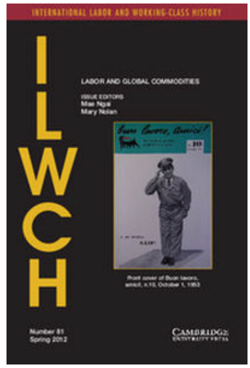

The Work of Invisibility: Radiation Hazards and Occupational Health in South African Uranium Production

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The Work of Invisibility: Radiation Hazards and Occupational Health in South African Uranium Production

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Abstract

This article explores the technopolitical mechanisms by which radiation hazards in South African uranium production were rendered invisible. The occupational health effects of underground uranium mining were deeply contested for decades, all over the world. From the 1950s to the 1990s, the volatile nature of labor relations under apartheid shaped how the South African mining industry responded to the presence of radon gas. With occasional help from state scientists, the industry muffled the political menace of radon gas by making its physical presence difficult to see. Sometimes this invisibility resulted from deliberate decisions, sometimes from structural suppression, sometimes from the tangle of both. This article argues that maintaining radon's invisibility took work.

From the earliest years of the Cold War, the atomic bomb appeared to replace colonialism as an instrument of global power. The development of civilian atomic energy in the 1960s turned nuclear power into an equally powerful symbol of modernity, prosperity, and postcolonial order in many nations.[1] Yet uranium—the essential commodity of the so-called "nuclear age"—remained deeply embedded in imperial relations. In any given year of the Cold War, for example, between a fifth and a half of the Western world's uranium came from African mines.

For decades, the occupational health effects of producing all this uranium were deeply contested. Radon gas pervaded mineshafts, decaying into other elements known as "daughters." These decays release radioactive alpha particles, which miners inhaled. Many of these workers developed lung cancer (among other diseases). But did radon daughters actually cause the cancer? As I have argued elsewhere, the question had no single, abstract answer above and beyond the politics of expert controversy, labor organization, capitalist production, or colonial difference and history.[2] Apartheid South Africa, whose uranium reserves gave it a significant role in the "defense of the West," provides an especially clear illustration.

This article explores the technopolitical mechanisms by which radiation hazards in South African uranium production were rendered invisible. Throughout the twentieth century, the South African mining industry—with plenty of help from the state—made certain lung diseases hard to see.[3] Nevertheless, despite the considerable power of both the state and the mining industry, maintaining invisibility took work. For decades, South African radon

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repeatedly threatened to become visible. On some occasions it peeked through the work of South African scientists. Other times, it loomed through the queries of international experts. The volatile nature of labor relations under apartheid—including issues such as white miners' anxieties about the color bar, the recognition of black trade unions, and shifting migration patterns—shaped how the mining industry responded to the presence of radon. With occasional help from state scientists, the industry muffled the political menace of the gas by making its physical presence difficult to see. Sometimes this invisibility resulted from deliberate decisions, sometimes from structural suppression, sometimes from the tangle of both.

As we will see, establishing a *credible* dosimetric regime—a program that met international scientific standards for measuring the radiation doses absorbed by workers—required three related perspectival shifts. The first involved seeing mine work in *nuclear* terms. The second involved seeing existing radon surveys as products of *apartheid* science. And the third involved rejecting assumptions that nuclearity began only with white, mid-level technicians.

Before delving into the historical substance of my argument, however, I must explain one of its central conceptual terms: nuclearity.

Nuclear Ontologies

What makes things "nuclear," and how do we know? Are the criteria for nuclearity scientific? Technical? Political? Systemic? I've argued that these questions are matters of ontology: questions about the things and categories of things that exist. Historical actors often deployed an ontology that appeared fixed, incontrovertible, and transparently empirical, in which essential qualities rigidly separated the nuclear from the non-nuclear. Scholars have generally left this assumption unchallenged. Yet close examination shows that the boundary between the nuclear and the non-nuclear has been frequently contested. The qualities that make a nation, a program, a technology, a material, or a workplace count as "nuclear" are unstable. There is not one nuclear ontology, but many.[4] My term for this, this unsettled classificatory scheme is *nuclearity*.

Radiation is a physical phenomenon that exists independently of how it's detected or politicized. *Nuclearity* is a *technopolitical* phenomenon that emerges from political and cultural configurations of technical and scientific things, from the social relations where knowledge is produced. Nuclearity is not so much an essential property *of* things as it is a property *distributed among* things.[5] *Nuclearity is not the same everywhere*: It is different in the United States and France, in South Africa and Gabon. *Nuclearity is not the same for everyone*: It has different meanings for geologists and physicists, geneticists and epidemiologists, managers and workers. *Nuclearity is not the same at all moments in time*: Its materialization and distribution in the 1940s and the 1990s differed markedly.

Radiation matters, but its presence does not suffice to turn mines into nuclear workplaces. After all, as the nuclear industry is quick to point out, people absorb radiation all the time by eating bananas or sunbathing or flying over the North Pole. For a workplace to fall under the purview of agencies that monitor and limit exposure, its radiation levels (irrespective of intensity) must be man-made, rather than "natural." But is radiation emitted by underground rocks natural (as mine operators sometimes argued) or manmade (as occupational health advocates maintained)? For mines to be treated as "nuclear" workplaces in any meaningful scientific, political, or cultural sense, their radiation levels must be detected and recorded using instruments, laboratories, and comparison data. If these devices and institutions don't exist—or if they break down, or if the connections between them are weak—then the mines devolve into ordinarily dangerous workplaces rather than specifically nuclear ones.

How, then, was nuclearity made—and unmade—in South African uranium production?

