The Nuclear Sensorium: Cold War Nuclear Imperialism and Sensory Violence

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Abstract

This paper traces the sensory dimensions of nuclear imperialism focusing on the Cold War nuclear weapons tests conducted by the United States military in the Marshall Islands during the 1950s. Key to the formation of the "nuclear sensorium" were the interfaces between vibration, sound, and radioactive contamination, which were mobilized by scientists such as oceanographer Walter Munk as part of the US Nuclear Testing Program. While scientists occupied privileged points in technoscientific networks to sense the effects of nuclear weapons, a series of lawsuits filed by communities affected by the tests drew attention to military-scientific use of inhabitants' bodies as repositories of data concerning the ecological impact of the bomb and the manner in which sensing practices used to extract this data extended the violence and trauma of nuclear weapons. Nuclear imperialism projected its power not only through weapons tests, the vaporization of land and the erosion of the rights of people who lived there, but also through the production of a "nuclear sensorium"—the differentiation of modes of sensing the bomb through legal, military, and scientific discourses and the attribution of varying degrees of epistemological value and legal weight to these sensory modes.

Keywords: environmental litigation, nuclear weapon tests, dark ecology, Cold War politics, Atomic Energy Act 1946, sensory practices

Résumé

Cet article trace les dimensions sensorielles de l'impérialisme nucléaire en se concentrant sur les essais d'armes nucléaires de la Guerre froide qui ont été conduits par les Forces armées des États-Unis dans les îles Marshall pendant les années 1950. Les éléments clés de la création du « Sensorium nucléaire » reposaient sur les interfaces entre la vibration, la contamination sonore et la contamination radioactive. Ces interfaces ont été mobilisées par des scientifiques tels que l'océanographe Walter Munk dans le cadre du programme d'essais nucléaires américain. L'impérialisme nucléaire a non seulement projeté son pouvoir par des essais d'armes, la vaporisation des terres et l'érosion des droits des personnes qui y vivaient, mais également à travers la production d'un « Sensorium nucléaire » – une différenciation des modes de détection de la bombe à travers les discours juridiques, militaires et scientifiques ainsi que dans l'attribution de différents degrés de valeurs épistémologiques et juridiques à ces modes sensoriels.

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Mots clés : litige environnemental, essais d'armes nucléaires, écologie noire, politiques de la Guerre froide, la Loi sur le contrôle de l'énergie atomique de 1946, pratiques sensorielles

Introduction

This paper traces the way figurations of the physical environment cut across scientific, military, and legal discourse surrounding American nuclear weapons tests in Pacific Proving Ground (PPG) in the 1950s. I focus on the way ecological and legal figurations of nuclear spaces and bodies were made accessible to the senses and how these figurations connect and then regulate relations between sensory practices, knowledge production, and military violence. These interdisciplinary figurations of contamination and containment constitute a crucial dimension of what Joseph Masco (2004) refers to as nuclear technoaesthetics, or the "evaluative aesthetic categories embedded in the expert practices of weapons scientists" (350) which shape the way scientists interact with nuclear technologies. Here, I focus on the early period of nuclear testing, when such tests were conducted above ground and had specific sensory and perceptual effects on scientists present during the tests. The subsequent phases of nuclear testing—first to underground testing and then to virtual testing through computer simulation—diminished the embodied sensory experience of nuclear weapons and led to an increasingly abstract notion of their destructive power. While the distancing of human bodies and environments from nuclear testing may appear to be a positive development, a number of scientists who contributed to early phases of nuclear weapons development later asserted that the physical experience of nuclear weapons—its assault on the senses and the consequent pleasure-terror experienced by the subject—had the potential to "foster international enlightenment in the form of disarmament" (Masco 2004, 350). The increasing prostheticization and virtualization of nuclear experimental regimes contributed to the diminishment of precisely those forms of sensory experience that seemed to have the greatest potential to motivate and maintain the disarmament movement.

However, the relationship between the nuclear and the senses was mediated by a complex set of institutions, technologies, systems of knowledge, and cultural practices as well as by the material contingencies of nuclear test environments. The nuclear tests conducted by the United States at the PPG during the 1950s produced a new sensory framework which extended and integrated embodied and machinic sensing but also established an order and hierarchy of ways of sensing that supported nuclear imperialism. As Laura Martin (2008) demonstrates in her analysis of these early nuclear tests, nuclear imperialism demanded new forms of scientific knowledge about the web of relations between bodies, machines, and environments that would transmit the force of the bomb and shape the flow of radiation. Building on Elizabeth DeLoughrey's (2012) work on the discursive legitimation of nuclear violence in the PPG through its construction as isolated and uninhabited, Martin suggests that the idea of the environment-as-ecosystem has its origins in interests of the military in predicting, manipulating, and maximizing the effects of "nuclear violence," including radiation, on human and nonhuman bodies and their environments in the PPG. The radioactive bioaccumulation studies commissioned

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by the US Atomic Energy Commission in the PPG are particularly significant in this regard since they demonstrate how the notion of ecosystem first emerged among scientists who worked in close physical proximity to the "large-scale destruction of environments" and who regarded the large-scale release of radioisotopes as an opportunity for the advancement of scientific theory by enabling ecosystems to be rendered visible for the first time (569). The ecosystem as a concept as well as the development of radioecology as a field were at this stage under the control of the military since, in order to study the global movement of radioactive isotopes, scientists needed access to military resources. While the US *Atomic Energy Act of 1946* "placed atomic energy development under civilian control," the military was required for "physical security and technical and logistical support" due to the scale and remoteness of the tests (Gladeck et al. 1982, 1). Given this dependence on military logistics and infrastructure to conduct the tests that enabled ecology, it is not surprising that ecological concepts and the modes of sensing ecological pathways were initially oriented toward military interests. As DeLoughrey points out, it wasn't until the 1960s that the ecosystem concept was mobilized by communities displaced by the nuclear tests to oppose the forms of nuclear violence which gave rise to that concept in the first place (585). Similarly, Martin argues that "destruction was the enabling condition for understanding life as interconnected" (584). Indeed, as Rothschild notes, the Lucky Dragon accident in 1954, in which the twenty-three crew members of a Japanese fishing vessel became contaminated by radioactive fallout from the US thermonuclear test Operation Bravo, led to the formation of the US Congress Joint Committee on Atomic Energy and its series of hearings on the environmental impact of nuclear weapons in the late 1950s. Ecologists called to testify before the committee provided a "grim picture," which in turn persuaded many committee members of the environmental impact of nuclear weapons (525). This included the vivid testimony of John Wolfe, who noted that postattack fires from a hypothetical nuclear detonation on the US East Coast would destroy "the entire forest cover, leading to severe erosion, flooding of valleys, and the complete un-inhabitability of these regions" (524). In addition to these highly publicized channels, scientific visualizations of the concentration of radioactivity in biota (e.g., via radioautography) made the pathways for energy and matter between organisms visible, increased the credibility of the environment-as-ecosystem, and eventually worked against nuclear imperialism when these images and the notion of ecosystem were incorporated into anticolonial and antinuclear struggles (585).

This paper builds on the literature on nuclear imperialism and emphasizes the role of military-scientific sensory practices in the exercise of imperial power and the legal framework which enforced a colonial division of sensed and sensing subjects within the nuclear regime. It is the case, as Holly Barker (2015, 382) argues, that nuclear imperialism rests on the "ability of nuclear states to gain access to resources, occupy lands, and build economic and military strength." Yet what is perhaps unique to nuclear imperialism is the extent to which its legal, administrative, and military structures sought not only to occupy and control but to transform colonized spaces and bodies in order to use them as laboratories for sensing, collecting, and monopolizing data about weaponized energy (radiological, acoustic, etc.).

