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Cellular Narratives in Nuclear Time: On Living with the (Epigenetic) Memory of Trauma

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Abstract

With the imminent threat of nuclear arms race acceleration, and in the context of ongoing colonial nuclear violences, this paper seeks to trace the biological consequences for lives altered by the atom bomb, through Karen Barad's agential realist ontology. To do this, I first present the paradigmatic development in the field researching the effects of radiation exposure, from direct genetic mutagenesis to the contribution of epigenetic responsivity. Based on the congruence of the epigenetic model with agential realism, I forward a speculative yet scientifically informed interpretation of epigenetic mechanisms as materially manifesting multiple temporalities of entangled events. To give a felt sense of the implications of this interpretation, it is diffractively read through a profound semi-autobiographic literary moment in Kyōko Hayashi's novella *From Trinity to Trinity*, a testimony of the transformative effect of recontexualizing memories through their entanglements, as told by a survivor of the atomic bomb dropped on Nagasaki in 1945. By introducing a different conceptualization of epigenetic function, I aim to share my deep appreciation of the richness of cellular biology, and to stir new imaginings congruent with the relational, entangled nature of epigenetic mechanisms. Thought through the processing of trauma, it may offer possibilities of living and dying otherwise.

Keywords

Agential realism, nuclear, Kyōko Hayashi, epigenetic memory, chromatin, Walter Benjamin, temporality, temporal-intersectionality

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> Without sustained remembrance, we cannot learn to live with ghosts and so cannot think.
> —Donna J. Haraway, *Staying with the Trouble*

Prologue

On the morning of August 9, 1945, fourteen-year-old Kyōko Hayashi was working at the Mitsubishi Weaponry Ōhashi Factory in Nagasaki, where she and her peers had been mobilized for the Japanese war effort. At 11:02, the 4.5-ton plutonium bomb dropped by the US Air Force 1.3 kilometers away, was detonated approximately 500 meters above ground for maximal damage (Kerr et al. 2005). More than 500,000 people were exposed to the two atom bombs dropped three days apart in August 1945, on Hiroshima and Nagasaki. Many thousands perished immediately from the tremendous heat, impact, and radiation of the nuclear blast. Within five months, more than 210,000 people died of injuries and radiation poisoning. "More than 210,000 remaining victims…survived the first five months of death and agony and became *hibakusha*" (Tomonaga 2019, 493), literally, "persons who experienced the explosions"; among them the now-fifteen-year-old Hayashi.

Introduction

The list of symptoms suffered by *hibakusha* in the aftermath of the explosions is long and excruciating. The significant increase in leukemia cases shortly afterward (Folley et al. 1952; Preston et al. 1994), and increase in solid tumors in later years (Thompson et al. 1994; Tomonaga 2019), was attributed to the mutagenic effects of ionizing radiation (IR).[1] This effect, first recognized in the 1920s (Muller 1927; Stadler 1928a, 1928b), had become a matter of popular knowledge and continued to be the focus of scientific research for decades—it was, after all, *The Century of the Gene* (Keller 2002; Calabrese 2015).

In what follows, I briefly present the traditional linear model of mutagenic radiation effects, noting its incongruence with both empirical data and the physics that produced the effects it aims to explain. A relatively recent alternative epigenetic model, with better explanatory rigor and emergent empirical support, is then introduced. This model implicates the involvement of complex reactive mechanisms guiding cellular responsivity to IR. It also sits well with the broader understanding of epigenetic mechanisms as mediating cellular responsivity to the environment, an understanding that has enticed scholars to hail it as holding the promise of tying the biological with the social. Yet, so far, the success of epigenetic research in realizing these promises has been limited, with growing critique from science and technology studies (STS) and other researchers.

Following a short discussion of this situation, I propose an alternative analysis of epigenetic function drawing on the existing scientific conceptualization of

epigenetic mechanisms as materially bearing the impressions of experiences, as it is read through Karen Barad's (2007) agential realist ontology. My intention is to unsettle the reductionist and determinist paradigmatic hold on epigenetic research, by demonstrating that it is possible to come up with radical interpretations, with reformulations of causality, which are interdisciplinarily informed, including by molecular biology itself. In doing so, I hope to convey my own appreciation of the richness of cellular biology, in which the "resolutely unpoetic language" of epigenetics (Lock 2015, 166), criticized for its reductionist translation of life experiences into indistinguishable molecular marks (e.g., Landecker 2016), isn't a biological feature but rather an articulating choice of the scientists who research it.

To give readers an embodied sense of this interpretation, I return in the following section to Kyōko Hayashi and a literary semi-autobiographic moment taken from her novella *From Trinity to Trinity* (2008, 2010), as read by Barad (2017a). This powerful depiction is then diffractively read through the very materiality of epigenetic function, to introduce a speculative story of what might be happening in cell nuclei as they negotiate living within this world. It demonstrates how the events of our lives continually gain meaning—including biological meaning—through contextualization, and how even acutely traumatic events can be recontextualized through their entanglements.

The Biology of Radiation Exposure

The linear model

The traditional scientific understanding of the effects of exposure to radioactivity (and other forms of IR) that has been broadly accepted for decades is based on the linear no-threshold (LNT) genetic model. According to this model, the adverse health consequences of IR are caused by its mutagenic effects. It determines that only cells directly exposed to IR sustain damage, and this damage occurs immediately or shortly after exposure in a manner that is directly and linearly linked to the level of radiation exposure. Under this framework, prolonged effects may only be caused by unrepaired mutations that are passed to progeny (cells or offspring) (Schofield and Kondratowicz 2018; Belli and Tabocchini 2020). In other words, the LNT model assumes that the effects of radiation remain local and discrete, both spatially and temporally.

Right from the onset of research, however, the biology seemed to be telling a more intricate story (Mothersill and Seymour 2012; Calabrese 2013, 2017). The findings of decades of laboratory as well as epidemiological studies simply do not fit the LNT model (Calabrese and Golden 2019).[2] Unlike the model's predictions, radiation can have delayed carcinogenic, as well as other detrimental effects, sometimes taking years or decades to develop, even presenting only generations later (Tamminga et al. 2008; Kamstra et al. 2018; Dubrova and Sarapultseva 2022).

At lower doses, IR can actually induce adaptive and even hermetic (beneficial) effects (Averbeck et al. 2018; Shibamoto and Nakamura 2018; Ghosh 2022). Furthermore, and inconsistent with this model, cells and tissues not directly exposed to radiation are often affected through two distinct physiological processes (Bhat and Chadha 2021; Mothersill and Seymour 2022).[3] The phenomenon of *bystander effects*, in which those unexposed develop distinct radiation exposure responses by proxy, have even been observed at the inter-organism level, for example in crustaceans, fish, and rodents (Mothersill and Seymour 2012; Reis et al. 2018), demonstrating that radiation can impact neighboring, non-exposed individuals. Let me reiterate: In some cases, sharing an environment with an organism that has been exposed to IR is sufficient to induce a distinct IR response in other individuals, and even invoke IR responses of an entire (not directly exposed) ecosystem (Mothersill and Seymour 2009; Smith et al. 2013; Reis et al. 2018; Matarèse et al. 2020). So, while IR does indeed cause mutations, the observed effects simply cannot be accounted for by the LNT paradigm, or more broadly by the traditional paradigms of biological information inheritance.