The Disappearing Nuclearity of South African Uranium (1): Mines

Apartheid in South Africa formally began after the National Party came to power in 1948. Conceived as a technopolitical project and a sweeping modernist system, grand apartheid built on mechanisms of spatial and racial control that had been pioneered by the gold mining industry earlier in the century. Such mechanisms sustained the technopolitical illusion of complete knowledge and control over Africans.[6]

The ideological apparatus of the apartheid state (and its industrial elites) included a historical narrative that situated South Africa within the grander story of Western technological progress. The uranium industry offered a vehicle for this narrative, not the least because Cold War Western leaders had their own reasons to include South Africa within the fold. South Africa had the world's largest known uranium reserves buried in gold mine shafts and tailings piles; in 1950, the United States and the United Kingdom contracted to purchase some 10,000 tons of South African uranium over the subsequent 14 years.[7]

At first, the mines themselves seemed poised to become fully nuclear workplaces. In the late 1940s and early 1950s, for example, the newly created National Physics Laboratory measured radiation and radon levels in a few mines.[8] In one of these—a small mine that extracted thorium, another radioactive element that scientists had hoped might also serve as a nuclear fuel—the laboratory used dosimetric film badges in order to track the gamma radiation absorbed by individual workers. The badges revealed that in just four months, twenty-five percent of black manual labor and fourteen percent of white supervisors were exposed to the annual maximum dose recommended by the International Commission for Radiological Protection. The establishment of change-houses, along with training and dust reduction programs, apparently improved the situation—as did relying on shorter contracts for black migrant workers who, in principle, could exceed six-month stints "only if their radiation exposure were low."[9] The foundational components of nuclearity appeared to be in place: research projects, monitoring instruments, special instructions, and job rotation to avoid high exposures.

The National Physics Laboratory did not remain interested in mine radiation, however. Research on this topic was next taken up by S. R. Rabson, a scientist at the Dust and Ventilation Laboratory (DVL) operated by the Chamber of Mines, an umbrella organization for the gold mining industry. Rabson surveyed radon in seven gold mines, five of which also produced uranium, between 1958 and 1961. He found peaks that exceeded international recommended limits by nearly seven times. His report, however, emphasized *average* concentrations, which mostly remained within international limits. Despite taking very few samples and surveying only five of the twenty-seven uranium-producing mines, Rabson concluded that with a few exceptions, "personnel are seldom exposed to radioactive concentrations in excess of the so-called 'tolerance level.'"[10]

Rabson would have liked to conduct more research, but his ambitions were quickly frustrated. Medical data proved inadequate to the task of correlating lung cancer with radon exposure. While "there appeared to be quite a number" of lung cancer cases among workers employed in surface operations, researchers couldn't establish whether this unspecified number exceeded that of the general population. Finding enough manpower to conduct in-depth radon surveys also impeded research.[11] Maintaining nuclearity by continuing research, acquiring more instruments, and training more experts required resources. Rabson's report hadn't accorded much significance to the radon peaks. No one mentioned (or perhaps even noticed) that he hadn't taken enough samples to produce conclusive results. Whatever nuclearity mine shafts might have acquired had disappeared by 1963.[12] As we will see, it would be the 1980s before radon exposures in the mines would acquire any visibility.

The Disappearing Nuclearity of South African Uranium (2): Processing Plants

The ore that came out of the ground contained both uranium and gold. Special processing plants were required in order to extract the uranium from this ore, and by the late 1950s, seventeen such plants were in operation. For a brief time, these uranium processing plants seemed stronger candidates for nuclearity than the mines themselves. In order to understand how nuclearity in these plants disappeared, we must return to the early 1950s.

In 1951, Leonard Taverner, the director of South Africa's Government Metallurgical Laboratory (GML), became interested in radiation exposure at the processing plants. He had been struck by the efforts that American, Canadian, and British uranium plant operators made to protect workers against radiation and toxicological hazards. After a visit overseas, Taverner proposed a set of health and safety precautions for South African uranium plants.

South African uranium ore was low-grade, so Taverner did not expect gamma radiation (which could lead to external contamination) to pose a big problem. But uranium in the plants continued to emit radon, which could lead to internal contamination. Uranium also had toxic properties and could cause significant kidney damage if ingested. The lead content of the ore and the sulfuric acid used in the plant also posed threats. To mitigate these dangers Taverner proposed that the Chamber of Mines require its members to institute a few basic precautions: monitor radiation levels, issue respirators and protective clothing, build change-houses to prevent contaminants going home on work clothing, and prohibit smoking, eating, and drinking in work areas.[13]

Even the simplest precautions, however, struck the Chamber as "unnecessarily elaborate." Industry officials worked to banalize uranium hazards, asserting that these were less threatening than those posed by exposure to mercury, lead, or cyanide. They claimed a man could eat up to one pound of uranium oxide "without effect." Chamber officials especially objected to prohibitions on workplace eating and drinking, which would force employees to go through the change-rooms to get needed refreshments. Because the uranium plants operated continuously, this would require hiring "spare men." The industry should avoid "installations and . . . precautions which would seriously affect the economics of the uranium project, and which would, in the long run, be found to be unnecessary."[14]

The industry—which was already experiencing trouble with unionized white labor—feared that "excessive" safety precautions would only alarm workers further. One official went so far as to warn that "the main danger to the personnel of the plant will be psychological if health hazards are overemphasised." Mine operators, he insisted, knew that "good industrial hygiene must be practiced in any plant and that the uranium plants will be no exception," and he concluded that "if there is not an over-emphasis placed on the health hazard involved in uranium production, little trouble can be expected from the personnel."[15]

Taverner defended his recommendations but lost the battle to Basil Schonland, South Africa's most prominent physicist, who had played an important role in launching South African uranium exports, had worked closely with atomic scientists in Britain, and knew their facilities well.[16] Schonland insisted that "there were no mysterious rays associated with the production of uranium" and that "radiation from the spillage of the liquors handled in the uranium plants would be innocuous."[17] His judgment carried considerable authority, enabling Chamber officials to insist that formal precautions should wait while the mining industry sent its own representative to visit overseas uranium plants.

In 1952, L. S. Williams, chief medical officer for the Goldfields mining company, undertook a visit to US uranium plants. Williams did seem impressed by the distinctive dangers posed by radioactivity, noting that it could take "twenty years or more to produce any evidence of radiation toxicity." He recommended ventilation, protective clothing, and (following the example of US plants), monitoring workers' hands and feet for radioactive contamination.[18] But Williams kept the Chamber happy by rejecting American proscriptions on eating, drinking, or smoking in the workplace. Periodic urine tests, he asserted, would suffice to monitor uranium ingestion without interrupting work flow or cutting into profits.

