S.A.P.I.EN.S

8.1 (2015)
Vol.8 / n°1

Carmella Gray-Cosgrove, Max Liboiron and Josh Lepawsky

The Challenges of Temporality to Depollution & Remediation

Electronic reference
Carmella Gray-Cosgrove, Max Liboiron and Josh Lepawsky, « The Challenges of Temporality to Depollution & Remediation », *S.A.P.I.EN.S* [Online], 8.1 | 2015, Online since 15 January 2016, connection on 16 February 2016. URL : http://sapiens.revues.org/1740

Publisher: Institut Veolia Environnement
http://sapiens.revues.org
http://www.revues.org

INSTITUT
Veolia Environnement

S.A.P.I.EN.S
Volume 8 issue 1 2015

Surveys

The Challenges of Temporality to Depollution & Remediation

Carmella Gray-Cosgrove[1], Max Liboiron[2] and Josh Lepawsky[2]

[1]Memorial University of Newfoundland, 230 Elizabeth Ave, St John's, NL, A1B 3X9,
E-mail : carmellagc@gmail.com

[2]Dr., Memorial University of Newfoundland, 230 Elizabeth Ave, St John's, NL, A1B 3X9

Abstract

Complete depollution and effective remediation are impossible for many wastes. Long-enduring and even permanent wastes such as nuclear waste, ocean plastics, orbital debris, and persistent organic pollutants (POPs), among others, present unique problems for remediation because of their temporality. While they may be spatially moved and "cleaned up," the hazardous or toxic substance themselves will continue to endure in time, which means remediation becomes an exercise in shifting materials in space rather than their elimination. This strategy means that spills, leaks, and future care are pressing problems that can reintroduce the substance to new environments and bodies. Thus, the main methods to address toxicity in the environment—depollution and remediation—are stopgaps at best. While different disciplines have been aware of these problems for years, an interdisciplinary synthesis is lacking. We offer one here by considering a range of research, case studies, and theories around the temporality of waste drawing from archaeology, biology, environmental science, geography, geology, history, science and technology studies (STS), and sociology. We first outline key concepts that describe waste's long-term temporality: deep-time, the Anthropocene, and slow violence. Then, we consider case studies of nuclear, plastic, and orbital wastes to illustrate these concepts. We conclude with an overview of waste management strategies designed to extend for centuries, including concepts of future generations and kinship. Our goal is to provide an interdisciplinary vocabulary and framework so researchers and waste managers can solve problems that track across challenges and types of waste.

Keywords: temporality, depollution, remediation, radioactive waste, plastics, orbital debris

TABLE OF CONTENTS

Published: 15 december 2015
Edited by: Nicolas Renard. This manuscript was reviewed by two anonymous referees.

1. INTRODUCTION

We trace the trajectory of how researchers have conceptualized and are attempting to deal with extremely long-lived waste and how the concept of extreme longevity and toxicity has influenced research across a wide range of disciplines. Researchers are increasingly concluding that complete depollution (eliminating pollutants in an area) and effective remediation (reversing or stopping environmental harm) are impossible for many wastes. Wastes characterized by slow decomposition or strong molecular bonds such as nuclear waste, plastics, persistent organic pollutants (POPs), and orbital debris, among others, pose an acute challenge to the very concept of depollution and remediation.

First, while pollutants may be "cleaned up" in a particular area, the hazardous or toxic substance itself will continue to endure in time, which means remediation becomes an exercise in shifting materials in space rather than eliminating harm altogether. Secondly, the extreme longevity of these materials challenges the logistics of containment central to depollution and remediation; spills, leaks, and future care are pressing problems that can reintroduce the substance to new environments and bodies. In short, very long-lived toxic and hazardous substances will continue to cause harm no matter where they are moved, and because they can persist in geological time—that is, longer than the human species—any containment in human-devised systems is temporary. On a human timescale, the disposal, containment, and management of long-lived waste present two main problems: 1) technological failure of infrastructure that may result in new needs for depollution and remediation, and 2) social challenges as waste siting often poses a disproportionate burden of environmental and health risks for Indigenous communities, racial minorities, and low-income populations that live where containment and processing are usually sited (Bullard, 2000; Nixon, 2011; Bohme, 2014).

Despite the realization that the temporal characteristics of some wastes pose unique problems to pollution practices, an interdisciplinary synthesis and a shared vocabulary for the problem are missing. As three experts in waste from different disciplines, we offer a synthesis of literature from a range of research areas, case studies, and theories around the temporality of waste drawing from archaeology, biology, environmental science, geography, geology, history, science and technology studies (STS), and sociology. In short, we offer our services here as interdisciplinary translators to document the trajectory of research on temporality across disciplines. First, we cover three main theories on the temporalities of waste as they relate to depollution: deep-time, the Anthropocene, and "slow violence." Then, we draw on our own research to highlight three examples of extremely long-lived wastes—nuclear contaminants, plastics, and orbital debris—and how their different material and temporal properties align (and do not align) with temporal theories of waste. We conclude with an overview of solutions that take the extreme longevity of certain wastes into account in terms of stewardship and perpetual care, almost all of which originate in nuclear waste management. Yet, these ideas, though fruitful, are only one set of guidelines for future actions. More are needed. Our goal is that this overview of the issue will provide a shared vocabulary and set of references so experts across disciplines can move forward in concert.