The interpretation of these observations is further complicated by the considerable variability in documented IR exposure phenotypes, depending on the characteristics of the individual organisms (or tissues) exposed (Paunesku et al. 2021; Mothersill and Seymour 2022). While accounting for much of this variability remains a point of profound paradigmatic dispute in the field, its existence underscores the complexity and contingency of biological responses to IR. Yet, despite repeated contestation, the LNT model has remained in use, and is still commonly employed to guide radiation risk assessment (UNSCEAR 2022; Jones 2019; Wojcik 2022).[4]

Accounting for nonlinearity: Epigenetic involvement in response to IR exposure

While IR has been traditionally associated with mutagenesis, epigenetic changes have been repeatedly suggested since the mid-2000s, as the "missing link" accounting for the observed effects of IR exposure, particularly in exposure to low and medium radiation doses (Baverstock and Belyakov 2005).[5]

To discuss these effects, a brief introduction to our understanding of epigenetic mechanisms is warranted, as they play a vital role in the development, morphology, physiology, and health of essentially all organisms (Willbanks et al. 2016). Epigenetic mechanisms function in response to environmental changes, for the most part by modifying the context of DNA, its organizing structures—known as chromatin (the stuff of chromosomes). This function is mediated through a range of specific marks added to chromatin to alter the physical characteristics and accessibility of genomic loci, and thus regulate their function (Soshnev et al. 2016).[6] Together, epigenetic mechanisms orchestrate complex nuanced responses to a wide range of external and internal environmental cues: from

changes in our body temperature, the quality of the air we breathe and the food we eat, to our cultural and social experiences (Jablonka and Lamb 2014). Most commonly but rather reductively, they are understood as the mechanisms that regulate gene activation, but it might be more accurate to say that epigenetic mechanisms participate in making our genomes tick.

Grounded in the historical development of genetics, radiation remained outside the discourse of environmental epigenetics for decades. But in recent years many of the observed IR effects have been shown to correlate with significant epigenetic changes, and, in some cases, the involvement of such mechanisms has been directly demonstrated (Schofield and Kondratowicz 2018; Dubrova and Sarapultseva 2022; Belli and Tabocchini 2020; Bhat and Chadha 2021). IR exposure seems to bring about epigenetic responses affecting various cellular pathways. Some, including DNA repair and cell signaling regulation—such as cell cycle arrest and programmed cell death (apoptosis)—allow cells to cope with the damage they sustained. Importantly, modifications related to both *intercellular* signaling and adaptive changes in cell radiosensitivity have also been observed. These findings offer a possible mechanistic explanation for the more complex phenomena briefly detailed above (Tharmalingam et al. 2019; Ghosh 2022). Thus, contrary to the LNT model, the data as well as the epigenetic model suggest active cellular responses to radiation at less-than-acute doses. That is, cells not only attempt to repair the damage caused by IR, but also undergo changes and reorganization to rearticulate themselves as cells of bodies that *have* experienced radiation.

The implications are, of course, not merely theoretical, nor limited to the past. Some researchers have raised concerns that the continued reliance on the LNT model may have led both scientists and regulating agencies to underestimate the risk of radiation, with devastating effects (e.g., Burgio et al. 2018; cf. Tharmalingam et al. 2019). They are referring, for example, to the increase in infant leukemia across Western Europe following the Chernobyl accident in 1986, while the increase in radioactivity levels was deemed negligible (Busby 2009). They are also referring to the apparent increase in solid tumors and leukemia among children living near nuclear installations (Fairlie 2014; Laurier et al. 2014; Fairlie and Körblein 2015; cf. Boulton 2019).[7]

Epigenetic Memory: Embodying Intersectionality

Unlike the relative stability of DNA and its inheritance, epigenetic marks are actively and directly responsive to the environment. As such, they may be temporary and reversible (epigenetic plasticity), an attribute that may, for example, contribute to the variability in observed IR exposure phenotypes. Importantly, epigenetic marks deemed relevant by the cell may also be transmitted to daughter cells and even to offspring, a phenomenon known as epigenetic inheritance, or epigenetic memory.[8] At the most fundamental level, epigenetic memory refers to the maintenance and transmission of altered gene expression states and the

correlating epigenetic patterns, long after the initiating environmental signal has passed (Cavalli and Heard 2019). This process is essential for epigenetic function, and may account for much of the extended effects of IR exposure.

As the inheritance of epigenetic modifications can be highly dynamic, responsive, and interrelated, we might ask *what* exactly is being transmitted. An important clue comes from what is known as epigenetic priming, where the transmitted epigenetic pattern differs from the initial epigenetic response to a particular environmental trigger. What is transmitted, then, is neither an activated response nor a reversion to the pre-exposed state. Instead, it is a distinct, "primed" pattern that may facilitate, for example, a robust and rapid reactivation of genes to recurring environmental challenges, including IR (Ghosh 2022; Mothersill and Seymour 2022). In other words, in extending the epigenetic response to environmental conditions through time and cellular lineages, what is passed on is not simply an epigenetic pattern, nor necessarily a change in gene expression, but an epigenetic encoding and memory of particular *experiences*, or more accurately, the impressions of experiences already enfolded with anticipation (Levenson and Sweatt 2006; Davis 2014; Lappé and Landecker 2015; Mansfield 2017; Meloni 2019; Aristizabal et al. 2020).

Thus, memories of a wide range of personal and lineal experiences are embodied through epigenetic mechanisms. Jörg Niewöhner describes these somatic memory effects as "extend[ing] the embedded body in time and across generations" (2011, 290). This embedded body is "heavily impregnated by its own past and by the social and material environment within which it dwells" (289; but see Richardson 2021 for important feminist critique). The importance of this biologically expressed embeddedness was initially celebrated in a wide range of social sciences and humanities publications, for its promise to extricate biological research from the confining determinism of the genetic code. Epigenetic function added relationality to the biological framework itself, suggesting the entanglement of the biological and social, nature and culture, self and environment, as well as past, present, and future (e.g., Jablonka and Lamb 1998; Keller 2005, 2014; Stotz 2008; Carey 2012; Guthman and Mansfield 2012; Lock 2013, 2015; Chung et al. 2016).