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In this way, the "irradiation of the Pacific Islands" directly impacted the food systems, health, and culture of local populations. But the post-test bioaccumulation studies were equally significant in terms of their contributions to what Elizabeth DeLoughrey (2009, 469) describes as the Cold War "economy of light"; the sensory techniques originally developed for writing about and mapping the effects of the bomb, along with the data collected through those techniques, were later mobilized as technological innovations, "such as the high-speed camera, color film, and radiotherapy" (469). In conjunction with the initial application of force (nuclear, electromagnetic, vibrational) to bodies and environments in the PPG via the nuclear detonations, the longer-term process of monitoring and mapping those forces in the PPG operated as instruments of sensory violence. By using these instruments on spaces and subjects that were supposedly outside or peripheral to modernity, nuclear imperialism produced new concepts, such as the environment-as-ecosystem, as well as new technologies that primarily benefited scientific, military, and industrial organizations which considered themselves to be the Western "core" of modernity.

To explore the manner in which sensing became an imperial instrument and a type of weapon in the early Cold War, I revisit the experimental work of prominent US ocean scientist Walter Munk, highlighting the ways in which scientific sensing techniques imposed colonial divisions across spaces and bodies in the PPG and how these divisions were recognized and enforced through legal regulations that governed the collection and use of data related to nuclear weapons tests. The argument I advance is that the colonial ordering of the senses evident in Munk's work was a central modality of nuclear imperial power. Nuclear imperialism projected its power not only through weapons tests, the vaporization of land, and the erosion of the rights of people who lived there, but also through the production of a "nuclear sensorium"—the differentiation of modes of sensing the bomb and the attribution of varying degrees of epistemological value and legal weight to these sensory modes. The legal framework for nuclear weapons tests ensured that the sensory practices and technologies of ecological research supported nuclear imperialism at the expense of communities in the PPG, whose knowledge and sensory practices were suppressed or dismissed. The forms of occupation, exploitation, and destruction characteristic of nuclear imperialism were enabled not only by nuclear might but also by an array of sensory techniques and discourses for capturing and deploying light, sound, and vibration and by legal discourse which presented discriminatory, exploitative, and violent sensory techniques as necessary for the production of scientific knowledge.

Sensing and Erasing the Marshall Islands

The legal framework of nuclear weapons testing may be conceptualized as an instance of what Andrew Rotter (2011, 5) calls "sensory civilization" and, in particular, the colonial belief that "a vital part of the civilizing process was to put the senses in the right order of priority and to ensure them against offence or affront … It was the duty of more sensorily advanced Westerners to put the senses right before withdrawing the most obvious manifestations of their power." In the past decade, historical work on the relation between empire and environment

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has pointed out that a common strategy of nuclear imperialism is the representation of environments targeted for destruction or development as "empty" (DeLoughrey 2012; Martin 2018). This representational strategy and its destructive effects may be particularly acute in the nuclear context but extends into other contexts as well. Rob Nixon (2011, 164) traces the symbolic emptying of "hydrological space" where, for example, the flooding of land by Indian megadam projects is justified through the "invention of emptiness" whereby communities living in the targeted space are constructed as lawless, propertyless, and "inconveniencing anachronisms." In this way the erosion of land and the erosion of rights reinforce one another.

In retracing the nuclear sensorium of US Cold War imperialism, I attend to a similar relationship between nuclear destruction and the representation of populations as having different capacities to sense the modalities of that destruction. Though irradiated subjects in the PPG were useful for both the development of ecological theory and the assessment and modeling of nuclear destruction, the embodied senses of those subjects were "inconveniencing anachronisms" in the development of military-scientific infrastructures and practices of sensing vibration, sound, and radioactive contamination. From Cold War nuclear destruction to contemporary megadam projects, there are several strategies of power that are consistently used by imperial actors across the decades to construct space as empty and inhabitants as lacking culture, infrastructure, and title to space. However, as Nixon notes in his analysis of strategies of power in the context of Indian megadam development, "Emptiness is an industry that needs constant rhetorical replenishment: the promotion of megadams depends on such emptying out, on actively administered invisibility. Within the dynamics of invisibility and hypervisibility, the myths of emptiness generate unimagined—or at the very least, underimagined—communities (165).

In the case of the PPG, emptiness depended on the representation of communities living there as (1) lacking the means by which to manage their environments and their health and (2) lacking the military-scientific sensory frameworks necessary for producing data and knowledge about the impact of nuclear weapons on their environment and on their own bodies. In regard to the first type of lack, the Trusteeship Agreement for the Former Japanese Mandated Islands, issued by the United Nations in 1947, set out the framework for US control of the PPG and its obligations to protect the resources and health of communities in the region. The second form of lack was constructed through the *Atomic Energy Act of 1946*, which provided the juridical means by which to use the PPG, as a territory under US control, as a test site for nuclear weapons experiments. The Act established the framework for civilian oversight of nuclear energy but at the same time provided the military with a monopoly over the use of nuclear materials and the production of knowledge for the development of nuclear weapons. Section 10 of the Act, "Control of Information," appears to balance the interests in secrecy and national security on the one hand with the advancement and dissemination of research on the other hand. Yet the structure of this clause on "restricted data" prioritizes information control over exchange: "The term 'restricted data' as used in this section means all data concerning the manufacture or utilization of atomic weapons,

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the production of fissionable material, or the use of fissionable material in the production of power, but shall not include any data which the Commission from time to time determines may be published without adversely affecting the common defense and security" (s.10(b)(1)). By default then "all data" related to nuclear weapons was restricted. This expansive category included the "lands and bodies" of Indigenous communities in the PPG, which were "classified information" insofar as they contained "restricted data" that could provide insight into nuclear weapons and radiation ecology (Schwartz, 7). Under the Act, scientific and technical means for extracting this data from land, bodies, and water were controlled by the Atomic Energy Commission and the military, and in practice, modes of sensing based on these data acquisition tools were privileged over the embodied senses of local communities. As communities returned to the PPG, they could see and feel the effects of the nuclear tests around them but such indications of health and environmental risk were ignored in favour of increasing scientific-technical sensing of the effects of radiation in bodies and environments. After removing communities from the islands in the 1940s and 1950s, the US government persuaded them to return in the late 1950s through the 1980s (Marshall Islands Nuclear Claims Tribunal 2007, 20). According to experts writing on behalf of displaced and irradiated communities in a tribunal regarding compensation for communities affected by tests, "Because of the blisters in their mouths from the food, and because they could see the effects of radiation in the trees and plants they ate from, the Rongelapese attribute their health problems to the presence of radiation in their environment" (24). Fifty years earlier, however, the legal structure of sensing in the nuclear testing regime constructed PPG inhabitants and their bodies as repositories of "restricted data" to be sensed and managed by the state rather than as actively sensing subjects. While this component of the legislation was amended in 1954, the revisions were focused primarily on the private production and use of nuclear power and benefited the emerging nuclear industry rather than communities affected by nuclear weapons tests.

The new division between sensed and sensing subjects shaped the practices of scientists such as oceanographer Walter Munk as part of the US Nuclear Testing Program, initially designed to survey the environmental impact of nuclear explosions and later to study the complex mediating effects of the environment on the global circulation, accumulation, and impact of radioactive fallout. Like many other scientists who were enlisted into the US military's nuclearization strategy, Munk played a key role in reconceptualizing and remapping the environment in a way that would facilitate knowledge acquisition and prediction of the bomb's effects. Munk is perhaps better known today for his controversial attempts in the 1990s to use high powered acoustic pulses in the ocean to monitor global warming (Munk 1990). Munk initially developed an appreciation for long-distance propagation not in relation to sound waves but in relation to ocean waves and tides; his expertise in this area led the Pentagon to hire him to develop a prediction model for wave height that would enable the planning of naval operations. This work steered Munk in the direction of long-distance propagation of waves—the source of swells for instance in particular regions of the ocean which had long-reaching effects on wave height in other parts of the world. This work was based on

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the concept of the "wave path," the global curves of which could be traced through the ocean in order to predict the direction, temporality, height, and impact of waves on ships or shores (von Storch and Hasselmann 2010, 3-8). This remapping of the ocean as a system of pathways or channels later informed Munk's notion of using acoustic paths in the ocean to transmit sound waves around the world and pick them up again by sensors placed along the ray path.

