Sara B. Pritchard

Japan Forum

An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima

Abstract

This essay uses literatures and concepts from environmental history, the history of technology, and disaster studies to analyze what took place at Fukushima Daiichi nuclear power station on March 11, 2011, and all that has transpired in the months since. In particular, it considers Charles Perrow's "normal accidents" and Thomas Parke Hughes's "technological systems," emphasizing the contributions and limits of these frameworks. It then uses the notion of envirotechnical systems, a blending of ecological and technological systems, to analyze the normal operating procedures at Fukushima as well as the emergency measures taken during the actual crisis. It argues that environmental factors such as radioactive elements, water, air, and also human bodies are critical to understanding how the events at Fukushima unfolded. Yet there is a risk in naturalizing the disaster. Ultimately, a complex, dynamic, porous, and inextricable configuration of nature, technology, and politics helps us understand all that "Fukushima" now signifies.

Sara B. Pritchard, "An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima," *Environmental History* 17 (April 2012): 219–243.

doi:10.1093/envhis/ems021
Advance Access publication on February 23, 2012

Introduction

It was a triple disaster: a magnitude 9.0 earthquake followed by a 14-meter tsunami and the subsequent full meltdown, possibly even melt-through, of three of the six nuclear reactors at the Fukushima Daiichi nuclear power station owned by Tokyo Electric Power Company (TEPCO) in northeastern Japan.[1] A single word—Fukushima—now stands for the multifaceted complexity of the events that took place on March 11, 2011, and all that has transpired in the months ever since.[2]

Even before Fukushima, the early twenty-first century had already offered environmental historians several significant teaching moments—for better and for worse.[3] Now the triple disaster provides yet another opportunity for environmental historians to engage with pressing questions—questions about the construction and maintenance of energy regimes, both politically and technologically, in the modern world; the development, expansion, and implications of the atomic age for both humans and nonhumans; and the relationship between nature (including human bodies) and technological systems.[4]

Several leading scholars, including sociologist Charles Perrow and historian Thomas Parke Hughes, have studied the design and operation of large-scale modern technological systems like those at Fukushima.[5] Building on their insights, in this essay I examine Fukushima as an envirotechnical disaster, a result of the convergence of natural and sociotechnical processes.[6] I argue that the concept of envirotechnical systems is a useful way to explain what happened at Fukushima that also goes beyond what Perrow and Hughes offer through their concepts of "normal accidents" and technological systems, respectively. In the final section, I use the notion of envirotechnical regimes to stress the strategic configuration of Fukushima's envirotechnical system, in particular highlighting the ways in which political and economic power shaped the making of the facility, both during normal operations and during the events that began to unfold on March 11, 2011.

Envirotechnical Analysis

In 1984 Charles Perrow published *Normal Accidents*, his now classic study of the partial meltdown at Three Mile Island five years earlier, arguing that complex, tightly coupled systems like the nuclear reactors at Three Mile Island (and, as it turns out, the ones at Fukushima) invariably lead to accidents.[7] In his analysis, Perrow highlighted the unpredictable dynamics of these sociotechnical systems given their size, complexity, and inextricability.[8] Journalists from the *New York Times* expressed a version of Perrow's idea two days into the Fukushima crisis when they described "a cascade of accumulating problems."[9]

Perrow asserted, however, that it is misleading, if not hazardous, to use the common term *accidents* to describe situations like Fukushima because it minimizes the inherent risks of modern technological systems.[10] Such language implies that accidents are caused by technical glitches or human error when instead they should be understood as inherent to those systems. In short, accidents are normal and systemic, not extraordinary and inadvertent.[11] Yet, in the aftermath of disasters like Chernobyl, Hurricane Katrina, the blowout at BP's Deepwater Horizon drill rig, and now Fukushima, government regulators and industry officials often focus on trying to fix the technology in question and attempting to reduce the likelihood of future human error, rather than asking deeper, far more difficult questions about those technologies—questions such as whose goals do these technologies serve? What political and economic interests shape the design and use of complex technological systems? And what assumptions about the natural world and human–natural relations are embedded in these technologies?[12]

Also in the mid-1980s, Thomas Parke Hughes theorized the concept of technological systems within the context of the history of technology. In his influential book *Networks of Power* (1983), Hughes traced the development of electricity networks in the United States and Western Europe, demonstrating their establishment by a coalition of entrepreneurs, politicians, and engineers. By focusing on systems, Hughes showed how technological artifacts rarely exist in isolation. Moreover, "system builders" create not just technical infrastructure like power lines but also the capital, political support, market demand, and values that help enable and perpetuate that system.[13]

Hughes's understanding of technological systems was predicated, in part, on an explicit conceptualization of the relationship between the environment and technology. As Hughes declared, likely echoing the language and mindset of the systems theorists he studied, "Those parts of the world that are not subject to a system's control, but that influence the system, are called the environment. A sector of the environment can be incorporated into a system by bringing it under system control. An open system is one that is subject to influences from the environment; a closed system is its own sweet beast, and the final state can be predicted from the initial condition and the internal dynamic."[14] In Hughes's view, technological systems "incorporate" the environment if and when they need, say, coal, oil, copper, or a river's flow.[15] At the same time, Hughes suggested that such factors can "influence" systems, at least "open" ones. By conceptualizing technological systems in this way, Hughes assumed and thus reproduced a clean boundary between technology and the environment. Yet Hughes held a much more uncertain view regarding nature as a technological agent, his ambivalence ultimately destabilizing such a clear-cut assumption. In his formulation, technology shapes the environment; but at certain times, the environment can also influence technology.[16]

Perrow was wrestling with these very issues on the edges of his own work. He is best known, of course, for the concept of normal accidents, but Perrow developed an ancillary concept, "eco-system accident," predicated on something called an "eco-system" (not to be confused with ecosystem), in his thick tome. Perrow did not define eco-system, but he did define eco-system accident. As he put it, such an accident is the result of "an interaction of systems that were thought to be independent but are not because of the larger ecology." More precisely, "eco-system accidents illustrate *the tight coupling between human-made systems and natural systems*. There are few or no deliberate buffers inserted between the two systems because the designers never expected them to be connected."[17] Perrow argued, then, that historical actors (with technical experts the foremost suspects) may have conceived of technological systems as distinct from natural systems, but he questioned these assumptions, maintaining that while actors may have firmly and neatly cleaved technological and natural systems, this was actually difficult to achieve in practice. According to Perrow, eco-system accidents result precisely from the inability to realize this goal, which brings us back to Fukushima.

Given what has already taken place in Japan, not to mention what will no doubt develop in the years ahead, Perrow's eco-system probably resonates with us more than Hughes's technological system. Indeed, it seems increasingly tough to sustain the tidy categories, as well as some of the suppositions, informing Hughes's concept of technological systems. After all, Hughes expressed confidence in "system control" and seemed to advocate the realization of closed systems (those "sweet beasts"). Hughes's analytic framework may reflect, then, the modernist technocratic ideals of his so-called expert actors.[18] Furthermore, although Hughes left room for the environmental shaping of systems, he seemed to suggest that technology can, will, and should ultimately control nature. Environmental historians, who generally relish evidence of the dynamism, complexity, and mutual shaping of nature–culture, will likely find such arguments difficult to understand, let alone defend. This is particularly true now, in the early twenty-first century, with climate change altering supposedly remote environments, technologists seeking to mimic nature, and endocrine disrupters challenging the seemingly stable category of sex.[19] Hybrids of nature–culture and nature–technology surround us. And, arguably, we humans are hybrids, too.[20] Fukushima may not only confirm these insights but even come to illustrate them in ways that are powerful, disturbing, and also humbling.