Armed with Williams's report, the Chamber reached an accommodation with the Government Mining Engineer (which was charged with regulating the mining industry) to postpone formal regulation. Instead, a newly constituted Health Committee at the Atomic Energy Board would keep an eye on things. In 1955, this committee helped industry develop a code of practice that duly avoided "over-stringent precautionary measures." The code did prescribe protective clothing and double change-houses.[19] Rather than prohibiting eating, drinking, or smoking, however, it recommended that "operators be instructed to wash their hands well" before engaging in these activities. The code called for "adequate ventilation," but did not specify figures for maximum permissible levels of any contaminants or toxins. Making no mention of radioactivity, it ignored Williams's suggestion to monitor gamma and alpha radiation. Extraction plants could simply tell workers that uranium was "an extremely poisonous material" to be handled "with extreme care."[20] The code prescribed monthly urine tests for workers exposed to the highest concentrations of uranium and dust, which included most workers in the uranium oxide plant. Ten percent of the remaining labor force should be randomly sampled every three months for urine testing.[21] Urine test results for "European" workers should be filed with their medical records but "should be regarded as extremely confidential [and] must not be shown to the employee concerned."[22]

The industry wanted to keep records confidential because it worried that these would lead "Europeans"—that is, unionized white workers—to cause trouble. In one instance in 1952, two men had attributed "strange symptoms" to "the effects of radiation."[23] The Minister of Mines himself had publicly dispelled those fears by asserting that tests had shown that "there was no trace of Radon gas" and "no signs of radio-activity of a dangerous level" in the plants. Since then, labor had apparently remained quiet on the subject.[24] In the 1950s, the industry faced growing (white) union concerns about the diagnosis, treatment, and compensation for silicosis and tuberculosis.[25] On no account could employers let concerns about radiation provide further fodder for contestation.

The 1955 code of practice for processing plants thus focused only on the chemical toxicity of uranium. In giving relatively little importance to radiation risks, the code minimized the nuclearity of jobs held by white workers at processing plants. In the next section, I show how radiation hazards at the plants disappeared even further during the course of the 1960s and how contamination absorbed by black workers was made invisible.

(Dis)counting Racialized Contamination at the Plants

Some uranium plant managers made a good-faith effort to comply with the minimalist code of practice. But many disliked the need for urine tests and double change-houses. Early compliance reports tended to be extremely cursory.[26] Irritated Chamber officials sternly reminded plant managers that if plants didn't persuasively document compliance, the Government Mining Engineer might institute formal regulations. The rebuke worked to prompt more detailed reporting, though not necessarily better health and safety.[27]

To fend off formal regulation, the Chamber's Dust and Ventilation Laboratory decided to conduct its own checks. In 1957 (a year before beginning the radon study mentioned earlier), S. R. Rabson began collecting dust samples in plants to check the effectiveness of control measures. He found "exceptionally high counts" at the Calcined Products plant, where uranium from all the other plants was further concentrated for export. Urinalyses confirmed "cases of high contamination" in which workers were somehow ingesting uranium. Wagging the stick of formalized inspections, Rabson persuaded the plant to improve its housekeeping and ventilation.[28]

Meanwhile, Rabson and his colleagues looked for patterns in the urine data from the seventeen extraction plants. They found that "people with beards appeared to have higher counts than those without." But the highest uranium counts of all were recorded in "natives" (i.e., black workers). Rabson attributed this to a lack of "personal cleanliness."[29] The vast racial disparities in working conditions had become so normalized that it apparently didn't occur to him that "personal cleanliness" was difficult to maintain when one towel was issued per three Native workers, "all natives of each shift … have a common 'clean' and 'dirty' locker for their clothes," or men had to launder their own work clothes using a courtyard water spigot.[30]

Anyone who fell ill had only himself to blame. Calcined Products became Nufcor in the late 1960s, and its operating manual from 1971 made this clear: "Nobody has ever been sick at Nufcor from breathing in uranium dust. But, we do know that some Bantu have been careless because we have found uranium in their urine. That is why we check your urine."[31] Black workers certainly felt the surveillance. One worker recollected white supervisors looking down at the shop floor:

> You can't believe what a good job it was, just to look on black people … Just watching the black people when they [were] working. If they go to toilet you have to write down, see the time, you write the time … Black people were working very hard, pushing some drums or everything like that … But white people just think up there, you know …, looking [at] the black people down there.[32]

There was nothing unusual about this division of labor under apartheid, of course. For these workers, urine tests seemed simply another humiliating surveillance tool.

No surprise, then, that "natives" would never see their test results. Nor would they benefit from "the same stringent medical examinations as applied to European employees." This was ostensibly because "natives were essentially migratory workers and, therefore, not subject to the same hazards as permanent

European employees."[33] At the conclusion of a contract, a black worker's medical record and fingerprints would be sent to the mining industry's recruiting agency. "If such a Native re-engaged for work" and "it was found that the fingerprints agreed with those of a Native already in the files, the previous medical record card would be extracted from the file and sent to the mine which had engaged him."[34]

Actual implementation of such a process, however, was impossible. Matching fingerprints was a logistical nightmare.[35] The 1955 code of practice failed to mention radiation, the plants failed to measure radioactivity, and the forms used by the recruiting agency did not have a specific rubric for radiation exposure.[36] Competing indexing systems made a mockery of meaningful record-keeping. Urine records were kept separate from medical records, making correlations impossible.[37] The medical records didn't have a specific rubric for uranium exposure any more than for radiation. Recruitment clerks did not appear to have the training required to interpret notations about kidney damage as evidence of uranium exposure or "radiation history." Sometimes, in fact, they couldn't even tell which records corresponded to which workers.[38] In 1959, one medical advisor complained that "Native employees are designated only by company numbers and on the discharge of any of these Natives, his number is transferred to a new entrant—consequently subsequent samples may be shown against the original worker who no longer works in the plant."[39]

The claim that black workers' uranium-related health histories were being reliably recorded represented, at best, a control fantasy. As one official noted in 2004, "We now have a system where . . . we should be able to go back about ten years. Before that, it's very tenuous—there may be some records somewhere, but . . .. Let me put it this way. If some worker, somebody who had worked there in 1970 came and said, 'I've got . . . problems because of an overdose of uranium . . .' We'd really struggle to find any documentation to refute it."[40]

Once the initial challenge of data collection and interpretation gave way to routine practice, interest waned, especially after Rabson died in 1969. By 1972 the mining industry's insurance arm began to wonder, "What is done rising from all this effort and information? Do we need it?" Surely the Chamber felt "satisfied that the safety precautions in force in the industry are perfectly adequate, and that the time has come to put an end to the medical examinations and urine checks."[41] Before moving to eliminate the health surveillance program, however, the Chamber generated urine count graphs for white and black workers denoted respectively as "skilled" and "unskilled." Levels were "satisfactorily low," experts proclaimed, indicating that the two curves had roughly the same shape. No one commented that the relative scales of the two graphs differed substantially, clearly demonstrating that a larger percentage of "unskilled" workers had high uranium concentrations.[42]

The graphs, furthermore, reflected only urine counts. The separation of urine test results from medical records made it impossible to determine whether workers had suffered other damage from their uranium exposure.