Life circumstances, including living environments and lived experiences, are strongly related to geo-socioeconomic distribution and further intersecting categories of identity and oppression. The biological mechanisms that react to environments, and possibly transmit their influences over generations, are thus inherently of political importance, making environmental epigenetics and related research inherently political in its potential to shed light on local and global conditions of health inequalities (Richardson and Stevens 2015; Meloni 2016; Pentecost and Cousins 2017; Meloni, Cromby et al. 2018; Niewöhner and Lock 2018; Penkler, Hanson et al. 2019; Penkler, Jacob et al. 2022; Pentecost et al. 2024).

Drawing from developments in critical theory, scholars have associated epigenetic mechanisms as embodying intersectionality, offering the possibility for a nuanced research perspective on how multiple intersecting vectors of privilege and oppression become biologically and physiologically integrated (e.g., Weasel 2017).

The intersectionality of radiation exposure

Like other environmental exposures, radiation has a particular geo-socioeconomic distribution. Therefore, an analysis of the intersecting forces that influence the effects of radiation exposure (which, as stated are complex and varied) must be carefully considered within the specific and localized conditions of those exposed.

Significantly, while the 1945 devastation of Hiroshima and Nagasaki, and the effects of high-profile nuclear disasters such as Chernobyl (1986) and Fukushima (2011) have deservedly received much attention, intersectional aspects of radiation exposure and harm are particularly evident in *ongoing, continuous* nuclear violence. As Jessica Hurley summarizes, "Indigenous lands and communities are by far the most damaged by the ongoing mining, processing, testing [of more than 2,000 nuclear weapons worldwide], and dumping practices of the nuclear–military–industrial complex" (2020, 191). Entangled with other forms of (reproduced, ongoing, systemic) colonial violence, the "slow violence" (Nixon 2013) of nuclear colonialism is one of several determining features by which lives and land contaminated for generations (virtually for eternity, due to the long half-life of enduring isotopes) become rearticulated as already living within what Hurley calls the mundane apocalypse.

The institutional disregard of the lives of those actually exposed is not only through where these practices are located, but continues on multiple fronts through negligent plans and regulation, numerous leakage cover-ups, ridiculously ineffective "cleanups" (Brown 2013; Nadesan 2018), and oversimplified radiation risk assessments that ignore "the specific and localized conditions of those exposed": crucial socio-material factors such as age, sex, and geo-sociocultural contexts (ICRP 1975, 2002; Acheson 2022). The slow response of regulating agencies to the growing body of work demonstrating epigenetic involvement in the biological effects of radiation exposure may be trifling in light of such overarching systemic discrimination and negligence, but the political and health implications of bodies that reorganize as experiencing and anticipating radiation deserve further consideration. Yet acknowledging epigenetic involvement in itself may be insufficient.

The pitfalls of epigenetic research

In analyzing current epigenetic research more broadly, both STS and other social sciences scholars find that it fails to meet the early expectations and excitement,

reducing epigenetic's much-anticipated plurality, and incorporating it into the existing biomedical framework of binary and mechanistic determinism (for a meta-review see Dupras et al. 2019). Current research practices collapse socio-environmental complexity through uncritical conceptualization and categorization of what is being studied (e.g., Clare 2019; Packer 2022), including oversimplified causation inquiries (e.g., Kenney and Müller 2017; Chiapperino 2021; Meloni et al. 2022), and the "molecularization of biography and milieu" (Niewöhner 2011, 291). The latter flattens and reduces profoundly different experiences to molecular mechanisms acting on chromatin, and ultimately serving as "volume controls for genes" (Kuzawa and Sweet 2009, 5; Landecker and Panofsky 2013; Meloni and Testa 2014; Lloyd and Raikhel 2018; Chiapperino and Panese 2018). In this formulation genes remain the functional center, and the focus for both examination and the possibility of delivering change.

As with the specific case of IR exposure, these shortcomings are more than theoretical. In its present formulation, scholars caution that epigenetic research and related public health policies lead to new forms of social discrimination, through equally problematic environmental- and epigenetic-determinism (e.g., Landecker 2011; Lock 2013; Mansfield and Guthman 2015; Waggoner and Uller 2015; Richardson 2015, 2017; Meloni 2017, 2019; Müller et al. 2017; Saldaña-Tejeda and Wade 2019; Valdez 2021). Over and over again, scholars have demonstrated how unacknowledged biases and failure to address the intersectional complexity of exposure, configure research structure, analysis, and implementation (e.g., Mansfield 2012; Kenney and Müller 2017; Packer 2022; see also Chiapperino et al. 2024). These misconfigurations culminate in unwarranted, often contextually impossible demands placed on marginalized and discriminated populations, shifting "the focus from systemic violence to 'damaged' bodies" (Keaney et al. 2024, 2), and in particular maternal bodies.

Given these challenges, epigenetic research has reached a sort of impasse, struggling both to draw concrete meaning from the complexity of the functions it studies (Chiapperino and Paneni 2022) and to fulfill its political potential. Keeping this in mind, I move away from the contemporary debate, looking for alternative paths of exploration to rethink epigenetic's molecular materiality through Barad's agential realist ontology (2007, 2017a, 2017b).

Researching Otherwise: The Potential Contribution of Agential Realism

Through its firm (yet creative and critical) grounding in scientific knowledge, agential realism rearticulates concepts that are also central in epigenetic discourse, including materiality, temporality, entanglement, and indeterminacy. Together with its political implications (Barad and Gandorfer 2021), these

attributes make agential realism particularly relevant and fruitful for exploring epigenetic function.

Indeed, the potential contribution of Barad's work to epigenetics has been recognized by several scholars (e.g., Niewöhner 2011; Weasel 2016; Warin and Hammarstrom 2018; Warin and Martin 2018; Roberts and Sanz 2018; Warin et al. 2022; see below the analyses of Davis 2014, 2017). Barad's profoundly relational ontology, in which entities are determined only through their intra-actions (rather than interaction) within phenomena, allowed scholars to powerfully articulate the multilayered entanglement embodied by epigenetic mechanisms. As stated above, these include the celebrated entanglement of self and environment, the material-discursive, cultural-biological co-production of bodies, as well as the temporal entanglement that epigenetic inheritance produces.

And yet epigenetic's molecular materiality, the actual physical embodiment of entanglements, has so far only been referred to in abstract terms. This is a shame, as Barad's (2007, 2010) neo-material appreciation of matter as meaningful and agentive, not a thing but a ceaselessly generating and generated relational process, offers an unexplored avenue to understanding epigenetic function. Building on existing scholarship, I therefore take Barad's lead into this field of knowledge to consider what the epigenome *does in its materiality*, outside its conventional framing as regulating gene expression. In following recent scientific studies, I ask how may the scientifically acknowledged function of epigenetic marks as bearing the memories of personal and lineal experiences be tied with the very materiality of chromatin.