2. THEORIZING PERMANENCE

2.1 DEEP TIME AND THE ANTHROPOCENE

"Deep time" is a concept of geologic time conceived in the 18th century to describe the age of the earth (Irvine, 2014). Many wastes invented since the 19th century exist in geological, or "deep" time on the scale of planetary processes and as such will outlive the human species. While radioactive waste has long been linked to deep time (Benford, 2000; Ialenti, 2014), other materials are increasingly understood on, and defined by, a geologic time scale, including plastics (Corcoran et al., 2014) and orbital debris (Gorman, 2014). "The Anthropocene," first popularized in the *Global Change Newsletter* in 2000 by atmospheric chemist Paul Crutzen, is being used to describe the current geologic period during which humans have permanently and irreversibly changed planetary cycles of biology, chemistry, and geology through wastes such as excess carbon dioxide (Crutzen & Stoermer, 2000). While the Anthropocene is not (yet) an official geologic epoch, the term situates anthropogenic waste on the geologic timescale providing an appropriate focus with which to understand the long timescales of permanent and persistent waste, as well as their effects on a global scale. The wastes we consider here can be properly called "Athropocenic wastes".

2.2 SLOWNESS & UNEVENESS

Yet the longevity of materials is only one aspect of the problem. The continuous pollution caused by some materials has uneven geographies, effecting certain bodies and areas more than others. Fence-line or down-wind communities are the "long-termers" (Nixon, 2011: 17) of the effects of persistent waste, living on land that has been "stripped of the very characteristics that made it inhabitable" (p.19). "Unequal exposures" (Bohme, 2014) to toxic waste mean that it is often Indigenous peoples, racial minorities, and low-income groups that are disproportionately affected not only by the immediate effects of waste and pollution such as acute exposure, but also by the longue durée of persistent waste and pollution. As such, environmental and social justice is always part of waste remediation and containment.

Humanities scholar Rob Nixon has coined the term "slow violence" to describe the effects of waste and pollution,

> "[...] that occurs gradually and out of sight, a violence of delayed destruction that is dispersed across time and space, an attritional violence that is typically not viewed as violence at all. Violence is customarily conceived as an event or action that is im-

> mediate in time, explosive and spectacular in space, and as erupting into instant sensational visibility. We need, I believe, to engage a different kind of violence, a violence that is neither spectacular nor instantaneous, but rather incremental and accretive, its calamitous repercussions playing out across a range of temporal scales." (Nixon, 2011: 2).

Waste literature is slowly accounting for the effects of waste beyond the "point in time" of a pollution-event and is beginning to look at a longer, potentially uneven,v "period" of pollution (Kümmerer, 1996; Erikson, 1995) to permit a continued understanding of often-imperceptible damage. Concepts such as the "slow violence" of industrial particulates and effluents (Nixon, 2011), the "slow bombs" of radioactive emissions from nuclear waste produced by the manufacturing of nuclear arms[1], and "zombie mines" with permanent heavy metals and leachates (Sandlos & Keeling, 2013), are used to describe the longevity and persistence of often invisible harm.

From another disciplinary perspective, disaster studies is also looking at the slow, difficult to detect, longue durée of crisis. Disaster is often defined as a sudden event that disrupts normal functioning of a community or society, but increasingly disaster research shows that "slow disasters" like living near interred chemicals that leak, such as the disaster at Love Canal (Levine, 1982), also produce the same sorts of disruption and trauma as event-based disasters like hurricanes and floods. In the 1990s, sociologist Kai Erikson emphasized that "chronic conditions as well as acute events can induce trauma, and this, too, belongs in our calculations" of disaster (1994: 20). Erikson describes a "chronic dread" and sense of helplessness among people subject to daily exposure, or even potential exposure, to radiation and toxic chemicals and argues that these exposures create a new, insidious type of trauma, one deserving scholarly and political attention. "Slow disasters" refer to sites that require remediation or depollution to reduce the concentration of harm, but it can also refer to sites next to containment of these same remediated materials.

"Slow disaster" is a fitting concept for remediation and depollution efforts in the Anthropocene. "Disaster" occurs when the usual methods of triage no longer work in the face of new scales of crisis, when efforts to remediate and depollute in the face of extremely long-lived pollutants are a type of disaster in and of themselves. Thus, while slow disaster might refer to certain cases and locales, it also describes the crisis of methodology facing management of certain 21st century wastes.

3. CASE STUDIES

The following case studies come from each author's own research and areas of expertise. We use them to show the difference in how the larger concepts of deep time, slowness, and environmental and social justice work differently through different long-lived waste materials. As such, the theories outlined above are not universalizing theories that apply in the same way to all cases; rather, they are coordinating theories that touch on issues present across cases.

3.1 RADIOACTIVE WASTE

Nuclear waste is an extremely long-lived waste. For instance, the mining and milling of uranium-238, the most commonly occurring isotope of uranium, produces waste comprised in part of thorium-230 and radium-226[2]. These by-products have half-lives of 75,400 years and 1,600 years respectively[3] (US EPA, 2000a; US EPA, 2000b), while uranium-238 has a half-life of 4.5 billion years[4]. These are just three among many radioactive byproducts produced by nuclear industries. The International Atomic Energy Agency estimates that, annually and worldwide, nuclear power facilities alone produce approximately 200,000 m3 of low- and intermediate- level radioactive waste and approximately 10,000 m3 of high-level waste (Letcher & Vallero, 2011: 103). This does not include waste produced by major nuclear events like the Chernobyl and Fukushima Daiichi disasters, waste produced in mining and refining of radioactive ores for nuclear weapons, nor does it include fallout from nuclear testing in places like the Nevada desert and the Bikini Atoll.