This circuit-like view of the ocean consisted of a lattice of predictable structures that were shaped like layers but which were invariably depicted and described in scientific and technical discourse as channels, paths, or rays for the conveyance of vibration (Shiga 2015). This channelized view of the ocean had the advantage of enabling scientists to conceptualize acoustic and other types of force as propagating over long distances, perhaps even globally, but also contained within linear structures within the ocean. The channel became a key spatial figure through which Munk and other researchers conceptualized the transmission of water waves, acoustic waves and, as discussed in subsequent sections, the shock waves and radioactive fallout of nuclear weapons. As Lieven De Cauter (2004) observes in the context of global capitalism, the "first world" experience of mobility, change, and frontierless extraction and consumption depends paradoxically on the "capsularization" of space manifested in the hardening of boundaries, barriers and walls. The channelized ocean and the broader figure of the ecological pathway were congruent with this imperial representation of global space as both boundless (to imperial expansion and force) and enclosed (and thus knowable, predictable, and controllable).

Oceanographic research on ocean currents, deep water circulatory systems, and underwater acoustics became a key site for the articulation of ocean science to military interests in expansion and control (Rainger 2000). Through the lens of the channel, the ocean environment was represented as a system of pathways which could be exploited in environmental monitoring programs, first established during the Cold War, to model and measure the flow of radioactive isotopes generated by nuclear tests "in media such as air, water, soil, plants, animals, and humans" (Bruno 2003, 240). One of the key factors driving scientific efforts to sense radiation and trace its pathways was the anticipation of nuclear warfare. Another factor was the belief held by most scientists and military officials working in this field during the 1950s and 1960s that existing levels of nuclear testing could be carried out indefinitely since they were no different from natural disasters (Martin 2018, 581). What enabled ecologists to regard nuclear detonations along the same lines as forest fires or storms was the notion of "natural reservoirs" or containers for nuclear fallout and waste in the oceans, in the atmosphere, and underground; these seemingly limitless containers for nuclear contaminants were assumed to "reduce greatly the probability that such materials [would] get incorporated in the bio-chemistry of living organisms, including man" (Bruno 2003, 245). What Sarah Daw (2016) describes as "dark ecology" began to emerge at the intersection of nuclear weapons and the environmental sensing apparatus developed to regulate the impact of those weapons. Similarly, Martin notes, "destruction was the enabling condition for understanding life as interconnected." (584). In Daw's view, dark ecological discourse posited that an "infinite" or "total" mesh "must contain everything,

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including what is perceived to be 'anti-ecological,' such as the destructive potential of the nuclear bomb" (121). It may be characterized as "dark" ecology in the sense that the study of the environmental impact of nuclear weapons generated ecological models which in turn supported the notion that nuclear weapons testing and even nuclear war could be sustained indefinitely; as a set of military and scientific practices, dark ecology aimed "both to exploit nature's resources and to manage the effects of a nuclear war" (Bruno 2003, 257).

The methods and models of contemporary environmental science descend from Cold War environmental monitoring programs for sensing, tracing, and predicting the ecological effects of the propagation of acoustic force, shockwaves, radioactive isotopes, and other contaminants through pathways that cut across machines, bodies, and environments. What made the global release of these contaminants thinkable was the development of a system of containment, including infrastructures for sensing and capturing contamination on a scale that was imagined to be always larger than the scale of contamination.

The militarization of ecological knowledge paralleled and supported the militarization of space. As Pierre Bélanger and Alexander Arroyo (2016, 16) have demonstrated, the Cold War was marked by the rise of US military logistical infrastructure that was "oceanic and orbital in scale" as the US military became "the single largest landowner, equipment contractor and energy consumer in the world," encompassing "561,975 facilities (buildings and structures) located on more than 4,855 sites, on approximately 24.9 million acres"—a matrix of spatial power that is now distributed across "all 50 states, 6 U.S. territories and outlaying areas, and 42 foreign countries." While the pace and scale of militarization increased during the Cold War, public access to this space was extremely limited due to "new ontologies of spatial power" driven by the fusion of military command and control with the technoscientific network-building. Space was, continues to be, reconfigured in military and technoscientific mapping practices through broad categories such as the "white space" of administrative accounting, the "black space" of covert sites, and the "grey space" in between. As these abstract headings in the new typology of space suggest, the "planetarity" of military infrastructure during the Cold War coincided with the increasing inaccessibility of this infrastructure to the senses; the visible signs of militarized space—military vehicles, administrative structures and industrial installations—were but the surface of a network transecting terrestrial space, the atmosphere, and "3.4 million square nautical miles of ocean (larger than the combined land area of all fifty [US] states" (17).

A key modality for the production of subjectivity within this new "ecology of power" was the practice of mapping logistical infrastructures and their operational environments. These logistical maps function as "representations of who we—as the project of, and projection from the 'West'—are, what we are doing, how we are doing it, and how far we will go" (18). At the same time, such maps of military force across political and geographic space were largely closed off to public scrutiny. Thus, a central paradox of the Cold War was that the planetarity of military operations coincided with a decline in the sense-ability of militarized space. For Bélanger and Arroyo, "so vast and omnipresent is this infrastructure beyond the battlefield that we are no longer able to detect its extents, rendered virtually invisible by its scale" (17).

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Foucault's (2012, 9) account of gradual disappearance of physical punishment in public space in the early nineteenth century can be extended a century and a half later where the new condition of imperceptibility began to characterize modern military operations and infrastructure: "it leaves the domain of more or less everyday perception and enters that of abstract consciousness; its effectiveness is seen as resulting from its inevitability, not from its visible intensity." A similar dynamic characterized modern forms of military power, which became increasingly ubiquitous yet imperceptible via media systems that transect sea, land and sky—what Lisa Parks (2016, 233) has called technologies of "vertical mediation" that use "the vertical field in efforts to materially reform life on earth." These two major transformations in military force—the decline in perceptibility through ubiquity and obfuscation and the instrumentalization of the vertical field—are particularly evident in the case of nuclear weapons testing, where the force of the bomb registered not only as pressure, heat, and shock but more enduringly and less obviously at the scale of atomic particles and DNA, both "sideways" through the bodies and spaces and upwards and downwards through layers of the biosphere.

As a counter-strategy, those whose lives and landscapes had been rewritten by the nuclear testing apparatus attempted to mobilize juridical frameworks and sensory and representational practices that would render perceptible the impact of nuclear imperialism at various spatial and temporal scales. Indeed, as discussed in subsequent sections, the sensory violence, or what Masco (2004, 350) refers to as the "nuclear sublime," experienced by those within the nuclear testing apparatus had the potential to generate subjectivities opposed to nuclear weapons. In an early instance of what is referred to today as the formation of "sensor publics," the communities who had been displaced by the weapons tests and then prematurely resettled in an irradiated landscape began to mobilize their own embodied sensory practices as well as testimony about the sensory violence of the nuclear testing regime (Waller and Witjes 2017, 40). As the technoaesthetic practices of nuclear testing regimes shifted toward remote sensing of detonations below the surface of the ground and the sea, and later into computer simulation, the sensory encounters that led to the push for disarmament in the early Cold War period began to wane. Nevertheless, the public testimony and ensuing controversy over the impact of nuclear testing and sensing on local communities through the Nuclear Claims Tribunal had the potential to "provoke reorderings between politics and its environments" (40). While this paper only provides a brief glimpse into such counter-strategies of sensing, it is suggestive of the potential for local communities to challenge dominant notions of whose senses matter in the governance of nuclear weapons.

The Volatilization of Subjects and Spaces

For the military, the planetary scale of weapons systems raised an urgent problem: How could these new ontologies of spatial power be sensed? More specifically, what configurations of technology and subjectivity might enable military force in the atmosphere, the ocean, and underground to be made accessible, at least temporarily, to human senses? Walter Munk's career highlights two intertwined Cold War technoaesthetic strategies of rendering this new type of infrastructural space:

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objectification (representation of the targets, means, and operational environments of command and control) and *volatilization* (disruption of constitutive relations within and between environment, culture, and subject). While modes of objectification have received considerable attention in critical studies of (mostly visual) military media, here I want to shift the focus to environmental and subject volatilization. The rendering of subjects and spaces as volatile and open to disruption and reconfiguration tends to be neglected in critical histories of the Cold War that focus on the construction of geopolitical space as a "closed-world" of "global surveillance and control through high-technology military power" (Edwards 1996, 1). This section elucidates the multiple ways in which Cold War imperialism manipulated the relationship between the senses and the environment to render islands, local communities, and scientists volatile and open to rapid and ongoing reconfiguration.