Both Perrow and Hughes, though, help us begin to understand scenarios like Fukushima. Perrow's work challenges reductive thinking and has allowed scholars, not to mention technologists and policymakers, to perceive the systemic vulnerabilities within complex technologies like nuclear reactors.[21] For instance, in the case of Fukushima, high pressure inside the reactors made it difficult for emergency workers to inject necessary cooling water. Consequently, in one of the Faustian bargains that were made and will continue to be demanded in Japan, plant operators repeatedly released vapor contaminated with radioactivity to reduce the pressure within the reactors to avoid an even more catastrophic situation.[22] In addition, Perrow's less known notion of "eco-system accidents" may have particular appeal to environmental historians, especially after Fukushima. Hughes, meanwhile, reminds us—citizens, technical experts, and scholars alike—to take heed of the whole. Backup generators, for example, may seem mundane technologies, especially in the so-called advanced West, but as Fukushima made abundantly clear, they are critical to the safe operation and shutdown of nuclear power stations in times of emergency.[23]

At the same time, scholarship at the intersection of environmental history and the history of technology both extends and refines the important contributions that Perrow and Hughes offer us as scholars and also as planetary citizens.[24] Over the past two decades, those working at the nexus of these fields have developed several historical and analytical insights. Some have focused specifically on actors' ideas about nature, technology, and their relationship, sometimes tracing how these cultural attitudes then shaped interactions with the material world. Particularly crucial is actors' strategic definition of these terms, for example, hydraulic engineers naturalizing dams to help justify large-scale intervention in human and nonhuman communities.[25] Other scholars have explored how various historical actors used the environment, particularly managed and harnessed "natures," as technology to do things.[26] Still other scholars have argued that environmental factors shape (but do not determine) technological change, an assertion that modifies recent accounts of technical development within the history of technology, which has worked to highlight the social, political, and cultural shaping of technology.[27] Together, envirotech scholarship, which has been influenced by theoretical work on hybridity, actor networks, and coproduction, has sought to explore dynamic relationships between nature and technology—physically and culturally, historically and historiographically.[28]

Integrating the contributions of this literature with the insights of Perrow and Hughes better explains what took place at Fukushima and why. Envirotech scholars push us to see the environment as *always* part of technological systems, not just, as Hughes asserted, of "open" systems. The concept of *envirotechnical system* encapsulates and specifically foregrounds this dynamic imbrication of natural and technological systems.[29] As the term itself suggests, we might think of these systems as mutually articulating.[30] Yet, as Fukushima showed, their choreography is not necessarily synchronized or even synchroniz*able*.[31] However, these specific reblendings of environmental and technological systems do not emerge out of thin air. Rather, they arise from specific historical, cultural, and, importantly, political contexts. Thus a related concept—*envirotechnical regime*—stresses the historical and political production of envirotechnical systems like those at Fukushima. This concept emphasizes the specific, often strategic reblending of natural and technological systems to serve particular ends, although, as Fukushima demonstrated, these configurations do not always develop exactly as the people and institutions promoting them intended. Radioactive elements may have been harnessed to produce energy, yet as we are now painfully aware, their properties did not easily conform to mechanistic models. Envirotech perspectives also call attention to how historical actors thought about the definition, relationship, and dynamics between natural and technical systems, often quite strategically. In the wake of Fukushima, for example, government regulators and industry officials have conveniently pointed to the earthquake and tsunami in an attempt to absolve themselves of responsibility. These kinds of insights thus complicate and enrich Hughes's understanding of technological systems, in the process lending more credence to Perrow's "normal accidents."

Interpreting "3-11"

On one level, Fukushima's reactors were envirotechnical by design. Radioactive elements fueled nuclear chain reactions that eventually generated electricity—the whole point of the facility.[32] Reactors "incorporated," to borrow Hughes's phrase, water to regulate cooling processes in their cores, as well as the storage ponds housing thousands of spent fuel rods.[33] From the outset, these entities were at once both natural and technological in that they were mobilized for their valuable properties yet also managed in specific ways, from producing energy to diffusing heat. Almost two decades ago, Arthur McEvoy also encouraged environmental historians to consider the bodies of workers—in this case, usually short-term laborers subject to questionable labor, health, and safety standards—as part of the nature of industry.[34] While some environments were integral to the basic functioning and operation of the reactors, others were explicitly kept out. Or at least this was the goal. Engineers designed the facility to withstand a maximum tsunami height of 10.5 feet. Because the complex was located on a cliff 13 feet above the Pacific Ocean, they believed that Fukushima Daiichi would be safe. But on March 11, 2011, the tsunami was almost twice the combined height of the facility and cliff.[35]

During the actual crisis, government officials, plant managers, and workers both tightened and transformed the imbrication of the natural and the technological at Fukushima. We can see these processes at work by examining, in turn, water, air, and the bodies of workers at the complex, although it is worth noting that these terms do not fully represent their hybrid forms at Fukushima. Water was at the center of emergency measures during the initial phase of the crisis. As the first forty-eight hours of the disaster unfolded, our television and computer screens were filled with images of standard firefighting equipment—trucks, hoses, and diffuse spray, all of which seemed utterly dwarfed by the enormous facility. The fear was that failing to restore normal cooling processes or establish effective emergency measures to replace them—and quickly—might lead to a catastrophic situation. As reporters from the *New York Times* explained in rather dry language on March 13, "A partial meltdown can occur when radioactive fuel rods, which normally are covered in water, remain partially uncovered for too long. The more the fuel is exposed, the closer the reactor comes to a full meltdown."[36]

Indeed, water levels inside the reactor cores had already begun to fall. Estimates varied during the initial few days, in part because key gauges were not working properly.[37] However, government officials and industry specialists guessed that the top 4 to 9 feet had been exposed to air, which risked leading to a partial and possibly full meltdown of the reactor cores. To compound matters, it was not just water in the cores that incited concern. It was also the cooling ponds for spent fuel rods, recently discharged from the reactor cores and thus highly radioactive. Just two days into the disaster, experts had already expressed fears that some of these rods had become exposed to the air and begun emitting gamma radiation, the most lethal form of radiation to people.[38] The material properties and qualities of water from the surrounding natural environment initially external to the facility were thus vital to the safe operation of a complex, ostensibly high-tech system. The emerging crisis highlighted, indeed magnified, this dependency.[39]

Part of the problem facing those trying to control the situation at Fukushima is that nuclear reactors are never—and can never be—completely off. A nuclear chain reaction may be stopped and the reactor is, at least in theory, safely shut down at that point. Fukushima's managers and technicians did have time to perform these protocols before the reactor cores started melting. This was a major difference from Chernobyl, which also lacked a hard containment shell. However, residual heat in the reactors remains for two reasons. First, the reactors had been operating at high temperatures (550°F) that resist dissipating very quickly. Second and more importantly, the fuel still produces heat, even once the facility has technically been turned off, due to continuing radioactivity, the release of subatomic particles, and of gamma rays. It may be only 6 percent of the heat produced during normal operations, but that is still plenty. Pumps must therefore keep water circulating through the reactor core and spent fuel storage ponds, and, crucially, the temperature of that water must be closely regulated by pulling warmed water to a heat exchanger and bringing in new cool water to draw off that heat. Otherwise, the cooling fluid will evaporate—and, unfortunately, rather quickly. Recalling Perrow, a cascade effect threatens to make a bad situation even worse: as radioactive decay continues, more heat is produced, which boils off more water, causing water levels to drop further, exposing more fuel to steam and air, which results in greater fuel damage, raising temperatures even higher, which causes even more water to evaporate, and so on. This downward spiral only increases the possibility of a meltdown. Without electrical power at Fukushima, customary cooling processes were inoperable and thus ineffective, thereby precipitating precisely the kind of scenario described earlier.[40]

Several hard-learned lessons have come to light in the hindsight of 3-11 and its continuing aftermath. The properties of radioactive elements and water—and, importantly, how they interact with one another—matter during both normal operations and "normal accidents." Radioactive elements also do not and cannot conform to the mechanical idea—or perhaps ideal—of an on/off switch. In fact, when it comes to nuclear reactors, the common and convenient dualism of on/off is not only reductive but inadequate; as we have seen, the reality is much more complicated.