To deal with these large quantities of radioactive waste, it has become increasingly common to inject High-Level radioactive Waste (HLW) into deep geological repositories in the earth (Hadjilambrinos, 1999; Loubergé *et al.*, 2002; Rempe, 2007) and to contain Low-Level radioactive Waste (LLW) for permanent storage (Schweitzer & Robbins, 2008). Such repositories are archetypal examples of techniques that use space to manage the time scales of persistent waste. This type of containment lacks the temporal focus necessary to grapple with the longevity of radioactive waste. For example, in deep geological repositories for HLW in Olkiluoto, Finland (Aikas, 2009), New Mexico, USA (Galison, 2014; Van Wyck, 2004), and in Lower-Saxony, Germany (Schwartz, 2010), among others, the toxic half-lives of radionuclides often exceed the lifespan of materials and vessels used for their containment. Even while these materials and vessels are intact, leakages are documented and expected from deep geological repositories (Loubergé *et al.*, 2002; Rempe, 2007; Perrow, 2011). Further, management of radioactive waste must account for changing

---

[1] See the documentary film Uranium (1990), directed by Magnus Isacsson, produced by the National Film Board of Canada.

[2] Information retrieved from the website of the Canadian Nuclear Safety Commission: http://nuclearsafety.gc.ca/eng/waste/uranium-mines-and-millswaste/index.cfm (published 16 February 2015, retrieved 1 April 2015).

[3] Information retrieved from the website of the US Environmental Protection Agency: http://www2.epa.gov/radiation/radionuclide-basics-radium and http://www2.epa.gov/radiation/radionuclide-basics-thorium (accessed 14 April 2015).

[4] The half-life of any radioactive element is the amount of time it takes for that isotope to become half as radioactive by different processes of radioactive decay—the emission of ionizing radiation. As a radioactive isotope begins to decay, it emits radioactive particles (alpha, beta, and gamma particles). Through these emissions the isotope shifts to different, and less radioactive, isotopes down its decay chain. In some cases this halving of radioactivity can take seconds or days. In the case of many highly radioactive isotopes produced in nuclear industries, for example u-238, this halving of radioactivity can take billions of years.

geologic conditions at storage sites—such as rising ocean levels at the Drigg repository—which present challenges like erosion, changing ground water conditions, and shifting storage temperatures (Sumerling *et al.*, 2011; Won *et al.*, 1997). Some radioactive waste storage sites will have to be managed hundreds of thousands of years into the future. In the near and distant future, all sinks are spills (Gabrys, 2009); that is, there is no permanent, "ultimate" sink (Tarr, 1996) from which wastes cannot escape and cause more and future pollution events. Construction of the proposed HLW repository at Yucca Mountain in Nevada, USA has been cancelled due to concerns like these, among a myriad of other complications with HLW siting, funding, and public policy (Beaver, 2010; Ialenti, 2014; Shrader-Frechette, 2005).

A second type of problem in the remediation and depollution of radioactive waste occurs when radioactive pollution is dispersed. The long lifespan and invisible spread of radionuclides from environmental catastrophes like the Chernobyl explosion, the meltdown of the Fukushima Daiichi reactor, or the nuclear tests in the Bikini Atoll are spatially and temporally unbound in Earth systems. These events have effects on human and ecological health that are difficult to trace or measure and which will continue for millennia. In the cases of Fukushima Daiichi and the bombings of the Bikini Islands, these effects are exacerbated by the spread of radionuclides through oceans. Likewise, less acutely irradiated zones like decommissioned uranium mines and mills present similar challenges as radioactive elements are taken up in bodies and spread through lake and river systems as well as through groundwater (Leddy, 2011; Masco, 2004). In all cases, pollution "sites" are either non-existent in the traditional sense of the term, or unevenly "everywhere," an equally difficult "site" to remediate, depollute, or manage.

Importantly, the spatial and temporal challenges of nuclear waste management are fraught with a set of social conditions and inequities in siting both nuclear industries and nuclear waste repositories. Around the world the environmental and health burdens of storing and managing nuclear waste fall disproportionately on Indigenous peoples, low-income groups, and racial minorities (Barker, 2012; Kosek, 2006; Kuletz, 1998; LaDuke, 1999; Masco, 2006; Van Wyck, 2010). This is true of fallout zones and of siting both nuclear industries and nuclear waste repositories. In Canada, the United States, Australia, the Marshall Islands, Madagascar, and Gabon, among many other countries, nuclear waste zones and repositories are sites of what Valerie Kuletz calls "nuclear colonialism" (1998)—the process by which zones of concentrated nuclear activity like mining, bombing, storing, and dumping have disproportionate effects on Indigenous peoples. The long timescales associated with the radioactive emissions of nuclear waste mean that nuclear colonialism extends far beyond the boom and bust of nuclear industries, nuclear zones, and nuclear dumps in colonized countries. Nuclear colonialism is continually iterated after the closure of nuclear-industry facilities by the radioactive emissions of nuclear waste. In other words, just as radioactive elements continue to emit radiation long after the industry that produced them ceases to exist, nuclear industries continue colonization long after the industry itself ceases to produce.