The subject position of scientists, particularly those who studied the relationship between military technology, environments, and bodies, had already undergone considerable change during the Second World War. For example, in order to conduct research on underwater sound, oceanographers required access to submarines, sonar, and research funding, which, during this period, were controlled by the military. Until the end of the Second World War, oceanographers had been assimilated into economic, cultural, and organizational structures of the Navy and were permitted to conduct research in this space only insofar as the results could be put to immediate use in the Allied war effort. As Ronald Rainger (2000, 370) has shown, during this period oceanographers' work on underwater acoustics "accrued to the military's advantage … thereby contributing to the effort to understand and control the war-fighting environment."

At the end of the war, a new problem emerged for the military which had by this point become accustomed to dictating the terms of environmental knowledge production by monopolizing logistical, transportation, and sensory (acoustic, electromagnetic, etc.) infrastructures on which the access to remote spaces such as the deep ocean depended (Ritts and Shiga 2016). With demobilization, the military required a new framework to capture and direct scientific expertise. As Chandra Mukerji (1989, 48–9) has argued, Munk and thousands of other scientists who worked on the early Cold War nuclear tests were part of a large-scale "workfare" research system whereby military funding for scientific research on the interaction of nuclear weapons and environments would simultaneously promote basic science and produce information to guide nuclear strategy. The US government's "soft money" research system supported a broad range of projects, some of which had immediate applications in nuclear strategy while others contributed to basic science or were driven by the research agendas of particular scientists. The flexibility of the new funding model was intended to attract and retain expertise so that the state would have access to "an elite reserve of scientists" to carry out the nuclearization of the military in the coming decades (49).

Munk's research in the PPG was emblematic of the broad directives of the soft money funding system—a paradigm which generated knowledge with applications in nuclear warfare (e.g., the study of wave formation and the flow of radiation around underwater nuclear detonations) while at the same time supporting a range of

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projects driven by scientists' interest in advancing theory and basic science (e.g., the discovery of the secondary circulation system in island lagoons). At this stage, there was considerable uncertainty as to the specific types of knowledge that would be required to develop nuclear strategy. Munk and thousands of other scientists working in the PPG provided the military with a pool of scientific expertise that could be drawn upon, mobilized and directed to specific problems according to the changing needs of the military (Mukerji 1989, 50).

Munk spent a considerable amount of his time in both military research and in oceanography on mapping acoustic force. He was continually drawn to the development and occupation of multi-sensory vantage points in the military-scientific complex; many of these points were located midway along on the spectrum of sound and force, listening and feeling, which proved to be effective for witnessing environmental and bodily volatilization. Among the first of these waypoints or contact zones constructed by Munk (along with thousands of other scientists and military personnel involved in the coordination of campaign-like operations) between sound and force was the 1952 US hydrogen bomb test at Enewetak Atoll, which Munk described as "the site of the perfect oceanographic experiment" (von Storch and Hasselmann 2010, 25). Volatilization strategies took a variety of forms at Enewetak, some generated by nuclear sensing infrastructure and weapons, as discussed below, and others through tactics of persuasion designed to modify subjectivities and weaken bonds between communities and particular geographic locations. The indigenous population was misled regarding the nature, duration and likely impact of the tests and persuaded to relocate prior to the test (since at least one of the islands would be vaporized). This process was facilitated by the vertical mediations of aerial photography which framed the islands as "distant and primitive" in military discourse and in the "documentary" films produced by the US military for public consumption in which the islands were likened to "beads of a necklace"—an imperial framing which aimed to legitimate the appropriation, depopulation and destruction of the atoll (Mielke 2005, 32).

Munk was concerned that, since the atoll was part of a raised seamount extending 18,000 feet from the seafloor, the atomic blast might trigger an underwater landslide on the seamount, which could in turn generate a tsunami that would endanger those who remained on islands outside the test zone (von Storch and Hasselmann 2010, 27). Munk and his colleagues convinced military officials to develop an evacuation plan that would be executed if Munk's team detected a "tsunami signal," that is, a fluctuation of pressure waves transmitted from the seamount to metal anchors on the peak of the seamount, through a piano wire that was connected to a pressure gauge calibrated to respond to the tsunami frequency and a paper tape recording that traced the pressure levels, which Munk read through high-density goggles on a three-by-three-foot raft floating thousands of feet above the peak of the seamount (Figure 1). If the pressure gauge detected the tsunami frequency in the seamount, Munk would signal to the *USS Estes* using a semaphore system ("BAKER BAKER BAKER" meant "destructive tsunami Marshall Islands" whereas "ABLE ABLE ABLE" signalled "destructive tsunami Pacific Ocean") and the ship would then relay the message to the evacuation zones (von Storch and Hasselmann 2010, 27). This improvised nuclear-generated tsunami sensing system was configured to

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Figure 1 Walter Munk's colleague, Willard Bascom, on a 3- by 3-foot raft from which he watched, and felt, the Ivy Mike hydrogen bomb test at Enewetak in 1952 (von Storch and Hasselmann 2010, 28).

detect and relay pressure changes on the threshold between sound and inaudible acoustic force (shockwaves conveyed by piano wire from the peak of the seamount to the raft on the surface), triggering a pen-and-paper inscription of the pressure differences over time. Tuned to the signature vibration of a tsunami, the action of the apparatus would set in motion another series of transductions: from the mechanical energy of geophysical displacement, piano wire vibrations, pressure gauge, and pen and ink to optical communications (flag signals), electrical signalling (ship-to-shore communications links) and finally bodily and vehicular movement (evacuation of the islands).

Given the predominant reading in critical studies of Cold War surveillance in terms of the discourse of containment (e.g., Edwards 1996), what stands out here in the "management" of atomic shock waves is the strategic production of disorder in local material environments and human societies subjected to the centrifugal forces of nuclear weapons tests and "humanitarian" relocation and evacuation before and during such tests. Operation Ivy and other early nuclear weapons tests suggest that strategies of containment work in tandem with another biopolitical modality based on volatilization. As DeLoughrey (2012, 168) argues, two concepts

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drove nuclear weapons testing in the Pacific: the "isolate" (articulated in the military's treatment of the Pacific island as a closed-system and therefore useful as a nuclear weapons testing laboratory isolated from the rest of the world) and the "flow of energy" (enacted in ecological studies funded by the Atomic Energy Commission (AEC) of the flow of subatomic particles through bodies and environments). The binding of these two concepts enabled the deeply imbricated relationship between US military nuclearism and environmentalism. Understood as an isolated laboratory space, the Pacific island appeared to the military as the ideal site for producing local disorder, uncertainty, disruption, and trauma via nuclear weapons, which in turn enabled the imposition and naturalization of imperial divisions and relations between people, things, and environments. In this context, from the vantage of Munk's floating nuclear tsunami detector, the iron cage of threat detection becomes the reassuring basis for nuclear experiments in environmental and bodily volatility. Similarly, O'Gorman and Hamilton (2011, 43) argue that "the rationalization of nuclear weapons, in a psychoanalytic sense, has depended on 'rationalization' in the Weberian sense of the 'expansion of empirical knowledge, of predictive capacity, or instrumental and organizational mastery of empirical processes.'" My suggestion here is that the global mesh of military-scientific sensing provided some reassurance that experiments in nuclear, acoustic and blast wave volatility of environments (e.g., island vaporization) and bodies (e.g., effects of radiation on military personnel and local communities) could be contained within bounded spaces which the military referred to as "danger zones."