However, although the plant's cooling system and backup support had failed, operators perceived the nearby Pacific Ocean and the air surrounding Fukushima as part of an emergency control system. Or rather, they could become part of that system, indeed vital to it. Consequently, Fukushima operators quickly developed a makeshift practice whereby they flooded—or tried to flood—the reactors' containment vessels with seawater and let the fuel cool by boiling off that water.[41] However, as that water boils, pressure in the vessel increases and can become too high to inject more water. As one American official explained, forcing water into the vessel is like "trying to pour water into an inflated balloon." They therefore "have to vent the vessel to the atmosphere, and feed in more water, a procedure known as 'feed and bleed.'"[42] The key was to ensure that plant operators kept an adequate supply of water flowing into the containment vessels to make up for the lost water as it heated, turned into steam, and was eventually vented. Instrument problems only compounded an already difficult situation because technicians were not sure how much water remained in the reactors and therefore how much more water needed to be injected. In effect, they were "flooding blind." Furthermore, the emergency solution was not even a short-term fix. Nuclear engineers estimated that the process of injecting water could entail several thousands of gallons per day, for "potentially as long as a year."[43] After all, given the radioactive elements' continuing decay (not to mention their long half-lives), the process of injecting water, followed by its warming, evaporation, and sanctioned release, would necessarily be ongoing. In retrospect, we now know that these efforts, heroic but piecemeal, did not prevent the meltdown of three reactor cores.

The emergency practices did, however, create new relationships between ecological and technological entities within and outside Fukushima, demonstrating that the boundaries of these systems were fluid, dynamic, and negotiable. Some of the ensuing relationships were inadvertent because certainly no one had wanted or planned the earthquake, tsunami, or reactor problems at Fukushima (let alone all three) in the first place. Nonetheless, the tsunami had blurred the borders of the Pacific and nuclear reactors, hydraulic and atomic. But, as we have seen, other relationships were intended to solve or at least diminish the severity of the disaster, precisely because plant operators and nuclear regulators perceived environmental and technological boundaries as negotiable and sought to make them even more permeable as part of their crisis management efforts. The "feed and bleed" procedure is a prime example of the ways in which borders broke down because historical actors perceived them as porous and reacted accordingly. Yet, in the process, desperate officials and workers ended up unintentionally introducing new wrinkles in the "cascade of accumulating problems" at Fukushima Daiichi.

The influx of seawater from the Pacific Ocean, later laced with boric acid to prevent the fuel from reaching criticality, attempted to contain a situation that seemed to be spiraling out of control.[44] That fluid may have averted even more disaster; and yet, this solution ended up creating a new problem: the liquid, once savior, had now itself become dangerous, a risk object.[45] Not all of the doctored seawater injected into the reactors boiled off (and thankfully so). Consequently, what remained became contaminated with radiation as well. By late June 2011, more than 100,000 metric tons of "water"—in reality, a salty noxious mixture of seawater, fresh water, and radioactive materials—had collected in the bowels of the stricken reactors. One journalist called the brew "a radioactive *onsen* (hot bath)," an erroneous translation of the Japanese word for natural hot springs.[46] Moreover, every day an additional 500 metric tons of seawater is poured into the facility because leaks have prevented normal cooling systems from being restored.

To contend with this literal and figurative overflow of contaminated liquid, TEPCO installed devices to filter radioactive residue from the infusion. The utility did so for two reasons: to reduce the volume of contaminated fluid overall and to decrease the amount of radiation so that some of that fluid could be reused on the fuel rods. After all, the rods still needed to be cooled, but without being filtered first, the infusion would leave radiation levels in the reactors too high for cleanup workers to continue their mitigation efforts. Importantly, this precaution suggests not only that human bodies were themselves becoming envirotechnical objects, but also that actors perceived them as such, points to which I return. However, a trial run with the filtering devices was aborted after less than five hours when it captured as much cesium 137 as they expected to be filtered in an entire month. In addition, the capacity of enormous tanks TEPCO delivered to store some of the excess fluid proved entirely inadequate, especially as workers continue to spray the reactors daily. Facing a situation that evokes Sisyphus, TEPCO released more than 11,000 metric tons of the toxic brew into the Pacific in April 2011. The rationale? Dumping less contaminated water allowed limited storage facilities to be dedicated to more highly contaminated water. Only two months later, more sanctioned releases were expected.[47] If the enormous tsunami had confounded the boundaries of the oceanic and the atomic, sea and reactors, then cleaning up Fukushima only blurred those borders even more.

Other boundaries were also transgressed at the nadir of the calamity: just as the water of the Pacific became an integral part of Fukushima in the attempt to manage the crisis, so too did the atmosphere surrounding the facility. Once doctored seawater was injected and began boiling, plant operators planned releases of steam to reduce the pressure in the reactors. The aim here was to ease the infusion of even more fluid while simultaneously reducing the likelihood of a catastrophic explosion that might rupture containment shells and release much higher doses of radiation from the reactor cores and spent fuel storage ponds into the atmosphere. Radioactive contamination within the reactors meant, however, that this vapor was contaminated as well. Initially, when the fuel was intact, the steam workers released was infused by "modest" amounts of radioactive materials "in a non-troublesome form." However, as the condition within the reactors deteriorated and fuel became damaged, that steam became "dirtier."[48] Without these planned releases the situation might well have worsened. Still, they were apparently not enough. Explosions rocked four of the reactors during the first few days, indicating that technical experts did not have as much control over the process of venting excess pressure as they had hoped. These episodes undermined confidence in the notion of system control, suggesting that large-scale modern technological systems were more vulnerable than many believed or represented.[49]

I have focused thus far on the complex dynamics of radioactive elements, water, and air in and beyond the reactors. But we must not forget the human element—from the so-called Fukushima Fifty, a core set of workers who remained at the facility as the crisis deepened in a desperate attempt to regain control over the precipitous cascade of events, to the more than eighteen thousand men who had participated in cleanup efforts by early December 2011.[50] These workers were vital to the system in a situation of crisis. Their labor, their physical bodies, which attempted to feed and bleed, flood and vent in precariously precise proportions, were crucial to getting the new envirotechnical system of Fukushima under control, indeed modifying it to reduce the level of risk. However, the degree of their radiation exposure is yet unknown and will probably be debated, if not hotly contested. Given their extended proximity to Fukushima, these workers will likely embody, quite literally, new configurations of the natural and technological in the latest chapter of Japan's atomic age.

TEPCO and nuclear regulatory officials themselves perceived these connections, both as the disaster unfolded and as the herculean cleanup efforts have begun. Four days into the crisis, TEPCO's leaders asked the government to allow them to pull the remaining skeleton crew of workers, obviously fearing these men would be exposed to extremely high doses of radiation.[51] The nuclear power utility thus constructed workers' bodies as a site where the atomic and biological were coming together dangerously during the disaster. Conveniently, this allowed the company to claim that it was concerned about the health and safety of these nuclear heroes, a concern that they had apparently not had for workers during the facility's normal operation and maintenance.

During mitigation, thousands of workers are part of the new system at Fukushima. These temporary laborers are let go from their jobs once they reach their radiation exposure limit, a practice that again suggests how actors perceive—and fear—the merging of the natural and the technological in the workers' own bodies. Structuring labor in this way is thus not only a political and economic act, a point I will discuss later, but it is also an envirotechnical one. Unfortunately, these workers have a strong financial incentive to forget the dosimeters that measure their radiation exposure during a given shift to prolong employment, thus increasing their levels of exposure. Their bodies suffer the consequences.

