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Africa and the Nuclear World: Labor, Occupational Health, and the Transnational Production of Uranium

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What is Africa's place in the nuclear world? In 1995, a U.S. government report on nuclear proliferation did not mark Gabon, Niger, or Namibia as having any "nuclear activities."[1] Yet these same nations accounted for over 25 percent of world uranium production that year, and helped fuel nuclear power plants in Europe, the United States, and Japan. Experts had long noted that workers in uranium mines were "exposed to higher amounts of internal radiation than ... workers in any other segment of the nuclear energy industry."[2] What, then, does it mean for a workplace, a technology, or a nation to be "nuclear?" What is at stake in that label, and how do such stakes vary by time and place?

In both political and scientific discourse, an apparently immutable ontology has long distinguished nuclear things from non-nuclear ones. The distinction has seemed transparent, fixed, and incontrovertible—ultimately a matter of fission and radioactivity. Scholarship on the history, culture, and politics of the "nuclear age" has also assumed the self-evidence of "nuclear" things. No one questions whether bombs and reactors are "nuclear," even while bitter battles rage over their political, military, or moral legitimacy.

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[1] Office of Technology Assessment, *Nuclear Safeguards and the International Atomic Energy Agency*, OTA-ISS-615, Apr. 1995, App. B.

[2] D. A. Holaday, "Some Unsolved Problems in Uranium Mining," in, International Atomic Energy Agency, International Labour Organisation, and World Health Organization, *Radiological Health and Safety in Mining and Milling of Nuclear Materials: Proceedings*, vol. 1 (International Atomic Energy Agency, 1964), 51.

Beyond these clear-cut cases, however, the category of the "nuclear" has never been defined by purely technical parameters. Like other master categories that claim global purview, the "nuclear" both inscribes and enacts politics of inclusion and exclusion. Neither technical function nor radiation sufficed to make African nations and their mines "nuclear" in geopolitical terms. Such outcomes, I have suggested elsewhere, were closely tied to the political economy of the nuclear industry, with profound consequences for the legal and illegal circulation of uranium and other radioactive materials and for the global institutions and treaties governing nuclear systems.[3] Here, I argue that the historical and geographical contingencies affecting the "nuclear" as a category have also had significant consequences for the lives and health of mineworkers. I focus on African uranium miners, whose labor has fueled atomic weapons and nuclear reactors around the world for over six decades. That these people have been ignored both in histories of the nuclear age and by Africanists speaks to mutually reinforcing assumptions about Africa's place, and lack of place, in a highly technological world. Challenging such assumptions requires that we enter that world via its technologies.

The essay thus explores the nuclear world in Africa, and Africa in the nuclear world.[4] I identify three moments of global imperception in the making and legitimation of knowledge on radiation hazards: moments when African people and workplaces went unaccounted for in "global" scientific knowledge production. ("Global," here, refers above all to the aims and claims of knowledge producers.[5]) I juxtapose these moments with three uranium histories, situated in Madagascar, Gabon, and South Africa, which analyze the labor arrangements and regimes of perceptibility that produced such global imperceptions. The production and dissolution of nuclear things in African places, I argue, occurred in the friction between the transnational politics of knowledge and (post)colonial power, between abstract prescriptions and embodied, instrumentalized practices. Radiation infiltrated workers' bodies; sometimes, however, it also opened political possibilities.[6]

[3] Gabrielle Hecht, "Nuclear Ontologies," *Constellations* 13, 3 (Sept. 2006): 320–31; and "Negotiating Global Nuclearities: Apartheid, Decolonization, and the Cold War in the Making of the IAEA," in John Krige and Kai-Henrik Barth, eds., "Global Power Knowledge: Science, Technology, and International Affairs," special issue of *Osiris* 21 (July 2006): 25–48.

[4] For broader debates, see Jean-François Bayart, "Africa in the World: A History of Extraversion," *African Affairs* 99 (2000): 217–67.

[5] I draw inspiration here from Frederick Cooper, *Colonialism in Question: Theory, Knowledge, History* (University of California Press, 2005); James Ferguson, *Global Shadows: Africa in the Neoliberal World Order* (Duke University Press, 2006); Geoff Eley, "Historicizing the Global, Politicizing Capital: Giving the Present a Name," *History Workshop Journal* 63 (2007): 156–88; Antoinette Burton. "Not Even Remotely Global? Method and Scale in World History," *History Workshop Journal* 64 (2007): 323–28.

[6] In this and other ways, we might think of radiation as "imperial debris"; see Ann Laura Stoler, "Imperial Debris: Reflections on Ruin and Ruination," *Cultural Anthropology* 23, 2: 191–219.

My core premise is that uranium mines are not born nuclear, in part because the "nuclear" is not merely about radiation. Instead, I treat the nuclear as a highly contingent technopolitical product of historical circumstances. Before attending to my main argument, let me explain what this means by surveying what I call "nuclear exceptionalism" and briefly discussing a few key concepts.

NUCLEAR EXCEPTIONALISM

In the aftermath of Hiroshima and Nagasaki, the grip of atomic bombs on global imaginaries derived strength through assertions of exceptionalism. Proponents and opponents alike portrayed nuclear weapons as fundamentally different from any other human creation by virtue of their apocalyptic potential. As discourse, nuclear exceptionalism spanned spatial and temporal scales. On a micro scale, fission—the physical process that powered atomic bombs—meant splitting atoms. This deliberate rupture of nature's building blocks propelled claims to a corresponding, macro-scale rupture in historical time: the "nuclear age." Geopolitical status became proportional to atomic weapons capacity. Nuclear nationalism in Britain and France allayed anxieties about the loss of empire and U.S. imperialism, while in India it promised a postcolonial reordering of global power.[7] Even for states that did not aspire to atomic weapons, nuclear energy could symbolize the zenith of modernity. Anti-nuclear movements, meanwhile, also engaged in nuclear exceptionalism by highlighting the dangers posed by human-made radioactivity, dangers unprecedented in their longevity and scope. Nuclear accidents at Three Mile Island and Chernobyl came to symbolize the nadir of modernity. Morality-talk further magnified the stakes of exceptionalist assertions, depicting nuclear things as salvation or depravity.

Yet nuclear exceptionalism went well beyond rhetoric—it was materialized in objects, systems, and practices. It depended on sophisticated marshalling of scientific knowledge, technologies of measurement and control, institutions, social networks, imagery, and more. It needed national and international atomic energy agencies, which built new systems of financing and accountability for nuclear endeavors, separate from other governance institutions. It relied on disciplines such as health physics, whose very epistemology was predicated on isolating radiation from other health hazards. It required instruments such as dosimeters, which measured radiation in people, and Geiger counters, which measured radiation in places. And it thrived on the countless articles, movies, novels, and images that came to constitute "atomic culture."[8] As the

[7] Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II* (MIT Press, 1998); Itty Abraham, *The Making of the Indian Atomic Bomb: Science, Secrecy and the Postcolonial State* (Zed Books and St. Martin's Press, 1998).

[8] There is a range of scholarship on these themes: M. Susan Lindee, *Suffering Made Real: American Science and the Survivors at Hiroshima* (University of Chicago Press, 1994); John Krige, "The Peaceful Atom as Political Weapon: Euratom and American Foreign Policy in the Late 1950s,"

alliances among (and within) such formations of power varied across time and place, so too did the effectiveness of nuclear exceptionalism, and indeed the very meaning and material substance of the "nuclear."

This, then, is why I refer to the nuclear as a *technopolitical* outcome of historical processes. Politics shape its technologies, but its technologies also shape its politics. Materiality matters tremendously. Enough atomic explosions really can destroy the planet; radiation exposure really can cause cancer. But as countless works in science and technology studies have shown, material realities emerge from complex networks in which the social and the technical are inseparably intertwined.[9] In the domain of occupational exposures, for example, instruments, labor relations, scientific disciplines, expert controversy, and lay knowledge combine to create what Michelle Murphy has called "regimes of perceptibility"—assemblages of social and technical things that make certain hazards and health effects visible, and others invisible.[10] Here I put Murphy's concept in dialogue with Anna Tsing's notion of "friction," a metaphor for the creative and destructive power generated by universal aspirations as they travel along changing axes of inequality.[11] The notion of friction calls attention to the unevenness with which knowledge travels, the always-local circumstances that change its content along the way, and the material consequences of its motion. Regimes of perceptibility in African uranium mines, I argue, emerged from the friction between universalizing

Historical Studies in the Natural Sciences 38, 1 (2008): 9–48; Itty Abraham, "The Ambivalence of Nuclear Histories," in John Krige and Kai-Henrik Barth, eds., "Global Power Knowledge: Science, Technology, and International Affairs," special issue of *Osiris* 21 (July 2006): 49–65; Joseph Masco, *The Nuclear Borderlands: The Manhattan Project in Post-Cold War New Mexico* (Princeton University Press, 2006); Paul Boyer, *By the Bomb's Early Light: American Thought and Culture at the Dawn of the Atomic Age* (Pantheon Books, 1985); Spencer Weart, *Nuclear Fear: A History of Images* (Harvard University Press, 1988).

9 For a more extended discussion of technopolitics, see Hecht, *Radiance of France*. Other works that explore these themes include: Donald A. Mackenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (MIT Press, 1990); Wiebe E. Bijker, *Of Bicycles, Bakelite, and Bulbs: Toward a Theory of Sociotechnical Change* (MIT Press, 1997); Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (Oxford University Press, 2005); Timothy Mitchell, *Rule of Experts: Egypt, Techno-politics, Modernity* (University of California Press, 2002).