But the sensors did two unexpected things which disrupted the notion that danger could be contained within the military's logistical mesh. First, they demonstrated that the slow violence of ecological destruction generated by nuclear weapons could not be contained within a particular locality or designated region. Whereas the assumption underlying the tests was that "fallout, once leaving the danger zone, would dissipate quickly and evenly as it was borne away by winds and ocean currents" and would be "harmless within a few miles," it was found that "geophysical forces spared no place on earth from radioactive contamination," and that "ecological-biological mechanisms" introduced additional complexities in the environment's storage and transportation of fallout (Higuchi 2010, 304).

Second, the sensors and sensory practices used to monitor the flow of contaminants became an extension and amplification of the nuclear violence they were designed to monitor, contain, and hold at a distance. As discussed in the next section, the routine use of Geiger counters, for example, projected military power through the sounding of bodies of people who had been displaced by the nuclear testing program and inscribed gender differences in the sensory and experiential dimensions of this nuclear catastrophe (Schwartz 2012).

As is the case with armed conflict in general, the exercise of power through the nuclear tests in the PPG was articulated through the use of force but also through differences in the capacity to sense, record, and control information about destruction as well as through the use of force. Military documentation (Joint Task Force Seven 1952, 8) of the thermonuclear nuclear test "Mike" lists eleven experimental programs that were conducted before, during, and after detonation, some of which involved the development of specialized media adapted to the spatial parameters

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and temporalities of nuclear weapons, including cameras capable of running anywhere from 16 to 3,500,000 frames per second for documenting "ball-of-fire growth, cloud development, and illumination versus time … measurement of the internal temperature distribution … and the MIKE crater structure." Another experimental program was devoted to sensing blast waves and "their propagation through air, water and earth, and their transient effects upon these media" (11). To that end, instruments were devised to sense changes in acoustic pressure at various depths of water, "shock wind" and "afterwind," water and air pressure changes, and "acoustic pressure waves at great distances" (11). The report notes that a key finding of these studies was that "inhomogeneities" in air and other elemental media "markedly affect the blast variables at great distances from large yield weapons" (11). Volatility—or knowledge about the range of potential blasts and fallout trajectories and the risks posed by their environmental impact—was in this sense mobilized as a resource for the exercise of power. One way of mobilizing this resource was to create locations within infrastructures that would control the way material disturbances (e.g., shock waves) were registered and transduced into humanly sensible phenomena.

Munk appears to have been working within the blast wave studies program, which included "a newly devised light and inexpensive deep sea mooring, utilizing the top of under-sea mountains rising to some 5,000 feet under the surface," which, according to the report by the Joint Task Force Seven, and contrary to Munk's account discussed above, was "highly successful" and could "offer a valuable contribution to ocean studies in general" (12). The privileged points of sensory experience within the circuit of vibrational force were not the "god's eye view" or the "view from nowhere" often associated with Cold War military-intelligence practices of seeing and mapping the earth from above; rather, the privileged points within a system geared for maximum material and psychological disruption were the nodes connecting imperceptible nuclear substance and force with sensory modalities. In other words, the strategic position was the point at which unseen and unheard force of atomic shock became sensible in advance of the impact of this force on the environment and the entities within it.

In the case of atomic shockwaves, this in-betweenness depended on the intermediality of Munk's atomic tsunami warning system, which was key to the terrifying technoaesthetic sensory experience of the body on the brink of nuclear volatilization:

> Time zero had been set for 1952 November 1 0715.000 hours [Enewetak] local time. It was before dawn, cold and wet. I put on my high-density goggles. An instant heat blast signaled the explosion. At 0721 a 5-millibar air shock arrived, followed by angry rumbling. After that, nothing. By then the mushroom cloud had reached 20 miles. I was 72 n. miles from Eluklab Island (which by then had evaporated) but the appearance was that I was beneath a raging inferno. I kept adding 5-minute time marks to the straight line drawn by the pressure recorder. (von Storch and Hasselmann 2010, 29)

Approximately thirty minutes after detonation, Munk was ordered to abandon his raft and board the *Horizon*, which sped away from the islands to avoid fallout. The following morning, Munk returned to the raft and examined the spool of

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his recorder, which continued to trace pressure changes after he left. Approximately ninety seconds after Munk abandoned the raft, the spool showed a spike in pressure—and yet there was no tsunami. The spike, Munk guessed, was likely caused by a glitch—noise in the pressure readings somewhere in the link between seamount, piano wire, pressure gauge, and recorder. But had he remained on the raft, Munk claimed, he would have relayed the tsunami vibration through his flag signal, triggering the evacuation of thousands of people with a false alarm and, as he speculated years later, would likely have been too ashamed to return to his post at the Scripps Institute (von Storch and Hasselmann 2010, 30).

The force of the atomic bomb as a shockwave that ripped across the water and the seafloor reveals in both its sensorial and speculative dimensions the technoaesthetic mediation of nuclear force in the PPG. More specifically, one of the unique elements of the early nuclear weapons testing regime was its orientation toward tactility, whereas the technoaesthetic practices of subsequent testing regimes privileged visualization. Tactility has long been associated with "nearness, intimacy, touch, and affection … positive experiences of belonging, rootedness and intimacy" (Pallasmaa 2017, 17). But Munk's account of the Mike shot thermonuclear explosion is a reminder of the political history of hapticity and the manner in which the meanings associated with haptic elements (vibration, pressure, and shock) are contingent upon the material conditions of sensory experience, including the modes of perception and signifying systems of the nuclear technoaesthetic shared by scientists and military officials. The pressure gauge, the piano wire, and the spooling recorder mediate vibration as inscription; here "touch" produces distance and abstraction through inscription and quantification even as the heat and pressure on Munk's skin signified the co-presence of the bomb and the technoaesthetic subject. Further, the "noise" in the medium ("perhaps the pressure gauge had slipped down the mooring wire") points to the contingency of the meanings of vibration and hapticity on the elemental milieu or the "operational environment," in this case, sea water (von Storch and Hasselmann 2010, 30). Moreover, Munk's account makes clear the extent to which this haptic subject position constructed within military logistical media may indeed produce a sense of proximity to the thermonuclear event but it does so through the (relatively) safe distance afforded by Munk's improvised prosthetic sensing and signalling system.

One aspect of this experimental nuclear infrastructure that distinguished it from its successors was the physical proximity of bomb, sensory system, and subject. The early testing regime kept these elements sufficiently close to one another that the subject could feel the force of the bomb and at the same time monitor the output of prosthetic sensors. Rather than construing the difference between technoaesthetic regimes in terms of direct and indirect or unmediated and mediated experience of the bomb, Munk's account demonstrates that it is the multimodal tactility, visuality, and aurality that characterized the early nuclear technoaesthetic regime. The emphasis on the haptic and the aural in scientists' accounts of these early tests is not surprising given the limitations of visual perception in negotiating thermonuclear detonations and their aftermath. O'Gorman and Hamilton (2011, 47) note that "a great portion of the apparatus that surrounded the bomb device was created in order to scientifically measure the nature and scale of its effects.

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And, in this regard, the most 'natural' of human measuring devices, the eye, was manifestly inadequate." Some of the immediate effects of the shock wave and thermal emissions were plain to see given the wide blast radius of each nuclear test (Figure 2). But radiological contamination was much more difficult to detect because, like other forms of what Rob Nixon (2013) refers to as "slow violence," radiation impacts bodies and environments over much longer periods of time than an explosive shockwave or acoustic blast. As one community member on Bikini atoll put it, "There is a lot of cancer … What radiation does psychologically tends to supersede the fear and the reality of cancer. You can't really see it or touch it, but it produces a heightened sense of danger" (Guyer 2001, 1373).

To manage these effects across different spatial and temporal scales, nuclear weapons research programs developed modalities of sensing that extended well beyond visible light to radiation, low frequency sound, and seismic waves (Joint Task Force Seven 1952, 12).