To do this, I follow Barad's own methodology of diffraction, which involves "reading insights through rather than against each other" (2017a, 64), revealing transdisciplinary entanglements that are already materially there. Diffraction, by its very nature, is a performative troubling of analogically presupposed binaries and boundaries, holding the potential to be at once affirmative and profound, in rigorously working with multiple knowledges (Van der Tuin 2011; Juelskjær et al. 2020). This process leads me to offer a speculative, affirmative exploration of molecular function, perhaps even a molecular fable of response-ability of sorts, an attempt at a formulation that accounts for lives already altered by violences (Kenney 2019; Meloni and Müller 2018).[9] In what follows, I present this diffractive reading by first returning to Kyōko Hayashi, introduced at the beginning of this paper, and the memory of August 9 she has been carrying throughout her life.

Staying with the Trouble: Living with August 9

As a survivor of the atom bomb, the data briefly presented above suggests that Hayashi's memories of the nuclear blast and of her continued exposure to radioactive fallout (Hayashi 2007) left epigenetic imprints on her body. Research into the biological response to trauma (Ramo-Fernández et al. 2015; Morrison et

al. 2019; Mehta et al. 2020; Neves et al. 2021; Smeeth et al. 2021; Richter and Hunter 2021), suggests that the devastation and loss she experienced not only haunted her mind, were not only etched, scarring her irradiated body, but were also marked on her chromatin as her cells rearticulated themselves as cells that have experienced the bomb, cells that could never stop anticipating the bomb. From the nuclei of plutonium isotopes to the nuclei of her cells, what else can a body do with such memories?

Committed to the memory of classmates "who were robbed of their own deaths by unspeakable violence" (Barad 2017, 70), and to fellow *hibakusha*, Hayashi devoted her adult life to chronicling August 9 in its entanglements. Her stories reveal the most intimate, devastating details of lives altered by the bomb, including their mental and physical health soaked in the personal and political implications of surviving or not the A-bomb (e.g., Hirosuke 1993; Hayashi 2005, 2008, 2010, 2015, 2017). In the novella *From Trinity to Trinity* (2008, 2010), we meet Hayashi fifty-four years after Nagasaki, now an elderly *hibakusha*, as she embarks on a political-spiritual pilgrimage to the site of the first atomic bomb test, Trinity, New Mexico, where a plutonium bomb was detonated shortly before Nagasaki, on July 16, 1945.

Hayashi's narrating style is multitemporal, her protagonist "'travel hops' from one spacetime point to another, circling back, re-turning and turning our attention to a multiplicity of entangled colonial histories condensed into 9 August" (Barad 2017a, 69). Barad's diffractive reading of the novella reveals this multitemporality not merely as an epistemic stance but an onto-epistemological feature of this world. Time, rather than a simple blank axis along which events and phenomena unfold, is itself part of the radical indeterminacy of the world, contingent on the intra-actions that articulate it and its intra-actions within phenomena, evolving in an open ongoing becoming. "Intra-actions," explains Barad, "are [thus] temporal not in the sense that the values of particular properties change in time; rather, which property comes to matter is re(con)figured in the very making/marking of time" (2007, 180). Hayashi's travel hopping attentively traces specific entanglements of August 9, and in that asserts their mattering.

In their work, Barad also introduces the related concept of a *thick-now*, invoking a "thick sense of multiple historicities and temporalities" (2017b, 76) through their entanglements and the quantum field theory understanding of "each moment as a condensation of other beings, places, and times" (2015, 416). This multiplicity of entanglements is not simply an alignment of events constituting a coherent story; rather, moments are ontologically threaded through each other, living inside each other, formed by and contingent upon each other (Barad 2017b). In Hayashi's recounting too, events become meaningful through diffraction, threaded through August 9 and through each other. When she arrives at Trinity's Ground Zero, this

super-positioning of specific spacetime points, this travel hopping, this particular thick-now, allows her narrator to undergo a profound transformation. She writes,

> I have always been aware of being a *hibakusha*. But my always-present awareness of being a victim disappeared from my mind. It was as if I became a fourteen-year-old again… [I]t was when I stood in front of the memorial [at Trinity] that I was truly exposed to the atomic bomb.
>
> Looking back, I did not shed a tear on August 9. As I ran with the pack of people whose hands, feet, faces no longer looked human, no tears came to me. . . .
>
> For the first time here at Trinity, however, I might be crying with the human tears that I did not shed on August 9. Standing on the land that speaks no words, I shivered, feeling its pain. Until today, I have lived with merciless pains that hurt my mind and body. But it could have been the pain of the skin that grew from August 9. Here in this desert I had momentarily forgotten my life as a *hibakusha.* (Hayashi 2010, 50–51)

Memories orient us, allowing us to interpret the world and ourselves within it; without them, the present is undifferentiated. But in themselves, memories too are indeterminate. It is not only the present that takes on meaning through its contextualization within the memories threaded through it, but memories too gain meaning only when they are contextualized within other memories and within the present. We relate to our experiences and their memories as the determining features of our lives, and indeed they are, but because we and our lives are open phenomena, *how* memories determine who we become is continuously rearticulated.

We are dealing here with trauma and its enduring memory. Trauma victims are often uncontrollably and excruciatingly sucked into those moments that changed their lives forever (Ehlers et al. 2004). But here Hayashi is courageously allowing us to witness something profoundly different. In the short essay accompanying her 2008 English translation of the novella, Kyoko Selden writes, "Having completed the journey that was at once real and symbolic, Hayashi takes a new direction. Not that she no longer writes about Nagasaki, but she handles the theme differently" (Hayashi 2008, 28–29). The significance of this moment lies not solely in her painful return to August 9, but in her diligence in tracing its entanglements. Arriving at the Trinity site thick with the memories of its own reconfigurations, including its nuclear and other colonial histories (Barad 2017a; Engelmann 2022), Hayashi realizes with her marked and wounded body the entanglements of Nagasaki and Trinity, beyond linear time, as she re-members. As she comes to recognize her senior *hibakusha* siblings at Trinity, animate and inanimate, and the violent colonial past they have been enduring, August 9 ceases

to be a sealed memory and her own phenomenon is reconfigured together with the phenomena of which she is part. August 9 is contextualized, further grounded through its entanglements as *of this world*, its past, present, and future. Through her courageous labor of tracing, experiencing its excruciating pain, Hayashi goes through the heavy transformation from victim to survivor.

This transformation must have been expressed in her body, but how? Barad insists that tracing entanglements is an embodied labor; "Hayashi's…body does not represent the story," reiterates Annouchka Bayley, "her body *is* the story" (2019, 82). I can imagine its impact on her posture, her tonus, the tone of her voice, in her eyes shedding the tears of August 9 for the first time. Science tells us that surviving Nagasaki is written into Hayashi's chromatin, along with and related to her complicated medical history. But what of the transformative, super-positioned event she details? If her materiality carries the history of her phenomena, as Barad's ontology tells us, and if epigenetic mechanisms biologically mark her experiences, surely this is one to remember!?

