also essential to their authority as works of popular science. Choi and Leckie do not merely suggest that narrative can take an under-sourced work and make it seem compelling—though that may well be true. Their point is that narrative itself can be a way of synthesizing evidence; it is not simply a value-neutral mode of communication. However,

like the scientific sleuthing they purported to show, popular texts often treated it this way; detective fiction proves to be a good way of helping maintain the illusion of objectivity. This is true in part because the form itself drew on models of scientific reasoning. Lawrence Frank writes that authors such as Poe, Dickens, and Doyle consciously incorporated science into their fiction. Hersey and Bradley used other genres—along with heavy doses of mystery—to similar effect (2003). Our analysis, of course, need not be tied to their assumptions. Nevertheless, we should recognize their power. We have become increasingly used to the idea that science is not separable from the mode of expression used to communicate it. This carries the comforting thought that we can effect change with critical attention to our writing and our speech. Perhaps. It also may be that the narratives we use to talk about science are harder to shake than we imagine.

Acknowledgements Thank you to Jacob Darwin Hamblin for the invitation to submit this piece, as well as for advice and suggestions on the article itself—along with Karen A. Rader, Linda M. Richards, Marsha Richmond, and two anonymous referees whose feedback greatly improved it.

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Erika Lorraine Milam, *Creatures of Cain: The Hunt for Human Nature in Cold War America*, (Princeton: Princeton University Press, 2019), 408 pp., 33 b/w illus., \$29.95 Cloth, ISBN: 9780691181882

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Accepted: 25 February 2021 / Published online: 16 March 2021
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In *Creatures of Cain*, Erika Milam is concerned with “racialized, gendered, and political landscapes in which conversations about human nature took place in the United States between 1955 and 1975” (p. 11). In fact, the history of these “conversations” reads like an unending battle for the human soul. Milam begins painting her picture of the aggressive human animal on the canvas of postwar optimism. Human evolution appeared as a path away from animal nature and towards the development of peace and brotherhood, even a post-racial age (through admixture). The elucidation of this deep past met with some restraints, however, as fossil evidence was still rather sparse, and in the context of the civil rights movements, cultural anthropologists questioned the admissibility of using indigenous groups as stand-ins for “our” evolutionary history. Animal behavior, and first and foremost the new primatological field studies, seemed increasingly promising. This message of anti-racism and human peacefulness was certainly not universal, but renowned scientists and scholars tried to bring such messages into schools and to the wider public, sometimes even choosing material such as ethnographic footage very selectively indeed to get the right moral across.

In the second part of the book, Milam introduces a clear break from this tradition with the theories of Robert Ardrey, Konrad Lorenz, and Desmond Morris. Ardrey did not invent the killer ape theory in his *African Genesis* of 1961, but he advertised it to a general audience. In his search for the nature of early man in Africa, he “promoted images of Africans that cultural anthropologists, civil rights leaders, and the designers of *Man: A Course of Study* were desperately trying to combat but that a reading white public eagerly consumed” (p. 91). Ardrey drew on the discoverer of the australopithecines, the importance of which for human evolution dawned on anthropologists in the 1950s, when arguing for their bloodthirst and armed aggression. This was clearly a story from the pen of a man who was

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not only an anthropologist but also a screenwriter. Ardrey's main argument was the importance of animal behavior for understanding human nature, particularly of the animal instincts of dominance and territory that in civilized man find expression in the striving for status, wealth, and power – the things women find attractive in men. Hence, *man* mostly meant *men*. While the book was a popular success, the scientific community did not widely engage with it. When it did, the response was mostly critical.