The military desire to bring the enemy closer—to make contact for the purpose of prediction, control, and eventual destruction—is often rendered through mapping, targeting, visualization, and other processes of objectifying the enemy Other. What seems significant here is that "contact" sought in the case of the Mike shot, as with other nuclear weapon tests, is with the force of the device itself, felt and rendered legible through its impact on the environment. Haptic media are in this way oriented not so much toward the signification of objects in space but to the sensing and mapping of energy or force and the consequent disappearance and

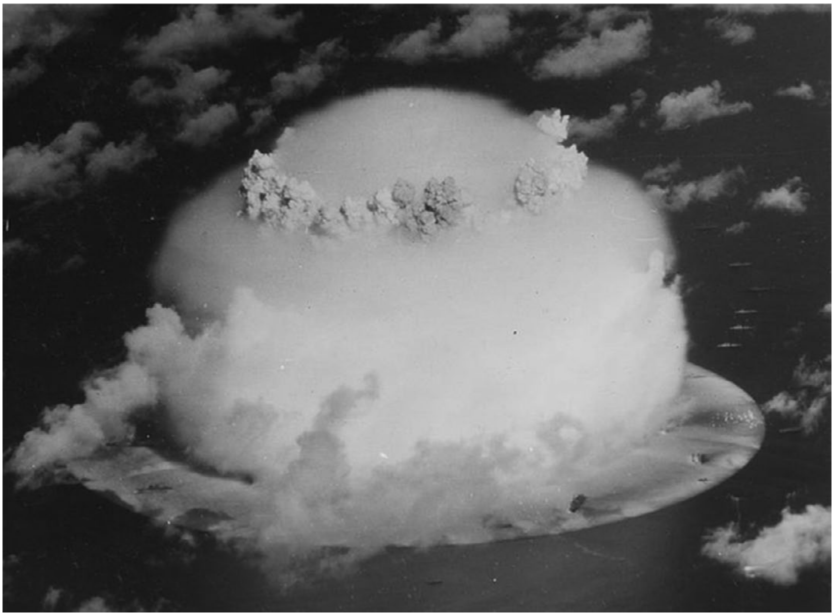

Figure 2 Photograph in US Library of Congress handout showing the formation of a mushroom cloud during Operation Crossroads at Bikini Atoll, Marshall Islands (Brunnstrom 2014).

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emptying of space (the vaporization of Elugelab and several other islands—see Figure 3). The political significance of military haptics—in this case, the imbrications of seamount and pressure gauge, water and wire, the elemental and the technical—stem in part from the way such haptics are configured in the broader nuclear technoaesthetic to construct subject positions in relation to mechanical force, compression waves, oceanic vibration, and radioactive fallout.

Sensing Irradiated Subjects

The entwined practices of feeling, inscribing, and reading vibration described above in the nuclear technoaesthetic provide insight into mid-twentieth-century military-scientific forms of "environmentality," which Agrawal (2005, 166) defines as "a framework of understanding in which technologies of self and power are involved in the creation of new subjects concerned about the environment." While today, "concern" in this context might be read as "care for" the environment, modern environmentality initially emerged from the "dark ecology" of military science and was shaped by the need to construct the relation between nuclear violence (thermal, acoustic, compressive, radioactive) and natural environments as something that could be sensed, represented and managed through military-scientific infrastructures and practices (Daw 2016). This effort to construct nuclear weapons and their environmental impacts as manageable and sustainable over long periods motivated the study of the impact of nuclear weapons on the environment as well as the strategic use of oceanic, atmospheric, and terrestrial environments through monitoring and forecasting to ensure "optimal" outcomes of the deployment of nuclear weapons and the tracking of their effects. Contemporary ecological notions of human-nonhuman coexistence have their origin in the military concern with complexity and uncertainty stemming from the new interconnectedness of ocean, sky, soil, plants, and bodies as pathways for nuclear isotopes.

International law participates in the construction of military spatial ontologies and the modulation of subjectivities according to the dark ecology of military-industrial science. The relevant body of international law in this context consists of international treaties and, more specifically, the responsibility of states for "transboundary interference," that is "environmental interference which originates in activities within the jurisdiction or control of a state and cause harm outside the jurisdiction of that state" (Lefeber 1996, 10). The responsibilities of states to prevent harm to the "global commons" was a later development, usually traced to the 1972 UN Stockholm Declaration on the Human Environment (191–92). Even this later development constrained the degree to which states can be held responsible for transboundary effects of nuclear weapons and the myriad technologies which support them. According to Principle 21 of the Declaration, "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction" (United Nations 1972, Principle 21). The principles of the Declaration were subsequently "considered to be basic rules of international environmental law. Principle 21 in particular is regarded as a basic

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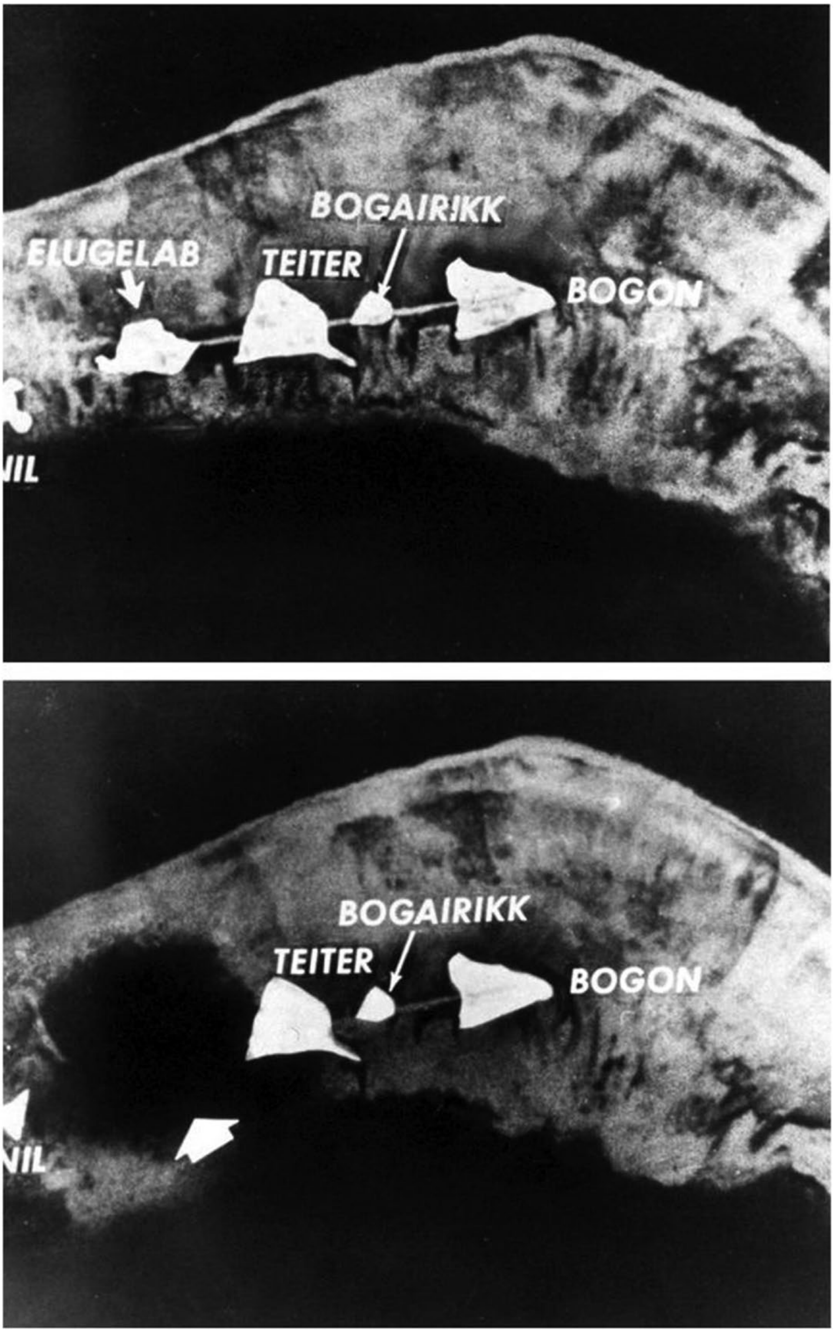

Figure 3 Pre- and post-test aerial photography of Mike shot. Top: atoll before Mike shot, including Elugelab on the left. Bottom: the crater left by Mike shot in the atoll (bottom) (Wikimedia Commons).