10 Michelle Murphy, *Sick Building Syndrome and the Problem of Uncertainty: Environmental Politics, Technoscience, and Women Workers* (Duke University Press, 2006). For how such issues relate to radiation exposure, see Adriana Petryna, *Life Exposed: Biological Citizens after Chernobyl* (Princeton University Press, 2002). For exploration of "historical ontology" in relation to occupational and environmental health debates, see Christopher Sellers, "The Artificial Nature of Fluoridated Water: Between Nations, Knowledge, and Material Flows," in Gregg Mitman, Michelle Murphy, and Christopher Sellers, eds., "Landscapes of Exposure: Knowledge and Illness in Modern Environments," *Osiris* 19 (2004): 182–200; as well as other contributions to that special issue. See also Christopher Sellers, *Hazards of the Job: From Industrial Disease to Environmental Health Science* (University of North Carolina Press, 1997).

11 Anna Lowenhaupt Tsing, *Friction: An Ethnography of Global Connection* (Princeton University Press, 2005).

claims to, or denial of, nuclearity and particular imperial histories, with consequences for occupational exposures, their legibility, and workers' changing political options.

Consider a question that deeply concerned some of the people who appear in this essay: does exposure to radon gas cause cancer? Uranium atoms decay into radon, which in turn decays into other elements known as its "daughters." These decays release radioactive alpha particles, which miners inhale. Determining causality via accepted scientific practice demands isolating the effects of radon exposure—deciding whether illness in uranium miners comes only from radon exposure, or also from other contaminants. There is also the question of deciding what constitutes a radiation effect. Lung cancer? Genetic mutations? Epidemiologists and geneticists respond differently. When do "effects" occur? Is lung cancer thirty years after the victim's last exposure an "effect"? Labor lawyers and mining corporations offer different answers.

Regardless of perspective, all these questions ultimately required knowing how much radiation mineworkers absorb. Before the 1980s, personal dosimetry—giving each worker a film badge or a dosimeter pen—only detected the external exposures produced by gamma rays emitted by radioactive rocks. Such instruments did not detect the alpha radiation emitted by inhaled radon daughters. In many places, mine managers also feared personal dosimetry would scare workers by alerting them to an otherwise invisible danger. Ambient dosimetry could accommodate the heavier instruments required to "capture" radon daughters. Less personally intrusive, it involved installing instruments throughout the mine and averaging out their readings. But averages did not account for the experience of men assigned to "hot spots": spots far from air intakes, where reduced ventilation meant elevated radon-daughter levels and higher temperatures—the kind of place where, for example, white foremen stationed black workers in South African mines.

The scientific (and apparently presentist and delocalized) question of causality—"does radon cause cancer?"—is thus also, always, a historical and geographical question. It has no single, abstract answer above and beyond the politics of expert controversy, labor organization, capitalist production, or colonial difference and history. That answers depend on the friction between these, however, is only visible at the technopolitical margins of nuclearity.[12]

GLOBAL IMPERCEPTIONS, I

In 1963, at the first international conference on "Radiological Health and Safety in Mining and Milling of Nuclear Materials," in Vienna, Duncan Holaday of

[12] As one reviewer was kind enough to point out, this point resonates strongly with the argument made by the editors and contributors in Veena Das and Deborah Poole, eds., *Anthropology at the Margins of the State* (School of American Research Press, 2004).

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the U.S. Public Health Service (PHS) reported on early results from his study of radon exposure in U.S. uranium miners. He framed his remarks like this: "Among workers in the nuclear energy industry, uranium miners constitute a unique group, in that the effects of exposure to excessive amounts of radon and its daughters were observed and studied long before the fission of uranium was discovered. As a group, they are exposed to higher amounts of internal radiation than are workers in any other segment of the nuclear energy industry."[13] Holaday's audience, specialists on radiological exposure from twenty-four countries and five international organizations, probably found this statement unremarkable. They all knew about studies from the early twentieth century showing high incidence of lung cancer among Czech radium/uranium miners. In the historical context of struggles to regulate radon levels in American uranium mines, however, two things stand out: first, Holaday's alignment of uranium miners with other nuclear workers, instead of with other miners; and second, his insistence that these miners were *more* vulnerable to radiation exposure than any other nuclear worker. The U.S. Atomic Energy Commission (AEC) did not officially accept either of these premises in the 1960s. From a legal standpoint, digging uranium ore out of U.S. soil did not count as a nuclear activity until much later.

Created in 1946, the AEC immediately fostered a massive uranium boom by offering monetary rewards for ore strikes. In response, prospectors and small mining consortia dug hundreds of mines on the Colorado Plateau. They sold their ore to the AEC, the sole legal purchaser and consumer. But when AEC scientists and others began expressing concern about miners' radiation exposure, the agency refused to accept regulatory responsibility. Using arguments that would be echoed decades later by the South African Chamber of Mines, it insisted that uranium mines fell under the ordinary jurisdiction of state and federal agencies rather than the special, nuclear provisions of the Atomic Energy Act. The AEC delegated the task of regulating radon levels to state regulators, the PHS, and other federal agencies, none of which had sufficient expertise, infrastructure, or authority to implement or enforce standards. Some mine operators voluntarily upgraded their ventilation systems to decrease radon exposure, but many did not. After bitter jurisdictional battles, a nationwide exposure standard finally passed in 1967, but several more years elapsed before it became enforceable. Dozens of former miners died from lung cancer and other diseases as a result of their exposures.[14] Lawsuits

[13] Holaday, "Some Unsolved Problems," 51.

[14] Peter H. Eichstaedt, *If You Poison Us: Uranium and Native Americans* (Red Crane Books, 1994); Robert Proctor, *Cancer Wars: How Politics Shapes what We Know and Don't Know about Cancer* (Basic Books, 1995); Valerie Kuletz, *The Tainted Desert: Environmental Ruin in the American West* (Routledge, 1998); J. Samuel Walker, *Containing the Atom: Nuclear Regulation in a Changing Environment, 1963–1971* (University of California Press, 1992).

against the federal government failed to win compensation for miners and their families. In 1990, the Radiation Exposure Compensation Act finally made uranium miners from the early Cold War era eligible for "compassionate payments," in recognition of their contributions to U.S. national security, provided they could prove via medical tests and administrative histories that they had acquired a radiation-related illness. Only then did U.S. uranium mining become uncontestedly nuclear work.

Holaday's insistence on the nuclearity of uranium mining may have reflected the contested status of U.S. mines in 1963, but to French members of his audience in Vienna he had only stated the obvious. The Commissariat à l'Energie Atomique (CEA) had taken such nuclearity for granted from its inception. It monitored all manner of radiation in French uranium mines itself, with the same labs and equipment used in reactors and other "nuclear" workplaces. CEA experts had presented their first miner-exposure data five years earlier, at a 1958 Geneva conference on peaceful uses of atomic energy. By contrast to the U.S. AEC, French papers in Geneva and Vienna blared out nuclearity. They described in painstaking detail how CEA experts set maximum permissible levels, measured radon and radiation, and tracked exposures for each worker, presenting images of dosimeters, film badges, and the iconic lead-lined suits worn to work in highly radioactive environments.

The CEA had configured the nuclearity of French uranium mines by turning radiation and radon into objects of exceptional workplace control. Dosimetry—calculating the radiation dose absorbed by people—formed the core of this configuration. In 1962, the CEA had amassed thirty-five thousand radon samples, compared to the PHS's six thousand.[15] While the PHS measured only alpha radiation emitted by radon, the CEA also measured gamma radiation emitted by rocks; to this end, miners (like reactor workers) wore dosimeter pens or film badges.[16] CEA radiation protection experts emphasized their "exceptional policing role," which (at least in principle) gave them hierarchical power over mine superintendents whenever they found exposures in excess of maximum permissible levels.[17] By contrast, PHS scientists took measurements under

[15] F. Duhamel, M. Beulaygue, and J. Pradel, "Organisation du contrôle radiologique dans les mines d'uranium françaises," 63; and D. A. Holaday and H. N. Doyle, "Environmental Studies in the Uranium Mines," 19; both in: International Atomic Energy Agency, International Labour Organisation, and World Health Organization, *Radiological Health and Safety in Mining and Milling of Nuclear Materials: Proceedings*, vol. 1 (International Atomic Energy Agency, 1964).

[16] D. Mechali and J. Pradel, "Evaluation de l'irradiation externe et de la contamination interne des travailleurs dans les mines d'uranium françaises," in, International Atomic Energy Agency, International Labour Organisation, and World Health Organization, *Radiological Health and Safety in Mining and Milling of Nuclear Materials: Proceedings*, vol. 1 (International Atomic Energy Agency, 1964): 373.

[17] Robert Avril et al., "Measures Adopted in French Uranium Mines to Ensure Protection of Personnel against the Hazards of Radioactivity," in *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Held in Geneva, 1–13 September 1958, Vol. 21: Health and Safety: Dosimetry and Standards* (United Nations, 1985), 63.

the sufferance of mine operators, and only after agreeing not to inform miners about their purpose. In France, dosimetry conferred social power on a new class of experts, turning uranium mineshafts into nuclear workplaces. Dosimetric results legitimated and extended that power; in 1958 the radiation protection division proudly declared, "There has not been one instance of over-exposure." As proof, it provided the quantities of radon inhaled by mine personnel in each of the "mining divisions in Metropolitan France."[18]

Decades later, interviews with former French uranium miners suggest that especially at first, radiation monitoring practices were unevenly implemented. Workers remember early mineshafts with little ventilation, and places that made the needles on their dosimeters fly instantly off the scale. Working conditions quickly became the focus of labor union demands. By the early 1960s, French miners had their own version of what made their work nuclear, and made their own set of demands based on that nuclearity.[19] Unsurprisingly, conference presentations by the CEA's radiation protection division did not discuss these alternate productions of nuclearity. Here, however, I call attention to another absence, lurking in the reference to *metropolitan* France.