Nevertheless, the Chamber's medical superintendent asserted that any kidney damage he'd detected "appears to have been completely unrelated to the level of uranium excretion in the urine" and that "clinical and radiological examination of the lungs has not shown any particular pattern which might be attributed to the inhalation of acid mists or of uranium dust. Neither was there any detectable radiological change in the lungs which could be related to ionising radiation."[43] He concluded that in the absence of "incriminating" information, the testing program could be reduced or eliminated. Industry experts convinced themselves that by treating uranium as a purely toxicological hazard, processing plants offered sufficiently safe working environments for blacks and whites alike.

Let us now return to the mines.

Making Radon Visible in the Mines

In 1969, the South African Atomic Energy Board (AEB) established a licensing branch to develop safety standards for the nuclear power plants that would soon be built. The licensing branch was a small division, initially staffed by British and German scientists. Delays in reactor construction made it increasingly difficult to do much work on safety protocols, so the staff decided to keep busy by investigating other components of the nuclear program. The team quickly determined that no part of the system—from the AEB's research facilities to the uranium mines and plants—was subject to inspection and licensing.

British-born scientist Phil Metcalf took on the investigation of safety standards in uranium mining, milling, and conversion. He quickly realized that South Africa had been producing uranium for over twenty years with no formal regulation of hazards. In the mid-1970s he traveled overseas to learn about international regulations and monitoring and returned to South Africa full of ideas. South African practices, he noted, did not meet North American or Australian standards in several respects. There were no inspection procedures. There was no "competent" radiological protection staff or monitoring in the plants or the mines. And "the keeping of dose and health registers [was] not in line with normal practice."[44] But Metcalf's early—and, by his own admission, somewhat naïve—attempts to implement change came to naught.[45]

In 1979, the licensing branch persuaded Ampie Roux, the AEB's powerful president, to write Secretary for Mines W. P. Viljoen about radiation exposure in the mines. Roux, however, did not seem committed to strong AEB oversight of mining. He maintained that the nuclearity of hazards increased linearly as uranium traveled from mine to mill to conversion to enrichment to reactor. "The intrinsic risk of nuclear damage associated with the early part of the nuclear fuel cycle," he wrote, "increases progressively from the ore mining stage onwards through ore beneficiation to the production of U_3O_8."[46] This sentence could have caused US epidemiologists, French health physicists, and Metcalf himself to gasp in dismay. By 1979, international consensus was that radon exposure in mines posed an even greater risk to workers than radiation exposure in processing plants.[47] But Roux reflected the South African consensus that occluded radon risk in mines. Many South African experts, like Roux, believed that nuclear risk—being quintessentially modern—primarily threatened white technicians and scientists, not mineworkers (whether white or black).

Roux reassured Viljoen that he understood the "sensitive" nature of "the question of possible radiation induced injuries" and potential for creating labor unrest. Any form of regulation or control required "circumspection so as not to cause alarm or provoke other unwarranted adverse reaction within the industry." The AEB, Roux insisted, wanted to do only "the minimum necessary consistent with its statutory obligation." Following "proper procedures," he concluded soothingly, would probably lead to the exemption of mines from nuclear licensing.[48]

Roux's sympathetic stance notwithstanding, Viljoen must have found the letter's timing unpropitious. Labor tensions had been building throughout the 1970s. The withdrawal of Malawian workers from the labor pool in 1974 prompted mining houses to recruit more labor from within South Africa. Faction fights were on the rise, partly as a result of the arrival of new ethnic groups but also in response to changes in job grading that dramatically increased wages for just some black miners. To address projected shortages in skilled labor and dissatisfaction among black workers, some mining houses had begun to push for the elimination of the color bar and the legalization of black unions. The white Mine Workers Union strongly opposed such measures, but in 1977 the government created the Wiehahn commission, which recommended the end of the color bar and the legal recognition of black trade unions. Just weeks before Roux's letter, the white union had launched a strike to protest these recommendations.

Viljoen feared that implementing radon controls might lead the white union to press for "radiation induced disease compensation."[49] Reluctantly, he agreed to a meeting between the AEB licensing branch and the Government Mining Engineer to discuss the control of radiation hazards in the mines. But there were no further meetings.[50] Shaun Guy, another British scientist who worked for the licensing branch, later recalled how the mining industry argued that "there was no hazard, no indication of hazard." Guy added that "because the licensing branch didn't have access to [radon] studies at the time ... they couldn't come at them with a piece of paper and say, hey, this has been measured, this is what we calculate these people get if they work 2000 hours and something must be done about it."[51] Without data, the power disparity between the industry and the licensing branch was too large to overcome.

As apartheid violence intensified and states of emergency multiplied, Guy, Metcalf, and their colleagues stepped up their own battle to regulate the mines. Data would offer the best weapons. Guy knew that South African data existed: "I went through the [AEB] 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."[52] The Chamber never yielded its secrets, but the Government Mining Engineer's office did. Guy found a hoard of documents, including Chamber correspondence,that revealed clear problems with radon levels.

Buried among these documents were Rabson's results from the early 1960s, complete with raw data showing high peaks in radon levels. Following Rabson's death, the Government Mining Engineer had asked the Chamber to conduct another radon survey in 1969–1970, which found "only two" mines with high levels. That confidential report had estimated that some 180 "skilled" and 1600 "unskilled" workers had been "exposed to concentrations above the accepted tolerance level." (Because South Africa had no official standard in 1970, the report used the much-contested US limit as the "accepted tolerance level.") The percentage game rendered this into a perfectly acceptable result, as the number of over-exposed workers represented just one percent of the workforce at the surveyed mines.[53] Another study had concluded that "the death rate from lung cancer among White South African miners has not been increased by radon exposure" and that "although this investigation was undertaken as a pilot study, it appears that no improved results would be obtained by increasing the sample size."[54] A common South African refrain: No problems detected, no further study needed.

