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TRACING-AT-A-DISTANCE, OR A MEANINGFUL LEVEL OF RADIOACTIVITY

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Abstract: This article argues that radioisotopes – atoms with unstable nuclei which undergo decay and become detectable against less energised backgrounds – can be understood as a form of media, one that challenges the seeing-at-a-distance of the televisual with a 'tracing-at-a-distance' of radioactive decay. These energetic entities, largely released in the development and subsequent use of nuclear weapons, became indispensable tools for US ecologists during the Cold War, where tracing radioisotopes became a means to reveal biological pathways and biospheric processes with atomic precision. Thinking radioisotopes within the context of the televisual affords the opportunity to challenge the distinction between inscriptive and transmissional media, while bringing media studies into closer contact with the energy humanities and environmental history.

Keywords: Cold War, ecosystems ecology, energy humanities, environmental history, media studies, nuclear science, radioactivity, radioisotopes

1 Introduction

On the first day of Seth Siegelaub's landmark conceptual art exhibition, *January 5-31, 1969*, the artist Robert Barry buried a small container of the synthetic radioisotope barium-133 somewhere in New York City's Central Park. That artwork, *0.5 Microcurie Radiation Installation, January 5, 1969, Barium-133, Central Park, N. Y., 10 year duration (approximate)*, was the final entry in a list of eight others Barry contributed to the show; the list itself, published in the exhibition catalogue, provided more to look at than the artworks themselves.[1] Of the three that actually made it to the venue, only one was visible, and barely so: *Wall to Wall Interior Piece*, a thin line of black plastic affixed to the wall just above the floor. The other two, *88 mc Carrier Wave (FM)* and *1600 kc Carrier Wave*, were radio wave works whose transmitters had been tucked away into a closet. *40 KHZ ultrasonic soundwave installation* arrived at the venue a day before the exhibition began, was (inaudibly) played, and then removed.

Most of Barry's contributions to *January 5-31, 1969* relied on the emission energies, and the physical absence of the devices doing the emitting would seem to suggest Barry was more interested in the energies themselves. From that perspective, the exhibition space was suffused in radio waves, but even then, literally *just* the waves. As media art historian Douglas Kahn explains in his analysis of Barry's radio pieces, what they transmitted "were merely the base frequencies through which signals would be carried," devoid of the sounds, songs, or words we tend to expect from a radio broadcast.[2] Weirdly enough, the only one of Barry's artworks here that could produce audible sound was *0.5 Microcurie Radiation Installation* – assuming you scoured Central Park with a Geiger-Müller counter and listened for one of the twentieth century's most ominous ticks.

That's because barium-133 is a *radioisotope*, an atom with an excess of neutrons uneasily contained in an unstable nucleus.[3] Regular barium only has 81 neutrons and the '-133' here indicates how many neutrons this isotope of the element restlessly holds together (alongside the 56 protons that elementally define barium). The unstable nuclei of radioisotopes undergo *radioactive decay* as they strive to find an energetic equilibrium; this decay can take multiple forms, from high-intensity gamma radiation to conversion electrons, and alpha or beta particles. In each instance, the ionizing radiation of a radioisotope's decay excites electrons in the vicinity, leaving a trace of its presence, which is detectable by specialised devices – from the first electroscopes of the nineteenth-century, then to the twentieth-century's Geiger-Müller counters and liquid scintillation counters, and on to today's advanced positron emission tomography (PET) scanners. The iconic ticking sound one hears from a Geiger-Müller counter is triggered when radioactive decay excites electrons in the device's gas-filled glass tube, creating an electrical current which is then transduced into sound; the faster the ticks, the more radiation.

Radioactive decay is effectively a loss of energy that is also – lest we forget $E=mc^2$ – a loss of mass; the time it takes for a given radioisotope to lose half its energy/mass to radioactive decay is described as its *half-life*, which can vary wildly. Some radioisotopes, like polonium-214, have half-lives measured in microseconds, meaning they decay near instantaneously and release high intensity radiation in the process. Eons by comparison, the radioisotope technetium-99m decays in about six hours. Many more eons than that, there's postassium-40 in your body right now decaying at a rate of billions of years, meaning it poses no harm whatsoever to its surroundings.[4] Other radioisotopes decay less energetically over the course of decades, but as they do, they break down into higher energy, far less stable, shorter-lived radioisotopes – what is also known as a 'decay chain'. This is the case with the iconic Cold War isotope cesium-137, whose thirty-year half-life is incessantly punctuated by decay into the gamma-emitting barium-137m, with a half-life of just under three destructive minutes.

The 10-year duration of Barry's *0.5 Microcurie Radiation Installation* was determined by barium-133's half-life. As he explained to art critic Ursula Meyer, 'the "half-life" in this particular case was ten years, which means that every ten years its energy is decreased by half; but it goes on to infinity, it never goes to nothing.'[5] Technically speaking, Barry is only half-right when it comes to half-life. In the 56 years since the barium-133 was buried, it's been decaying into the stable (i.e., nonradioactive) isotope of cesium-133. This is the only naturally occurring isotope of cesium and, interestingly, the isotope by which the extreme precision of atomic clocks are calibrated. As you can see, this decay chain is only four neutrons short of the far more dangerous pair above.