Epigenetic Entangled Temporality

In its present performative state, the science of epigenetics is unable to address the complexity of intricate layering of experiences, the effects of a personal, epistemic, yet colossal and ontological, transformative journey. Epigenetics gives me no answer and so, I am left speculating…But, although Hayashi lived to (die of) old age, there is nothing I can say about the correlation between her experiences, epigenetic markings, and health. I cannot speak of the probability of malignancies, the possibility of a heart attack, known to occur with increased rates in elderly *hibakusha*, or of the disorders associated with trauma.

Instead, I wish to consider epigenetic memories, their temporality and entanglements. If this thickness of dis/continuous multiplicity of temporalities is ontological; if Hayashi's act of recontextualizing her history through tracing the entanglements of this thick-now is, as Barad claims, ontological, might we also trace their epigenetic manifestations?

That the epi/genome's materiality does not embody a linear temporality is clear. Changes to DNA and to epigenetic patterns are not organized along chromosomes in chronological order. In Baradian terms, we might say that chromosomes are the nonlinear sedimentations of entangled memories of different timescales and different times (Niewöhner and Lock 2018). Indeed, the nonlinear temporality of epigenetic function has been discussed (in abstract terms) by several scholars, as exemplified earlier by Niewöhner's much quoted articulation. Julie Livingston also asserts, "epigenetic time is hard to hold onto…It is layered, accelerant, recursive, contingent, scalar, linear, and circular all at once…We will need ways of thinking and talking about time that allow for its embodied florescence" (in Lock 2015, 166–67).

While this paper aims to contribute precisely to this effort, it is crucial to recognize that scientific conceptualizations are never politically naïve, and gain concrete significance through research intentions and biases. Even articulating an "embodied florescence" isn't in itself sufficient to extricate science from its determinist trudge. Becky Mansfield (2017), for example, describes how the folding of past and future into the present, as perceived in mainstream epigenetic inheritance research, results Sin the formulation of interventionist reproduction policies. Through such policies, an ever-receding future of next generations—vulnerable fetuses that *do not* and *may not* exist—becomes privileged over the present and in particular over the present of women and girls, of (potential) mothers. Furthermore, this temporal rationalization supports interventionist public health policies that are intended to protect exposed populations but fail to address the underlying environmental damages imposed upon them, and at the same time disregard their particular cultural and marginalized circumstances, ending up adding another layer to the intersectional harm they are already suffering from (e.g., Mansfield 2012; Packer 2022).

Conversely, Indigenous Australian scholars (Pember 2015, 2016; Warbrick et al. 2016; Conching and Thayer 2019; Paul 2020), utilize the resonance of epigenetic temporality with Indigenous ontologies to "transmut[e]…scientific knowledge through decolonial imagery" (Warin et al. 2022, 19).[10] They thus articulate a nondeterminist, situated, postcolonial postgenomics "as a model of collective embodiment and distributed responsibility" (1). Their unique articulation, in turn, serves as the ground for ongoing community collaborative health initiatives.

Noela Davis (2014, 2017) specifically elaborates on epigenetic temporality through agential realism. She identifies epigenetic mechanisms as agential realist apparatuses performing agential cuts, making determinate specific phenotypes from the indeterminacy of the genome. Davis thus elegantly reverses the proclaimed determinism of the genetic code, and creatively demonstrates the contingency of a virtually undisputed scientific conceptualization.[11] In their agentive function, states Davis, epigenetic mechanisms also materialize the particular cause-and-effect relations within the phenomenon under investigation, enfolding and materializing experiences and memories of the past, as well as the anticipatory preparation for future possibilities (for example, of a stressful life).

These scholarly works importantly elaborate on the type of temporality that epigenetic function manifests, but as epigenetic mechanisms are first and foremost material phenomena, here I seek to explore how this complex temporality might be embodied in their molecular materiality.

Epigenetic Materiality: Chromatin Organization

While research looking into epigenetic embedding of experience and memory primarily focuses on the changes in epigenetic composition in response to exposures, it is important to note that these changes do not simply mark loci on linear genomes. Rather, they induce alterations in the specific and even overall nuclear organization of chromatin (Maeshima et al. 2021). "This," notes Maurizio Meloni, "is where epigenetics really matters: not so much as 'tags' or 'bookmarks' added to linear DNA sequences but as the complex machinery that spatially rearranges and regulates chromatin" (2018, 22). Together with recent technological advancements, this insight drives a thriving 3D genomics research front, involved in understanding this materiality—its structures, regulation, and functional effects (e.g., Quinodoz et al. 2018; Saintillan et al. 2018; Sun et al. 2021; Amiad-Pavlov et al. 2022; Nollmann et al. 2022). And while the functional significance of chromosomes as long linear segments is undeniable (for example, during the orchestration of cell division), it is increasingly chromatin's *in vivo* nonlinear and dynamic features, its loops and folds, that are at the center of investigation (Landecker 2012).

Without techniques to differentiate specific genomic regions, outside the iconic chromosomal organization in meiosis and mitosis, a cellular nucleus looks for the most part like a randomly packed bundle of long windy thin threads of chromatin. Nuclear architecture research, however, reveals a complex structured hierarchy in chromatin organization. The most fundamental chromatin units are nucleosomes, each consisting of 147 base-pairs of DNA wrapped around a protein histone core in 1.65 turns. This first step contributes a degree of condensation and organization, but the human genome (for example) condensed into a micrometer-size cellular nucleus, contains more than three billion base-pairs, reaching roughly two meters in length when stretched. The necessary further organization is achieved through progressively increasing orders of controlled looping and folding that bundles specific genomic sections together up to chromatic mega clusters called *chromatin compartments*, which are further organized into *chromosomal territories*. This controlled yet dynamic spatial organization produces biological function and meaning through regulating gene expression and other nuclear processes (Magaña-Acosta and Valadez-Graham 2020). That is, the nuclear location of specific DNA loci in relation to other loci translates into cellular behavior. For example, within chromosomal territories active genes tend to be grouped together in certain compartments, while non-active regions are grouped in others. Moreover, changing the transcription level of a gene may cause its relocalization (Brueckner et al. 2020) and vice versa: Experimentally inducing a shift in a gene's nuclear position may change its expression profile (Reddy et al. 2008). As changes in epigenetic composition over time and circumstances bring about structural reconfiguration (Cavalli and Heard 2019; Bourbousse et al. 2020; Harabula and Pombo 2021), this allocates the genome with both a lifespan and a dynamic physical body (Lappé and Landecker 2015).