AMBATOMIKA, SOUTHERN MADAGASCAR, 1950S–1960S

From the mid-1950s onward, CEA radiation protection experts published a steady stream of papers on their exposure-monitoring programs in uranium mines. None of these, however, included data from CEA-owned mines outside the metropole. The first of these mines to produce significant quantities of uranium were open-cast quarries of uranothorianite ore in the Androy desert in southern Madagascar. Launched in 1953, when Madagascar was still under French colonial rule, these operations were considerably more rudimentary than metropolitan mines. Run by a dozen or so French geologists, metallurgists, and mining engineers, they often could not pay for themselves. Dedicated radiation protection experts did not figure in their budgets. In the metropole the nuclearity of uranium mines may have seemed self-evident, but in Madagascar it remained as fractured and lumpy as the rocks that emerged from the quarries.

Expatriates saw their work as nuclear because it fed their nation's atomic energy program. The tricolor French flag flying over the central camp reaffirmed this, as did yearly trips home where talk and images of reactors and atom bombs enabled them to visualize their contribution to the "radiance of France."[20] Visions of reactors and bombs did not, however, transfix Tandroy

[18] Ibid.

[19] Philippe Brunet does an excellent job analyzing this history in his book, *La nature dans tous ses états: Uranium, nucléaire et radioactivité en Limousin* (Presses Universitaires de Limoges, 2004).

[20] Robert Bodu, "Compte-rendu de mission à Madagascar," Direction des Recherches et Exploitations Minières, Mars 1960, Cogéma archives, accessed 1998 and 2000; Hecht, *Radiance of France*.

or Betsileo mineworkers. The former miners and mill workers I spoke with in 1998 knew neither the purpose of their ore nor the existence of reactors and bombs. When I explained, they laughed and shook their heads. "*You crazy vazahas* [white foreigners]," said one man. "*Why do you want this stuff?*"[21] Another, thinking of the region's recently opened sapphire mines (where my translator sometimes worked), shrewdly asked what sapphires were used for.[22] In their eyes, I was just another foreigner interested in rocks.

The time of *vatovy* (the local term for uranium ore) was indeed exceptional for the Tandroy who lived through it, but that exceptionalism had little to do with radiation, or with things that their French supervisors considered nuclear. It had a lot to do with value, especially wages, and the investments and business opportunities that they made possible. Fanahia worked in the mines for thirteen years. "*I bought 50 zebu* [cattle]," he said, "*and a bicycle … and a cart, and a radio, and a watch that I ordered from France. … I did some trading in watches. I would order them from Besançon and resell them to other men who worked with the vatovy.*"[23] Above all, *vatovy* exceptionalism had to do with the arduous task of breaking rocks with jackhammers, and the backbreaking work of loading rocks into wooden carts. Mahata worked in the quarries with his father and two brothers, until his father fell on a pneumatic drill and lost a leg. "*We tell our children, you must guard the zebu carefully, because the work we did to get them was painful. We broke our legs and our feet doing that. So the zebu that are there must be well guarded. Because you, you aren't able to do that hard work. … Better to guard the zebu than to work there.*"[24] Tales of rock slides and lost body parts abounded.

Radiation was not totally absent from Tandroy memories, but it appeared indirectly: nested in needles, displaced into dosimeters, yoked to discipline, and merged with medical monitoring. Some workers, for example, used Geiger counters on a daily basis, to sort rocks into "*good and bad piles.*"[25]

[21] Author's interview with Mahata, Tsilamaha, Madagascar, 16 Aug. 1998. Interviews with Tandroy and Betsileo mineworkers were conducted with the aid of translators M. Abdoulhamide and Georges Heurtebize. Quotations that appear in italics indicate the words of the interviewee as related by the translators; insertion of the first person is mine, and replaces the translators' use of the third person.

[22] Author's interviews with Fanahia and Itirik, Andolobé, Madagascar, 13 and 14 Aug. 1998; translator: M. Abdoulhamide. Although I did not know it at the time, such questions had their obverse in northern Madagascar, where miners speculated that sapphires were used in bombs. See Andrew Walsh, "In the Wake of Things: Speculating in and about Sapphires in Northern Madagascar," *American Anthropologist* 106, 2 (2004): 225–37.

[23] Fanahia interviews, op. cit. Such investments strategies contrast with the "daring consumption" that Andrew Walsh describes for some young men working in the 1990s in the sapphire-mining town of Ambondromifehy, in " 'Hot Money' and Daring Consumption in a Northern Malagasy Sapphire-Mining Town," *American Ethnologist* 30, 2 (2003): 290–305. The people I interviewed were, necessarily, long-term inhabitants of the region with deep social networks that bolstered and justified such investments; I do not know how migrant workers spent their wages.

[24] Mahata interview, op. cit.

[25] Fanahia interview, op. cit.

The needle on the counter told the whole story: "*When there is vatovy, the needle goes to 500 or higher*."[26] The presence of *vatovy*—unmediated by radiation—made the needle jump. For French managers, radiation connected the Geiger counters used for radiometric rock sorting and the dosimeters worn by employees to measure their external exposures.[27] For workers, however, dosimeters seemed disconnected from Geiger counters, less instruments of work than objects of discipline. "*If you didn't wear them, you were out. They kept track of that*," said Joseph Ramiha.[28] "*It was the boss who put them on us. He fixed them on our clothes*," remembered a woman who had worked in one of the mills.[29] Those who remembered wearing dosimeters often linked them to illness and doctors. Some stories resemble radiation rumors from elsewhere, complete with fears of sterility: "*Yes, we asked why they were putting them on and the boss said there was sickness inside, there was gas. … Yes, he said what kind of sickness but we didn't understand anything about that. … Yes, we were worried … [the boss] said that maybe there was sickness in there. There were others who said that you couldn't have children with the sickness from vatovy. We were afraid at first, but then there was nothing*."[30] If women remained fertile, perhaps there was no danger after all.

In the Androy, the application of the CEA's prescriptions for radiation monitoring was uneven at best, and depended entirely on individuals. Mines and mills operated by private contractors—colonial concessionaires who sold their ore to the CEA—did not use dosimeters at all. Fanahia worked in both types of mines and remembered this well: "*At the CEA they had them, but not elsewhere*."[31] At the CEA mines, meanwhile, some supervisors tried to explain radiation hazards to their employees, but others did not bother. One report portrayed Tandroy and Betsileo workers as irredeemably uncivilized, so primitive that they would not even benefit from a job-training program. If people could not understand radiation, then surely its hazards would remain inexplicable.[32]

Nor did CEA facilities always heed metropolitan injunctions to design processes with the goal of minimizing exposure. One CEA metallurgist, visiting Ambatomika for a few weeks to help with the milling process, bemoaned

[26] Author's interview with Jeremy Fano, Tranomaro, Madagascar, 18 Aug. 1998; translator: M. Abdoulhamide.

[27] Antoine Paucard, *La Mine et les mineurs de l'uranium français. II: Le Temps des conquêtes* (Editions Thierry Parquet, 1992), 323.

[28] Author's interview with Joseph Ramiha, Tranomaro, Madagascar, 12 Aug. 1998; translators: M. Abdoulhamide and Georges Heurtebize.

[29] Author's interview with group of women, Madagascar 1998, anonymity requested.

[30] Ibid.

[31] Fanahia interview, op. cit. This contrast was remarked upon by visiting CEA personnel as well: Robert Bodu, "Compte-rendu de mission à Madagascar," ix–4.

[32] Marc Edmond Morgaut, "Mission à Madagascar pour le Commissariat à l'Energie Atomique du 11 au 21 novembre 1958," Cogéma archives.

the crude methods used to dry the wet ore concentrates emerging from the mills: "Concentrates are spread out in the sun on big sheets of corrugated metal and turned over periodically by a worker ... this procedure is clearly archaic, long, and above all dangerous because the worker is exposed to dust and radiation."[33] This visitor's mandate did not, however, include measuring specific worker exposures, let along mitigating them.

CEA production managers did not discuss exposures either. Tales of inclement weather and technical woes filled the pages of their activity reports. They devoted almost no space to radiation exposure. They clearly knew that some jobs, such as packing uranothorianite concentrates for shipment to France, presented significant exposure hazards.[34] But they did not report on the processes for distributing or collecting dosimeters, nor did they provide tables of dosimeter readings. Reports only invoked exposures indirectly, when accounting for production slowdowns resulting from moving overexposed workers to less radioactive sites.

Such absences speak to the fragility of Madagascar's ties to the nuclearity that infused metropolitan uranium production. Of the three hazards signaled by metropolitan radiation experts—radon, dust, and gamma rays—managers in the Androy only made external gamma exposures perceptible. Measuring levels of radon and dust; estimating the long-term exposures of individual workers to these contaminants; weighting those exposures according to CEA formulas; plugging all the weighted exposures into an equation in order to derive the total monthly exposure for each employee—all that was well beyond the technical capacity or expertise of managers in the Androy, operating far from the CEA's infrastructural support. So dosimeters were distributed, gamma doses tracked just long enough to determine whether job rotation was required that month, and there the monitoring ended. By 1967, people, equipment, and quarries were all exhausted. The CEA packed its bags and went home.

Even for CEA experts, the nuclearity of Androy mines was brittle and intermittent. Threads of geological and metallurgical nuclearity ran through the consultants who visited occasionally to advise managers about prospecting or ore treatment. These experts noticed high radiation levels in passing, but those levels did not shape design choices as they had in French mines. In Madagascar, job rotation occurred in response to a single month's dose, not as part of systematically tracking long-term exposures. Radiation monitoring did not empower a distinct class of experts there. Exposures made cameo appearances in activity reports, but I found no evidence that anyone had compiled cumulative numbers to produce scientifically legible data sets. We can only speculate

[33] Bodu, "Compte-rendu de mission à Madagascar."
[34] Y. Legagneux, "Rapport d'Activité du Service 'Expoitation,'" May 1955, p. 21. CEA-DREM, Mission de Madagascar, Division du Sud. Cogéma archives.

about the reasons. Perhaps the numbers themselves instantly became imperial waste, discarded as soon as they were produced. If the raw numbers did make it to France, perhaps they became waste there, consigned to accumulate dust because no one thought they mattered. Maybe metropolitan radiation researchers did not trust the numbers because they had not collected the data themselves.