This may seem like a serious (and seriously technical) digression, but Barry's work is special for the ways in which it entangles arts and energies together—and with energies like these, it's important to be precise. Kahn, whose scholarship is emblematic of handling arts and energies with care, suggests that Barry 'introduced electromagnetism per se – waves, fields, and radiation – as artistic raw material and demonstrated that art could take up different stations all along the electromagnetic spectrum.'[6] Another term for 'artistic raw material' is 'media', at least in a narrower, art historical sense. Whereas medium is the broader stylistic convention, like painting or sculpture, media is the physical stuff which makes up a specific artwork; this could be acrylic, marble, or in Barry's case, radio frequencies and barium-133. Such unconventional media was integral to the conceptual art of Barry's time. Here was a movement intent on interrogating the material limits of, and even the predominance of vision within, the visual arts – all to create space for other forms of meaning-making beyond established boundaries. This idea is critical for what follows.

While Barry's *0.5 Microcurie Radiation Installation* raises the possibility of radioisotopes as media in a strict, art historical sense, the decades leading up to its exhibition saw the radioisotope configured as media in a far more expansive understanding of the term. Beginning with their first scientific uses in the early twentieth century and then during the Cold War, radioisotopes were traced at bodily and biospheric scales to render an image of life on earth with a literally atomic level of granularity. At its core, this essay seeks to unfold that longer, radioactive media history.

All radioisotopes can be traced by virtue of their decay, assuming sensitive enough equipment, but not all radioisotopes are ideal *radiotracers* as that term is commonly used. Radioisotopes tend to be chosen as radiotracers because, most importantly, they are not sufficiently radioactive to cause severe tissue damage, and because their nonradioactive counterparts are commonly found in the molecules of biological systems, such phosphorus or iodine. These non-radioactive atoms are then 'labeled' with a radiotracer and, using the devices mentioned above, their pathways can be traced with a molecular level of precision.[7] Originally called the 'isotopic indicator method,' this revolutionised physiology in the early twentieth century.

With the production of nuclear weapons and their subsequent use in the mid-twentieth century, the number of radioisotopes decaying across the world grew exponentially. These too were figured as radiotracers, predominantly by ecologists funded through the United States Atomic Energy Commission (AEC). As they settled upon the earth's surface and, inescapably, the insides of its lifeforms, these radioactive signatures were traced to reveal pathways at planetary scale. The release and subsequent tracing of such materials proved so effective in articulating ordinarily unseen dynamics – from microscopic nutrient flows to biospheric processes – that field ecologists began deliberately irradiating environments (and their inhabitants) with less damaging radioisotopes to better understand their hidden interactions.

In the postwar era, the production of nuclear munitions and the production of ecological knowledge were indissociable – a historical connection explored in great depth by historians of science, environmental historians, STS scholars, and anthropologists.[8] In what follows, this research is mobilised to make the case for reading the radioisotope as a form of media and an object of an energetically inclined media studies analysis.

The radioisotope, once traced, became a means to grasp the planet at a distance; in this way, it somewhat aligns with this special issue's focus on the historical relations between electromagnetism, its energies, technologies, and the televisual. I say 'somewhat' because there is productive tension here. The radioisotope enacts less an instance of television, or seeing-at-a-distance, and more a tracing-at-a-distance, a tele-detection, which challenges the hegemonic visuality of the remote-viewing paradigm. Even in the absence of vision, the radioisotope made a remarkable contribution to how we sense and make sense of the world.

The radioisotope's challenge to visuality in the present context echoes the more fundamental challenge it mounts to how we distinguish between inscriptive and transmissional media. Using Kahn's terms and distinction, inscriptive media rely on the trace of a surface to be stored and retrieved, contrary to the always-live relay of electromagnetic signals that enliven transmissional media.[9] The radioisotope somehow encompasses both. It is resolutely energetic, and insofar as its particle decay releases photons and excites neighbouring electrons, its effects are electromagnetic. Yet, that same decay – the transmissional process by which the radioisotope becomes detectable as a signature – is emblematically of the trace; it registers the presence of something no longer present. As historian of science Hans-Jörg Rheinberger puts it, 'at the very moment that the trace is produced the [radioactive] marker by decaying irrevocably abolishes itself.'[10] An energetic inscription, a *radiotrace*.

Thus, the radioisotope may be read alongside other counterintuitive forms of media that do not signify in conventional ways while nevertheless enabling and sustaining the transmission of meaning. Here I am thinking of recent debates within media studies concerning the entanglement of processes of mediation and the environment. These tend to bifurcate between critical explications of the relations between media technologies and the physical matter and energetic processes that compose them (as with the extraction of rare earth minerals and the manipulation of temperature in the production of contemporary electronics), and more media theoretical discussions which position such matter and processes *as media* in their own right.[11] To this second strand of thought specifically, John Durham Peters' characterisation of elemental media is apt, since it frames environmental backgrounds like air, water, and earth as the physical conditions of possibility for more conventional forms of media, like print or television.