A dynamic spatial segregation makes, of course, functional sense in regulating gene expression.[12] But the importance of overall nuclear architecture regulation seems to exceed this function. For example, in nearly every type of cancer studied, this regulation goes awry: Studies find massive epigenetic changes, beginning prior to cancer development, and continuing as cancer progresses. Importantly, these changes seem to have little direct effect on gene expression, but greatly impact chromatin organization itself (Madakashira and Sadler 2017; Xu et al. 2020). The specific organization of chromatin within the nucleus, therefore, seems to serve additional functions. In the following section, I wish to suggest that epigenetic temporality and entanglement as previously expressed is embodied in the structures and dynamism of nuclear architecture, as an essential part of its function.

Accounting for the materiality of epigenetic memory: Chromatin constellations

For an agential realist understanding of the material architecture of chromatin, its folding and looping, I turn to Barad's (2017b) diffractive reading of their own quantum-field-theory-based thick-now (introduced in their reading of Hayashi's work), through Walter Benjamin's (2006) notion of now-time (*Jetztzeit*). Now-time describes the present moment, shot through with a specific multiplicity of temporalities, together forming a crystalline *constellation* of events that gives the moment its meaning (e.g., Benjamin 1999, 2006). Benjamin's utilization of this concept is not trivial; though starry constellations "seem to be purely spatial arrangements [he] uses them in a temporal modality" (Barad 2017b, 34). He can do that because the stars we see as we gaze into the night sky are not only *of* space but also *of* time. Since the speed of light is constant, the more distant the star, the further into the star's past we are looking. As the stars within a single constellation are at different distances from us, "constellations are…images of a specific array of past events, a configuration of multiple temporalities" (Barad 2017b, 34).

Of the various metaphors Benjamin offers, constellations are particularly meaningful when thinking about epigenetic function. As epigenetic marks are understood *in science* as a form of memory, epigenetic governing of chromatin structures can be thought of as functioning through integrating, storing, sorting, and relaying memory via shape (Jablonka and Lamb 1998; Lappé and Landeker 2015). Yet, so far, the joint significance of epigenetic memory and the related loopy arrangements of chromatin have not been addressed. It is exactly in considering both attributes together that chromatin clusters emerge as meaningful spatio-temporal constellations entangling particular memories in an individual's personal and lineal life.

Genomic loci held together materially and functionally influence each other, becoming entangled, contingent upon each other and continuously rearticulated by their multiple entanglements. I wish to suggest that in this they articulate a particular thick-now of bound memories that produces biological and functional meaning, in driving cellular decision-making and activity. This view offers a different explanation for chromatin organization, and a different yet not mutually exclusive system of causation. The identity and functionality of a cell can be said to be (at least partly) determined by the genes it activates, which for purposes of efficiency it groups together. The identity and functionality of a cell can also be understood as dependent on the choices it makes in grouping *memories* together, integrating a biologically coherent reference system, a context, a narrative even of lived experiences, through which it understands itself within the world, and interacts (or more precisely, intra-acts) within it.

What has been labeled *epigenetic memory*, starting from the transmission of epigenetic marks on particular DNA sequences, becomes complex, highly dynamic, and contextualized. In this view, epigenetic memory driving cellular identity and decision-making is multilayered. It includes both an overview of the entire historical background manifest by the overall nuclear landscape, and particular historical memories inscribed at specific loci. Here I suggest that it also includes the particular spatio-temporal entanglement of memory bearing loci with other such loci, determining which of these memories and in what constellations come to *matter now*. Through this organization of memories, cellular ongoing becoming is entangled not only with its environment at the present, nor simply with the integrated context of the past—that had been and passed (Chung et al. 2016; Pitts-Taylor 2018). Rather, it is also determined by the living entanglement of the present with specific memories and anticipations, particular re-collections, as they are materially articulated through chromatic constellations.

Tracing entanglements, insists Barad, is an embodied labor, and I propose further that it involves the agency of all bodily scales, including the molecular arrangements of cellular nuclei. Chromatin constellations are the material embodiment of epigenetic multitemporal entanglement and non-trivial causality. They demonstrate one way in which the materiality of our bodies is continuously (re)articulated in particular, yet multiple thick-nows. Following Barad's ontology, and the contingency of time, we might say that in its organization and dynamism, chromatin agentially participates in materializing time itself. If chronological, linear, and progressive time plays a part here, it is only one of many.

For every life story, for every present, there are multitudes of possible narratives, possible choices. Enacting particular ones performatively configures the phenomena—a reality. Every cell nucleus (as an open indeterminacy) holds within it a multitude of possible chromatic constellations. As with our cognitive organization, the cellular interpretation of the present doesn't depend

deterministically and linearly on the additive effects of its experiences, but on the choices through which it deems (through nuclear organization) particular memories relevant. It is this organization, of memories that *matter*, that drives a particular cellular onto-epistemological response to and in the present.

Tying things together

Barad's (2017a) reading of Hayashi's (2010) novella can help us grasp the onto-epistemological impact constellations may have. They give us the theoretical grounding for a literary moment articulating a reconfiguration of a thick-now, of a constellation. In that moment in Hayashi's novella, a tangible thick now of non-chronologically bound events recontextualized through each other, produces a transformative meaning for an acutely traumatic event. Hayashi demonstrates how profound this can be, not a time-traveling sci-fi cascading change of events, but a reconfiguration of reality that nonetheless integrates everything that had taken place. As Barad demonstrates time and again, this is an onto-epistemological feature not unique to the human mind, but continuously articulating the world, occurring for example in quantum physics experiments and in living cells. Likewise, epigenetic plasticity and chromatin dynamics suggest that chromatin not only contextualizes memories and events, but holds an inherent ability to recontextualize them. Thus, the agential cuts that epigenetic mechanisms enact, which as Davis (2014, 2017) elaborates, configure causation itself, are not only of the functional-biological choice, but also of its framing, the context within which it is made. In this reading, already at the most basic biological units, it is not only experiences that matter, but also the onto-epistemological choice of their contextualization, the way in which they are configured, and may be continuously recontextualized and reconfigured within dynamic chromatic structures.

This reading, in which chromatic structures and not only the marks they bear, participate in (re)determining cellular activity, presents a different system of causation and cellular decision-making, grounded in living experiences, beyond the traditional linearity and universality in scientific narratives.

Discussion: Chromatin Constellations and the Possibilities for Living and Dying Otherwise

This paper presents an agential realist reading of the nuclear materiality of epigenetic mechanisms. Reading through extra-disciplinary sources, I propose Benjamin's metaphor of *constellations* as an addition to the classic understanding of epigenetic landscape, emphasizing cellular agentivity through nuclear organization.[13] The explanatory framework this metaphor allows for sits well with available scientific data, and yet responding to justified critique of the current reductionist language of epigenetics, it offers a different conceptualization of

function and causation. It is in itself a reformulation through diffraction, demonstrating one of multiple available reformulations.