Whatever the case, Malagasy radiation exposures did not appear in CEA radiation protection publications. Today, there appears to be no way to recover the cumulative *exposures* of Malagasy uranium workers. We do know that because of their thorium content, these ores emitted exceptionally high levels of gamma radiation (over twice that of pitchblende, very high-grade uranium ore). A 1976 IAEA manual on radiological safety, coauthored by one of the CEA's radiation protection experts, mentioned this in passing, while describing the hazards posed by gamma radiation in uranium mills: "In some cases, concentrate of pitchblende has been reported to give rise to radiation fields up to 40 mR/h. . . . Readings of up to 100 mR/h have been reported for concentrates of uranothorianite mixed in the Malagasy Republic. . . ."[35] This reference to the radioactivity of the rocks, rather than the exposures of those who had sorted and milled them, reflected the regime of nuclear perceptibility that governed Malagasy uranium. CEA radiation-protection experts took account of the ores' high radioactivity levels only when the rocks entered the metropolitan processing plant. That was where they acquired their full nuclear significance, where their radioactivity seemed high by comparison to other ores, where extra precaution was required in handling them. Those radiation readings were the ones whose scientific value got traction, the ones that—nearly a decade after the mines themselves had shut down—made it into an international manual prescribing safe labor practices. Users of this manual in the late 1970s probably did not wonder about who mixed those uranothorianite concentrates, what levels of radon (and the equally hazardous thoron produced by the thorium in the rocks) might have accumulated around piles of ore, whether workers had been adequately monitored, how such dosimetric readings might have affected international data sets, or what follow-up studies of worker health might have revealed.

Following the CEA to Madagascar suggests that nuclearity came in different technopolitical registers. The geological nuclearity of uranothorianite did not automatically translate into occupational nuclearity for Malagasy workers, or epidemiological nuclearity for their exposure data. More robust assemblages of instruments and expertise might have extended the fragile regime that made different forms of exposure perceptible. Additional, or different circuits

[35] An mR/h is a unit that measures the radioactivity level of a substance. It signifies milli Roentgens per hour. International Atomic Energy Agency, *Manual on Radiological Safety in Uranium and Thorium Mines and Mills* (International Atomic Energy Agency, 1976), 9.

of knowledge might have generated the friction and translations that would have made Malagasy uranium production more nuclear, and its workers more visible. The imperceptibility of exposures, the absence of friction and translation, and the consequent long-term invisibility of Malagasies as radiation workers: all of these emerged within geographically and temporally specific colonial and postcolonial circuits of power.

This does not mean, however, that we can gesture grandly at "colonial power" to explain the unevenness of nuclearity. The geographic and temporal specificities of these circuits of power matter tremendously to what was rendered perceptible, to whom, when, and with what physiological and political results. To understand this, we must enter other circuits.

GLOBAL IMPERCEPTIONS, II

In September 1974, the CEA and the International Labor Office (ILO) hosted an international symposium on "Radiation Protection in Mining and Milling of Uranium and Thorium" in Bordeaux, France. Co-sponsored by the World Health Organization and the International Atomic Energy Agency, the conference took stock of work on the occupational health of uranium miners, methods of monitoring exposures, and international differences in the maximum permissible levels of radon, dust, and gamma radiation.

Two decades had passed since the International Commission on Radiological Protection (ICRP) had issued its first guidelines on maximum permissible levels (MPL) of radon in mines. As with all ICRP guidelines, these were merely advisory; the commission had no enforcement power.[36] National regulatory bodies had to translate ICRP recommendations into mandatory standards. Still, the commission's legitimacy was considerable; the United States and France developed their own formulations for maximum permissible levels, but most other places based their MPLs on the methods outlined in ICRP texts.

Nevertheless, controversy visibly flourished at international conferences like the one in Bordeaux. There was widespread acceptance of the "fundamental" occupational exposure limit of 5 rems, the maximum amount of radiation workers could absorb in any given year. But how should this generic number translate into specific MPLs for different types and sources of radiation? The data informing this translation were disciplinarily heterogeneous:

[36] The ICRP was started in 1928 as a group of physicists and radiologists trying to figure out how to limit their own occupational exposure to radiation. After World War II its membership grew and its aims broadened. By the mid-1950s, the ICRP was issuing recommendations on permissible doses for externally and internally absorbed radiation in all manner of occupations. For an insider history, see Roger Clarke and Jack Valentin, "A History of the International Commission on Radiological Protection," *Health Physics* 88, 4 (2005): 1–16. For an insider history of radiological standards in the United States, see J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (University of California Press, 2000).

epidemiological studies on the correlation between exposure and lung cancer, lab experiments that exposed rats to radon, autopsies of dead miners, lung function tests, and more. They were also empirically heterogeneous: there were studies of uranium miners per se, but also epidemiological studies of Hiroshima and Nagasaki victims, research on "non-nuclear" dust exposures related to diseases like pneumoconiosis, and so on. Experts disagreed about the relative significance of these data, and even their legibility. American epidemiologists did not think French experiments exposing rats to radon said much about radon effects in people. French health physicists thought that the ongoing U.S. PHS study measured radon levels inaccurately. As Henri Jammet of the CEA noted in his opening remarks in Bordeaux, even within the ICRP itself "there were passionate discussions." This had led to "apparent, and sometimes real differences" in workplace norms in different international organizations and countries.[37] Such divergences could be extremely difficult to assess, because they often stemmed from differences in the objects and tools of measurement. The French, for example, calculated and weighted cumulative exposures from three hazards (radon, dust, and gamma radiation), rather than assuming that only radon mattered, as was standard in U.S. mines. The Americans, meanwhile, measured the concentration of radon *daughters* directly because the daughters (rather than pure radon) were what caused tissue damage. Measuring daughters directly required expensive, complex instruments, which partly explained why the PHS scientists had relatively few data points and thus, by French standards, poor dosimetric accuracy. The French, along with the ICRP, believed that in most mines a relatively simple formula could translate radon gas values into daughter concentrations. And so on.

The 1974 Bordeaux conference was one of many sites in which such disagreements played out. Discussions there did not bring closure to the controversies (some aspects of which persist today). They did, however, enable French experts to argue at length for the superiority of their approach to radiation monitoring. Given the March 1974 announcement of a massive expansion of France's nuclear power program, there could not have been a more fortuitous time to display dosimetric mastery.

Most striking for my purpose here, one of the longer presentations at the conference was offered by Massan Quadjovie, an official in the Gabonese government's Direction des Mines. His audience included delegates not only from North America and Europe, but also from India, Egypt, Iraq, Libya, Turkey, Zambia, and Zaire—all potential customers for the CEA's instrumentation

[37] Henri Jammet, "Les problèmes de protection posés dans l'extraction et le traitement de l'uranium et du thorium," in, International Labour Office, *Radiation Protection in Mining and Milling of Uranium and Thorium* (from a symposium organized by the International Labour Office and the French Atomic Energy Commission, in cooperation with the World Health Organization and the International Atomic Energy Agency, Bordeaux, France, 9–11 Sept. 1974) (International Labor Office-Geneva, 1976), 3–10. All translations from the French are my own.

and training programs. Listening to Quadjovie, they might well have concluded that operations in Gabon offered a model exemplar of French dosimetric practice.

According to Quadjovie, film badges to measure gamma exposures were distributed and collected monthly, then sent to the CEA's lab in France which reported the results back to the Compagnie Minière d'Uranium de Franceville (COMUF), the company operating the mines. In underground operations, radon was measured via ambient sampling. Both gamma and radon results were recorded on each employee's exposure chart. If any "abnormal results" occurred, "an investigation is immediately conducted to determine the causes of the anomaly and take the necessary measures." Quadjovie dutifully admitted to some imperfections in the system: "Obviously this type of control implies that one can trust the personnel, each employee being responsible for his film badge. There are still some cases of forgetfulness, or of imaginative use of the film. Sometimes the badge is lost or put into an environment that is not representative of the working environment. One must therefore take all these anomalies into account when compiling the results, and periodically run checks at the worksite."[38] Unlike their Malagasy counterparts, then, Gabonese workers were not completely invisible in the international space of knowledge production. Making them visible, however dimly, enabled the Gabonese state to display regulatory competence. Doing so at an international conference, in turn, helped CEA experts display the meticulousness and portability of their approach. Visible workers, finally, could shoulder the blame for any failures.

Still, Gabonese dosimetric *results* did not make it into the international scientific literature any more than Malagasy ones had. To perceive them, we must look in Gabon, and go back in time to the first decade of uranium production at the COMUF.

MOUNANA, EASTERN GABON, 1960S–2000S

The COMUF was a joint venture between the CEA and Mokta, a mining company with long colonial experience. Launched in 1957, the site began producing ore four years later. Xavier des Ligneris, the first director, had previously run CEA uranium mines in France. In Gabon he tried to follow the CEA's prescriptions directly, treating radiation as separate from other health and safety issues in the workplace. Anticipating the need for gamma, radon, and dust monitoring, for example, he requested a technician solely dedicated to radiation protection. Although he left the development of all other health and safety guidelines to his managers, he personally wrote and signed those pertaining to gamma rays, radon, and dust. The newly independent government

[38] Massan Quadjovie, "Mesures techniques et administratives de radioprotection dans les exploitations d'uranium de Mounana," *Radiation Protection in Mining and Milling of Uranium and Thorium* (International Labor Office-Geneva, 1976), 141.

had many other things to worry about, and quickly issued a stamp of approval.[39]

Getting workers to wear the dosimetric film badges according to prescription was less straightforward. At first they did not wear the films regularly enough. Operations managers repeatedly issued warnings that films were "absolutely obligatory," and sanctions would ensue for non-compliance.[40] Then workers apparently wore the films too much: directives began warning employees not to take their films outside the workplace. Film distribution became the responsibility of supervisors, who keyed them to timecards.[41]

Des Ligneris expected that enforcing correct procedures would automatically control exposures. But it did not. It could take up to eight weeks to obtain results back from the CEA lab that processed the films. This lag time, coupled with the inherent unpredictability of the ore body, meant that spikes in external exposures continued.[42] Once underground mining started, radon added to his anxieties: the average concentrations of radon in the stopes regularly exceeded MPLs, sometimes by a factor of twelve.[43] Many employees consistently exceeded their annual exposure limits, sometimes in less than eight months. All the surveillance in the world could not stop the inexorable—and aleatory—course of radioactive decay in the stopes. Nor could high exposures be easily attributed to African incompetence. For one thing, ambient sampling of radon meant that good results did not depend on individuals wearing instruments correctly. For another, European employees also charted high readings. Reports did not always indicate the difference in African and European exposures, but when they did the amount of overexposure seemed comparable.[44] Many more African workers got overexposed, however, reflecting the political economy of labor.