Yet, often these "sites" are everyday spaces. Historian Kate Brown, for example, argues that "atomic cities" (Hanford in the United States, and Mayak, in the former Soviet Union, both former plutonium production facilities) are "slow-motion disasters" for workers and residents because, over time, each has released more curies of ionizing radiation into the environment than the Chernobyl disaster (Brown, 2013). At both sites, the releases were not primarily the result of meltdowns or catastrophic events, rather of normal operating procedures, aging infrastructure, and, in some cases, experiments. Unlike the Chernobyl disaster, releases took place over decades instead of days. These are wastes that remediation and depollution miss, even if they are materially the same as those found in Superfund sites.

3.2 PLASTICS

Plastics also exist in deep time. Rather than degrade into their constituent molecules, plastic polymers fragment into smaller and smaller pieces of plastic, and this "degradation of cm-size plastics results in microscopic particles that remain in Earth's environment indefinitely" (Cooper & Corcoran, 2010: 652). In fact, a new type of "stone" called plastiglomerate has been announced recently (Corcoran *et al.*, 2014). It is formed through intermingling of melted plastic, beach sediment, basaltic lava fragments, and organic debris, creating a permanent anthropogenic marker in the geological record.

Like nuclear waste and other long-lived waste, the longevity of plastics means they are shifted around in space rather than eliminated. For example, when NGOs, municipalities, and other organizations work to "clean up" ocean plastics through beach cleanups or create technologies for removing plastics from marine environments, they merely move plastics from oceans to landfills, where they will remain until landfills are covered with water, erode, or are otherwise disturbed and the plastics are able to travel downhill to oceans once again.

Unlike nuclear waste, which has high levels of bureaucracy, regulation, and infrastructure dedicated to its management (though waste still escapes from nuclear containment systems), plastics are part of municipal (MSW) and industrial solid waste (ISW) systems, where such bureaucracy, regulation, and infrastructure do not exist in the same way. Plastics escape this infrastructure with regularity, flying or falling out of bins, trucks, transfer stations, and container ships. Many countries in the Global South do not have MSW infrastructure at all, contributing a larger share of marine plastics in the near term (Jambeck *et al.*, 2015). Once escaped, plastics are ingested by marine life, from plankton (Cole *et al.*, 2013) to seabirds (Moser & Lee, 1992; Ryan, 2008), they become habitats for a variety of species (Lobelle & Cunliffe, 2011), and they mingle with sediments (Claessens *et al.*, 2011; Carson *et al.*, 2011), making them complex and intractable parts of ecosystems. Their radical dispersal throughout the world's oceans, shores, and landscapes, including their presence within bodies, as well as their extreme longevity, which enable dispersal to continue even after efforts at containment, make plastics impossible to remove from environments completely. Clean up becomes anachronistic, a strategy suited to pre-industrial forms of waste.

Like radioactivity from nuclear activities, contaminants from plastics are often site-less, making their complete immediate and long-term containment impossible. While plastics are made of long, strong polymer bonds, they also contain plasticizers such as bisphenol A (BPA), dioxins, and phthalates, among thousands of others (Jaeger & Rubin, 1970). Plasticizers are added to plastics to give them certain characteristics such as UV resistance, colour, flame retardance, or flexibility. Some of these plasticizers, such as the phthalates found in soft plastic toys, are persistent organic pollutants (POPs). POPs are characterized by their extreme persistence in the environment, toxicity to humans, ability to bioaccumulate in lipids and biomagnify in food chains, and their capacity for long-range, transboundary atmospheric transport and deposition (Jones & De Voogt, 1999). Most of these plasticizers are also endocrine disruptors (Jobling et al., 1995), which can cause transgenic effects, meaning that if a pregnant person or animal is exposed, the effects may not be apparent for three generations (Vom Saal *et al.*, 2007; Shostak, 2013), adding a generational effect to "slow violence." The uneven effects of plastic pollution also manifest in terms of who is most affected: because most plasticizers are endocrine disruptors, they have the greatest impact on fetuses (Bergman *et al.*, 2013). If a pregnant woman with a female fetus is exposed, she, her fetus, and that fetus' eggs are potentially affected.

Like radioactive wastes, endocrine disruptors effect future generations, and both affect the genetic expressions of those future generations, but in different ways. Both can cause transgenic effects, meaning that a mother's exposures can impact unborn children. But endocrine disruptors increase effects transgenically—they are more dangerous to fetuses than to adults—while radioactive materials technically, slowly, decrease effects over time across newly exposed generations because of their half lives, even though these timescales are very long. Comparing plastics to nuclear waste show some of the differences between the unevenness of effects on future generations, even when the mechanics of harm, transgenic effects, are similar.

3.3 ORBITAL DEBRIS

Orbital debris is part of a broader category of discards arising from human extra-terrestrial activity that is of sufficient density that archaeologists have been referring to it as a "cultural landscape" for over a decade (Rathje, 1999; Gorman, 2009; 2014; 2015). Like the other forms of modern waste described above, orbital debris is heterogenous, synthetic in its composition, and is very long lived. Unlike other cited examples however, orbital debris maintains the additional ability to travel and impact worlds beyond the bounds of Earth.