Power and Politics at Fukushima

As an environmental historian, I have not only emphasized the nature of the technological system at Fukushima but also argued that we should think of these systems as envirotechnical to capture the ongoing ways that environmental processes shape and are shaped by technologies. Doing so helps remind us, as William Cronon argued in his celebrated essay "The Trouble with Wilderness," that humans are part of the natural world—even, we might add, in highly managed, engineered technological spaces like those of nuclear reactors.[52]

However, there is a real risk in naturalizing 3-11—paying too much attention to environmental factors and processes involved either in the normal functioning of these reactors or during the crisis. Over a decade ago, Ted Steinberg stressed the unnatural history of so-called natural disasters in his book *Acts of God*. Unfortunately, Hurricanes Katrina and the oft-forgotten Rita and the differential effects of earthquakes in places like Haiti and Chile have recently only reconfirmed Steinberg's insights.[53]

In fact, some Japanese actors today are wary of analysis that stresses the role of nonhuman nature in modern technological systems or anything resembling what Brett Walker calls hybrid causation.[54] Although it may be tempting for scholars to dismiss their understanding of historical causality, arguing that it is too simplistic, the past very much matters to citizens of Japan today. And it informs their views of nature, technology, politics, and their relationship. Other calamities—perhaps most prominently, Hiroshima, Nagasaki, and Minamata—understandably loom large in the nation's memory, particularly for those active in citizens' movements and the litigation related to these crises. In their view, focusing, say, on the properties of mercury or how different organisms, including humans, absorbed it at Minamata diverts attention from the corporate and government decisions that contributed to the poisoning of two thousand victims in the 1950s, with an untold number of others not officially recognized. In short, they fear that multicausal accounts reflecting complex understandings of historical agency that decenter people as primary causal agents threaten to diffuse, if not undermine, the responsibility and ultimate culpability of powerful groups.[55] Given that the lengthy court battle over Minamata only ended on March 22, 2011, eleven days after the situation at Fukushima began, the protracted legal process likely explains these citizens' skepticism about framing technological systems as envirotechnical.[56] After Fukushima, they may be even more dubious.[57] It seems, at least at first glance, too apolitical: pointing to environmental factors can naturalize a crisis while technical explanations carry the false sense of objectivity, both of which evade fundamental questions of power.

Yet, as Douglas Weiner so nicely put it in his American Society for Environmental History presidential address several years ago, "Every environmental story is a story about power."[58] Indeed, politics are central to the Fukushima of today because they are central to its history. They were inscribed into the facility from the very outset, starting with Japan's decision to develop atomic energy. Facing growing pressure from the antinuclear movement, industry supporters, not just in Japan, invoked the mantra of safety time and again.[59] Yet, as one former plant operator stated after Fukushima, "You can take all kinds of possible situations into consideration, but something 'beyond imagination' is bound to take place, like the

March 11 tsunami."[60] As he suggests, probabilistic thinking, which inherently downplays possibilities like a magnitude 9.0 earthquake or 14-meter tsunami (let alone both), dominates the nuclear industry, although it is certainly not unique. For example, this tendency toward probabilistic thinking is signaled by the fact that Japan's Nuclear Safety Commission (the equivalent of the US Nuclear Regulatory Commission) did not include any measures regarding tsunamis in its guidelines until 2006, long after the country's reactors were actually built.[61] Perrow argued in an essay published several weeks after Fukushima that we should instead "consider a worst-case approach to risk: the 'possibilistic' approach," a concept articulated by sociologist Lee Clark.[62] There are, of course, powerful vested interests against adopting such an approach. Highlighting two factors, the ways in which notions of the nation and the nuclear have become entwined in the post-1945 world, including in Japan, helps to explain past decisions such as this "safety myth" and inadequate government regulation of TEPCO.[63] In addition, economics are a powerful form of politics. One TEPCO engineer admitted that he falsified records regarding the containment vessel of reactor number 4, and design decisions may have prioritized convenience and economy over safety.[64]

Politics also significantly shaped the ways the natural and the technological intersected at Fukushima, whether before 3-11 or after. The concept of envirotechnical regime foregrounds the politics of this process, including how particular groups and institutions pushed for linking nature and technology in specific ways, both in situations of normalcy and those of crisis. Let me return to three examples that I have cited in this essay.

First, Japan established and expanded a nuclear industry on the edge of the Pacific Ring of Fire, a perimeter known for its major earthquakes and potential for destructive tsunamis. Imperatives of reconstruction, nation-building, industrialization, and modernization drove such decisions in spite of the hazardous environment in which they were being undertaken. Lesson? In the context of powerful political and economic motives, supporters of nuclear power in Japan conveniently differentiated natural and technological systems, even as these material linkages were actually being forged and strengthened on the ground.

Second, the timing of the seawater injections at Fukushima has been much contested. It has been suggested that TEPCO's administration delayed flooding the reactors with water from the Pacific because doing so "amounted to sacrificing the reactors."[65] As *Wall Street Journal* reporters wrote on March 19, "TEPCO considered using seawater from the nearby coast to cool one of its six reactors at least as early as last Saturday morning, the day after the quake struck. But it didn't do so until that evening, after the prime minister ordered it following an explosion at the facility. TEPCO didn't begin using seawater at other reactors until Sunday." According to Akira Omoto, a former TEPCO executive and a member of the Japan Atomic Energy Commission, the utility "hesitated because it tried to protect its assets."[66] Lesson? Seawater injections may indeed illustrate the reblending of environmental and technological systems at Fukushima, but the context, timing, and meaning of that process matter as much as the act itself. In other words, it is not just that the oceanic and atomic were again linked through the desperate emergency protocol, but that they were connected only when TEPCO, pressured by government officials, was forced to recognize how truly disastrous the situation had become.

Finally, the "Fukushima Fifty" have received a great deal of attention, heralded in the national and international media for their selfless sacrifice. But, as we have seen, many more labor below the radar screen—or, perhaps more aptly, the dosimeter. However, it is not just a question of the forgotten masses, focusing on the nuclear heroes at the nadir of the crisis while ignoring the thousands of short-term workers carrying out cleanup as the disaster fades from our memories—at least for those of us who are located thousands of miles away from northeastern Japan. Rather, as Gabrielle Hecht powerfully shows, the political and economic context of their presence, their work, and their bodies is noteworthy. The structure of subcontracting work in the nuclear industry—in Japan and elsewhere—is such that these workers, often called "nuclear nomads," are basically left unprotected by environmental health and safety regulations, unaccounted for by corresponding statistics. Furthermore, most of them are men from the evacuation zone surrounding Fukushima who are desperate for work because the disaster left them unemployed or poor day laborers who live in slums surrounding Japanese cities. This practice conveniently elevates the safety ratings of a given utility like TEPCO or that of the nuclear industry overall while reducing official statistics regarding human health exposure. Lesson? It is not just any bodies that are being exposed to increased rates of radiation in Japan, before and after Fukushima.[67] Rather, some of the poorest, most economically vulnerable people in Japan are more likely to be affected (and affected more significantly) by the merging of the biological and the atomic.

As these examples illustrate, the political shaping of Fukushima's technological system is unquestionably vital. But it alone does not explain the triple disaster. Obviously, the enormous earthquake and tsunami have a bearing. As do the properties of radioactive materials, water, air, and human bodies, and the relationships among them both during normal operations and "normal accidents," both purposefully and inadvertently. At the same time, as the concerns of skeptical Japanese citizens suggest, it is indeed hazardous to focus on the nature of the disaster alone, isolating it from the larger system of which it was a critical part. It is precisely the complex, dynamic, porous, and inextricable configuration of nature, technology, and politics that *together* helps us understand all that the single word "Fukushima" now signifies.[68] It was due to an earthquake, nuclear reactors, *and* delayed injections. A huge tsunami, backup generators located in the basement, *and* probabilistic thinking. Continued radioactive decay, spent fuel ponds, *and* weak government oversight of industries characterized by high-modernist technologies. As Michelle Murphy states in a different context, "*And. . . . And . . . And . . .*"[69]

Fukushima explodes, so to speak, Hughes's idealized representation of "closed" and "open" technological systems, where "closed" systems are those that have brought the environment under system control and "open" systems remain subjected to environmental influences.[70] Instead, by thinking in terms of envirotechnical systems, we can avoid the pitfalls of such tidy categories, firm borders, and static notions of both nature and technology that fall apart in places like Fukushima while the concept of envirotechnical regimes allows us to focus on the political processes by which these systems are brought into existence. This approach therefore encourages us to consider how, why, and in what ways technological and natural systems articulate with one another, even when "designers never expected them to be connected."[71] Examples abound, especially in the early twenty-first century, but Fukushima has particularly and painfully brought these lessons home.

Sara Pritchard *is assistant professor in the Department of Science & Technology Studies at Cornell University and author of* Confluence: The Nature of Technology and the Remaking of the Rhône *(Harvard University Press, 2011).*

Notes

I would like to thank two anonymous reviewers, Ian Miller, Julia Adeney Thomas, and Brett Walker for their insightful comments on a previous version of this essay. I also thank Nancy Langston for soliciting the piece, Tyson Vaughn for his critical research contributions, and Connie Hsu Swenson for her editorial assistance.