Radon turned labor management into a calculus of exposure. Employees worked in high-level shafts until they had reached or exceeded their annual

[39] Xavier des Ligneris to Secrétaire Général, 8 July 1961; Xavier des Ligneris, "Consignes Relatives à la Protection Contre les Dangers dus à la Radioactivité," Mounana, 5 May 1961; approuvé par le Directeur des Mines du Gabon, Libreville, 1 June 1961, COMUF archives, Mounana, accessed 1998.

[40] Pierre le Fur, Note de Service 072bis, 3 Sept. 1964, COMUF archives.

[41] Henri Pello, Service Exploitation, Note d'organisation, "Stockage et distribution des film detecteurs de radioactivité," 26 Sept. 1966, COMUF archives.

[42] Xavier des Ligneris, "Rapport—Contrôle des radiations," HR/AP n° 2076, 5 Jan. 1968, COMUF archives.

[43] Xavier des Ligneris, "Rapport—Contrôle des radiations," HR/AP n° 2076, 5 Jan. 1968; Xavier des Ligneris, "Rapport—sur le contrôle des risques radioactifs. Février 1968," YT/AP n° 2169, 21 Mar. 1968, COMUF archives.

[44] See, for example, Xavier des Ligneris: "Rapport—Contrôle des radiations," HR/AP n° 2076, 5 Jan. 1968; "Rapport—sur le contrôle des risques radioactifs. Février 1968," YT/AP n° 2169, 21 Mar. 1968; "Reference: Votre UF/JL/JF29/68," HP/MB n° 210/69, 27 Jan. 1968; and "Rapport sur le contrôle des risques radioactifs. Mois de Mai 1968," YT/LR n° 2275, 20 June 1968, COMUF archives.

limit, at which point they were moved to workplaces with lower radiation levels. In and of itself, job rotation would have been familiar to des Ligneris: one high-grade shaft in France had registered such high gamma levels that individual workers could only work there for four hours every two weeks.[45] At that level of exposure, and in the metropole where mine operators could get quick turnaround on dosimetric results, rotation could be planned in advance. Internal radon exposures were less predictable than external gamma exposures, however, and tougher to control. Furthermore, Mounana ore was of lower grade, which meant that the mine ran on a tighter budget. By 1967, production had fallen well behind schedule.[46]

All this made des Ligneris anxious, especially because there were other limits to how well job rotation could address the problem of over-exposure. As the mine got deeper and radiation levels increased, management feared it would run out of skilled workers. Continually hiring new personnel offered one solution, since new hires were assumed to be radiation virgins. But it took time and effort to train new workers, canceling out the exposure benefits from labor turnover.[47] To address the problem, des Ligneris finally decided to make some costly upgrades to the ventilation system. This worked, at least temporarily, and from March to May 1968 radon levels decreased significantly.

In the meantime, however, corporate headquarters called for a change in leadership at Mounana. As a CEA man, Xavier des Ligneris's mining career had focused entirely on uranium ore. His expertise had been key to finding and mapping the deposit, drafting the initial mining plan, and building a strong prospecting team. He had also fostered a tight articulation between Mounana's production program and the CEA's nuclear fuel requirements. But Mokta had expressed displeasure with des Ligneris's direction for some time. It wanted someone less concerned with the nuclear dimensions of his work, and better attuned to budgetary constraints. In mid-1968, Mokta sent one of its own to replace him: Christian Guizol.[48]

Gabonese employees remembered Guizol as a hard, uncompromising man. His "severity" prompted complaints that, "It's South Africa at Mounana; blacks at the bottom and whites on top."[49] When gamma exposures climbed back up in late 1968, Guizol—deeming his predecessor soft on discipline—blamed the workers for not wearing films correctly. He tightened disciplinary and surveillance measures around film use, and placed test dosimeters in the shafts to compare with the ones worn by workers. Test results disappointed

[45] Paucard, *La Mine et les mineurs*, 96.

[46] J. de Courlon to Xavier des Ligneris, 10 Mar. 1967, COMUF archives.

[47] Ibid.

[48] Paucard, *La Mine et les mineurs*, 213; and author's interview with Christian Guizol, Paris, 26 Feb. 1998.

[49] Author's interviews with Juste Mambangui and J.-M. Malékou, Mounana, Gabon, 16 July 1998; François Mambangui, Libreville, Gabon, 31 July 1998.

him: they matched worker badges. Radon levels also climbed back up: seventy-eight workers registered overexposure in November 1969.[50]

So Guizol reconfigured the calculus of exposure. Rather than intensifying job rotation, as des Ligneris had done, he raised the MPLs. He had noticed that the ILO's 1968 radon guidelines, which used a different formula to calculate total exposure, ended up being less restrictive than the 1959 French guidelines used by the COMUF. After a few numerical gymnastics, Guizol wrote a report that justified the equivalent of a three-fold increase in radon MPLs and aligned these with ILO guidelines. The new levels, he remarked bluntly, were "more advantageous" to the company.[51] The effect was immediate. As of March 1970, not a single worker registered overexposure.[52]

No wonder, then, that Quadjovie could report complete success with the COMUF's radioprotection program in 1974. His Bordeaux paper offered a sanitized account of the switch in MPLs, making no mention of the overexposures that prompted the switch. Indeed, he may not have known about them: I found nothing in the COMUF archives to suggest that Gabonese state officials ever actually inspected radiation, radon, or dust in the mines.[53]

Not long before Guizol raised the MPLs, Marcel Lekonaguia began to question his working conditions. In the mid-1960s he became a shift boss in the shafts, in charge of blasting. Company guidelines specified that workers should wait fifteen minutes after the blast before returning to the workplace.[54] Lekonaguia probably did not know that French radiation protection guidelines specified a waiting period of at least thirty minutes, to let the dust settle and to give the ventilation system time to evacuate the extra radon released by blasting rocks apart. What he did know, all too well, was that "after the blast, there's a lot of dust. . . . It is the dust that wasted us . . . you swallow it, you breathe it." Protective gear did not help: "Those little masks, they didn't hold up well. They're made of paper . . . if it gets a little wet—paf!"—the mask would dissolve. That, he insisted, was how he developed the cough, and assorted other ailments, that would plague him for the rest of his life.

Lekonaguia also thought about the film badges, especially the tight discipline they incarnated. "They said this film here, you must always keep it. At the end of the month, they check them, they send them to see if the men reached

[50] Ch. Guizol, "Rapport sur le contrôle des risques radioactifs. Mois de Décembre 1969," YT/sc n° 0118/70, 9 Feb. 1970, COMUF archives.

[51] Ibid.

[52] Ch. Guizol, "Rapport sur le contrôle des risques radioactifs, Mois de Mars 1970," YT/sc n° 0184/70, 27 Apr. 1970, COMUF archives.

[53] The COMUF granted me free access to its archives when I visited in 1998. These were not at all organized, however, which made it impossible for me to find complete records on any single topic. Thus, though I did not find records of state inspections, I cannot state conclusively that none took place.

[54] "Consigne pour la distribution et l'emploi des explosifs," COMUF, Exploitation de Mounana, n.d. (ca. 1959), COMUF archives.

[the limit]. The results, they don't give them to people."[55] All he ever learned was whether he had reached some limit that would prompt job rotation. He never found out what the numbers were, how close to the limit he had come, how much he had accumulated over time, or even what the limit meant. What, he wondered, was all the secrecy about?

His brother, Dominique Oyingha, became convinced that the company and its doctor, Jean-Claude Andrault, were hiding something. And the state was in on it. "Uranium caused many deaths, but the COMUF didn't want to recognize that," he told me. "Nor did the state, because this was the big company of the territory, whose secrets couldn't come out ... so as not to scare the workers."[56] Only independent, external expertise could be trusted. Oyingha took his brother to the Congo for tests. He knew there had once been a uranium mine there, and he hoped Congolese doctors might help. Apparently the doctors immediately guessed from Lekonaguia's health condition that he worked at the COMUF.