The scientific data briefly presented in the first part of this paper, together with a diffractive reading of Hayashi's novella and oeuvre, serves as a case study of sorts. The data itself provides two distinct (but intra-related) relevant aspects: First, it suggests that contrary to accepted dogma, even ionizing radiation—biologically the most unmediated form of environmental exposure—can invoke long-term and wide-reaching epigenetic changes. This data already implies that surviving cells and surviving bodies are never simply passive recipients of the environment,[14] but rather actively reorganize and rearticulate themselves in response, enacting new agential cuts. Second, the wide variability in phenotypic and epigenetic responses to similar exposures (such as IR) between species, cell types, but also cell (and individual) histories, further demonstrates the non-trivial, contextual nature of the agential cuts enacted by cells and bodies.

Together these two aspects challenge popular conceptualizations of epigenetic function as *becoming with* the environment (Packer 2022), by which "the *environment actually comes into the body*" (Guthman and Mansfield 2015, 565). While these conceptualizations have been powerful in refuting genetic determinism, such emphases obscure the indeterminate *agentive* mediating role of epigenetic mechanisms, demonstrated by both epigenetic memory and epigenetic variation. Cells do not simply embody the meeting of two determinate systems—namely, the environment and the genome; epigenetic marks aren't simply the manifestation of "the environment coming into the body." Rather, they reveal cellular *integration and interpretation* of experiences within an evolving context, by which cells self-narrate the world and themselves within it as an essential (and onto-epistemological) part of their ability to respond, their ability to exist.[15]

Scientifically, this interpretive and phenotypic variability, produces "non-ideal observations for substantiating a link to a specific cause" (Richardson 2024, 157) in research fields such as environmental epigenetics and the related Developmental Origins of Health and Disease (DOHaD). Accordingly, the anticipation for an objective, linearly discernable biological, and epigenetic proof for the intersectional, detrimental health effects of oppression, discrimination, and violence, produces what Sarah Richardson (2021, 2024) calls the acceptance of causal crypticity. But what if variability—which for the most part is neglected as a source of information (for various reasons) (Penkler, Keaney et al. 2024)—were to become the focus of attention?

Attending to variation is itself multifaceted, requiring an openness in experimental structuring to allow for the breadth of epigenetic responsivity to be observed.[16] Likewise, outside the lab, attending to the details of *lived experiences* may set the course of research away from the tendency to label individuals and

whole populations as "damaged" (Tuck 2009; Saulnier and Dupras 2017; Pentecost 2021; Keaney et al. 2024) and allow for a more inclusive investigation of epigenetic outcome (Warin and Hammarström 2018; Moormann 2024). A more open setting can include particular, intersectional, rearticulated knowledges of harm, of resilience and growth, including Indigenous biological and ontological modes of healing and strength and their epigenetic manifestations. Within this framing, the epigenetic and overall wisdom of those whose lives have been altered by violences can be cherished and celebrated, without diminishing the demand for accountability and change.[17] Such investigations may also produce insights into epigenetic processes themselves, as lived experiences and their biological and personal interpretation lie at the core of their function. For this to occur, epigenetics and related biosciences must reconfigure as collaborative knowledge-production processes that benefit more profoundly from the accrued knowledge of disciplines such as Indigenous, feminist, Black feminist, postcolonial and queer theories, disciplines that have been addressing lived experiences *in their specificity*. In this, I join the many scholars who have been calling for such an interdisciplinary practice.[18] While its implementation has been slow and limited (Penkler, Keaney et al. 2024), by its very structuring, interdisciplinary knowledge production is well suited to creatively realizing entanglements, and in that, potentially producing better research and more informed, participatory policies.

The ethico-onto-epistemology of tracing entanglements

When considering lived experiences, stories of personal transformation manifesting the creative agency of the self—like the one presented in this paper—can serve as double-edged swords. Without attending to entanglements, such stories may be recruited, in a neoliberal climate, to emphasize the responsibility of individuals over institutional accountability. As described above, this is already a troubling pitfall of public health policies derived from epigenetic and DOHaD insights. But Hayashi's novella doesn't lend itself to such narration; her transformative journey doesn't read as a simplified triumphant story of overcoming adversities. Clearly, powerful and ontological as it is, her journey does not erase or absolve the past-present and future accountability of the nuclear-military-industrial complex. On the contrary, in her unwavering commitment to trace entanglements, Hayashi not only exposes the threads of August 9 entanglement with past acts of colonialism soaked into the land she is visiting, but also weaves in the entanglements of complex presents and futures. Through travel hopping, the need to pass down the realities of the bombing to younger generations is brought up (with both urgency and subtlety) already on the very first page, while later on, her intense day in New Mexico ends with the news of the 1999 Tōkaimura nuclear accident. Read through our own post-Fukushima perspective, the entangled future is already present in her thick-now, in ours, and in the mundane apocalypse of those still living under nuclear colonialism and violence and their consequences.

It is this commitment that allowed Hayashi to place the unbearable memory of August 9 within context. It is no less devastating—facing and reliving the incalculable, she risked her own sense of self, her very existence. But as some of her entanglements were realized, so too was her place in and of this world: She is the elderly *hibakusha* on a pilgrimage to Trinity, she is her own past iteration—the fourteen-year-old girl experiencing the atomic explosion, both living in the world of which August 9 is a part, of which Trinity (with all its violent colonial past) is a part, of which Tōkaimura is a part.

The political significance of a thick temporality and the temporal dimension of intersectionality

Hayashi's journey demonstrates that tracing the thickness of time and entanglements is not merely a fanciful theoretical interjection, but a powerful agentive transformative methodology. Although her story is a personal one, tracing and realizing entanglements is neither the prerogative nor the responsibility of individuals alone, but an onto-methodology of rearticulation at all scales, with political ramifications (Barad 2007, 2010, 2012a, 2019; Barad and Gandorfer 2021).

Indeed, the political implications of multi-spatio-tempo-material entanglement are central to its metaphysical framing by both Benjamin and Barad. Barad understands time-being "as a specifically political and material practice…attuned to the possibilities for liberation, for justice, in the now of the present moment" (2017b, 38). Benjamin's (1999) rejection of progress as a founding concept of history, along with his now-time and the related image of constellations, were theologically-inspired, politically-charged formulations of resistance to fascism. For him, they are explicitly tied with the possibility of fighting "for the oppressed past" (Thesis XVII, 396).