Though it may seem an exotic form of pollution, orbital debris is anything but. Its presence in near-Earth orbit presents a significant enough risk that both the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) maintain offices solely dedicated to tracking and modeling orbital debris. Since the launch of Sputnik in 1957 over 100 million pieces of debris have so far accumulated in orbit[5]. They range in size from a few millimeters to intact but non-functioning spacecraft. Even small fragments pose a growing risk to normal space operations. For example, the International Space Station (ISS) performed five debris avoidance maneuvers in 2014, a fifth of all such maneuvers it has performed since 1999 (Orbital Debris Program Office, 2015).

Like our other examples, orbital debris brings to the fore the issue of temporality for depollution. As the altitude above Earth of orbital debris increases, so does its longevity in orbit, making this unique in our case studies as its spatiality impacts temporality. Above 1000 km, it will typically remain in orbit for at least a century[6]. However, this general relationship is complicated by the mass and velocity of the debris in question. Spacecraft are comprised of heterogeneous materials (including heavy metals and toxic chemicals) and use a variety of fuel systems, including forms of nuclear power. Thus when they cease to function and become debris, spacecraft can entrain both toxicological and radiological consequences for Earth similar to our two case studies above. For example, in 1978 a Soviet nuclear powered satellite named Cosmos 954 failed, tumbled out of orbit, and crashed in Northern Canada. Its breakup on impact spread a radioactive debris field over a 15,000 square mile area (United States Department of Energy, 1978: 14). Debris recovered from the Cosmos 954 crash included sand-grain sized particulate matter of uranium 235 and fission products. The particles were "scattered randomly and quite far apart" through Alberta, Saskatchewan, the Northwest Territories, and Nunavut, which, though it made "cleanup in towns or whereever crowds of people were expected to congregate" feasible left the rest of the landscapes, biota, and populations to fend for themselves (*ibid.*: 59). Most of these populations are Indigenous and Aboriginal peoples, adding an orbital element to "nuclear colonialism" discussed above.

More than a decade before the Cosmos 954 event, an American satellite launched from Vandenburg Air Force Base failed to reach orbit on 21 April 1964. On board was a Systems for Nuclear Auxiliary Power (SNAP) unit powered by nearly 1 kg of Plutonium 238 (Pu-238). The SNAP was not designed to withstand an uncontrolled reentry. Consequently, when it burnt up in the atmosphere its Pu-238 power source was dispersed into the atmosphere. This single event tripled the global fallout of the Pu-238 isotope after accounting for all atmospheric nuclear weapons tests conducted to that point (Hardy *et al.*, 1972: 1). Orbital debris accounts for major quantities of spatially dispersed radioactive waste that endures in deep time.

---

[5] NASA Orbital Debris FAQs: http://orbitaldebris.jsc.nasa.gov/faqs.html. Accessed June 26 2015.

[6] NASA Orbital Debris FAQs: http://orbitaldebris.jsc.nasa.gov/faqs.html. Accessed June 26 2015.

Orbital debris entails similar challenges of temporality to both nuclear and plastic wastes, yet comes with an added twist. Neither storage nor containment offer viable interventions for remediating or depolluting orbital debris, even though orbital debris, like nuclear waste, has massive attendant infrastructures for monitoring and control. This makes orbital debris a unique case for looking at how technical experts approach a permanent waste problem without recourse to depollution or remediation as mitigating methodologies. Proposed solutions usually entail making less debris in the first place, and attempting to manage flow before dealing with the stock of debris already present (Kessler *et al.*, 2010).

4. DEPOLLUTION GIVEN PERMANENCE

Nuclear waste management is at the forefront of thinking about how to manage permanent waste. In 2005, the U.S. Environmental Protection Agency proposed new regulations for Yucca Mountain with the goal "to provide public-health protection for the next million years" (Shrader-Frechette, 2005: 518). The United States nuclear waste inventory, which falls under the purview of the Department of Energy, supports a Long-term Stewardship Program as well as an Office of Legacy Management for radioactive site management. These initiatives recognize problems of permanence and seek concrete ways to address them. However, the effectiveness of the "legacy management" mandate of these programs has been questioned by Shiloh Krupar, who draws attention to the ways in which federal stewardship policies focus on rhetorical approaches to waste management and may not effectively serve to remediate or depollute (Krupar, 2011). How do you actually provide protection for the next million years? How would you remediate waste in space as well as time?

Most research in this area across disciplines is on non-scientific processes to improve the efficacy of waste management because from a technical standpoint, failure will occur at some level over millions of years (Beck, 1992; Perrow, 2011). Instead, social processes are thought to occur on a larger scale, arranging or stewarding future technologies and technical processes. The literature proposes that stewardship and perpetual care of persistent waste sites can be framed as an *ethics of perpetual care*, which considers the importance of continuity in future approaches to long-lived waste, communication with future generations, and stewardship to the endurance and feasibility of waste management strategies. For example, analysts Katherine Probst and Michael McGovern (1998) in *Resources for the Future Center for Risk Management* assert, "The notion of stewardship carries with it something more than simply a list of tasks or functions to be implemented … It connotes a sacred responsibility to protect human health and the environment for future generations" (p.114). That is, perpetual care includes political organization, infrastructural dedication, and an ethical framework to unite them.