'"Media," understood as the means by which meaning is communicated, sit atop layers of even more fundamental media that have meaning but do not speak;' nor do they create images.[12] And while the radioisotope's challenge to visuality aligns it with elemental media, it also pushes this idea to its limit: to examine the radioisotope in these terms is to ask just how *elemental* media can get, where even decay events in an atomic background are implicated in historically and technically specific processes of meaning-making.

This article unpacks that historical and technical specificity across five sections with a specific focus on the US context (excluding the first). The story begins at the University of Manchester's Institute of Physics during the early twentieth century, where the traceability of radioisotopes was first discovered and instrumentalised in the study of single organisms. The next section arrives at Linsley Pond, Connecticut, where the novel concepts of energy began to transform ecological discourse, helped in large part by a similarly novel application of radiotracer methodologies. The United States' Pacific Proving Grounds in the Marshall Islands constitute the locus of the following section, where irradiation, further ecosystems research, and other environmental sciences are ever deeper entangled.

The essay concludes with brief remarks on the broader implications of the radioisotope as a form of media and what a meaningful level of radioactivity means.

2 The Institute of Physics, University of Manchester, c. 1911

This section limits its historical scope to the uses of radioisotopes in the earlier twentieth century, before they were accidentally and deliberately released at scales larger than single organisms. Issues of scale are significant here because only once radioisotopes reach a certain level of environmental saturation does the tracing-at-a-distance of signature and background truly activate. Prior to this, the use of radioisotopes was more or less strictly controlled in laboratory settings and relegated to the tracing of biological pathways at the organismic level. Nevertheless, these early experiments lay important groundwork for what's to come.

Hungarian chemist George de Hevesy originated the scientific use of radiotracers in the early twentieth century while working under the supervision of Ernest Rutherford at the University of Manchester's Institute of Physics. Upon meeting in 1911, Rutherford gave de Hevesy a task: 'My boy if you are worth your salt, you try to separate radium D from all that lead.'[13] Unbeknownst to both men at the time, this separation was physically impossible; the unfolding of that impossibility ultimately led to the development of radiotracers, or what de Hevesy initially called the 'isotopic indicator method.'

Radium D is actually a radioisotope of lead (lead-210, to be exact), and while its nuclear composition is distinct, its electron shell is not, meaning it chemically interacts in basically all the ways lead would.[14] This chemical isotropy means Radium D could not be separated from its nonradioactive milieu, but because of its radioactive decay, its excitation of neighbouring electrons can be detected – in this case, by an electroscope, the period's key radiation detection mechanism. At base, de Hevesy surmised that nonradioactive lead could be labelled with its radioactive counterpart and traced once administered in different experimental contexts.

Outside the lab, and equipped with copious amounts of radioactive lead, de Hevesy found surprising ways to test his indicator method. Perhaps the most amusing happened in his Manchester boardinghouse. Unsatisfied with the meals provided by his landlady, de Hevesy had a sneaking suspicion he was being fed leftovers instead of fresh food. The landlady was deeply offended and denied such an unscrupulous accusation, though de Hevesy's indigestion suggested otherwise. After dinner one night, the intrepid experimentalist added a new ingredient to the scraps left on his plate: radioactive lead. Using an electroscope smuggled out of the lab a few days later, de Hevesy examined another ‘fresh’ meal and found something that didn’t agree with him: radioactive lead. Supposedly, the landlady believed de Hevesy’s budding method to be nothing less than ‘magic.’[15]

Beyond the boardinghouse, the first major study of radiotracers in biology was published by de Hevesy in 1923, The Absorption and Translocation of Lead by Plants: A Contribution to the Application of Radioactive Indicators in the Investigation of the Change of Substance in Plants. It began matter-of-factly: ‘The investigation of the absorption of lead by plants can be carried out quite simply by dipping them into a solution which contains a radioactive isotope of lead, and determining the radioactivity of the ash from various parts of the plant.’[16] Once immolated, the varying levels of radioactivity in different parts of the plant – *Vicia Faba*, the humble fava bean plant – indexed the absorptive rates and pathways travelled by the radiotracer. The plant’s annihilation in the process of experimentation is grim foreshadowing of the radioactive history soon to unfold.

At this point, however, the levels of radioactivity were minute, at least when compared to the scientific insights they were delivering. The indicator method won de Hevesy the 1943 Nobel Prize in Chemistry. ‘The most remarkable result obtained in the study of the application of isotopic indicators,’ he wrote in his Nobel lecture,

> is perhaps the discovery of the dynamic state of the body constituents. The molecules building up the plant or animal organism are incessantly renewed. In the course of this renewal… atoms and molecules located in one organ or in one type of molecule will soon be found in another organ or in another type of molecule present in the same or in another organ.[17]

Which is to say, differently, radiotracers revealed with atomic granularity the permeability of the tissues and systems of an individual organism. This constraint of scale was both methodological and practical. Physiology is the study of organisms and their parts, and the cyclotrons used to produce scientific-grade radioisotopes were only invented in 1929.

All of this is to say that large-scale radioisotope studies beyond single organisms were not on the radar at this moment. But, if the overall objective is to understand how radioisotopes enacted a tracing-at-a-distance and mediated a more traceable *world*, the shift from de Hevesy’s radiotracing of single organisms to the radiotracing of biospheric flows is critical. Of course, the development, production, and use of nuclear weapons is integral here – the sheer number of radioisotopes generated in the lead up to and after 1945 provided both a means and demand to trace radioactivity at planetary scale. However, this is not when the environment was first imagined as radiotraceable – that moment took place just a few years prior.