1 The U.S. Geologic Survey concluded that the Tōhoku earthquake, now called the "Great East Japan Earthquake," on March 11, 2011, was magnitude 9.0, although some newspaper accounts cite 8.9, http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/usc0001xgp.php. Reports of the tsunami's height also vary. In a recent *Scientific American* article, David Biello refers to 14 meters ("Fukushima Meltdown Mitigation Aims to Prevent Radioactive Flood," *Scientific American*, June 24, 2011, http://www.scientificamerican.com/article.cfm?id=fukushima-meltdown-radioactive-flood). Charles Perrow quotes estimates ranging from 30 to 46 feet ("Fukushima, Risk, and Probability: Expect the Unexpected," *Bulletin of the Atomic Scientists*, April 1, 2011), and a *New York Times* journalist referenced 50 feet (Hiroku Tabuchi, "Company Believes

3 Reactors Melted Down in Japan," *New York Times*, May 24, 2011). In June 2011, Japan's Nuclear Emergency Response Headquarters declared that three reactors experienced full meltdowns (CNN Wire Staff, "3 Japan Nuclear Reactors Had Full Meltdown, Agency Says," June 6, 2011, http://news.blogs.cnn.com/2011/06/06/3-japan-nuclear-reactors-had-full-meltdown-agency-says/). The following day, *The Daily Yomiuri* (*Yomiuri Shimbun*), a leading Japanese newspaper, expressed concern that the reactors had actually experienced "melt-throughs," which are more severe than core meltdowns and "the worst possibility in a nuclear accident" ("'Melt-Through' at Fukushima? Govt Report to IAEA Suggests Situation Worse Than Meltdown," *The Yomiuri Shimbun*, June 8, 2011, http://www.yomiuri.co.jp/dy/national/T110607005367.htm). A subsequent government report asserted, however, that Fukushima had not experienced a melt-through: "Concerning Units 1 to 3 of the Fukushima Dai-ichi NPS [Nuclear Power Station], as the situation where water injection to each RPV [Reactor Pressure Vessel] was impossible to continue for a certain period of time, the nuclear fuel in each reactor core was not covered by water but was exposed, leading to a core melt. Part of the melted fuel stayed at the bottom of the RPV." See "Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety—The Accident at TEPCO's Fukushima Nuclear Power Stations," 8, http://www.kantei.go.jp/foreign/kan/topics/201106/iaea_houkokusho_e.html. For an accessible overview of what occurred at Fukushima, see the *New York Times*'s "Status of the Nuclear Reactors at the Fukushima Daiichi Power Plant," last updated April 29, 2011, http://www.nytimes.com/interactive/2011/03/16/world/asia/reactors-status.html?ref=earth. See also the *New York Times* blogs during the early days of the crisis such as http://thelede.blogs.nytimes.com/2011/03/11/ and http://thelede.blogs.nytimes.com/2011/03/12/ for more detailed coverage of events as they evolved.

2 Kent Anderson argues that some have started referring to the disaster as "3-11," obviously evoking the political valence of 9-11 in the United States and forging a parallel between the two crises and societies. See his essay, "A Hundred Days after Japan's Triple Disaster," *East Asia Forum*, June 20, 2011, http://www.eastasiaforum.org/2011/06/20/a-hundred-days-after-japan-s-triple-disaster/. I emphasize "ever since" because Japan's atomic commission announced in late October 2011 that it may take more than three decades to clean up Fukushima (http://www.guardian.co.uk/world/2011/oct/31/fukushima-nuclear-plant-30-years-cleanup).

3 A number of environmental historians have engaged with recent crises and debates. On Hurricane Katrina, see Ari Kelman, "Nature Bats Last: Some Recent Works on Technology and Urban Disaster," *Technology and Culture* 47 (2006): 391–402; Ari Kelman, "Boundary Issues: Clarifying New Orleans's Murky Edges," *Journal of American History* 94 (2007): 695–703. On hydraulic fracturing in the Marcellus Shale ("hydrofracking"), see Joel A. Tarr, "There Will Be Gas," *Pittsburgh Post-Gazette*, August 2, 2009, http://www.post-gazette.com/pg/09214/987834-109.stm. On the Deepwater Horizon oil spill, see Christopher Jones, "Defining the Problem," posted to H-Energy, June 27, 2010, http://www.h-net.org/~energy/roundtables/Jones_Gulf.html; Peter Shulman, "A Catastrophic Accident of Normal Proportions," posted to H-Energy, June 27, 2010, http://www.h-net.org/~energy/roundtables/Shulman_Gulf.html; and several other responses at http://aseh.net/teaching-research/environmental-historians-respond-to-the-gulf-oil-spill/copy_of_ehresponsetoGulfOilSpill.pdf. A number of scholars of Japan from diverse disciplinary backgrounds (and nationalities) have contributed to the scrutiny of Fukushima since March 11, 2011; for

over a hundred analyses, see *The Asia-Pacific Journal*'s forum on the triple disaster, http://www.japanfocus.org/Japans-3.11-Earthquake-Tsunami-Atomic-Meltdown.

4 On "energy regimes, both politically and technologically," I am influenced here by Gabrielle Hecht's notion of technopolitics, which emphasizes the specifically technological means of political ends, Paul Edwards's arguments regarding the power (and often invisibility) of infrastructure, and Thomas Parke Hughes's work on the "momentum" of technological systems. See Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II*, 2nd ed. (Cambridge: MIT Press, 2009); Paul N. Edwards, "Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems," in *Modernity and Technology*, ed. Thomas Misa, Philip Brey, and Andrew Feenberg (Cambridge: MIT Press, 2003), 185–226; Thomas Parke Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore: Johns Hopkins University Press, 1983), especially 14–15 and Chapter 6. On the relationship between fossil fuels and political systems, see Timothy Mitchell, "Carbon Democracy," *Economy & Society* 38, no. 3 (2009): 399–432; a much elaborated version is his more recent *Carbon Democracy: Political Power in the Age of Oil* (New York: Verso, 2011). For a few implications of the atomic age, see Stephen Bocking, "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory," *Journal of the History of Biology* 28 (1995): 1–47; Jacob Darwin Hamblin, *Poison in the Well: Radioactive Waste in the Oceans at the Dawn of the Nuclear Age* (New Brunswick: Rutgers University Press, 2008). For syntheses of literature at the intersection of environmental history and the history of technology, see Jeffrey K. Stine and Joel A. Tarr, "At the Intersection of Histories: Technology and the Environment," *Technology and Culture* 39 (1998): 601–40; Martin Reuss and Stephen H. Cutcliffe, eds., *The Illusory Boundary: Environment and Technology in History* (Charlottesville: University of Virginia Press, 2010), especially the introduction, afterword, and essay by Hugh S. Gorman and Betsy Mendelsohn, "Where Does Nature End and Culture Begin? Converging Themes in the History of Technology and Environmental History" (pp. 265–90); Sara B. Pritchard, *Confluence: The Nature of Technology and the Remaking of the Rhône* (Cambridge: Harvard University Press, 2011), introduction.

5 I do not take up the question what makes technological systems "modern" here. One classic study is Bruno Latour, *We Have Never Been Modern*, trans. Catherine Porter (Cambridge: Harvard University Press, 1993). It is also possible to question the use of singular "system" (versus "systems") to describe Fukushima. As the loss of electrical power at Fukushima demonstrated, "high-tech" reactors were dependent on seemingly "low-tech" technologies like power grids. In a recent talk, Paul Edwards highlighted the problems when multiple technological systems do not articulate effectively with one another, especially in times of crisis. This issue raises concerns about not only the vulnerabilities of an individual system but also the ways in which systems are often entangled and interdependent, thereby creating new vulnerabilities from their synergies and dissonances. See Paul N. Edwards, comments at "Infrastructure(s) and the Fukushima Earthquake: A Roundtable on Emergencies, Nuclear and Otherwise," annual meeting of the Society for the History of Technology, November 3–6, 2011.