Shaun Guy, however, found numerous problems with these radon studies. For example, one study 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."[55] Yet Chamber officials had measured actual radiation levels in only about ten percent of the mines. And as Guy quickly determined, 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. Guy explained that

> 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.[56]

Digging through data from the 1950s and 1960s, Guy saw many instances of substantial radon build-up in working shafts, some reaching ten times international recommendations for dose limits.[57]

These data alone might have justified regulatory measures, but the industry was not about to cave in to a small group of foreign upstarts relying on old data.

If anything, argued the Chamber, nuclear regulation of mines seemed less justified than ever, because South African uranium production had slumped by the mid-1980s.

Guy and Metcalf weren't ready to give up. Proving that "hot spots" still existed, however, required new data. Accompanied by two inspectors from the Government Mining Engineer, Guy and Metcalf met in 1986 with the manager at West Rand, the mine where Rabson had registered the highest radon levels in the 1960s. They slyly proposed to use West Rand as a "model facility with regard to testing survey methods." Initially hesitant, the manager 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." At that time, neither white nor black workers knew about radon.[58]

The preliminary West Rand survey showed radon levels two to five times the International Commission on Radiological Protection (ICRP) limits. The licensing branch expressed concern that "workers appear to have been routinely exposed at these and higher levels for the last 30 years."[59] Backed by these data and the Government Mining Engineer (GME), Guy and his colleagues carried out extensive surveys of many Rand mines, an arduous task both technologically and socially. Calibration became a major bone of contention because instruments used by the mines gave readings that diverged widely from those used by the licensing branch. When Guy descended into the shafts without the protection of a GME inspector, he was subject to harassment by managers, foremen, and white workers who worried that regulation would put them out of their jobs.[60] When all was said and done, however, the survey results showed systemically high radon levels.

Making Mine Shafts Nuclear

Obtaining data was only the first step toward regulation. Battles continued while the institutions of apartheid began to crumble in the late 1980s. All manner of national laws were being rewritten, including the Nuclear Energy Act. In 1988 the licensing branch obtained institutional independence and renamed itself the Council for Nuclear Safety. The new body was tasked with licensing all nuclear installations as well as "sites and activities involving radioactive materials." As far as Guy, Metcalf, and others were concerned, they now had purview not just over uranium-producing mine shafts, but also over any mines that had significant radon levels.

The prospect of the new council having such broad regulatory scope alarmed the mining industry, which continued to fight throughout the 1990s against designating mine shafts as "nuclear" workplaces subject to licensing. Industry officials reiterated their arguments about the absence of adequate data, the ambiguities of nuclearity, and the peculiarity of South African conditions. The Chamber of Mines, for example, protested that the wording of existing South African legislation was ambiguous: The legal definition of "nuclear hazard material" included uranium or "any radio-active daughter product thereof," but the legal definition of a "nuclear installation" specifically excluded "any installation, plant or structure which is situated at any mine or works." The Chamber wanted the Government Mining Engineer (rather the Council for Nuclear Safety) to regulate radiation levels in mines, claiming that this approach was more "in line with international practice."[61]

"International practice" was a double-edged sword, however. Regulatory approaches varied by country. The Chamber itself rejected certain international standards as unfeasible under "South African conditions," an argument that it had long made with respect to other occupational hazards.[62] Personal radon dosimetry (which had become standard in France by 1990) "could not necessarily be adopted in the South African mining industry because of the large numbers of employees involved."[63] The new radiation monitoring procedures, Chamber officials insisted, were "inappropriate for South African mines" because they were "too comprehensive." South Africa, they argued, lacked the equipment and expertise required to enact such recommendations uniformly. This time around, however, the Council of Nuclear Safety held on to its authority.

Producing nuclearity entailed significant time and start-up costs, precisely because nuclearity was distributed among instruments, experts, data, standards, and legislation. The Council invited IAEA experts to South Africa to offer training and advice on radiological protection. It established technical specifications for dosimeters and reporting requirements. It designed protocols for surveying radiation at each mine. The surveys themselves could take from three months to two years to conduct. All the while, industry complained: The measures cost too much; the Council didn't provide enough consultants; its experts were autocratic, disdainful, and unreasonable; they failed to appreciate the complexities of ventilation; they took the side of labor.[64]

Legitimacy through Internationalism

The ongoing struggle between the CNS and the mining industry over the terms of regulation spilled out into the international arena. In 1990, the International Commission for Radiological Protection recommended a sixty percent reduction in the occupational dose limits. This new ICRP recommendation caused acute concern among mine operators around the world. What exactly did the new number imply for radon exposure and mining in general? The International Atomic Energy Agency convened meetings to study the question. The Council for Nuclear Safety and the mining industry both sent representatives, each hoping to influence international standards and gain support for their domestic positions.

In these meetings, Chamber experts found to their delight that colleagues elsewhere had already elaborated extensive arguments against lower radiation limits. Many of these arguments could readily apply to South Africa: Nature was varied and unpredictable; the ICRP overestimated how long miners would work underground over their lifespan; the cost of stringent radiation protection was disproportionately high and would jeopardize the mitigation of other, more immediate (and conventional) hazards. The mining industry claimed that ICRP recommendations dealt a particularly strong economic blow to third world countries that depended on mining.[65]

Chamber experts particularly liked this last line of reasoning, which seemed tailor-made for South Africa. The cost of implementing ICRP revisions, they insisted, would incur serious financial losses (up to forty-three percent) and threaten the jobs of some 90,000 workers, who in turn represented "the only means of support for nearly one million people throughout the sub-continent."[66] In international debates over how to implement ICRP limits, the mere act of quantification garnered attention. As one participant reported, "South Africa was the only country for which any attempt had been made to quantify the social-economic impact and this was recognized as an important contribution … *despite the exercise being necessarily a little speculative at this stage*."[67]

Although the South African numbers were pulled out of thin air, industry experts used them to argue that international safety standards should formally incorporate "flexibility" clauses. These would specifically allow mining operations in third world nations to exceed ICRP limits under certain circumstances. Regulatory experts, including Phil Metcalf from the Council for Nuclear Safety (CNS), opposed such flexibility. Among other things, they argued, it was impractical (even impossible) to keep consistent radiation exposure records over the course of an individual's lifetime—especially in "third world" countries. Without accurate records, the best way to control exposure was to keep workplace doses low. Regulatory experts pointed out that the mining industry around the world had a history of "whining" about regulation: Its appeals for flexibility were simply more of the same. Finally, industry experts liked to cite a clause in ICRP recommendations that allowed for national social and economic differences in how regulations were implemented. But Metcalf and other regulatory experts argued that this clause was not meant to confer sole power onto companies, governments, or even regulators. Labor unions should also have a voice, since they represented the people subjected to radiation exposure.[68]

In 1993 experts at these international meetings finally reached a compromise. "Special circumstances" could exist, but these had to be clearly limited in duration. National regulators could make exceptions to dose limitations, but exemptions should be granted only after regulators had consulted *both* employers and workers.[69] International consensus thus came down in favor of anointing national regulators as the ultimate arbiters of radiation exposure limits. In South Africa, too, regulators acquired greater formal authority. A 1993 amendment to the Nuclear Energy Act gave the CNS power to license gold mines and other installations where radioactivity levels reached a certain threshold.