3 Linsley Pond, Connecticut, c. 1941

At nearly the moment ecologists conceptualised the environment in explicitly energetic terms, did its radiotraceability appear. Bearing this out requires a brief foray into that moment in ecology’s intellectual history where, in the years leading up to 1945, ‘energy’ entered into and dramatically transformed the discipline. A full recounting of prewar ecology’s debates is well beyond the scope of this article but suffice it to say there were competing visions of what actually and fundamentally constitutes an ecology.[18] One of the most important figures to emerge from these debates was Raymond J. Lindeman, and it was through Lindeman that ecology took a serious turn towards energy, or, as he called it at that time, the ‘trophic-dynamic aspect’.

In *The Trophic-Dyanmic Aspect of Ecology* (1942), Lindeman argued an ecology is best understood through the flow of energy amongst its constituent parts, and critically, that those parts could not be inflexibly delineated between ‘living’ and ‘non-living.’ Aligning his viewpoint with the ‘biogeochemistry’ of Valdimir I. Vernadsky, Lindeman suggested that

> the discrimination between living organisms as parts of the 'biotic community' and dead organisms and inorganic nutrients as part of the 'environment' seems arbitrary and unnatural.... The constant organic-inorganic cycle of nutritive substance is so completely integrated that to consider even such a unit as a lake primarily as a biotic community appears to force a 'biological' emphasis upon a more basic functional organization.[19]

That 'more basic functional organization', according to Lindeman, 'is the transfer of energy from one part of the ecosystem to another. All function, and indeed, all life, within an ecosystem depends upon the utilization of an external source of energy, solar radiation.'[20]

Vernadsky's influence is critical. He coined the term 'biosphere' as it is used today, framing it as a complex entanglement of biological, geological, and chemical forces – hence 'biogeochemistry'. If Lindeman's provocation was to think all features of an environment together – living or not – through their energetic interactions, Vernadsky's ideas were indispensable. This becomes even clearer once we recognise Vernadsky's own energetic inclinations. For him, 'the biosphere is at least as much a *creation of the sun* as a result of terrestrial processes,' so much so that the biosphere 'must, therefore, not be considered as a region of matter alone, but also as a region of energy and a source of transformation of the planet.'[21] In so many words, Lindeman was proposing something similar, though at a far smaller and more constrained scale.

The ecosystem concept, only then recently introduced to ecology, allowed Lindeman to maintain a focus on everything entailed by 'biogeochemistry' while constricting the spatial boundaries of observation. Coined by Arthur G. Tansley in 1935, the 'ecosystem' was a more 'fundamental conception' of an environment and its inhabitants, since it suggested

> the whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome—the habitat factors in the widest sense.[22]

This wideness, of course, demanded a degree of artificial isolation, since such a deeply entangled mass of factors could never be *really* delineated, as Tansley himself admitted. The cut of artificial isolation meant the ecosystem could be no larger than a lake, as it was for Lindeman, or, in Tansley's speculations, even an atom.[23]

The coupling of the ecosystem concept with an energetic view of ecological interaction – phrased as *energy flow* – thoroughly transformed ecological discourse during and beyond the mid-twentieth century. In many ways, 'ecology' became a shorthand for 'ecosystems ecology'. And energy flow became so pervasive a concept that, by the 1960s, statements like 'the environment has significance to an organism through the flow of energy and only through the flow of energy' were ecological orthodoxy.[24]

Of course, before energy flow could take hold in such a profound way later in the century, it required empirical verification. No easy task, especially seeing as the first manuscript of The Trophic-Dynamic Aspect was rejected for being too theoretical, too unmoored from the field; it even required the help of Lindeman's doctoral adviser, G. Evelyn Hutchinson (who may have introduced him to Vernadsky's work), to get the paper published.[25] Because Lindeman tragically passed shortly thereafter, Hutchinson himself set out to ground his late student's theory.

In 1941, Hutchinson began a study of the phosphorus cycle of Linsley Pond, Connecticut. The means of tracing that cycle? Phosphorus-32, a well-worn radiotracer familiar to many physiologists. This radiotracer allowed Hutchinson

> to follow the cycling of phosphorus through the phytoplankton and inorganic matter as 'a specific example of intermediary metabolism.' The body of water was like the body of an organism, whose chemical interrelations could be studied in situ.[26]

If indeed 'the body of water was like the body of an organism,' from de Hevesy onward there was ample research on the use of radiotracers to reveal bodily 'chemical interrelations.' Hutchinson's contribution would be to scale this process up, tracing the radioactive phosphorus throughout the whole pond and throwing into relief precisely the kind of 'organic-inorganic cycle of nutritive substance' Lindeman had theorised.

The concept of energy flow would be borne out by the literal flow of energy – if, at least, the ionising radiation emitted by unstable nuclei of phosphorus can be considered a kind of energy flow. The idea of environments sustained by nutritive pathways between sources of energy, inorganic matter, plants, and animals could be realised once those pathways were sufficiently irradiated and subsequently monitored. The material reality of those energetic connections could be glimpsed in the traceries of radioisotopic decay.