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rule for the elaboration of multilateral conventions" (Lefeber 1996, 23). The UN Declaration and Principle 21 make it the responsibility of states to prevent and address harm to the global commons (rather than only to national interests) but the Declaration also reinforces the constraints of international liability that had already become evident in the 1950s and 1960s by outlining responsibilities but not liabilities and making the object of regulation significant (and measurable) "environmental harm" rather than the more diffuse and complex domain of "environmental interference" which can include "persons and property" (23). Moreover, Principle 20 of the Declaration holds that "Scientific research and development in the context of environmental problems, both national and multinational, must be promoted … In this connexion, the free flow of up-to-date scientific information and transfer of experience must be supported and assisted, to facilitate the solution of environmental problems" (United Nations 1972, Principle 20). This principle of the "free flow" of environmental data crystalizes a view of scientific knowledge production as a counterbalance and solution to ecological crisis. However, the manner in which scientific modes of monitoring, sensing, and mapping the environment may themselves be causes of or contribute to "environmental interference," and may support "environmental harm" generated by nuclear weapons as discussed in the previous section, is not addressed by the Declaration.

These constraints and omissions in the Declaration, considered at the time to be a bold move in international law to curb the effects of state activities on the environment, are suggestive of the extent to which these legal developments enabled many activities which underlie the contemporary environmental crisis. In the 1950s and 1960s, the primary legal mechanism for addressing the impact of nuclear weapons was litigation on the grounds of non-compliance with obligations set out in bilateral treaties. As a regulatory mechanism, the lawsuits were a reactive instrument in the sense that they were mobilized after the fact in response to harms and damage that had already occurred. As with other forms of transboundary pollution, the most effective way of reducing the global impact of nuclear weapons would be to proactively prevent or minimize radioactive, acoustic, and thermal, etc. emissions, but litigation tends to confine legal action to damage to "national rights and interests" (Hanqin 2003, 191). Nuclear fallout lawsuits acknowledge past human and environmental trauma but tend to elide the ongoing impact nuclear weapons are having now and in the future; moreover, they address the impact on nations rather than environmental destruction beyond the control and interests of states.

Legal action against the US government in relation to its nuclear weapons tests in the PPG focused on three groups of victims: the Enewetakese, Bikinians, and Rongelapese communities who lived on the atolls; approximately 42,000 US military personnel who were involved in the tests (with apparently little attention given to documenting their exposure); and the crew of Japanese fishing boats and a freighter which were irradiated during the tests (as well as the Japanese fishing industry which experienced financial losses due to the radiological contamination of fish) (Guyer 2001, 1375; Lefeber 1996, 167–68). The US government provided compensation to all three groups to avoid further legal action. The indigenous communities of the Marshall Islands nevertheless initiated a series of lawsuits

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against the US government in the decades that followed, which alleged that the nuclear tests breached the US government's obligations under the Trusteeship Agreement for the Former Japanese Mandated Islands, issued by the United Nations in 1947. The agreement granted control over the atolls to the US government, and the atolls were now clustered together as in a zone that was renamed the Trust Territory of the Pacific Islands and which the US military referred to as the Pacific Proving Grounds (PPG). Under that agreement, "the United States had committed itself 'to protect the health of the inhabitants' (Article 6(2)) and 'to protect inhabitants against the loss of their lands and resources' (Article 6(3))" (Lefeber 1996, 168). In litigation, the Marshallese claimed that, to the extent that government officials knew that the nuclear tests would have deleterious effects on the environment as well as the social ties and cultural heritage of the Marshallese (e.g., through the relocation of communities to different islands and the disruption of dietary habits due to irradiation of plants and animals on the islands), the Nuclear Testing Program was a breach of the Agreement. The Republic of the Marshall Islands was established in 1979 and an agreement between the Marshall Islands and the United States, the Compact of Free Association, came into force in 1986. The Nuclear Claims Tribunal was established under the Compact to distribute funding to claimants for property damage, injury, and hardship caused by the nuclear testing program. Based on the testimony of medical experts, the Nuclear Claims Tribunal recognized "some thirty-six forms of radiogenic cancers and disease as resulting from nuclear weapons tests exposures. A review of Tribunal awards in 2007 found that most awards were for thyroid cancers and disease, pulmonary and lung cancer, cancers of the blood, bone marrow, and lymph nodes, breast cancer, and cancers of the ovary" (Johnston 2015, 147).

Since the atolls were under US control during this period, US laws governing nuclear power, in particular the *Atomic Energy Act of 1946*, shaped military and scientific practices of deploying, monitoring, and documenting nuclear force on and around the islands. The Act enabled the Atomic Energy Commission's Project 4.1, "The Study of Response of Human Beings Exposed to Significant Beta and Gamma Radiation Due to Fall from High Yield Weapons," which used the indigenous population as test subjects without their knowledge and at the same time, under the Act, "the lands and bodies of the Rongelapese were classified information, or secret 'restricted data'" (Schwartz 2012, 7). Indeed, the Advisory Committee on Human Radiation Experiments, established by the Clinton Administration in 1994 to investigate the claims of the Marshallese and other groups who alleged unethical conduct on the part of the US government during the Cold War, determined that "Government officials and investigators are blameworthy for not having had policies and practices in place to protect the rights and interests of human subjects who were used in research from which the subjects could not possibly derive medical benefit" (11). The President's advisory committee further states that "The greatest harm from past experiments and intentional releases [of radioactive substances] may be the legacy of distrust they created" due to the manner in which "information about human experiments was kept secret out of concern for embarrassment to the government, potential legal liability, and worry that public misunderstanding would jeopardize government programs" (13). The uneven

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distribution of the infrastructure required to sense and measure radiation levels effectively gave military officials a monopoly over knowledge produced by radiation surveys of the atolls, and that information was withheld from the Marshallese when they were told they could return to Rongelap atoll. As a Nuclear Claims Tribunal decision noted in 2007 in response to one of many class action lawsuits filed by the Marshallese for property damage associated with the Nuclear Testing Program, "Although the people were assured that it was safe to return to Rongelap in 1957, it was evident that the U.S. knew Rongelap was still contaminated at that time" (Marshall Islands Nuclear Claims Tribunal 2007, 29).

While the President's Advisory Committee on Human Radiation Experiments suggests that the tests were justified since at least some of the radiation experiments appeared to be intended to benefit the Marshallese, this response seems to operate in a mode of discourse Medovoi (2009, 113) calls "sustainability as disavowal," that is, "a split discourse that … both denies and refers to a painfully traumatic reality." It does so in part by glossing over the multiple positionings of Marshallese communities through the legal and sensory apparatus of the nuclear test regime. While the *Atomic Energy Act of 1946* was presented as a framework for ensuring nuclear science and technology would be developed in the interest of the US public, it can also be understood as a component of a biojuridical framework which encouraged human populations, along with flora and fauna, to be treated as biological strata of the PPG and as repositories of classified data regarding the effects of shock waves, heat, and radioactive fallout, and as potential liabilities. Although the US military knew, at least as far back as the Manhattan Project, that high intensity radiation would have harmful effects on human health, the weapons tests in the Pacific were designed on the assumption that military-scientific techniques for sensing and predicting environmental dynamics were sufficiently advanced to control and contain the effects of fallout within the "isolated" test sites of the atolls (Higuchi 2010, 306). While a danger zone was extended beyond the atolls to the high seas, "this precautionary measure proved not to be adequate due to errors made in the advance calculations of the magnitude of the explosion and the direction of the wind" (Lefeber 1996, 167). The fallout cloud that engulfed Japanese fishing vessels and freighters outside the proclaimed danger zone was the first of many indications that military officials and scientists had not taken into account "the role of the environment in mediating between human beings and radioactive fallout" (Higuchi 2010, 305). Follow-up surveys were conducted in the 1950s to trace the pathways of fallout through heterogeneous materials, including air, water, soil, animals, plants, and people as well as the pathways between them established by cultural practices such as dietary conventions. As lead marine biologist Lauren Donaldson wrote in her 1951 letter to the Atomic Energy Commission, "It is essential … that studies evaluating biotic contamination keep pace with the changes in weapon design, materials used, and efficiencies obtained" (Higuchi 2010, 304). The nuclear explosions were thus followed by a wave of sensory exercises in the 1950s designed to trace the active role of the environment in shaping the movement and impact of fallout. These large-scale and secret studies were principally motivated by US interests in predicting the likely distribution of radioactive fallout from nuclear detonations (304).