Nuclear Regulation

South Africa's transition to democracy provided the occasion for a large-scale inquiry into safety and health in the mining industry. For five weeks in mid-1994, the state-appointed Leon Commission held hearings that covered the full range of health and safety hazards in the mining industry, gathering testimony from unions, the Chamber, the Government Mining Engineer, the Council for Nuclear Safety, and others. The subsequent report clearly belied mining industry claims concerning adequate ventilation, finding that dust levels had remained high for decades. Although radon and radiation hazards had occupied only a small part of the proceedings, the Leon Commission's final report used radiation in mines as the paradigmatic example of South African failures to conduct solid research and to engage in adequate monitoring, deploring the lack of evidence on radiation levels.

The evidence that did exist suggested that in the mid-1990s, at least 10,000 current mineworkers were exposed to radiation levels above the ICRP's recommended limits. "On average," the report continued, "the 269,000 South African miners employed underground are exposed to ten times as much ionising radiation as medical staff (attributable to their job), three times the average background level to which we are all exposed, and twice the level entailed in working in the nuclear fuel cycle" (the latter presumably referring to the post-mine part of the cycle). The matter required "urgent attention" by qualified experts, not by "ad hoc groups or by inexperienced research workers."[70] The Leon Commission rejected the Chamber's recommendation that radiation regulation should fall to the Government Mining Engineer. Instead, it endorsed the National Union of Mineworkers' position: The Council for Nuclear Safety should continue its oversight.[71]

Clashes over nuclearity per se resumed where the Leon Commission left off. The 1994 elections that brought Nelson Mandela and the African National Congress to power offered renewed opportunities to dispute the nature of nuclear things. All manner of laws were being rewritten. Once again, nuclear legislation came up for debate.

During the course of these negotiations, the Council for Nuclear Safety sought even greater regulatory autonomy.[72] The mining industry renewed its opposition to this plan, this time suggesting that radiation protection fall under the purview of the Department of Health. Radon, the Chamber contended, was "essentially a health issue and not a nuclear energy issue."[73] Brazenly invoking "South Africa's transition to full democracy," the mining industry insisted that nuclear regulation of mines would impede economic and social development in the New South Africa. [74] The Chamber unblushingly accused the Council of being a "white, male organization" with an inadequate understanding of development challenges.[75] Once again, however, the Chamber's strategies failed—at least on paper. In 1999, the revised Nuclear Energy Act remade the Council for Nuclear Safety into the fully independent National Nuclear Regulator (NNR), cementing its authority to regulate radiation in mines.

By this point, regulatory experts had developed a reasonably good working relationship with the black-led (and, in the post-apartheid era, fairly powerful) National Union of Mineworkers (NUM). Building trust with labor had taken time, not the least because mine managers had long spread rumors that the regulators wanted to shut down the mines and take away jobs. At one mine with high radon levels, regulatory experts had eventually circumvented management altogether and offered a radiation seminar directly to workers. This broke the ice and led to recurring exchanges between NUM representatives and regulatory experts.[76]

Nevertheless, as union official Derek Elbrecht told me in a 2004 interview, the NUM still felt that it needed a regulatory agency "with more teeth—you know, to bite the industry when they go wrong." And industry continued to pit the union against the regulator. "Management actually used the workforce to pressurize the regulator not to close down the shafts" if workers absorbed excess radiation doses, explained Elbrecht. So "the dilemma for us as a union is in how … we manage that situation." Some of the union's health and safety officers would have liked to develop independent expertise in radiation exposure—for example, via a task force such as the one they'd set up for silicosis. But, officials explained ruefully, "the union does not have the resources to fund that kind of research." Turnover in union leadership also posed a challenge, given the amount of time required to get up to speed on matters of radiation exposure. The union and the NNR continued to conduct information sessions on radiation for workers, but these were limited in number because neither organization had sufficient personnel. One union official estimated that even in 2004, fewer than five percent of workers exposed to radiation knew what it was.

Measurement posed a perpetual problem. Down in the shafts, only team leaders carried a dosimeter. But their doses were not representative of those absorbed by other workers: The team leader normally stood "two, three, five metres away," Elbrecht explained, "and he moves around in a bigger circle … than the workers at the point of production." Even under the new regulatory regime, therefore, individual workers did not have a reliable record of the doses they'd absorbed. And even though mineworkers could (thanks to Leon Commission recommendations) refuse dangerous duty, Elbrecht noted that workers did not see radiation as dangerous, in part because they couldn't see it at all. Finally, even though the central union leadership tried its best to attend to radiation issues, local branches didn't see it as a "stand-alone issue. It's not seen as the major cause to certain diseases [such as silicosis]," Elbrecht explained. It certainly didn't command the attention required by Human Immunodeficiency Virus (HIV), which by the end of the century had become the most urgent and overwhelming health issue for mineworkers—and many others—in South Africa.[77]

Conclusion

Changes have certainly taken place in the South African mining industry's approach to radiation. Working through the Chamber of Mines, the industry has invested several million rand in cleanup operations for tailings dumps and contaminated scrap. Mines now have radiation protection officers, instruments, and procedures. Instead of denying the danger, AngloGold, the largest remaining mining house, now advertises its radiation monitoring program as exemplary of the company's commitment to occupational health and safety.[78] Yet much remains unspoken and unknown. The National Nuclear Regulator itself, meanwhile, has come under sharp criticism for lack of transparency and for appointing an industry insider to head the agency.[79]

As important as it is to make radiation in mining perceptible and subject to regulation, these achievements do not guarantee visibility of exposures to the miners themselves. Retired mineworkers—whether white or black, South African or foreign—have no way to correlate disease with work history. In addition to accurate dosimetry, such correlations require medical data far beyond the capacity of South Africa's current health system, overburdened as it is by other occupational diseases and the devastating HIV epidemic. They also require coordination with similarly overburdened medical systems in Lesotho, Mozambique, and other "labor sending areas" where thousands of former mineworkers now rely on their families for care.