And all of this *could* have been experimentally confirmed in 1941. When it comes to the radiotracer, however, larger scales require larger amounts of material. Ultimately, Hutchinson's study 'failed when the cyclotron at Yale produced only half the amount of isotope required for the experiment.'[27] Catalysed by Lindeman's energetic rendering of the environment, Hutchinson's work suggested the nascent possibility of radiotracing-at-a-distance, though the material conditions could not be met. There simply wasn't enough radioactive material to go around in 1941. With transformative effects for ecology – not to mention the whole of human civilisation – there would soon be more.

4 The Pacific Proving Grounds, Marshall Islands, c. 1954

In a frequently cited passage, environmental historian Donald Worster claimed that 'the age of ecology opened on the New Mexican desert, near the town of Alamogordo, on July 16, 1945, with a dazzling fireball of light and a swelling mushroom cloud of radioactive gases.'[28] On its face, Worster's proclamation suggests the destruction wrought by the advent of nuclear weaponry precipitated a countervailing recognition of the kind of fragile planetary interconnectedness that is the purview of ecological thinking. If 'for the first time, there existed a technological force that seemed capable of destroying much of the life on the planet,' then the Enlightenment project of nature's total domination was now literally radioactive with apocalyptic risk.[29] And Worster is correct in this; much of the anxiety around the bomb's aftereffects went a long way in animating a nascent environmental consciousness during the 1960s and 1970s.

There is also a grimmer association lurking behind what Worster says. As the Manhattan project got underway in developing the atomic bomb, fissile material production plants like the Hanford Site in Washington state, the Oak Ridge nuclear reservation in Tennessee, and the Savannah River Plant in Georgia began producing more radioactive material than they knew what to do with (or could contain); this eventually found its way into nearby rivers and the surrounding terrain. Though, as environmental historian Laura Bruno puts it, 'before World War II, no model existed for the behaviour of radioactive material in the environment and little was known about the spread, the persistence, and the accumulation of radioisotopes or about how fallout affected animal and plant life.'[30] Thus, in 1946 the United States Atomic Energy Commission was established and began funding ecosystems ecology and many other environmental sciences. And when thinking about the use of radioisotopes specifically, the sheer number of isotopic byproducts created in the synthesis of weapons-grade fissile material meant that radiotracers – ideally suited to studying the energy flows of an a soon-to-be ascendant ecosystems paradigm – were in vast supply. It's simply worth noting that Hutchinson's initially failed 1941 study of Linsley Pond was completed in 1947.[31]

So, when Worster suggested that the age of ecology began with the first test of the atomic bomb, this deep institutional entanglement is also called forth. As nuclear weapons testing rapidly increased in the 1950s, so did AEC funding, all in the hopes of harnessing ecology and other environmental sciences to better manage an increasingly irradiated world.

The United States' Pacific Proving Grounds in the Marhsall Islands saw some of the most frequent and varied nuclear weapons testing (rivaled only by the primal scene that was the Nevada Test Site)—it also hosted some of the most far-reaching, government-funded ecosystems research. Ecologists by the name of Eugene Odum, who was already associated with AEC through studies on the Savannah River Plant, and his brother Howard, were pivotal figures within this context. Howard, like Lindeman, was a student of Hutchinson, and both brothers were deeply invested in the energy flow model of ecosystems. Conducted at the Proving Grounds, their collaborative Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll (1954) was, at the time, the first and most comprehensive study of ecosystemic energy flow.[32]

Their deliberate introduction of more radioisotopes to the Pacific Proving ground may seem excessive; the area was already so irradiated that some fish and coral found in the lagoons, when placed atop photographic paper, revealed a hazy glow of decaying particles – what is known as an 'autoradiograph'.[33] The difference between the already-present radioactive contaminants and those deployed in the Odums' and others' studies was their 'cleanliness'. Radioactive contamination produced by the detonation of nuclear weapons is a messy mix of multiple radioisotopes at odds with the fine-grain traceability of a single-isotope radiotracer and thus unsuitable to the precision demanded by systemic energy flow studies.[34]

It's ironic, then – the rampant production of nuclear weapons generated, as byproducts, the trace-grade radioisotopes that enabled and sustained the intense ecosystems research taking place during the Cold War. The very same feature that made radiotracers useful for biological and ecological research – their ability to bind to common elements found in organic and inorganic matter – is what allowed radioactive fallout to become such a present and enduring risk. Strontium-90, another iconic Cold War radioisotope, 'found its way into humans via the ecological food chain as fallout in the soil was picked up by plants, further concentrated in herbivorous animals, and eventually consumed by humans.'[35] Soon it became possible to deduce how close someone lived to a nuclear test site by measuring the amount of Strontium-90 in their bones because of the radioisotope's chemical isotropy to calcium.[36]

