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ORIGINAL RESEARCH

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

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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 sociolegal 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 milliseviert)—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] Mitsuri 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 Minimata 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] Mitsuri 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 offsite 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; Mitsuri Katagiri and Aileen Smith Katagiri, Presentation, March 3, 1983, Folder 6, Box 5, Hess Papers.

[22] Mitsuri 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; Mitsuri 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/UC8phyT1CM4O8N7YJ_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 meterological 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).

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