Some of the concrete strategies offered under the perpetual care framework include communication with future generations through monuments, markers, text, archives, symbols, and landscape architecture as well as social technologies such as stories, ceremonies, archetypes, and art (Moisey, 2012; Benford *et al.*, 1991; Benford, 1994; Givens, 1982; Jensen, 1993; Kaplan & Adams,1986; Lomberg & Hora, 1997). Yet issues arise such as the cultural differences between societies millennia in the future, language barriers, loss of cultural memory, desirability of resources, and where and how to archive information about waste (Benford, 2000; Foote, 1990; Ialenti, 2014). Despite some criticism of these approaches from the sciences (Mann, 1986; Mörner, 2001), their strength lies in considering the social, cultural, and ethical aspects of longevity that material sciences generally do not.

Yet, many have criticized the concept of perpetual care because while it deals with the management of infrastructure and communication for the long-term, it does not necessarily account for slow violence, slow disaster, and environmental or social justice. The labour of perpetual care in irradiated zones, for instance, would again fall on the shoulders of the very people affected by radioactive waste in the first place: fence-line and downwind communities. STS scholar Maria Puig de la Bellacasa (2011) argues that an ethics of care must be concerned with questions such as: Who benefits and who is burdened by care? Who cares and for what? Why do we care, and how do we do the labour of caring for, as opposed to merely containing, wastes? Central to these questions is the equitable treatment and protection of our descendants (Shrader-Frechette, 2005: 519) as well as the people who do maintenance work, now and in the long future.

Perpetual care is focused on dealing with pollutants and wastes that have already been created. Some researchers, particularly in marine plastics, argue that a proper remediation or depollution approach needs to deal with the flow as well as the stock of pollutants. Scientists at the research institute 5 Gyres, for example, argue that solutions are needed "upstream" before plastics are created, rather than down steam after plastics are already in marine environments, if the oceans are going to be free of plastics one day[7]. This perspective on remediation, common but growing, expands the temporal dimensions of remediation and depollution to account for permanent wastes and as such adds activities like redesign and legislation.

Perpetual care and upstream solutions are just two of many potential ways to reframe depollution and remediation to deal with long-lived wastes. These approaches are premised on the argument that technological fixes for systemic problems are not adequate solutions (Rosner, 2013; Stabile, 1994). Researchers working on persistent wastes like plastics and orbital debris, among others like arsenic, phthalates, or mercury, for example, must foster similar discussions about what depollution might look like given permanence.

---

[7] See 5 Gyres Blog post "5 reasons why ocean plastic recovery schemes are a terrible idea," by Marcus Ericksen: http://www.5gyres.org/blog/posts/2015/6/17/5-reasons-why-ocean-plastic-recovery-schemes-are-a-terrible-idea. Published June 23 2015, accessed August 17 2015.

References

Aikas, T. (2009). Halfway to the Finnish: some 25 years after it began, Finland's high-level waste disposal programme is on schedule. Posiva is preparing a construction licence application and if all goes well operation should be on track for 2020. *Nuclear Engineering International* 54(660): 16-18.

Barker, H. (2012). *Bravo for the Marshallese: Regaining Control in a Post-Nuclear, Post-Colonial World*. Boston, MA: Cengage Learning.

Beaver, W. (2010). The Demise of Yucca Mountain. *Independent Review* 14(4): 535-547.

Beck, U. (1992). *Risk Society: Towards a New Modernity* (Vol. 17). Newbury Park, CA: Sage.

Benford G., C.W. Kirkwood, H. Otway, & M.J. Pasqualetti (1991). *Ten thousand years of solitude? On inadvertent intrusion into the waste isolation pilot project repository.* Los Alamos National Laboratory: Los Alamos, New Mexico.

Benford, G. (1994). Comporting ourselves to the future: of time, communication and nuclear waste. *Journal of Social and Evolutionary Systems* 17(1): 91-113.

Benford, G. (2000). *Deep Time: How Humanity Communicates Across Millennia*. New York: Harper Perennial.

Bergman, Å., J.J. Heindel, S. Jobling, K.A. Kidd, R.T. Zoeller & S.K. Jobling (2013). *State of the science of endocrine disrupting chemicals 2012: an assessment of the state of the science of endocrine disruptors prepared by a group of experts for the United Nations Environment Programme and World Health Organization*. World Health Organization.

Bohme, S.R. (2014). *Toxic Injustice*. Oakland, CA: University of California Press.

Brown, K. (2013). *Plutopia: Nuclear Families, Atomic Cities, and the Great Soviet and American Plutonium Disasters*. Oxford, UK: Oxford University Press.

Bullard, R.D. (2000). *Dumping in Dixie: Race, class, and environmental quality.* Boulder: Westview Press.

Carson, H.S., S.L. Colbert, M.J. Kaylor & K.J. McDermid (2011). Small plastic debris changes water movement and heat transfer through beach sediments. *Marine Pollution Bulletin* 62(8): 1708-13.

Claessens, M., S. De Meester, L. Van Landuyt, K. De Clerck & C.R. Janssen (2011). Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Marine Pollution Bulletin* 62(10): 2199-2204.

Cole, M., P. Lindeque, E. Fileman, C. Halsband *et al.* (2013). Microplastic ingestion by zooplankton. *Environmental science & technology 47*(12): 6646-6655.