In this context, epigenetic marks are bearers of the embodied memory of *oppressed pasts*, possibly over generations. Their political significance has been extensively discussed by others, as outlined above.[19] They mark inequalities, and in carrying the molecular histories of intersecting, cumulative experiences of systemic violence, they further increase the risk of those oppressed, discriminated, and marginalized, and the risk of their descendants for developing detrimental health conditions (Hanson and Gluckman 2014). Scientists often articulate their aspirations to redress this harm through intervention, by erasing its embodied epigenetic marks and essentially reversing to a pre-exposed phenotype; commentating scholars often accept this enticing terminology of reversal. But, in a world constituted through entanglements and thick with the memories of its previous iterations, erasure and reversal, tells us agential realist ontology, aren't really possible, and certainly don't align with epigenetic's "fluorescent temporality." The reading presented here takes in Benjamin's now-

time and Barad's thick-now to suggest the personal and political significance of their potential—the potential of the etched memories of oppressed pasts—not in eliminating or erasing them, but in reconfiguring and recontextualizing them through actions taken *now*.

Bearing the experiences of intersecting forces, epigenetic marks are understood as the context in which both acute trauma, and (socio-materially situated) daily lives are experienced, interpreted, processed, and integrated to become themselves embodied living context (Weasel 2017). But, while intersectionality attends to the *nonlinear* impact of intersecting forces, the nonlinearity of intersectionality's temporal dimension, or temporal-intersectionality if you will, also deserves attention. Because, it is not only that the present depends on the context of the past; Hayashi, Barad, and Benjamin tell us that the past too becomes recontextualized with the present. It is in tracing and realizing entanglements, through which reality is simultaneously acknowledged and rearticulated, that agential realist ontology holds the potential and hope for more just iterations. If we are willing to do the work, the agentive, interpretive, and integrative function of epigenetic mechanisms, bearing both memories and anticipation, holds the biological potential to reconfigure the phenomenon that is us, including our pasts and futures through re-membering.

Hayashi's documented labor of mourning, relentlessly revealing the entanglements of human cruelty and violence but also the possibility of rearticulation, can serve as a fitting guiding imperative to (re)think through both epigenetic research and derived public health policies, and to advance the possibility of living and dying otherwise.

Notes

[1] Ionizing radiation (IR) consists of subatomic particles or electromagnetic waves that have sufficient energy to ionize atoms or molecules by detaching electrons from them, including alpha, beta, and neutron particles, gamma rays, X-rays, and the higher-energy ultraviolet part of the electromagnetic spectrum (Reis et al. 2018).

[2] Laboratory research has been conducted on cultured cells and model organisms, most notably rodents. Epidemiological research collected data not only of the victims of Hiroshima and Nagasaki, but of the growing numbers of populations exposed to higher levels of radiation: from nuclear weapons testing, nuclear power stations—including leakages and accidents, professional and medical exposures, and from naturally occurring localized high-level background radiation. See UNSCEAR 2022.

[3] Both types of effects occur at tissues distant from the exposed cells. Abscopal effects seem to involve the immune system, and include, for example, the deterioration of untreated metastatic lesions after treatment of a distant tumor

location. Bystander effects include a wide range of changes induced through signal transmission in cells distant from the exposed ones.

[4] For critical analyses of the science politics through which the LNT model was selected to guide radiation risk assessment, see Calabrese 2013, 2015, 2017; Williams 2019; Folkers 2021.

[5] See Mothersill, Cocchetto, and Seymour 2022 for the more recent suggestions for the possible involvement of bio-electric signaling.

[6] Epigenetics has many, sometimes contradictory definitions (Cavalli and Heard 2019). Here, I follow Adrian Bird's (2007) biochemical, chromatin-centered definition. The range of modifications includes those added to DNA itself—such as cytosine methylation (by far the most studied, but other modifications are known), and changes to the molecular complexes around which DNA is arranged, such as histone variants and various histone modifications. Epigenetic mechanisms also include multiple functions of noncoding RNAs (ncRNAs); for more details, see Wei et al. 2017; Peixoto et al. 2020. For the involvement of ncRNA in response to IR, see May et al. 2021.

[7] Naturally, local increases in radiation levels affect not only the human population but the entire surrounding ecosystem (Körblein and Hesse-Honegger 2018; Hancock et al. 2019; Cannon and Kiang 2022).

[8] The extent of inter- and transgenerational epigenetic inheritance in humans is the subject of ongoing heated debate, with important social implications, among them the implications for second-generation *hibakusha* and their descendants (Hayashi 2008, 2010, 2015; Tomonaga 2019; Dubrova and Sarapultseva 2022). Here I restrict my discussion to the effects on those directly exposed, remembering that the impact of experiences does not begin with one's birth nor end with one's death.

[9] See Le Goff, Allard, and Landecker 2021 for an analysis of the conceptual legacy of negative definitions in epigenetic research.

[10] Warin and colleagues (2022) also note the resonance with agential realist temporality.

[11] Genetic determinism has been profusely challenged by many, but Davis challenges the conceptualization of the genetic code as in itself determinist.

[12] It is energetically beneficial, for example, to place genomic loci that require the same apparatuses together.

[13] The "epigenetic landscape" metaphor and its implications have been discussed by many in recent discourse, most profoundly by Susan Squire (2017).

[14] Therefore, cells never "flow simply into the mold of power," as philosopher Catherine Malabou (2016, 430) puts it.

[15] Cells also seem to further extend and share their interpretation with other cells, tissues, and organisms through bystander effects.

[16] See Schrader 2010 for a concrete biological example and the agential realist theoretical grounding. See also Hendrickx 2022. The possibility of biological wisdom gained through experiencing adversity, for example, has been so much outside conventional scientific interest that, even in laboratory research with model organisms under controlled conditions, the most trivial questions in this direction have, for the most part, not been rigorously tested (Sarkies 2020).

[17] The framing I suggest also enables recognizing the wisdom of those who suffered under nuclear aggression and nuclear colonialism, while insisting on institutional accountability and change. Following the nuclear test, it is estimated that the inhabitants who lived downwind of the Trinity explosion site, were exposed to ten thousand times higher higher radiation levels than those currently allowed, but no measures were taken to protect them before or after the blast (Tucker and Alvarez 2019). Despite the compelling life stories of many dealing with radiation related illness, to this day, they are still denied reparation, and are excluded from the Radiation Exposure Compensation Act (Tularosa Basin Downwinders Consortium, n.d.). This paper is dedicated to them.

[18] This repeated call for interdisciplinary practice is expressed in much of the work cited in this paper: See, for example, Landecker 2011; Mansfield 2012; Lock 2015; Dupras and Ravitsky 2016; Meloni 2016; Kenney and Müller, 2017; Müller et al. 2017; Meloni and Müller 2018; Murray 2018; Müller 2020; Mancilla et al. 2020; Lawson-Boyd and Meloni 2021; McKittrick 2020; Müller and Kenney 2021; Richardson 2021; Packer 2022; Saulnier et al. 2022; Rossmann and Samaras 2024.

[19] See, for example, Guthman and Mansfield 2015; Müller and Samaras 2018; Murray 2018; Dubois and Guaspare 2020; Taki and de Melo-Martin 2021; Valdez 2021; Packer 2022.

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