It's even more ironic that the very concept of the ecosystem was predicated on an artificial isolation (recalling Tansley) that nuclear fallout actively flaunts. That artificial isolation and its rupture were embodied in the Marshall Islands; the region was chosen for nuclear weapons testing and ecosystems research for basically the same reason: it appeared in the eyes of the US government as a series of untouched and unconnected sites for potential experimentation. Of course, these archipelagos were neither untouched nor unconnected; they were the home of the Marshallese, dispossessed of their land in the development of the Proving Grounds. The Marshall Islands could only ever be viewed as isolated laboratories through a colonialist epistemology where islands are never anything but peripheral to, and at the disposal of, a Euro- American centre.[37]

What took place at the Proving Grounds, ultimately, was impossible to contain. A primal scene in this context was the Castle Bravo test on March 1, 1954, which continues to hold the record for the highest-yield thermonuclear detonation by the US. The toxic cloud of ash released by the weapon far exceeded its 'safety zone' and veered far off course from the projections of military meteorologists. Some of this landed on a Japanese fishing boat, the *Daigo Fukuryū Maru* (Lucky Dragon), afflicting its twenty-three crewmen with acute radiation poisoning. Kuboyama Aikichi, the boat's radio operator, died in September of that year and is widely regarded as the first casualty of the hydrogen bomb. Not long after, radioactive tuna were found in Japanese markets, and fishing in the Pacific was radically disrupted.

Nearly all of this and the preceding section have focused on the discipline of ecology because of its deep, historical entanglement with the radioisotope as a means of tracing-at-a-distance; however, the nature of fallout by 1954 was such that the largely terrestrial discipline was unable to fully explicate its atmospheric and oceanic effects. Ecologists could study the effects of radioisotopes once they settled upon and suffused into soil, but soil was just one – and, considering its share of earth's surface area, relatively infrequent – destination of fallout.

As it drifted away from Bikini Atoll, the debris cloud of the Castle Bravo test

> was quickly transformed by earth scientists into a new kind of experimental lens, becoming a primary means of empirically documenting stratospheric flows, ultimately revealing with a new specificity how earth, ocean, and atmosphere interact.[38]

A more multidisciplinary effort was then mobilised by the AEC and climate science in particular became deeply entangled in Cold War nuclear weapons research. It was at this point that the backgrounds against which radioisotopes could be traced reached their (literally) upper limit and, as with much ecology during the Cold War, the insights of climate science were increasingly mediated by radiotracing-at-a-distance. As they facilitated the transport of radioactivity, previously undetected air and ocean currents were discovered and a more complete image of a planet at risk emerged.[39]

Once the background radiation of the Cold War reached a certain level, it was thrust into conscious awareness—and as Peter Sloterdijk reminds us, the further a background is explicated, the more it becomes a source of potential anxiety and threat.[40] The spread of radioactive fallout stands as a clear example of this, and figures as a key condition of possibility for the environmental movement writ large. So much so, one may be surprised to find that the first pollutant mentioned by Rachel Carson in her landmark *Silent Spring* (1962) was not a pesticide, but strontium-90:

> Strontium 90, released through nuclear explosions into the air, comes to earth in rain or drifts down as fallout, lodges in soil, enters into the grass or corn or wheat grown there, and in time takes up its abode in the bones of a human being, there to remain until his death. Similarly, chemicals sprayed on croplands or forests or gardens lie long in soil, entering in a chain of poisoning and death.[41]

At the time of her writing, nuclear fallout provided the most viscerally graspable analogue to agricultural pesticides. Carson's work would go onto to major acclaim and further spur the budding environmental movement, though in the text itself flickered a radioactive signature.

Ironically, the popularity of *Silent Spring* helped shift environmental consciousness away from nuclear fallout, as did test ban treaties in the 1960s. Radioactive material was still encircling the earth, ecologists were still radiotracing in their field studies, and radiation ecology even began to solidify as a significant subdiscipline.[42] Nevertheless, as the decade progressed, radioactivity as an icon of environmental threat became less pronounced and the spectre of contamination did what it tends not to: fade away.

5 A Meaningful Level of Radioactivity

Of course, many of the Cold War radioisotopes are still with us today; they persist in their decay as echoes of immensely energetic events, as transmissional traces. And while the tracing-at-a-distance of radioisotopic signatures against bodily or biospheric backgrounds doesn't resolve into the realm of vision the way iconic televisual technologies do, this does not mean there is nothing *tele*-about them, or that they do not constitute a kind of energetic media.

John Durham Peters tells us that 'media are vehicles that carry and communicate meaning,' and throughout the history outlined above, radioisotopes have made meaningful microscopic nutrient flows inside plants, animals, and their environments; as radioisotopes continued to spread through nuclear detonation, ever larger flows came into focus, giving shape to the contours of the whole biosphere.[43] Ultimately, a clearer – often frighteningly clearer – understanding of the earth has been carried along the transit of these energetic entities.

Radioisotopes hint at a meaningful level of radioactivity. Literally, as when the tick of the Geiger-Müller counter clues us into a possible dose of radiation we'd do well to avoid. Somewhat more metaphorically, the radioisotope's scattering decay acts much like light (well, it **is** light) and we've come to learn much about the world when it shines from an unexpected or unknown place. And yet, the well-worn link between knowledge and illumination clearly has its limits in this case. The decay that makes the radioisotope traceable decays what it touches, too.