Cooper, D.A. & P.L. Corcoran (2010). Effects of mechanical and chemical processes on the degradation of plastic beach debris on the island of Kauai, Hawaii. *Marine Pollution Bulletin* 60(5): 650-654.

Corcoran, P.L., C.J. Moore & K. Jazvac (2014). An anthropogenic marker horizon in the future rock record. *GSA Today* 24(6): 4-8.

Crutzen, P.J. & E.F. Stoermer (2000). The Anthropocene. *Global Change Newsletter* 41:17-18.

de la Bellacasa, M.P. (2011). Matters of care in technoscience: assembling neglected things. *Social Studies of Science* 41(1): 85-106.

Erikson, K.T. (1995). *A New Species of Trouble: The Human Experience of Modern Disasters*. New York: Norton & Company.

Foote, K. (1990). To remember and forget: archives, memory, and culture. *American Archivist* 53(3): 378-92.

Gabrys, J. (2009). Sink: the dirt of systems. *Environment and Planning D: Society and Space* 27(4): 666-81.

Galison, P. (2014). The future of scenarios: state science fiction. In: Blaagaard, B. (Ed.), *The Subject of Rosi Braidotti: Politics and Concepts*, pp. 38-46. London, UK: Bloomsbury Publishing.

Givens, D.B. (1982). From here to eternity: Communicating with the distant future. *Et Cetera* (39): 159-79.

Gorman, A.C. (2009). The gravity of archaeology. *Archaeologies-Journal of the World Archaeological Congress* 5(2): 344-59.

Gorman, A.C. (2014). The Anthropocene in the solar system. *Journal of Contemporary Archaeology* 1(1): 87-91.

Gorman, A.C. (2015). Robot avatars: the material culture of human activity in Earth orbit. In: O'Leary, B.L. & P.J. Capelotti (Eds.) *Archaeology and Heritage of the Human Movement into Space*, pp. 29-47. Springer International Publishing.

Hadjilambrinos, C. (1999). Toward a rational policy for the management of high-level radioactive waste: integrating science and ethics. *Bulletin of Science, Technology & Society* 19(3): 179-189.

Hardy, E.P., P.W. Krey & H.L. Volchok (1972). *Global Inventory and Distribution of Pu-238 from SNAP-9A*. HASL-250. New York, N.Y.: United States Atomic Energy Commission. http://dx.doi.org/10.2172/4689831.

Ialenti, V.F. (2014). Adjudicating deep time: revisiting the United States' high-level nuclear waste repository project at Yucca Mountain. *Science and Technology Studies 27*(2): 27-48.

Irvine, R. (2014). Deep time: an anthropological problem. *Social Anthropology*, *22*(2): 157-172.

Jackson, M. (2012). Plastic islands and processual grounds: ethics, ontology, and the matter of decay. *Cultural Geographies* (Oct): 147.

Jaeger, R.J. & R.J. Rubin (1970). Plasticizers from plastic devices: extraction, metabolism, and accumulation by biological systems. *Science* 170(3956): 460-62.

Jambeck, J.R., R. Geyer, C. Wilcox, T.R. Siegler, M. Perryman *et al.* (2015). Plastic waste inputs from land into the ocean. *Science* 347(6223): 768-71.

Jensen, M. (1993). *Conservation and retrieval of information: elements of a strategy to inform future societies about nuclear waste repositories.* Nordic Committee for Nuclear Safety Research, Nordic Council of Ministers.

Jobling, S., T. Reynolds, R. White, M.G. Parker & J.P. Sumpter (1995). A variety of environmentally persistent chemicals, including some phthalate plasticizers, are weakly estrogenic. *Environmental Health Perspectives* 103(6): 582-587.

Jones, K.C. & P. De Voogt (1999). Persistent Organic Pollutants (POPs): state of the science. *Environmental Pollution* 100(1): 209-21.

Kaplan, M. & M. Adams (1986). Using the past to protect the future. *Archaeology* 39(5): 7-8.

Kessler, D. J., N.L. Johnson, J.-C. Liou & M. Matney (2010). The Kessler Syndrome: implications to future space operations (AAS 10-016). In: McQuerry, S.C. (Ed.) *Advances in the Astronautical Sciences, Volume 137*, pp. 47-62. San Diego: American Astronautical Society.

Kosek, J. (2006). *Understories: the Political Life of Forests in Northern New Mexico*. Durham, NC: Duke University Press.

Krupar, S.R. (2011). Alien still life: distilling the toxic logics of the Rocky Flats National Wildlife Refuge. *Environment and Planning D: Society and Space* 29(2): 268-290.

Kuletz, V. (1998). *The Tainted Desert : Environmental Ruin in the American West*. New York: Routledge.

Kümmerer, K. (1996). The ecological impact of time. *Time & Society* 5(2): 209-35.

LaDuke, W. (1999). *All Our Relations: Native Struggles for Land and Life*. Cambridge, MA: South End Press.

Leddy, L. (2011). *Cold War colonialism: The Serpent River First Nation and uranium mining, 1953-1988*. ProQuest, UMI Dissertations Publishing, Wilfred Laurier University (Canada).

Letcher, T.M. & D. Vallero (2011). *Waste: A Handbook for Management*. Academic Press.