Contrary to Ardrey, the Austrian “animal psychologist” Konrad Lorenz was highly accredited and regarded as a founder of modern ethology. Nonetheless, when he published *On Aggression* (1966), the English-speaking readership seems to have lumped his more refined ideas together with Ardrey's killer ape. Lorenz was interested in the parallels between animals and humans and regarded instincts as purely inborn aspects of human nature that could, however, be held at bay by reason. Nonetheless, the claim for the genetic determination of traits easily made them seem unchangeable, as some critics noted. Furthermore, in addition to his involvement with the Nationalsozialistische Deutsche Arbeiterpartei, or NSDAP, Lorenz was accused of anthropomorphism and anecdotalism. The main debate, however, revolved around the question of whether humans were rational animals or their humanness meant that they were no longer instinct driven but had replaced, or should replace, instincts with cultural learning.

Entering the fray was a third, very popular but scientifically controversial book in 1967: Morris's *The Naked Ape*. This time the provocation really hit: Morris went on lecture tours, *Playboy* became interested, and Universal Pictures secured the film rights – no wonder, since Morris described man as the sexiest primate alive that had lost his body hair in order to be sexually more attractive. Morris had received his PhD from Oxford University under Nikolas Tinbergen, Lorenz's friend and co-founder of ethology. Still, while the media and the public were fascinated, though often throwing the three authors into the same pot, the spectrum of opinions within science was broad, with some evolutionary synthesists and humanists like George Gaylord Simpson and Ashley Montague at the opposite end from “the killer-ape theorists”. As if to signal public victory, in 1973 the film *The Naked Ape* appeared, combining live action with cartoons in a below-the-belt show of male sexual prowess and aggression.

It is in Part 3 that Milam engages with challenges to this kind of chauvinism. An increasing number of women in anthropology focused on the role of women in evolution, their contribution to contemporary societies and within nonhuman primate organization. The foci on female food provision and socializing, especially in the mother-infant bond, as well as the reevaluation of primate societies that had already been studied by men, put into perspective the emphasis on male aggression and the man-the-hunter theory at large. The challenge of the woman-the-gatherer perspective (Adrienne Zihlman) culminated in the open critique of the masculinist approaches by Elaine Morgan (who, unfortunately, somewhat disqualified herself by postulating an aquatic phase in human evolution).

In contrast, and possibly modelled on their own community networks, the anthropologists Robin Fox and Lionel Tiger have prioritized early male-male socialization and emphasized the exclusion and, at the same time, possession of women by

men, as an explanans for present society. With their demand that sociology needed to be put on a biological basis, they, to some extent, anticipated the new (socio-biological) synthesis of E. O. Wilson and Co. After an engagement in Part 4 with the application of the diverse scientific standpoints to threats such as the destruction of the environment, (nuclear) war, population increase – with high density figuring prominently as a cause for aggressive behavior –and more local challenges like the violent protests in the US, Milam discusses the controversies around sociobiology in Part 5. The causes and prevention of aggression grew into a concern of government, religious circles, education, as well as those themselves engaged in mass media and popular culture – groups with left, liberal, humanist, conservative, fundamental, scientific, entertainment industrial, and other standpoints that drew different individuals into heated debates.

While the historian of anthropology/biology is likely to be acquainted with the general outline of the debates that scientists also carried into the public, it is in such moments of widening the discussion even further that Milam, thanks to her history of knowledge approach, is at her best. This achievement is enhanced by the rich visual material from a broad spectrum of genres that she presents to the reader. I personally welcome her comprehensive outlook for following another thread than I did in my *History Within: The Science, Culture, and Politics of Bones, Organisms, and Molecules* (University of Chicago Press, 2016), in which I engage with (public) paleoanthropology from the end of the nineteenth century through the (public) challenges by “new Darwinists” from the 1920s onwards. After the Second World War, the humanist outlook of the latter gained international support and was taken on more strongly by some American figures like Theodosius Dobzhansky and Simpson, who also appear in Milam’s account. Instead of following the living pasts to offer human groups an orientation in socio-political presents from paleoanthropology and the new synthesis into genetic anthropology, as I do, Milam focuses on the role of animal behavior research. Most importantly—as in my engagement with the circulation of “scientific histories” in other disciplines, institutions (local to international), and in education, museums, literature, etc.—*Creatures of Cain* brings to light the ways in which the circulation of knowledge actually took place.

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