In 2004 the first lawsuit by a black mineworker against a South African gold mining company demanded compensation for silicosis. Filed by the British lawyer Richard Meeran, the suit followed his successful litigation against asbestos companies. The case was still in litigation in 2009, when it was estimated that over half a million current and former miners might be eligible for silicosis compensation.[80] It's likely that a significant number of these men were also exposed to high radon levels—probably more than the 10,000 workers estimated by the Leon Commission. But it will never be possible to reconstruct their full radiation history.

The work of maintaining invisibility, like that of creating nuclearity, has long-lived consequences.

NOTES

I thank Keith Breckenridge, Paul Edwards, Mae Ngai, Molly Nolan, and Jay Slagle for their comments on earlier drafts. This article is drawn from Gabrielle Hecht, *Being Nuclear: Africans and the Global Uranium Trade* (2012).

1. See for example Itty Abraham, *The Making of the Indian Atomic Bomb: Science, Secrecy and the Postcolonial State* (1998); Gabrielle Hecht, *The Radiance of France: Nuclear Power and National Identity after World War II* (new edition 2009).

2. Gabrielle Hecht, "Africa and the Nuclear World: Labor, Occupational Health, and the Transnational Production of Uranium," *Comparative Studies in Society and History*, 51 (2009):896–926.

3. See for example Randall M. Packard, *White Plague, Black Labor: Tuberculosis and the Political Economy of Health and Disease in South Africa* (1989); Jock McCulloch, *Asbestos Blues Asbestos Blues: Labour, Capital, Physicians & the State in South Africa* (2002). Jock McCulloch, "Counting the Cost: Gold Mining and Occupational Disease in Contemporary South Africa," *African Affairs* 108:561–602.

4. For other instances of historical ontologies, see Ian Hacking, *Historical Ontology* (2002); Christopher Sellers, "The Artificial Nature of Fluoridated Water: Between Nations, Knowledge, and Material Flows," in *Landscapes of Exposure: Knowledge and Illness in Modern Environments, Osiris* 19, ed. Gregg Mitman, Michelle Murphy, and Christopher Sellers *eds.,*(2004):182–200; Christopher Sellers, *Hazards of the Job: From Industrial Disease to Environmental Health Science* (University of North Carolina Press, 1997).

5. For an introduction to one strand of STS scholarship on the distribution of ontology and agency into things, see Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (2005).

6. K. Breckenridge, "Verwoerd's Bureau of Proof: Total Information in the Making of Apartheid," *History Workshop Journal,* 29 (2005): 83–108; Paul N. Edwards and Gabrielle Hecht, "History and the Technopolitics of Identity: The Case of Apartheid South Africa," *Journal of Southern African Studies* 36 (September 2010):619–639.

7. See T. Borstelmann, *Apartheid's Reluctant Uncle: The United States and Southern Africa in the Early Cold War* (New York, 1993); M. Gowing, *Independence and Deterrence: Britain and Atomic Energy, 1945–1952* (London, 1974); J.E. Helmreich, *Gathering Rare Ores: The Diplomacy of Uranium Acquisition, 1943–1954* (Princeton, 1986).

8. Elana Janson, "The Development of the Uranium and Nuclear Industry in South Africa, 1945–1970: A Historical Study," (Ph.D. dissertation, University of Stellenbosch, 1995), 84–85.

9. RSJ du Toit, "Experience in the control of radiation at a small thorium mine," in International Atomic Energy Agency, International Labour Organisation, and World Health Organization. *Radiological health and safety in mining and milling of nuclear materials: proceedings* (IAEA, 1964), quotes on 205 *passim.*

10. S. R. Rabson, "Radon and Radioactivity in Mines: Summary," November 30, 1962; S. R. Rabson, "Survey of Radon and Radon Daughters: Vogelstruisbult G.M. Co. Ltd.," September 30, 1962; P. Buckley-Jones, "Survey of Radon and Radon Daughters: Luipaardsvlei Gold Mining Co. Ltd.," November 30, 1962. Private papers of Shaun Guy (henceforth SG papers).

11. W. S. Rapson, Research Advisor to Mr. Gibbs, Government Mining Engineer, October 8, 1964. SG papers.

12. Rabson's project shifted to the jurisdiction of the Medical Panel at that point. Circular No. 19/63, "Record of Meeting of the Radioactivity Panel held on Wednesday, 19th December 1963 in the Chamber of Mines Building," December 30, 1963. SG papers.

13. "A Precis of 'Memorandum Regarding Health Hazards Relating to the Operation of Uranium Leach Plants to be Established on Certain of the Witwatersrand Gold Mines' (by Professor L. Taverner)," September 11, 1951. Chamber of Mines archives (henceforth CoM archives).

14. E. T. Pinkney, "Some Comments on Professor Taverner's Memorandum Relating to Health Hazards," September 11, 1951; Transvaal Chamber of Mines, "Report of Meeting held in the Office of the Government Mining Engineer on Wednesday, 3rd October, 1951, at 2:30 pm," October 8, 1951; R. R. Porter, "Review of the Toxicology of Uranium as Applied to Rand Ores," October 3, 1951. CoM archives.

15. Ibid.

16. Brian Austin, *Schonland: Scientist and Soldier* (2001); Saul Dubow, *A Commonwealth of Knowledge: Science, Sensibility, and White South Africa 1820–2000* (2002).

17. Transvaal Chamber of Mines, "Report of Meeting held in the Office of the Government Mining Engineer on Wednesday, 3rd October, 1951, at 2:30 pm," October 8, 1951. CoM archives.

18. L. S.Williams, "Report on a Study of Health Hazards in the Production and Handling of Uranium Compounds in England and America," April 30, 1952. CoM archives.

19. GMEU 9/11/1, "Minutes of the First Meeting of the Health Committee of the Atomic Energy Board, held in the Office of the Government Mining Engineer on Tuesday, the 6th July, 1954, at 10 a.m." NASA: GES 2175 ref 179/133.