Notes

1. The following is a transcription of Barry's contribution to the exhibition catalogue.
2. Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the* Arts (Berkeley: University of California Press, 2013), 221.
3. Technically speaking, radioisotopes are better understood as *radionuclides* to emphasise their specific nuclear properties. This term was introduced in 1947 but seeing as radioisotope is the more common of the two, it will be used in what follows. Truman P. Kohman, "Proposed New Word: Nuclide", *American Journal of Physics* 15, no. 4 (1947): 356–7.
4. Some perfectly harmless elements have recently been discovered to undergo decay rates longer than the age of the universe, meaning their radioactivity is so faint as to be practically nonexistent. For more, see: Louise Lerner, "Scientists measure half-life of element that's longer than the age of the universe", *University of Chicago News*, April 24, 20219, **https://news.uchicago.edu/story/scientists-measure-half-life-element-thats-longer-age-universe**
5. Robert Barry quoted in Ursula Meyer, "Robert Barry, October 12, 1969", in *Conceptual Art* (New York: Dutton, 1972), 38.
6. Kahn, *Earth Sound Earth Signal*. 220.
7. 'Radioactive labeling consists essentially in replacing individual atoms in biomolecules with their radioactive isotopes: the fate of these molecules can then be traced by recording radioactive decay events. Radioactive isotopes serve as molecular tracing instruments. Lodged deep in various metabolic pathways they act like tracer ammunition to make biomolecules visible.' Hans Jörg Rheinberger, *An Epistemology of the Concrete: Twentieth-Century Histories of Life* (Durham: Duke University Press, 2010), 230.
8. A few key texts across these disciplines are Steven Bocking, "Ecosystems, Ecologists, and the Atom: Environmental Research at Oak Ridge National Laboratory", *Journal of the History of Biology* 28, no. 1 (Spring 1995), 1–47; Angela N. H. Creager, *Life Atomic: A History of Radioisotopes in Science and Medicine* (Chicago: The University of Chicago Press, 2013; Elizabeth M. DeLoughrey, "Satellite Planetarity and the Ends of the Earth", *Public Culture* 26, no. 2 (2014), 257–280; and Joseph Masco, "Bad Weather: On Planetary Crisis", *Social Studies of Science* 40, no. 1 (February 2010), 7–40.
9. Here I am relying on Douglas Kahn's distinction between inscriptive and transmissional media unfolded in *Earth Sound Earth Signal*: 'Inscriptive media precipitate phenomena onto surfaces (pages, scores, screens, memory devices, etc.) and are associated with recording and storage awaiting revivification, reproduction, repetition, and more storage. Transmissional media (in my usage) are inseparable from electricity and electromagnetism; they differ from inscriptive media through basic physical states of energy (mechanics and electromagnetism) and are thus historically very recent when compared to the antiquity of inscriptive media. Telecommunications technologies like telegraphy, telephony, wireless telegraphy, radio and television broadcasts, and the internet are transmitted "live", even when they transmit recordings.' Douglas Kahn, *Earth Sound Earth Signal: Energies and Earth Magnitude in the* Arts (Berkeley: University of California Press, 2013),19–23.
10. Rheinberger, *An Epistemology of the Concrete*, 230.
11. For a selection of relevant readings, see: Yuriko Furuhata, *Atmospheric Control: Transpacific Experiments in Atmospheric Control* (Durham: Duke University Press, 2022); Jussi Parikka, *A Geology of Media* (Minneapolis: University of Minnesota Press, 2015); John Durham Peters, *The Marvelous Clouds: Towards an Philosophy of Elemental Media* (Chicago: The University of Chicago Press, 2015); and Nicole Starosielski, *Media Hot and Cold* (Durhan: Duke University Press, 2021).
12. Peters, *The Marvelous Clouds*, 2.
13. George de Hevesy, "Some Applications of Isotopic Indicators", The Official Website of the Nobel Prize, December 3, 2024, **https://www.nobelprize.org/prizes/chemistry/1943/hevesy/lecture/**
14. Hence why radionuclide is technically a more appropriate term than radioisotope, as mentioned above.
15. Oak Ridge Association of Universities' Museum of Radiation and Radioactivity, "Four Tales of George de Hevesy", December 1, 2024, **https://www.orau.org/health-physics-museum/articles/four-tales-george-de-hevesy.html**
16. George de Hevesy, "The Absorption and Translocation of Lead by Plants: A Contribution to the Application of the Method of Radioactive Indicators in the Investigation of the Change of Substance in Plants", *The Biochemical Journal* 17, no. 4–5 (1923), 439.
17. de Hevesy, "Some Applications of Isotopic Indicators", **https://www.nobelprize.org/prizes/chemistry/1943/hevesy/lecture/**