6 I set aside here the important issue of how natural and sociotechnical factors are categorized and differentiated, both historically and analytically. Sociologists and historians of technology often use the term *sociotechnical* to stress the

social and political shaping of technology, particularly as technical and technological are often placed in opposition to the social. Their larger point is to emphasize the mutual shaping of society and technology.

7 Charles Perrow, *Normal Accidents: Living with High-Risk Technologies*, 2nd ed. (Princeton: Princeton University Press, 1999). See also his more recent book, *The Next Catastrophe: Reducing Our Vulnerabilities to Natural, Industrial, and Terrorist Disasters* (Princeton: Princeton University Press, 2007). For a useful overview of Three Mile Island, see the U.S. Regulatory Commission fact sheet, http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html.

8 On the idea of sociotechnical systems, see Hughes, *Networks of Power*, 6. See also Wiebe Bijker, Thomas Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge: MIT Press, 1987).

9 David E. Sanger and Matt Wald, "Radioactive Releases in Japan Could Last Months, Experts Say," *New York Times*, March 13, 2011.

10 I use the adjective *hazardous* to evoke Leo Marx's argument regarding technology as a hazardous concept. See Leo Marx, "Technology: The Emergence of a Hazardous Concept," *Technology and Culture* 51 (2010): 561–77. He published an earlier version of this article in *Social Research* in 1997.

11 For these ideas in the context of the BP oil spill, see Shulman, "A Catastrophic Accident of Normal Proportions."

12 Discussions of "better" modeling techniques exemplify this kind of thinking, what historians of technology sometimes call a "techno-fix." For a consideration of models of nuclear reactors and the field of "atomic forensics" in light of Fukushima, see William J. Broad, "From Afar, a Vivid Picture of Japan Crisis," *New York Times*, April 2, 2011. In addition, scholars in science and technology studies (STS) would critique this approach because it focuses on either technical or social issues, reifying the binary in the process. Moreover, reflecting other fundamental STS insights, how the problem gets framed shapes what solution(s) are possible and thus actionable. For thoughts on this issue regarding the Deepwater Horizon, see Jones, "Defining the Problem."

13 Hughes, *Networks of Power*.

14 Hughes, *Networks of Power*, 6. However, on Hughes's last point, Perrow would probably argue that internal dynamics are often far more complex than Hughes implies here. He might also question whether a given system's final state can always be predicted, although, as his book *Normal Accidents* shows, Perrow ultimately believed in the ability of analysts and policymakers to classify and predict "normal accidents." In addition, in later work, Hughes seemed to return to these questions about the relationship between technology and the environment when he proposed the notion of "ecotechnological environment," which he defined as "intersecting and overlapping natural and human-built environments" (*Human-Built World: How to Think about Technology and Culture* [Chicago: University of Chicago Press, 2004], 153). In this book, Hughes discusses several examples that illustrate the interpenetration of the natural and technological but did not situate his analysis within existing literature or develop the concept as an analytic tool. Hughes also elaborated that "ecotechnological" focuses on "more sustainable" relations between nature and technology. I view "ecotechnological," at least as Hughes defines it, as a subset of the

envirotechnical, which are *any* connections between the environmental and technological.

15 One can also ask if everything comes under Hughes's definition of "environment" here, from unstable commodities prices to striking workers, as both may resist "system control." For an overview of fossil fuels, see J. R. McNeill, *Something New Under the Sun: An Environmental History of the Twentieth-Century World* (New York: Norton, 2000). On copper, see Timothy J. LeCain, *Mass Destruction: The Men and Giant Mines That Wired America and Scarred the Planet* (New Brunswick: Rutgers University Press, 2009). On harnessing rivers in different historical and national contexts, see Theodore Steinberg, *Nature Incorporated: Industrialization and the Waters of New England* (New York: Cambridge University Press, 1991); Richard White, *The Organic Machine* (New York: Hill and Wang, 1995); Mark Cioc, *The Rhine: An Eco-Biography, 1815–2000* (Seattle: University of Washington Press, 2002); David Blackbourn, *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York: Norton, 2006); Pritchard, *Confluence*.

16 On the problem of agency, see Linda Nash, "The Agency of Nature and the Nature of Agency," *Environmental History* 10 (2005): 67–69. It is worth noting that there were probably reasons why Hughes conceptualized technological systems in this way. For one, Hughes was influenced by post–World War II systems theory. He therefore seemed to use contemporary systems thinking to inform his historical analysis of earlier systems. On systems theory, see Agatha C. Hughes and Thomas Parke Hughes, *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After* (Cambridge: MIT Press, 2000).

17 Perrow, *Normal Accidents*, 14, 296. Italics added.

18 It's worth noting that Perrow expressed confidence in system control as well. After all, his book examines and classifies accidents in the hope that analysts can deduce their fundamental characteristics and identify common patterns, thereby improving the predictive power of both experts and scholars.

19 On climate change, see Clark A. Miller and Paul N. Edwards, *Changing the Atmosphere: Expert Knowledge and Environmental Governance* (Cambridge: MIT Press, 2001); Spencer R. Weart, *The Discovery of Global Warming* (Cambridge: Harvard University Press, 2003); Elizabeth Kolbert, *Field Notes from a Catastrophe: Man, Nature, and Climate Change* (New York: Bloomsbury, 2006); Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge: MIT Press, 2010). On remaking human bodies and the intersection of the body and environment, see Conevery Bolton Valenčius, *The Health of the Country: How American Settlers Understood Themselves and Their Land* (New York: Basic Books, 2002); Barbara Allen, *Uneasy Alchemy: Citizens and Experts in Louisiana's Chemical Corridor Disputes* (Cambridge: MIT Press, 2003); Gregg Mitman, Michelle Murphy, and Christopher Sellers, eds., *Landscapes of Exposure: Knowledge and Illness in Modern Environments* (Chicago: University of Chicago Press, 2004); Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Durham: Duke University Press, 2006); Linda Nash, *Inescapable Ecologies: A History of Environment, Disease, and Knowledge* (Berkeley: University of California Press, 2006); Gregg Mitman, *Breathing Space: How Allergies Shape Our Lives and Landscapes* (New Haven: Yale University Press, 2007); Jody A. Roberts and Nancy Langston, "Toxic Bodies/Toxic Environments: An Interdisciplinary Forum," *Environmental*

History 13 (2008): 629–703, and the related articles in this special issue; Sarah A. Vogel, "The Politics of Plastics: The Making and Unmaking of Bisphenol A 'Safety,'' *American Journal of Public Health* 99 (2009): 559–66; Nancy Langston, *Toxic Bodies: Hormone Disruptors and the Legacy of DES* (New Haven: Yale University Press, 2010); Joy Parr, *Sensing Changes: Technologies, Environments, and the Everyday, 1953–2003* (Vancouver: University of British Columbia Press, 2010); Brett Walker, *Toxic Archipelago: A History of Industrial Disease in Japan* (Seattle: University of Washington Press, 2011).

20 On hybrid landscapes, see White, *Organic Machine*; Mark Fiege, *Irrigated Eden: The Making of an Agricultural Landscape in the American West* (Seattle: University of Washington Press, 1999); Richard White, "From Wilderness to Hybrid Landscapes: The Cultural Turn in Environmental History," *Historian* 66 (2004): 557–64. "Nature–culture" is from Latour, *We Have Never Been Modern*, 7. A related concept, "naturecultures," is from Donna J. Haraway, *The Companion Species Manifesto: Dogs, People, and Significant Otherness* (Chicago: Prickly Paradigm Press, 2003); 1; Donna J. Haraway, *When Species Meet* (Minneapolis: University of Minnesota Press, 2008), 16.

21 On vulnerability, see Wiebe E. Bijker, "Globalization and Vulnerability: Challenges and Opportunities for SHOT Around Its Fiftieth Anniversary," *Technology and Culture* 50 (2009): 600–12.

22 Hiroko Tabuchi and Matthew L. Wald, "Japanese Scramble to Avert Meltdowns as Nuclear Crisis Deepens After Quake," *New York Times*, March 12, 2011; Sanger and Wald, "Radioactive Releases." The phrase "Faustian bargain" is from Christine L. Marran, "Contamination: From Minamata to Fukushima," http://www.japanfocus.org/-Christine-Marran/3526.