20. Hartebeestfontein Gold Mine, "Safety in the Uranium Plant," n.d. but ca. 1956–57. CoM archives.

21. "Safety Practices in Uranium Plants: Code of Practice," 20 May 1955. CoM archives.

22. Ibid.

23. The Rand Mutual Assurance Company, Memorandum to the General Manager, Chamber of Mines of South Africa, "Medical Examination of Employees in the Uranium Industry," August 10, 1972. CoM archives.

24. "No Radio-Activity Danger in Uranium Mines—Viljoen," extract from *Rand Daily Mail*, October 9, 1952. CoM archives.

25. McCulloch, "Counting the Cost."

26. Manager, Luipaards Vlei Estate and Gold Mining Company to General Manager, Transvaal and OFS Chamber of Mines, January 14, 1957. CoM archives.

27. Reports are far too numerous to cite individually—collected throughout uranium plant records for 1956 and 1957 in CoM archives.

28. Director, DVL to Manager, Calcined Products, March 14, 1957. CoM archives.

29. Circular no. 19/63, "Record of Meeting of the Radioactivity Panel held on Wednesday, 19th December 1963, in the Chamber of Mines Building," December 30, 1963. SG papers.

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31. NUFCOR, "Health and Safety: Respirators or Dust Masks," WLL/MK, March 4, 1971. NUFCOR archives.

32. Interview with Edwin Pheeha, April 29, 2004, Westonaria, South Africa.

33. GMEU 9/11/1, "Minutes of the First Meeting of the Health Committee of the Atomic Energy Board, held in the Office of the Government Mining Engineer on Tuesday, the 6th July, 1954, at 10 a.m." NASA: GES 2175 ref 179/133.

34. Transvaal and Orange Free State Chamber of Mines, "Explanatory Memorandum: Safety Practices in Uranium Plants: Code of Practice," June 6, 1955.

35. Breckenridge, "Verwoerd's Bureau." This argument is extended in Edwards and Hecht, "History and the Technopolitics of Identity."

36. McCulloch, "Counting the Cost."

37. The Rand Mutual Assurance Company, Memorandum to the General Manager, Chamber of Mines of South Africa, "Medical Examination of Employees in the Uranium Industry," August 10, 1972; Statistician, Memorandum to G. H. Grange Esq., Technical Adviser, Sept. 20, 1972. CoM archives.

38. Transvaal & Orange Free State Chamber of Mines, Employees in Uranium Plants, Medical Record (blank form, no date), CoM archives.

39. R. A. Mathews, Medical Advisor, Transvaal and Orange Free State Chamber of Mines, Social Services Department, A/18/4, "Memorandum for the General Manager," August 6, 1959. CoM archives.

40. Confidential interview, Johannesburg metropolitan area, South Africa.

41. The Rand Mutual Assurance Company, Memorandum to the General Manager, Chamber of Mines of South Africa, "Medical examination of Employees in the Uranium Industry," August 10, 1972. CoM archives.

42. Statistician, Memorandum to G. H. Grange Esq., Technical Adviser, Sept 20, 1972. CoM archives.

43. C. C. Freed, Medical Superintendent, Memorandum to Manager, The Rand Mutual Assurance Company Ltd., "Uranium Examinations," 6 November 1972. CoM archives.

44. LB/35/6/10, J. O. Tattersall to J. W. L. de Villiers, July 18, 1980, re: Chamber of Mines Code of Practice on Safety. SG papers.

45. Telephone interview with Phil Metcalf (then working at the IAEA in Vienna), June 17, 2004.

46. A. J. A. Roux to W. P. Viljoen, May 16, 1979, internal ref. LB/35/6/10. SG papers

47. Gabrielle Hecht, *Being Nuclear: Africans and the Global Uranium Trade* (2012).

48. A. J. A. Roux to W. P. Viljoen, May 16, 1979, internal ref. LB/35/6/10. SG papers.

49. S. Guy, "A review of files at the Government Mining Engineer concerning radiation in mines and works," August 26, 1986, 3. SG papers.

50. Ibid., 7.

51. Interview with Shaun Guy, Johannesburg, South Africa, July 12, 2004.

52. Ibid.

53. J. D. Grieg, R. Rolle, V. B. Dods, B. G. Hampson and J. P. du Plessis, "Report on a survey of Radon and Radon-daughter concentrations in Twenty-Five Gold Mines," Research Report No. 36/70, October 1970. Goldfields archives.

54. J. K. Basson et al. "Lung Cancer and Exposure to Radon Daughters in South African Gold/Uranium Mines," Atomic Energy Board: PEL 209. Pelindaba, March 1971.

55. Ibid., 12.

56. Guy interview.

57. "Results of Radon Daughter Sampling in Bird Reef," West Rand Consolidated Mines, Ltd., Mine Office, West Rand, December 13, 1973. SG papers.

58. S. Guy, "Memorandum: Meeting at West Rand Consolidated with the Mine Manager, February 24, 1986." LB/35/6/10/8. SG papers.

59. AEC Licensing Branch, "Report of the Underground Survey for Radon Daughters at West Rand Consolidated Mine, March 5, 1986," p. 5. May 23, 1986, LB/35/1/13; LB/35/6/10/8.

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62. McCulloch, "Counting the Cost."

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67. D. Wymer, "Report on Two Meetings at the International Atomic Energy Agency (IAEA), Vienna, 7–18 December 1992," December 31, 1992. Emphasis added. CoM-ES archives.

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71. Ibid., 104.

72. Thomas Auf der Heyde, "South African Nuclear Policy Since 1993: Too Hot to Handle?" Paper presented at the National Nuclear Technology Conference, September 6–9, 1998, South Africa. CoM-ES archives.

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77. Elbrecht interivew.

78. AngloGold Ashanti Annual Report 2007—Report to Society. Accessed August 16, 2010 on http://www.anglogold.co.za/subwebs/informationforinvestors/reports07/reporttosociety07/radiation-SA.htm.

79. David Fig, "In the Dark: Seeking Information about South Africa's Nuclear Energy Programme," in *Paper Wars: Access to Information in South Africa*, ed. Kate Allen. (2009):56–87. Fig also discusses the struggle of Pelindaba workers to obtain radiation exposure information.

80. McCulloch, "Counting the Cost."