18. For an overview of these debates, see: Worster, *Nature's Economy*; and Joel Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick: Rutgers University Press, 1992).
19. Raymond J. Lindeman, "The Trophic-Dynamic Aspect of Ecology", *Ecology* 23, no. 4 (October 1942), 399–400.
20. Ibid., 400.
21. Valdimir I. Vernadsky, *The Biosphere*, trans. David B. Langmuir (New York: Copernicus, 1998), 44. Vernadsky was developing these ideas as a Soviet scientist in the 1920s and 1930s, though his work wasn't widely recognised in the US until the postwar period.
22. Alfred G. Tansley, "The Use and Abuse of Vegetational Concepts", *Ecology* 16, no. 3 (July 1935), 299.
23. '…the series of *isolates* we make become the actual objects of our study, whether the isolate be a solar system, a planet, a climatic region, a plant or animal community, an individual organism, an organic molecule or an atom. Actually the systems we isolate mentally are not only included as parts of larger ones, but they also overlap, interlock and interact with one another. The isolation is partly artificial, but it is the only possible way in which we can proceed.' Ibid., 300.
24. David M. Gates, "Energy Exchange and Ecology", *BioScience* 18, no. 2 (February 1968), 90.
25. 'The manuscript was originally rejected by the editorial board *of Ecology,* and only through Hutchinson's intervention was it finally accepted by that journal." Hagen, *An Entangled Bank*, 88. I speculate on Hutchinson's exposure of Lindeman to Vernadsky on the grounds of Hutchinson's deep appreciation and adoption of Vernadsky's ideas. In 1970, Hutchinson edited a volume of *Scientific American* dedicated entirely to the biosphere concept and wrote its introductory article: G. Evelyn Hutchinson, "The Biosphere", *Scientific American* 233, no. 3 (September 1970), 45–53.
26. Angela N. H. Creager, "Timescapes of Radioactive Tracers in Biochemistry and Ecology", *History and Philosophy of the Life Sciences* 35, no. 1, Historical and Biological Times: A Festschrift for Hans-Jörg Rheinberger (2013), 85.
27. Hagen, *An Entangled Bank*, 113.
28. Donald Worster, *Nature's Economy: A History of Ecological Ideas* (Cambridge: Cambridge University Press, 1977), 342.
29. Ibid.
30. Laura A. Bruno, "The Bequest of the Nuclear Battlefield: Science, Nature, and the Atom in the First Decade of the Cold War", *Historical Studies in the Physical and Biological Sciences* 33, no. 2 (2003), 238.
31. G. Evelyn Hutchinson and Vaughan T. Bowen, "A Direct Demonstration of the Phosphorus Cycle in a Small Lake", *Proceedings of the National Academy of Sciences of the United States of America* 33, no. 5 (May 15, 1947), 148-153.
32. Howard T. Odum and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Eniwetok Atoll", *Ecological Monographs* 25, no. 3 (July 1955), 291-320. This research won the Ecological Association of America's prestigious Mercer Prize.
33. Laura J. Martin, "Proving Grounds: Ecological Fieldwork in the Pacific and the Materialization of Ecosystems", *Environmental History* 23, no. 3 (July 2018), 574.
34. Bocking, "Ecosystems, Ecologists, and the Atom", 6.
35. Ralph H. Lutts, "Chemical Fallout: Rachel Carson's *Silent Spring*, Radioactive Fallout, and the Environmental Movement", *ER: Environmental Review* 9, no. 3 (Autumn 1985), 215.
36. Bruno, "The Bequest of the Nuclear Battlefield", 259.
37. For a reading of ecosystem ecology's history within this critical context, see: Elizabeth M. De Loughrey, "The Myth of Isolates: Ecosystem Ecologies in the Nuclear Pacific", *Cultural Geographies* 20, no. 2, Special Issue: Islanding Cultural Geographies (April 2013), 167-184; and Karen Barad, "After the End of the World: Entangled Nuclear Colonialisms, Matters of Force, and the Material Force of Justice", *Theory and Event* 22, no. 3 (July 2019), 524–550.
38. Joseph Masco, "The Age of Fallout", *History of the Present* 5, no. 2 (Fall 2015), 147.
39. Paul Edwards provides a deep technical and scientific links between nuclear weapons research and climate science: Paul N. Edwards, "Entangled Histories: Climate Science and Nuclear Weapons Research", *The Bulletin of the Atomic Scientists* 68, no. 4 (2012), 28–40.
40. For Sloterdijk, to explicate an atmosphere is to transform it into an object of design, an object of technical manipulation. And revealing the technical manipulability of something assumed as given creates a form of existential insecurity whereby that which went ordinarily unperceived emerges as a potential threat, and a feedback loop is fashioned where further technical manipulation aims to minimise its own explicative effects. For more on this, see: Peter Sloterdijk, *Terror from the Air*, trans. Amy Patton and Steve Corcoran (Cambridge: MIT Press, 2009).
41. Rachel Carson, *Silent Spring* (Boston: Houghton Mifflin, 1962), 6; quoted in Lutts, "Chemical Fallout", 221.
42. Eugene P. Odum, "Feedback between Radiation Ecology and General Ecology", *Health Physics* (1965), 1257–1262. For a historical overview of the development of radiation ecology, see: Chunglin Kwa, "Radiation Ecology, Systems Ecology and the Management of the Environment", in *Science and Nature: Essays in the History of Environmental Science*, ed. Michael Shortland (Oxford: Alden Press, 1993), 213–249.
43. Peters, *The Marvelous Clouds*, 2.

Biography

Nicolas Holt is an independent researcher who works at the intersection of contemporary art history, media studies, and the energy humanities. He earned his PhD in art history from McGill University in 2022 and is interested in the ways energies have been channelled in the arts and sciences of the 20th century.

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