23 Tabuchi and Wald, "Japanese Scramble." The tsunami apparently flooded emergency diesel generators. Battery power provided a second backup, but those batteries died fairly quickly. On the staying power of "old" technologies, see David Edgerton, *The Shock of the Old: Technology and Global History Since 1900* (New York: Oxford University Press, 2007).

24 For useful historiographical overviews, see Stine and Tarr, "At the Intersection of Histories"; Reuss and Cutcliffe, eds., *Illusory Boundary*, introduction and afterword; Gorman and Mendelsohn, "Where Does Nature End and Culture Begin?" in *Illusory Boundary*.

25 It is worth noting that these kinds of arguments illustrate the problematic boundary between the cultural and the material within environmental history. In addition, although a number of envirotech scholars have discussed the porous boundaries between environmental and technological entities (regardless of whether or not actors believed this was the case), it is critical for historians to differentiate between actors' and analysts' moves. Based on my own research, actors' claims provide a rich source to investigate in its own right. I discuss several examples of actors' strategic conflation and separation of nature and technology in *Confluence*.

26 Of course, managed and harnessed natures suggest how humans have interacted with and transformed "nonhuman" nature, thus further challenging the notion of a supposedly pristine nature without human influence. See Edmund Russell, "The Garden in the Machine: Toward an Evolutionary History of Technology," in *Industrializing Organisms: Introducing Evolutionary History*, ed. Philip Scranton and Susan R. Schrepfer (New York: Routledge, 2004). See also specific examples in William Boyd, "Making Meat: Science, Technology, and American Poultry

Production," *Technology and Culture* 42 (2001): 631–64; Robert Gardner, "Constructing a Technological Forest: Nature, Culture, and Tree-Planting in the Nebraska Sand Hills," *Environmental History* 14 (2009): 275–97; Ann Norton Greene, *Horses at Work: Harnessing Power in Industrial America* (Cambridge: Harvard University Press, 2008); and many of the essays in Scranton and Schrepfer, eds., *Industrializing Organisms,* and Reuss and Cutcliffe, eds., *Illusory Boundary*.

27 At times historical actors may have made this argument; for example, in my research, I have found that technical experts invoked environmental factors to support a particular "technical" design feature of a project. These factors may well have shaped the technology, but they may have also have been used to naturalize the ultimate "technical" choice and thereby obscure political, economic, and other considerations in shaping that decision. It is beyond the scope of this essay to detail historiographical trends within the history of technology. I will simply note here that although there are certainly analytical tensions between the history of technology (and science studies more broadly) and environmental history, largely centering on the inseparability of nature and knowing nature, the former's arguments regarding coproduction, materiality, and affordances and the latter's commitment to the "agency" of nature indicate productive synergies between the fields.

28 For critiques of dichotomies and the articulation of cyborg, "naturecultures," and companion species, see the works of Donna Haraway, especially "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," in *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 1991), 149–81; *Companion Species Manifesto*; and *When Species Meet*. For an overview of actor network theory, see Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* (New York: Oxford University Press, 2005). See also Michel Callon, "Society in the Making: The Study of Technology as a Tool for Sociological Analysis," and John Law, "Technology and Heterogeneous Engineering," both in *Social Construction of Technological Systems*. On mutual or coproduction, see Ronald R. Kline, *Consumers in the Country: Technology and Social Change in Rural America* (Baltimore: Johns Hopkins University Press, 2000); Sheila Jasanoff, ed., *States of Knowledge: The Co-Production of Science and the Social Order (*New York: Routledge, 2004).

29 Perrow's "eco-system" clearly seeks to emphasize the coupling of natural systems (abbreviated as "eco") and human-made systems (represented by "system"), although his play on ecosystem may end up somewhat obscuring the human component. In contrast, the "technical" in envirotechnical makes this explicit. I am grateful for the NSF-sponsored "Envirotech" workshop at the University of Maryland in 2006 for providing a stimulating environment to wrestle with these and related issues. I developed the concepts of envirotechnical systems and regimes in response to conversations at that workshop, presented them at the 2007 Society for the History of Technology meeting, and extended them in *Confluence*, especially the introduction. See also Hughes, *Human-Built World*; LeCain, *Mass Destruction*; Gardner, "Constructing a Technological Forest"; Reuss and Cutcliffe, eds., *Illusory Boundary*; Mark Finlay, "Far Beyond Tractors: Envirotech and the Intersections of Technology, Agriculture, and the Environment," *Technology and Culture* 51, no. 2 (2010): 480–85. Let me also clarify that I opt for envirotechnical systems, rather than working within Hughes's notion of "open" systems, for several reasons. Hughes defined "open" and "closed" systems relationally, indicating that "closed" systems exist and "open" systems can eventually be "closed." He therefore expressed

confidence in the ability of humans and technologies to attain "system control," as well as the notion that some systems are (and can be) entirely outside environmental influence. In contrast, the idea of an envirotechnical system works from the assumption that environmental factors and processes are always there (thus, by definition, there are no closed systems); however, these factors may be dynamic and the specific "environment" that is relevant is also historically specific. Why not just refer to such phenomena as nature and technology? Put simply, it reproduces the binary and distinction, rather than emphasizing hybridity and mutual constitution. STS scholars have used a number of terms such as *nature–culture, sociotechnical*, and *technopolitics* to instead highlight the inextricability of categories and materialities that are often opposed, thereby emphasizing their "*bothness*." Envirotechnical systems and related concepts attempt to do this for nature and technology. In other words, it is not that environmental systems become technological or technological systems become natural; they are *both* environmental and technological.

30 Again, this can be investigated both historically and analytically.

31 As mentioned in note 5, Edwards highlighted the fact that historians of technology rarely pay attention to the dynamics between or among systems, instead generally focusing on the history and production of a single system. In his talk, Edwards emphasized technological systems articulating with other technological systems. For instance, in the case of Fukushima, we are now aware of the consequences of electricity technologies not meshing with nuclear reactor technologies. Given what happened at Fukushima, one might push Edwards's argument further, to widen our notion of "systems" beyond technological ones and consider the ways that, say, hydrologic or atmospheric systems articulated or did not articulate with the systems of reactors.

32 During the crisis, some discussion focused on whether or not the reactors at Fukushima ran on a mixed fuel known as "mox," or mixed oxide, which includes reclaimed plutonium. If so, released steam could be more toxic than some other radioactive elements. Sanger and Wald, "Radioactive Releases."

33 For an overview, see Sanger and Wald, "Radioactive Releases."

34 Arthur F. McEvoy, "Working Environments: An Ecological Approach to Industrial Health and Safety," *Technology and Culture* 36 (1995): S145–72. On the hidden history of the subcontracting system centered on short-term employment in the nuclear industry, including but not limited to Japan, see Gabrielle Hecht, "Nuclear Nomads: A Look at the Subcontracted Heroes," *Bulletin of the Atomic Scientists*, January 9, 2012. I say "usually" because "since the late 1980s," states Hecht, "some 90 percent of nuclear power plant workers in the country [Japan] have been subcontracted."

35 Perrow, "Fukushima, Risk, and Probability."

36 Hiroko Tabuchi and Matthew L. Wald, "Second Explosion at Reactor as Technicians Try to Contain Damage," *New York Times*, March 13, 2011.

37 Meanwhile, as Japanese specialists were analyzing what was taking place at Fukushima, experts in "atomic forensics," or modeling atomic simulations abroad, were developing their own analyses of the situation. See Broad, "From Afar."

38 Sanger and Wald, "Radioactive Releases"; Sonja Schmid, "Both Better and Worse than Chernobyl," *London Review of Books*, March 17, 2011. On gamma radiation, see Parr, *Sensing Changes*, 66–67. In May 2011, TEPCO workers were finally able

to get close enough to reactor number 1 to fix a water gauge; once working, it showed that the water level in the reactor was much lower than expected, even with the massive infusion of seawater. In fact, "one of the most startling findings announced Thursday was that water levels in the reactor vessel, which houses the fuel rods, appeared to be about three feet below where the bottom of the fuel rods would normally stand." Quotation from Hiroko Tabuchi and Matthew L. Wald, "Japanese Reactor Damage Is Worse Than Expected," *New York Times*, May 12, 2011.