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In this way, the *Atomic Energy Act of 1946* privileged the right of the state to control nuclear weapons–related data over the rights of local communities to bodily integrity and thereby contributed to the formation of "dark ecology" or environmental subject formation which centered on sensing, tracing, mapping and measuring the "anti-ecological" force of nuclear weapons. Dark ecology aimed to trace the pathways of radioactive isotopes through the environment and led to insights that are foundational to contemporary ecology, such as the manner in which "pollutants could travel over long periods and distances, and that they could be accumulated in a reservoir or in organic matter. The research revealed how interconnected different ecosystems are and led to the view that our global environment cannot tolerate endless pollutants" (Bruno 2003, 237).

Yet the military's ecology, which inadvertently contributed to the emergence of contemporary ecological consciousness and the environmental movement, was "dark" not only because it used, as its medium of sensing, the "anti-ecological" agent of radioactive fallout to trace pathways through physical environments but also because this mode of radiological "feeling"—scanning, tracing, sweeping for isotopes—was anti-human or at least dehumanizing. In follow-up surveys, the US military scanned radiation levels not only on the islands where the nuclear devices were detonated but also on the bodies of those closest to explosions. The most heavily irradiated were the Rongelapese, who were relocated to the island of Kwajalein. As one Rongelap community member described in an exhibit submitted to the Nuclear Claims Tribunal, the manner in which the military deployed Geiger counters on their irradiated bodies paralleled the social disconnections triggered by the bomb and the subsequent relocations to other islands.

> In front of [the male Rongelapese translators] … three times a day for three months, the Rongelapese women were told to undress and stand naked at the lagoon's edge. The women would cry from embarrassment and try to cover their genitals with their hands. U.S. Government officials, all men, ran Geiger counters up and down the bodies of the naked women both before and after they bathed in the lagoon. Frequently, the Geiger counters would start clicking wildly when taking readings from the hair on the women's heads and from their pubic hair. The U.S. Government workers would tell the women to soap their pubic hair again, in front of everyone, before a second reading. [The male translators] … tried to avert their eyes whenever possible but their presence by their naked mothers and sisters was mortifying. (Marshall Islands Nuclear Claims Tribunal 2007, 22)

This passage highlights significant differences in what Jessica Schwartz (2012, 9) terms "nuclear encounter." The uneven distribution of the technical knowledge and infrastructure for sensing radioactive materials intersects with the mode of acoustic volatilization discussed in the first part of this paper. As Schwartz (2012, 10, emphasis in original) writes, "For women in this context, listening anew became aligned with taboo cultural practices and shameful engagement over which they had no control. The sound of the Geiger counter clicking wildly attuned the Rongelapese to an invisible, insensible poison that had been absorbed by their bodies and manifested as illness—and yet it sonorized a private experience of the irradiated female body for the public soundscape of *American male doctors*."

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Although the Nuclear Claims Tribunal and to some extent the President's Advisory Committee on Human Radiation Experiments appear to allow public scrutiny of what were largely classified practices of nuclear testing and sensing, they have the effect of limiting, containing, or deflecting critique from the nuclear volatilization of bodies, cultures, and environments in the PPG through their compensatory logic. The nuclear catastrophe becomes an isolated incident appropriately dealt with through the compensatory mechanism of litigation. In fact, by the early Cold War period, the ocean had already become thoroughly ensonified and rendered as a nuclear fuel dump, workshop, laboratory, and nuclear weapons "proving ground."

Legacies of the Nuclear Sensorium

The form of military environmentality first articulated in the Operation Ivy and Operation Mike experiments, both conducted in 1952, continues to shape the interaction of sound and force in ecological discourse and the geosciences. Since the early 1990s, scientific uses of ocean sound have come under increasing scrutiny by environmental groups and ocean governance institutions due to controversial acoustic experiments in the ocean, such as the Heard Island Feasibility Test, an acoustic tomography experiment in 1991 in which MIT researchers transmitted powerful low frequency acoustic signals throughout the world's oceans in an attempt to use the travel time of the sound to calculate global ocean temperatures.

Walter Munk was the primary figure behind the Heard Island Feasibility Test (Figure 4). While the energy source in this case was a series of high-power, low-frequency acoustic transmitters rather than nuclear weapons, key elements of the Heard Island Feasibility Test appeared to be shaped by Munk's previous experience

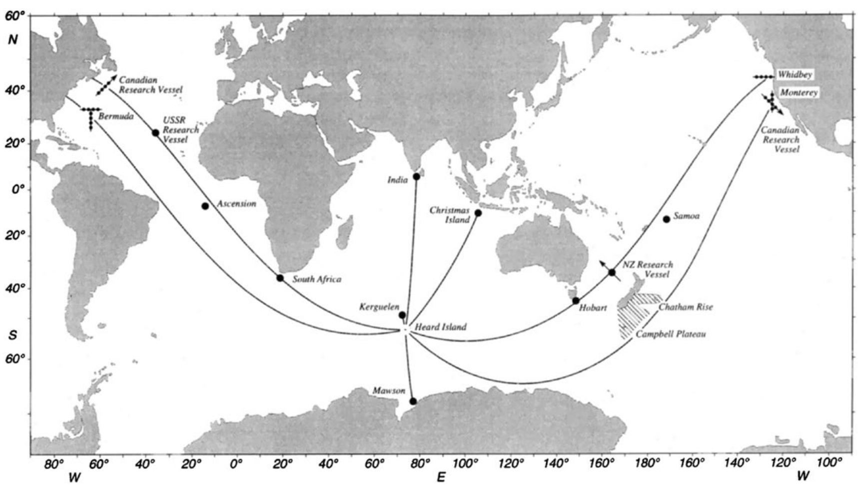

Figure 4 Diagram of the acoustic system used in the Heard Island Feasibility Test. Curved lines represent the ray path of low-frequency sound produced by an underwater transmitter near Heard Island (centre) and picked up by receivers (black dots). (Munk, Spindel, Baggeroer, and Birdsall 1994, 2331)

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tracing vibration through the ocean during the nuclear tests in the PPG. These elements include the structure of the test (an acoustic "shot" emitted in the ocean followed by sensing and measuring environmental effects), its scale (sound levels that are loud enough to propagate around the world), its material composition (expertise and equipment drawn from military, academic, and private institutions), its colonial configuration (using "remote" or "peripheral" spaces for the production of knowledge and technology in countries that are, or seek to be, part of the "core"), and its discursive minimization of claims regarding the threat to the entities caught in the test zone (the research team requested a permit from the National Marine and Fisheries Service to "take"—that is, harass, harm, or kill—over 500,000 animals) (Munk et al. 1994, 2331–33; Potter 1994, 53). As with Cold War techniques of environmental monitoring and governance described in this paper, the Heard Island experiment, and its successor, the Acoustic Thermometry of Ocean Climate (ATOC) experiment, were justified on the grounds that they would enhance scientific understanding of the environment. And, like the Cold War systems of sensory violence, we can also understand how the Heard Island test and subsequent programs using global acoustic sensing are "anti-ecological"—in this case, drastically increasing levels of ocean noise, which, according to the World Wildlife Foundation (2013, 89), "is a complex environmental threat. It is difficult to regulate as unlike other pollutants, it is invisible and odourless." While nuclear testing by Western imperial actors may have shifted from detonation in open environments to computer simulation, it seems likely that nuclear imperialism's logic of sensory governance will persist in contemporary discourses and practices of environmental security, where scientific modes of sensing are privileged above all others, including the senses of those who are volatilized in test zone.

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