Levine, A.G. (1982). *Love Canal: Science, Politics, and People*. Lexington, MA: Lexington Books.

Lobelle, D. & M. Cunliffe (2011). Early microbial biofilm formation on marine plastic debris. *Marine Pollution Bulletin* 62(1): 197-200.

Lomberg, J. & S.C. Hora (1997). Very long term communication intelligence: The case of markers for nuclear waste sites. *Technological Forecasting and Social Change* 56(2): 171-88.

Loubergé, H., S. Villeneuve & M. Chesney (2002). Long-term risk management of nuclear waste: a real options approach. *Journal of*

Economic Dynamics and Control 27(1): 157-80.

Mann, W.B. (1986). Identification of nuclear-waste sites over ten millenia. *Nuclear and Chemical Waste Management* 6(2): 95-100.

Masco, J. (2004). Mutant ecologies: radioactive life in post-Cold War New Mexico. *Cultural Anthropology : Journal of the Society for Cultural Anthropology.* 19(4): 517.

Masco, J. (2006). *The Nuclear Borderlands: the Manhattan Project in Post-Cold War New Mexico*. Princeton, N.J: Princeton University Press.

Moisey, A. (2012). Considering the desire to mark our buried nuclear waste: into eternity and the waste isolation pilot plant. *Qui Parle* 20(2): 101-25.

Mörner, N.A. (2001). In absurdum: long-term predictions and nuclear waste handling. *Engineering Geology* 61(2-3): 75-82.

Moser, M.L. & D.S. Lee (1992). A fourteen-year survey of plastic ingestion by Western North Atlantic Seabirds. *Colonial Waterbirds*: 83-94.

Nixon, R. (2011). *Slow Violence and the Environmentalism of the Poor*. Cambridge, Mass.; London: Harvard University Press.

Orbital Debris Program Office (2015). International Space Station performs fourth and fifth debris avoidance maneuvers of 2014. *Orbital Debris Quarterly News* 19(1):1-2.

Perrow, C. (2011). *Normal Accidents: Living With High Risk Technologies*. Princeton, NJ: Princeton University Press.

Probst, K.N. & M.H. McGovern (1998). *Long-Term Stewardship and the Nuclear Weapons Complex: The Challenge Ahead*. Washington: Routledge RFF.

Rathje, W.L. (1999). Archaeology of space garbage. *Discovering*

Archaeology 1(5): 108-11.

Rempe, N.T. (2007). Permanent underground repositories for radioactive waste. *Progress in Nuclear Energy* 49(5): 365-74.

Rosner, L. (Ed.) (2013). *The Technological Fix: How People Use Technology to Create and Solve Problems*. Milton Park, UK: Routledge.

Ryan, P.G. (2008). Seabirds indicate changes in the composition of plastic litter in the Atlantic and South-Western Indian Oceans. *Marine Pollution Bulletin* 56(8): 1406-9.

Sandlos, J. & A. Keeling (2013). Zombie mines and the (over) burden of history. *The Solutions Journal* 4(3): 80-83.

Schwartz, M.O. (2010). Clearing out Asse 2. *Nuclear Engineering International* 55(672): 26-27.

Schweitzer, G. & K. Robbins (2008). *Setting the Stage for International Spent Nuclear Fuel Storage Facilities: International Workshop Proceedings* (No. 9780309119627). Washington, DC, USA: National Academies Press.

Shrader-Frechette, K. (2005). Mortgaging the future: dumping ethics with nuclear waste. *Science and Engineering Ethics* 11(4): 518-20.

Shostak, S. (2013). *Exposed Science: Genes, the Environment, and the Politics of Population Health*. Oakland, CA: University of California Press.

Stabile, C.A. (1994). *Feminism and the Technological Fix*. Manchester: Manchester University Press.

Sumerling, T., P. Fish, G. Towler, J. Penfold, J. Shevelan *et al.* (2011). An assessment of the radiological impact of coastal erosion of the UK Low-Level Waste Repository. In: *ASME 2011 14th International Conference on Environmental Remediation and Radioactive Waste Management*, pp.1341-1350. American Society of Mechanical Engineers.

Tarr, J.A. (1996). *The Search for the Ultimate Sink: Urban Pollution in Historical Perspective*. Akron, OH: University of Akron Press.

United States Department of Energy (1978). *Operation Morning Light | Canadian Northwest Territories / 1978: A non-technical summary of U.S. participation*. EI.28:NV-I98. Las Vegas, Nevada: United States Department of Energy. http://www2.gwu.edu/~nsarchiv/nukevault/ebb267/11.pdf.

Van Wyck, P. (2004). *Signs of Danger: Waste, Trauma, and Nuclear Threat.* Minneapolis: University of Minnesota Press.

Van Wyck, P.C. (2010). *The Highway of the Atom*. Montreal; Ithaca: McGill-Queen's University Press.

Vom Saal, F.S., T. Benson, S.M. Akingbemi, L.S. Belcher *et al.* (2007). Chapel Hill Bisphenol A expert panel consensus statement: integration of mechanisms, effects in animals and potential to impact human health at current levels of exposure. *Reproductive Toxicology* 24(2): 131-138.

Won, K., J. Han & A. Bonne (1997). Radioactive waste disposal: global experience and challenges. *IAEA bulletin 39*(1): 33-41.