39 Edgerton, *Shock of the Old*.

40 This description is based primarily on Sanger and Wald, "Radioactive Releases."

41 Emergency measures were undertaken "quickly," but critics believe not fast enough. As I discuss later, seawater injections were probably delayed because of the economic costs of the decision: flooding the reactors with saltwater essentially meant scrapping them. TEPCO therefore had a strong financial incentive to try other emergency measures first, and the government did not push the company to do so until the severity of the crisis was apparent.

42 Quotations from Sanger and Wald, "Radioactive Releases."

43 Description of this process is drawn from Tabuchi and Wald, "Second Explosion"; Tabuchi and Wald, "Japanese Scramble"; Sanger and Wald, "Radioactive Releases"; Henry Fountain, "A Look at the Mechanics of a Partial Meltdown," *New York Times*, March 13, 2011.

44 Peter Behr, "Desperate Attempts to Save 3 Fukushima Reactors from Meltdown, *New York Times*, March 14, 2011. At the same time, there was some concern that delays in water injections worsened the situation at Fukushima. I discuss this point briefly later, but see also Norimitsu Onishi and Martin Fackler, "In Nuclear Crisis, Crippling Mistrust," *New York Times*, June 12, 2011.

45 Stephen Hilgartner, "The Social Construction of Risk Objects: Or, How to Pry Open Networks of Risk," in *Organizations, Uncertainties, and Risk*, ed. James F. Short and Lee Clark (Boulder: Westview Press, 1992).

46 Quotation from Biello, "Fukushima Meltdown." Biello's naturalization of the toxic liquid is particularly unfortunate, given that government and corporate interests have worked to focus attention on the earthquake and tsunami alone. Nonetheless, given the long-standing importance of bathing rituals and hot springs in Japanese culture, including Shinto religious traditions, the extensive contaminated fluids within and now beyond Fukushima are likely freighted with meaning, from offending animistic spirits to possibly being hell on earth. Interestingly, however, the boundaries between "baths" and "natural" hot springs may be increasingly unclear in Japan because these springs are often highly managed and cultivated landscapes, which would further complicate interpretations of Fukushima's fluids as a toxic *onsen*. I thank John S. Harding for his critical insights here.

47 Biello, "Fukushima Meltdown"; Andrew Monahan, "Tokyo Electric Power Delays Dumping Water at Fukushima Daiichi Plant," *Wall Street Journal*, April 11, 2011; Marran, "Contamination."

48 Sanger and Wald, "Radioactive Releases."

49 On the explosions, see Behr, "Desperate Attempts" and especially Onishi and Fackler, "In Nuclear Crisis, Crippling Mistrust." On vulnerability, see Bijker, "Globalization and Vulnerability."

50 Details regarding Fukushima workers are from Hecht, "Nuclear Nomads."

51 Apparently, on March 14 TEPCO's president asked Japan's prime minister Naoto Kan to allow the company to withdraw its employees from Fukushima Daiichi because it had become so dangerous. Kan refused and installed a trusted aide at the utility's headquarters the next morning. Some analysts have argued that closer government supervision altered the way TEPCO managed the crisis from that point forward. See Onishi and Fackler, "In Nuclear Crisis."

52 William Cronon, "The Trouble with Wilderness; or, Getting Back to the Wrong Nature," in *Uncommon Ground: Rethinking the Human Place in Nature*, ed. William Cronon (New York: Norton, 1995). See also Richard White's essay in that volume, "Are You an Environmentalist or Do You Work for a Living? Work and Nature," especially 182.

53 Ted Steinberg, *Acts of God: The Unnatural History of Natural Disaster in America* (New York: Oxford University Press, 2000).

54 Walker, *Toxic Archipelago*, especially 16–20.

55 The larger point here is that actors may strategically construct agency to suit their political (and perhaps legal) interests. This brief example suggests how historians can explore actors' conceptions of historical agency and causality in addition to developing their own theoretical approaches. For another example, this one focusing on the causes of hydrologic change in the Rhône valley amid postwar modernization efforts, see Pritchard, *Confluence*, Chapter 5. For analyzing technological determinism as an actor's move, see Gabrielle Hecht and Michael Thad Allen, eds., *Technologies of Power; Essays in Honor of Thomas Parke Hughes and Agatha Chipley Hughes* (Cambridge: MIT Press, 2001), introduction.

56 On the end of the Minamata court case, see Marran, "Contamination."

57 Cornell Science & Technology Studies PhD candidate Tyson Vaughn was recently discussing hybrid causation and envirotechnical analysis with several people in Japan involved in the Minamata debate, including the curator of the Minamata Disease Municipal Museum, http://www.minamata195651.jp/guide_en.html, the curator of Soshisha ("The Supporting Center for Minamata Disease," http://soshisha.org/english/index_e.htm), an *NHK* journalist, and "kataribe" (storyteller) Miyako Kawamoto, the widow of Teruo Kawamoto who had been the leader of one of the primary victims advocacy groups, http://www.nytimes.com/1999/02/22/world/teruo-kawamoto-victims-advocate-in-mercury-outbreak.html. Vaughn conveyed to me that all four individuals, but especially Miyako, were distressed by the notion of hybrid causation because, as I indicate in the body of the essay, they felt it watered down the assignation of responsibility to Chisso Corporation, the company that released mercury into Minamata Bay. Their response pushed me to consider more thoughtfully the political implications of envirotechnical analysis and inspired much of the discussion in this section. I am grateful to Vaughn for sharing this research story with me and allowing me to include it here. For more on Minamata, see Timothy S. George, *Minamata: Pollution and the Struggle for Democracy in Postwar Japan* (Cambridge: Harvard University Asia Center, 2002); Walker, *Toxic Archipelago*, especially Chapter 5. For parallels between Minamata and Fukushima, see Marran, "Contamination."

58 Douglas R. Weiner, "A Death-Defying Attempt to Articulate a Coherent Definition of Environmental History," *Environmental History* 10 (2005): 404–20.

59 See Jake Hamblin's accompanying essay on the motif of nuclear safety.

60 "Nuclear Crisis: How It Happened, Safety Vows Forgotten, 'Safety Myth' Created," *The Yomiuri Shimbun*, June 15, 2011.

61 Perrow, "Fukushima, Risk, and Probability"; Onishi and Fackler, "In Nuclear Crisis."

62 Perrow, "Fukushima, Risk, and Probability."

63 However, on the contested notion and definition of "nuclearity," see Gabrielle Hecht, "The Power of Nuclear Things," *Technology and Culture* 51 (2010): 1–30. On links between the nation and nuclear power in the French context, materially and culturally, historically and theoretically, see Hecht, *Radiance of France*.

64 On falsified records and the (convenient) design of the spent fuel storage ponds, see Perrow, "Fukushima, Risk, and Probability."

65 Quotation from Behr, "Desperate Attempts."

66 Quotations from Norihiko Shirouzu, Phred Dvorak, Yuka Hayashi, and Andrew Morse, "Bid to 'Protect Assets' Slowed Reactor Fight," *Wall Street Journal*, March 19, 2011. See also Ken Bradsher, Keith Belson, and Matthew L. Wald, "Executives May Have Lost Valuable Time at Damaged Nuclear Plant," *New York Times*, March 21, 2011. For discussion of another aspect of the injection debate, specifically the conflict between TEPCO executives and the manager of reactor number 1, see Onishi and Fackler, "In Nuclear Crisis."

67 Christine Marran emphasizes the ways that radioactivity can cross national and other political borders in "Contamination." I certainly do not question this argument. However, it is worth paying attention to the ways in which radiation exposure can affect all humans and also have differential impacts on certain bodies.

68 Paul Sutter, comment on J. R. McNeill's *Mosquito Empires: Ecology and War in the Greater Caribbean, 1620–1914*, American Society for Environmental History (2011); on hybrid causation specifically, see Walker, *Toxic Archipelago*.

69 Murphy, *Sick Building Syndrome*, 180.

70 Hughes, *Networks of Power*, 6.

71 Perrow, *Normal Accidents*, 296.