The two men returned to Mounana and confronted Andrault. The mine doctor scoffed: "Are you crazy? ... Who told you that uranium made people sick?" Oyingha laughed as he remembered this response. He respected, even loved, the doctor for the hospital he had set up. Andrault offered free medical care to everyone in the region, not just to COMUF workers, and that was precious beyond measure. But everyone had their limits, and Oyingha did not expect the doctor to acknowledge the possibility of occupational disease. He threatened Andrault: "I said, 'my friend, you are my friend, we have known each other for a good bit of time, but let me tell you that the sickness that my brother suffers from, it comes from uranium. And if you don't want the news to spread ... [so that] your workers don't become afraid, take proper care of my big brother. If he dies, I'm coming after you.'"[57] The COMUF granted Lekonaguia sick leave. But he wanted permanent leave and compensation. The company refused, insisting that Lekonaguia return underground if he wanted to draw his paycheck. In 1970, the two brothers filed a complaint with the state social security office in Libreville. This produced only a perfunctory inquiry, after which the company agreed to move Lekonaguia to the open pit.[58]

Undeterred, Lekonaguia asked for his medical file. Andrault refused, citing professional secrecy. No surprise there: "The doctor, he's just a lawyer for the COMUF." The more the COMUF resisted, the more Lekonaguia and his family

55 Author's interview with Marcel Lekonaguia, Mounana, Gabon, 21 July 1998.
56 Author's interview with Dominique Oyingha, Mounana, Gabon, 17 July 1998.
57 Oyingha interview, op. cit.
58 Christian Guizol letter to Directeur Général de la Caisse Gabonaise de la Prévoyance Sociale, 19 Oct. 1970, Objet: Allocations familiales de M. Lekonaguia Marcel; Christian Guizol letter to Directeur Général de la Caisse Gabonaise de la Prévoyance Sociale, 26 Oct. 1970, Objet: Monsieur Lekonaguia; J. C. Andrault letter to Docteur C. Gantin, 27 Oct. 1970, COMUF archives.

became convinced that his illnesses were work-related. Over the course of the 1970s and 1980s, more and more people from the region went to France as students, sometimes even on training stints sponsored by the COMUF, where they witnessed anti-nuclear protests. Lekonaguia's nephew, among others, returned with confirmation that, "This product that we're mining, it's a toxic product."[59]

Finally, Lekonaguia decided that if COMUF managers kept rejecting his demands then he would rebuff theirs. He began refusing to render his film badges on a monthly basis. He suspected that his diagnosis, along with the chain of causality that linked work to illness, could be read directly from the films. One day, he explained as he showed me one of the films, he would find someone else to read the results. He probably was not alone in this reasoning. In the mid-1980s, COMUF quarterly radiation protection reports routinely recorded the numbers of non-returned films. (This statistic had not appeared in earlier reports.) During some months over 25 percent were not returned.

Mining operations in Gabon were much more extensive than they had been in Madagascar, and lasted much longer (until 1999). Links with France were denser, more extensive, and more varied. By monitoring radiation separately from other workplace dangers, des Ligneris had granted it exceptional status, and made Mounana mines more nuclear than those in the Androy. Important aspects of the regime of perceptibility that he had established lasted: rather than report readings sporadically in the footnotes of productivity tables, as their counterparts in Madagascar had done, COMUF managers continued to report dosimetric results as distinct data, and continued to track both radon and gamma levels for individuals as well as for workspaces. But this regime only made exposures legible to upper management—not to workers. It produced managerial (and, for des Ligneris, technological) data, not health data; the company's much-vaunted medical service did not treat them as relevant to its clinical work. The nuclearity of uranium work resided primarily in dosimetric instruments whose esoteric legibility could only occur in France. That legibility, furthermore, depended on interpretive systems, such as formulae for calculating dose accumulations, whose meaning shifted when placed in different global circuits, as when Guizol moved from French to ILO standards. The Gabonese state, meanwhile, had neither means nor motive to broaden the COMUF's production of nuclearity. It had no reason not to rubberstamp the COMUF's request for a switch in MPLs, particularly when legitimated by a global organization like the ILO.

Unlike in Madagascar, however, the spatial and temporal dimensions of Gabon's postcolonial conditions did create spaces in which workers could acquire knowledge and experience outside the boundaries imposed by management. Access was slow and sporadic, operating through a trip to the Congo or a

[59] Oyingha interview, op. cit.

nephew with a French education. Such friction did produce other interpretations and contexts for the radiation recorded in film badges. But for decades these modes of perception offered only glimmers of politically significant nuclearity.

Yet many COMUF workers remained suspicious about their occupational health status well after the mine shut down in 1999. In 2001, Gabon passed a law creating a state agency to monitor radiation exposure, perhaps thanks to a former COMUF employee subsequently elected to Parliament.[60] Another three years elapsed before the agency came into existence. Nonetheless, former employees and Mounana inhabitants evidently still distrusted the state. They complained that remediation work focused only on containing loose ore left behind by the mining activities, and they sought a *medical* nuclearity for their work. Inspired by reports of Aghirin'man, an NGO that addressed illnesses in Nigérien uranium mines, in 2005 a group of Mounana residents formed the *Collectif des anciens travailleurs miniers de Comuf* (CATRAM) to advocate for a health and environmental monitoring program and a fund to disburse medical compensation claims.[61] The CATRAM joined forces with several French NGOs: a group formed of expatriate COMUF ex-employees, launched in 2005 by one of their widows; Sherpa, an association of high-profile legal experts formed in 2001 to investigate global human rights and environmental justice violations perpetrated by French companies; and most importantly, the CRIIRAD, an independent laboratory created after the 1986 Chernobyl accident to develop nuclear expertise unbeholden to the French state.

These NGOs eventually managed to send a small team of scientists, doctors, and lawyers to Mounana in June 2006. The team took independent environmental readings and interviewed nearly five hundred former COMUF employees about their health and work experience. Survey responses echoed narratives I heard from Lekonaguia, Oyingha, and others in 1998. Most reported no formal training on radiation or radon-related risks and no feedback on their monthly dosimetric readings; they agreed that the Gabonese state had done nothing to monitor working conditions or occupational health; and one former medical doctor testified that company clinicians had no training in uranium-related occupational health, and that the company's radiation protection division consistently refused to transmit dosimetric readings to the medical division. The report was released at a much-publicized press

[60] "Loi no. 11/2001 du 12 décembre 2001 fixant les orientations de la politique de prévention et de protection contre les rayonnements ionisants," *Hebdo informations, Journal hebdomadaire d'informations et d'annonces légales* 451 (23 Feb. 2002): 22–23 (Gabon).

[61] Jules Mbombe Samaki, "Memorandum sur la nécessité de la prise en compte de la Veille sanitaire et du dédommagement des anciens travailleurs miniers," private communication, Libreville, 25 Apr. 2005. See also reports in the Gabonese press: "Le Collectif des anciens travailleurs miniers interpelle la Comuf," *L'union*, 3 Feb. 2006; and "Les anciens travailleurs miniers de la Comuf réunis en collectif," *L'union*, 17 Feb. 2006.

conference in Paris in April 2007.[62] The following month, Areva (the second-generation corporate heir to French nuclear fuel cycle operations, and thus the new parent company for the COMUF) announced that it would install a "health observatory" in Mounana.[63] It remains to be seen what such an observatory will make perceptible, and to whom.

Invoking nuclearity—insisting on its insufficient recognition—ultimately gave former COMUF workers access to activists in Niger and France. Configuring nuclearity in medical terms required new networks to extend the boundaries of existing regimes of perceptibility. Their strength, in turn, depended on how extensively they could articulate a nuclearity for Mounana. It depended on how successfully these extended regimes could translate workplace exposures into technopolitical claims—complete with independent radiation readings—whose purchase would reach beyond the profoundly unequal relationships among the Gabonese state, the mining corporation, and its workers. In this reconfiguration timing and context made all the difference: at the most basic level, independent scientific expertise and transnational circuits of legal nuclear accountability were simply not available in the mid-1960s, when the Androy mines closed.

Clearly much more could be said about recent events in Gabon and their dependence on the production of technopolitical histories, contrasting regimes of perceptibility, and changing transnational legal circuits. I put these themes aside, however, in favor of a final example of the contingency of nuclear things. Mounana under Guizol may have seemed "like South Africa" to some. But what do we see if we compare the COMUF to apartheid-era uranium producers in South Africa?

GLOBAL IMPERCEPTIONS, III

A quick glance through the scientific literature could convey the mistaken impression that South Africans, like the CEA in France, considered uranium mining a fully nuclear task. At the 1958 Geneva conference on atomic energy they had presented one of only three papers on radiation in mines.[64] The paper described the 1956 visit of U.S. AEC experts to South African mines, where they conducted a brief survey of radon and radon daughters. Given that the AEC refused to monitor radon in American mineshafts, this visit might seem surprising. But it fit into a larger framework of uranium cooperation between the two nations. South Africa's famous Witwatersrand gold mines contained abundant quantities of uranium ore, and the United

[62] Samira Daoud and Jean-Pierre Getti, "Areva au Gabon: Rapport d'enquête sur la situation des travailleurs de la COMUF, filiale gabonaise du groupe Areva-Cogéma," Sherpa, 4 Apr. 2007, http://www.asso-sherpa.org/.

[63] "L'observatoire de Mounana," *L'union*, 1 June 2007.

[64] S. F. Oosthuizen et al., "Experience in Radiological Protection in South Africa," in *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, 1958), 25–31.

States and the United Kingdom had signed contracts to purchase some 10,000 tons of it. Lively scientific exchange had ensued among the three nations, as metallurgists and other experts collaborated on industrial processes to separate the uranium from the gold.[65] Dr. Roy Albert, probably one of the few in the U.S. AEC who had actually wanted his agency to monitor radon, went to South Africa as part of such exchanges.

The AEC radon survey found that average levels in South African shafts were tiny compared to U.S. figures, and only slightly above international limits. South African scientists attributed these results to "high ventilation standards" and concluded, "Probably as the result of the stringent safety precautions the radioactivity in South African mines does not represent a health hazard." Using Albert's analysis of Johannesburg hospital autopsy data for miners, the South Africans reported that this analysis did "not reveal any evidence of increased incidence of lung cancer in miners." They dismissed Albert's recommendation to conduct a more detailed follow-up study, arguing that their data suffered only from "the usual defects common to hospitals all over the world."[66]

By emphasizing the ordinariness of their dataset's defects, these scientists doubtless hoped to deflect their international audience's attention away from its racial dimensions.[67] Roy Albert himself must have expressed doubt and raised the possibility of including "natives" in a follow-up study, even if he himself ended up dismissing that option: his report to the AEC noted that short employment contracts and high mobility (information which he must have obtained from his South African hosts) made "the native population unsuitable for the radon study."[68] Perhaps this unsuitability obviated any mention of the fact that the Johannesburg hospital autopsy series included only white patients. In pre-civil rights America, this too must have seemed like a characteristic "common to hospitals all over the world."[69]

[65] Thomas Borstelmann, *Apartheid's Reluctant Uncle: The United States and Southern Africa in the Early Cold War* (Oxford University Press, 1993); Margaret Gowing, *Independence and Deterrence: Britain and Atomic Energy, 1945–1952* (Macmillan Press, 1974); Jonathan E. Helmreich, *Gathering Rare Ores: The Diplomacy of Uranium Acquisition, 1943–1954* (Princeton University Press, 1986).

[66] These were listed as "factors which influenced cases sent to autopsy by the medical attendants (personal interests and bias, etc.), religious grounds for relatives refusing autopsy, type of cases treated in the hospital (e.g., special clinics), etc." Oosthuizen et al., "Experience in Radiological Protection."

[67] On apartheid science, see Saul Dubow, *A Commonwealth of Knowledge: Science, Sensibility and White South Africa 1820–2000* (Oxford University Press, 2006).

[68] R. E. Albert (U.S. Atomic Energy Commission, Division of Biology and Medicine), memo to files, subject: "Medical Services in the South African Gold Fields and the Shinkolobwe Uranium Mine." NV0727618 in U.S. Department of Energy, Nevada Test Site electronic archives.

[69] For an analysis of how population categories have only recently changed in American medical research, see Steven Epstein, *Inclusion: The Politics of Difference in Medical Research* (University of Chicago Press, 2007).

South African scientists may have thought that this early radon study made further research unnecessary, but scientists in the U.S. Public Health Service and at the ICRP remained intrigued by the Witwatersrand shafts. They suspected that surveying these could help settle a major scientific debate over whether radiation exposure had any health effects below a certain threshold (as opposed to health effects remaining proportional to exposure no matter how small the dose). For a decade after the 1958 Geneva paper, PHS and ICRP scientists urged their South African colleagues to conduct more extensive research.[70] Growing condemnation of apartheid had begun to close down opportunities for international research exchanges, so such requests had become increasingly rare. Finally, J. K. Basson of the South African Atomic Energy Board (AEB) agreed to run a pilot study in collaboration with the Chamber of Mines. He wrote up the results in a 1971 report, concluding, "The death rate from lung cancer among White South African miners has not been increased by radon exposure," and "Although this investigation was undertaken as a pilot study, it appears that no improved results would be obtained by increasing the sample size."[71] A common South African refrain: no problems detected, no further study needed.

Once again, Basson's study involved only white miners. Once again, Basson's assertion, "This study had to be limited to White miners because the Non-White group . . . comprises mainly unskilled workers who come from rural areas and work for intermittent periods varying from a few months to 1 1/2 years before returning to their homelands," did not raise any American eyebrows. Foreign experts may not have realized that most of the several hundred thousand black workers returned repeatedly to the mines: an African mineworker's total time in the mines could exceed twenty years.

Yet even if U.S. experts had understood this, for them the omission would have paled next to Basson's conclusion, which explicitly addressed *American* debates about lowering permissible levels in mineshafts: "Although the induction of lung cancer by high concentrations of radon and radon daughters cannot be questioned, this study has produced no evidence for any effect at the cumulative exposures encountered in South African mines. . . . Consequently there is no support for the proposed decrease of the permissible radon daughter levels . . . as envisaged in the USA." To make matters worse for the PHS, Basson had sent the report directly to Union Carbide's uranium operation in Colorado, which had forwarded the report to other mining corporations and the U.S.

[70] For example: C. G. Stewart and S. D. Simpson, "The Hazards of Inhaling Radon-222 and Its Short-Lived Daughters: Consideration of Proposed Maximum Permissible Concentrations in Air," in *Radiological Health and Safety in Mining and Milling of Nuclear Materials: Proceedings*, vol. 1 (International Atomic Energy Agency, 1964), 333–57.

[71] J. K. Basson et al., "Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines," Atomic Energy Board: PEL 209, Pelindaba, Mar. 1971 (English-language abstract).

AEC.[72] The report landed late at the PHS. Frantic that it would serve "as ammunition to repudiate the PHS data and conclusions," experts there responded harshly. They accused the South Africans of "gross underreporting" of lung cancer and urged "that a competent epidemiologist, above suspicion of any possible conflicts of interest . . . be employed to pursue the problem in a technically competent manner, taking all the careful steps and precautions that he has been trained to take with such difficult data."[73] Reading a classic capitalist conflict between corporate interests and state regulation into Basson's data analysis, and panicked that the report might jeopardize their own hard-won standard, PHS scientists apparently did not wonder whether racial exclusion might have also skewed the data.

THE WITWATERSRAND ("THE RAND"), CENTRAL SOUTH AFRICA, 1980S–1990S

In 1980, a young British scientist named Shaun Guy accepted a job with the South African Atomic Energy Board's licensing branch. Moving to South Africa in the early 1980s was, he later admitted, an odd choice. The apartheid regime was getting steadily more violent and repressive, and the paramilitary wing of the ANC had begun to respond by sabotaging military and industrial installations. But Guy had trouble finding good employment at home, so he went.

The licensing branch was a small division, staffed by two other foreign transplants. Sometime around 1976, a few years before Guy's arrival, they had realized that South Africa had produced uranium for over twenty years with no regulatory oversight. Their early attempts to rectify this met with strong resistance from the mining industry, which insisted that mineshafts (contrary to a statement in South Africa's nuclear energy act) did not count as "nuclear" installations for regulatory purposes.[74] The Chamber of Mines closely guarded its data on radon levels, so the licensing branch had little ammunition.

[72] R. G. Beverly letter to J. T. Sherman, 25 May 1971, subject: report titled "Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines," NV0061126; R. D. Evans letter to C. R. Richmond, 2 June 1971, subject: "Report on Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines," NV0061125, Nevada Test Site electronic archives (both letters were given the quoted titles by the archives).

[73] A. H. Wolff letter to I. Mitchell, subject: "Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines" (no enclosures), 10 June 1971, NV0061124; M. A. Schneiderman (National Cancer Institute) letter to Deputy Assistant Administrator for R&D, Environmental Protection Agency, subject: "Report Concerning White South African Gold Miners and Bronchiogenic Cancer," June 18, 1971, NV0061122; V. E. Archer letter to A. Wolff, 16 June 1971, subject: Preliminary Report re: "Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines (Criticisms of Report)," NV0061123, all in Nevada Test Site electronic archives, which conferred the quoted titles.

[74] A. J. A. Roux to W. P. Viljoen, 16 May 1979, internal ref. LB/35/6/10, Shaun Guy, "A Review of Files at the Government Mining Engineer Concerning Radiation in Mines and Works," 26 Aug. 1986, 3, Shaun Guy private papers.

Soon after he arrived, Guy decided to poke around: "I went through the library and the archives, contacted people who worked at the AEB who . . . assisted me in getting hold of reports I couldn't ask for myself. So a lot of this was done underhand. . . . And there were quite serious security implications. . . . You had to sign an Official Secrets Act, so some of the stuff I did was illegal."[75] Guy ended up with a hoard of documents, including Chamber correspondence, which revealed clear problems with radon levels. Buried among these was Basson's 1971 report.

Guy covered his copy of the report with outraged notations. His interpretation of Basson's impulse to discontinue research (and radon monitoring) differed from that of American epidemiologists: "A lot of the senior scientists who were involved with the Chamber and the surveys and writing the epidemiological assessment from these results were very hostile to the ICRP and their new dose limits. . . . At that time also there was the whole thing of sanctions and this closing in and basically there was a lot of hostility to outside organizations which is a sort of political thing—it's part of the culture."[76] He also noticed problems missed by the Americans. Basson had calculated cumulative exposures "by multiplying the number of shifts worked underground on the gold mines by the estimated radiation levels for each mine on which they worked."[77] This statement earned a double question mark from Guy. First, Chamber officials had only measured actual radiation levels in about 10 percent of the mines. Second, averages were meaningless: even within a single mine radon levels could vary by several orders of magnitude. Variation had to do with ventilation, and ventilation had to do with race: "If you know anything about working underground at that time . . . even in the '80s . . . most of the work was done by the black guys who were on the face, the stopes. They tended to be in the areas (what they call the 'return airways') where the air is hotter, right? It's much cooler in the intake airways. So . . . white miners were mostly located for much of the time in the intake airways where their exposure would be less. So if you take the white miners [as] the base line for exposure . . . that's the wrong benchmark to take, it's a biased mark."[78] Digging around in data collected during the 1950s and 1960s, Guy saw many instances of substantial radon build-up in working shafts, in some spots reaching ten times ICRP dose limits.[79]

These old data alone could have justified regulatory measures. But the industry had successfully kept such measures at bay for over thirty years. It was not

[75] Interview by the author and Bruce Struminger with Shaun Guy, Johannesburg, South Africa, 12 July 2004. Guy generously gave me copies of the documents he had collected.

[76] Guy interview, op. cit.

[77] Basson, "Lung Cancer and Exposure to Radon Daughters," 12.

[78] Guy interview, op. cit.

[79] "Results of Radon Daughter Sampling in Bird Reef," West Rand Consolidated Mines, Ltd., Mine Office, West Rand, 13 Dec. 1973, Shaun Guy private papers.

about to cave to a small group of foreign upstarts relying on old data. Especially because South African uranium production had slumped by the mid-1980s so that many shafts had reverted to straightforward gold production. If anything, argued the Chamber, nuclear regulation of mines seemed even less justifiable. Nevertheless, Guy and his colleagues were not ready to give up.

The Chamber had argued that the mines were less nuclear because they produced less uranium. Yet radon could build up in shafts worked for gold too. Guy realized that before reaching active shafts ventilation sometimes circulated through old workings where radon accumulated. Proving that "hot spots" still existed, however, required new data. The licensing branch managed to enlist help from the office of the Government Mining Engineer. Accompanied by two GME inspectors, Guy and his colleagues met with the manager at the West Rand mine in 1986. They slyly proposed to use his mine as a "model facility with regard to testing survey methods." The manager resisted, but eventually agreed to a short survey provided that it remained "low key [and] confidential." He would have to obtain approval from his board for a longer-term survey "as it was a 'sensitive' matter given the union 'situation' at present." Neither white nor black workers knew about radon; white workers congregated around intake airways because they were cooler, not to minimize radiation exposure. Indeed, most workers did not know that the ore they sent up contained uranium in addition to gold.[80]

The preliminary West Rand survey showed elevated radon levels, up to two to five times the ICRP limits. The licensing branch remarked that this gave "cause for concern since workers appear to have been routinely exposed at these and higher levels for the last 30 years."[81] Backed by the GME and their data, Guy and his colleagues now felt unstoppable. Over the next two years, they carried out extensive surveys of many Rand mines. The results showed systemically high radon levels.

Still, obtaining data was only the first step toward regulation. The battles continued. As the 1980s drew to a close, the institutions of formal apartheid began to crumble. Laws were being rewritten, including the Nuclear Energy Act. As a first step in reorganization, the licensing branch achieved independent institutional status, becoming the Council for Nuclear Safety (CNS). Nevertheless, the question of *what* the new entity would regulate remained a battleground. The Chamber of Mines fought hard against designating mineshafts

[80] Shaun Guy, "Memorandum: Meeting at West Rand Consolidated with the Mine Manager, 24 February 1986." LB/35/6/10/8, Shaun Guy private papers. For a discussion of the "union situation" that the manager mentioned, see T. Dunbar Moodie with Vivienne Ndatshe, *Going for Gold: Men, Mines, and Migration* (University of California Press, 1994).

[81] U.S. Atomic Energy Commission Licensing Branch, "Report of the Underground Survey for Radon Daughters at West Rand Consolidated Mine, 5 March 1986," 23 May 1986, p. 5, LB/35/1/13; LB/35/6/10/8, Shaun Guy private papers. By this point, the South African Atomic Energy Board had changed its name to the Atomic Energy Corporation of South Africa.

as "nuclear" workplaces subject to CNS regulation, arguing that radiation protection should fall under the (less intrusive) purview of the Department of Health. Radon, insisted the Chamber, was "essentially a health issue and not a nuclear energy issue"; no matter how high their exposure, the hundreds of thousands of men laboring in the shafts were *mine*workers, not *nuclear* workers.[82] In a 1995 letter to Parliament, Chamber president A. H. Munro brazenly invoked "South Africa's transition to full democracy." He argued, "The Nuclear Energy Act does not provide for public participation, transparency or accountability. Instead it puts extensive power and decision-making responsibilities solely in the hands of expert authorities. Furthermore, it also makes no provision for making the essential social judgements in respect of acceptance of certain risks in exchange for benefits to society." Suddenly the Chamber invoked the ICRP as an ally: Munro quoted its 1990 recommendations that, "The selection of dose limits necessarily includes social judgements applied to the many attributes of risk. These judgements would not necessarily be the same in all contexts and, in particular, might be different in different societies."[83] Exposure limits could not be universal. Nuclear regulation of mines, Munro insisted, would impede economic and social development in the New South Africa. The Chamber, which had been one of the original architects of racial segregation in South Africa, unblushingly accused the CNS of being a "white, male organization" with an inadequate understanding of development challenges.[84] This time around, though, the Chamber's strategies failed. In 1999, the revised Nuclear Energy Act remade the CNS into the National Nuclear Regulator and granted it the authority to monitor radiation in mines. This victory was more legal than practical, but that is a story for another time.

In Gabon and Madagascar, we saw that nuclearity came in different technopolitical registers: geological, metallurgical, technological, managerial, and medical. Nuclearity in one register did not automatically translate into another. The act, and the consequences, of translation changed over time, depending not only on the assemblages that constituted regimes of perceptibility, but also on how the global friction generated by their data shifted (or did not shift) the boundaries of those regimes.

[82] "Draft: South African Energy Policy: Discussion Document: Comment," 2 Oct. 1995, 1, 11, Papers of the office of the Assistant Adviser on Safety and Environment, Chamber of Mines, accessed privately in May 2004, 8.

[83] A. H. Munro letter to M. Golding, 2 Mar. 1995, papers of the office of the Assistant Adviser on Safety and Environment, Chamber of Mines, accessed in May 2004, 5. For the 1990 ICRP recommendations, see *Annals of the ICRP* 21, 1–3, esp. pp. 25–32.

[84] D. G. Wymer, "Note for the Record: Meeting between the Chamber and Marcel Golding, Cape Town, 7 June 1995," 14 June 1995, papers of the office of the Assistant Adviser on Safety and Environment, Chamber of Mines, accessed in May 2004, 9.

In South Africa, however, the very act of generating perceptibility—*any* sort of perceptibility, associated with *any* sort of nuclearity—was itself a struggle. Establishing a credible dosimetric regime required, above all, a new perspective on South Africa's position in global circuits of knowledge production: it required the ability to see existing radon surveys as *apartheid* science, at odds with the norms and findings of globally-sanctioned practices (however unsatisfactory those practices themselves may have been). In effect, Guy saw first the *im*perceptions that South African data generated as they entered global circuits, a vision made possible by his own place as a foreign-trained radiation expert with more invested in trusting the ICRP than in upholding the technopolitics of South African mining. Constructing regimes of perceptibility in the mines meant pushing against the apartheid state, and its forms of capital, via the simultaneous assertion of expertise and of a spatial domain in which that expertise had authority.

CONCLUSION

Uranium mines were at the technopolitical margins of an industry driven by claims to exceptionalism. Compared to reactors and bombs they appeared banal and peripheral, more closely allied, both technologically and geopolitically, to other forms of mining than to other nuclear things. And indeed, many aspects of the stories I have told here do resemble the histories of labor and occupational disease in other mining sectors, such as asbestos or gold mining.[85] In some respects, it was precisely the commonplace nature of illegibility and secrecy that enabled radiation exposures to pass unnoticed or unintelligible, whether to global experts or to mineworkers themselves. Uranium mines had to be made nuclear—they were not born that way. Turning that nuclearity into forms of politically usable nuclear exceptionalism required material, discursive, technopolitical, global, and local work.

So the nuclear world in Africa emerged slowly, jaggedly, from frictions between the transnational politics of global knowledge production and the rule and remains of (post)colonial difference. As a form of power distributed in things and inscribed in bodies, nuclearity could make itself felt through absence as well as presence. Radiation did not, by itself, make uranium mining into nuclear work. It had to be made perceptible and allied to human agency. If such perceptibility and alliances marshaled nuclear exceptionalism effectively, radiation could serve as a mechanism for forming, maintaining, or disrupting power relationships. Dosimetric mastery thus empowered French radiation protection specialists, both in French mines

[85] For one example among many, see Jock McCulloch, *Asbestos Blues: Labour, Capital, Physicians & the State in South Africa* (James Currey, 2002).

and in dominant circuits of global knowledge production. In Madagascar, however, dosimetry filtered through other experts; it became little more than a short-term tool for making labor decisions and exerting power over colonial subjects. For Malagasy mineworkers, radiation remained a mysterious residue. Their work *never* became nuclear; their exposures *never* served as a resource for postcolonial claims-making. By contrast, Gabonese miners eventually found ways to claim nuclear exceptionalism for themselves, to represent their exposures as the distinctive consequence of globally known hazards *and* as (post)colonial injustice, and therefore as politically accountable in global circuits. South African mines show that dosimetry, while not sufficient, was nevertheless necessary to the production of nuclearity. Its long absence rendered radiation exposure utterly invisible to mineworkers, a form of colonial violence they did not know they had experienced.

Juxtaposing these various histories illuminates not just the uneven spatial distribution of nuclearity, but also its uneven temporalities. There was no moment in global time when the nuclearity of uranium mines became settled and forever mandated. Differences among places had to do with time as well as space, with *temporal* frictions between mine closures, transnational activism, global knowledge production, capital flows, postcolonial politics, the collapse of apartheid, and more. These spatio-temporal juxtapositions, in turn, bring into focus the double edge of governmentality. Dosimeters established forms of legibility whose first and sometimes only effect—for workers—was discipline. Records also carried within them the potential to discipline mine operators: hence managers' resistance to making, keeping, and revealing them. But that potential required the spatio-temporal extension of perceptibilities to gain momentum and become usable.

Meanwhile, the imperceptions produced by technopolitical marginality continued to ricochet around global circuits, gaining traction not by conspiracy but simply through the normal processes of transnational science. In the early 1990s, for example, an international group of experts conducted a massive re-analysis of data from the eleven *existing* studies of radon and lung cancer risk, which covered underground miners in Australia, Canada, China, Czechoslovakia, France, Sweden, and the United States. African exposures could not be reanalyzed, because they had never existed *as data* in the first place.[86] And so the stakes of Africa's absences from the nuclear world accumulate, both within and outside the continent.

The view from the margins challenges the ontological certainties of the center. We can readily make this point from a scholarly perspective. But making such challenges stick in the practices of the messy world requires

[86] Jay H. Lubin et al., "Radon and Lung Cancer Risk: A Joint Analysis of 11 Underground Miners Studies," NIH report 94-3644 (National Institutes of Health, 1994).

continuous work—as Gabonese mineworker advocates, South African nuclear regulators, and others have discovered. In the uranium boom currently in progress all over the African continent, mine operators and state officials, invoking the "social judgments" such as those written into ICRP texts on exposure limits and cited by the South African Chamber of Mines in the 1990s, pit the immediate urgency of "development" against the long-term uncertainties of exposure. The struggle to see Africa in the nuclear world, and the nuclear world in Africa, continues.

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