DISPARITIES IN WORK EXPOSURES, HEALTH, AND MORTALITY AT THE ALCOA ALUMINUM SMELTING FACILITY IN WEST BADIN, NORTH CAROLINA

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A dissertation submitted to the faculty at the University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Epidemiology in the Gillings School of Global Public Health.

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ABSTRACT

Elizabeth Sarah McClure: Disparities in Work Exposures, Health, and Mortality at the Alcoa Aluminum Smelting Facility in West Badin, North Carolina
(Under the direction of David Richardson)

Badin, North Carolina is the site of one of the nation's first aluminum smelting facilities, operated by Alcoa 1917-2007. Residences and jobs were racially segregated. The plant and its dumping sites are in West Badin, the Black side of town. The Concerned Citizens of West Badin formed in 2013 to advocate for remediation of contamination in their community. Since then, they have voiced concerns that the worst jobs in the plant were most frequently assigned to Black workers.

The first aim of this dissertation described differences in job characteristics by race and sex, using data from company records of workers employed at the Badin plant 1985-2007. Black males had the highest proportion of workers in high danger jobs at hire and persisting 20 years after hire. The second aim involved enumeration of a cohort of employees at the plant 1980-2007 from the United Steel Workers. We compared mortality rates in the cohort to North Carolina population rates using standardized mortality ratios, and mortality rates among ever pot room workers to those among never pot room workers using standardized rate ratios. All-cancer, bladder cancer, and mesothelioma were in excess. Workers in the pot room experienced higher all-cause and cancer-specific mortality rates than workers who never worked in the pot room.

Finally, the third aim critically evaluated race-based clinical metrics in occupational epidemiology. Workers' compensation for respiratory injury is determined by comparing raw

lung output to race-specific, algorithmically predicted capacities. By estimating compensation using race-corrected and uncorrected algorithms, we found that race-based clinical metrics result in Black workers being under compensated for lung impairment related to work exposures. This research serves as a starting point to addressing concerns about disparities in this group of former aluminum smelting workers. It may inform interventions to make departments equitably safe for workers.

To Steve.

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LIST OF ABBREVIATIONS

aSMR	Adjusted standardized mortality ratio
AMC	American Manufacturing Cohort
COPD	Chronic obstructive pulmonary disease
CCWB	Concerned Citizens of West Badin
CI	Confidence Interval
CRT	Critical Race Theory
dB	Decibels
DEG	Distinct exposure groups
FEV_1	Forced expiratory volume (in 1 second)
FVC	Forced vital capacity
HWSB	Healthy worker survivor bias
IRB	Institutional Review Board
IARC	International Agency for Research on Cancer
ICD	International Classification of Diseases
IQR	Interquartile range
JEM	Job-exposure matrix
LTAS	Life Table Analysis System
MN	Malignant neoplasm
NDI	National Death Index
NHANES	National Health and Nutrition Examination Survey
NIOCCS	National Industry and Occupation Computerized Coding System

NIOSH	National Institute for Occupational Safety and Health
NC	North Carolina
NCEJN	North Carolina Environmental Justice Network
NC OSHERC	North Carolina Occupational Safety and Health Education Research Center
Obs	Observed
OSHA	Occupational Safety and Health Administration
PM	Particulate matter
PPE	Personal protective equipment
PCBs	Polychlorinated biphenyls
PAHs	Polycyclic aromatic hydrocarbons
PHCRP	Publich Health Critical Race Practice
SSN	Social security number
SES	Socioeconomic status
SMR	Standardized mortality ratio
SRR	Standardized rate ratio
TPM	Total particulate matter
US	United States
USCG	United States Coast Guard
US EPA	United States Environmental Protection Agency
USW	United Steelworkers

SPECIFIC AIMS

Smelting poses a wide range of occupational hazards including exposure to heat, chemicals, and heavy metals. Aluminum smelting involves an electrolytic process from bauxite ore, generating a group of airborne chemical vapors and dusts which can be absorbed through inhalation or contact with the skin [1]. Their constituents include several known carcinogenic agents [2]. Badin, North Carolina was the site of one of the nation's first aluminum smelting facilities, operated by Alcoa from 1917 through 2007 [3]. When it was established by Alcoa, Badin was residentially segregated by race, and Highway 740 remains a physical barrier between the residing communities, with East Badin being majority white and West Badin largely Black [4]. The closed facility as well as its dumping sites are located in West Badin. The Concerned Citizens of West Badin formed in 2013 to advocate for remediation of contamination from the now closed Alcoa aluminum smelting facility in their community [5]. In interviews, former workers at the facility have voiced concerns regarding imbalances in occupational exposures by race and gender, as well as a high incidence of cancer in Badin.

Communities of color are disproportionately burdened by industrial pollution throughout the US [6,7]; and, at this facility, employees report that the least desirable jobs involved work in the pot rooms and were most frequently assigned to Black workers. Workplaces in the United States tend to be segregated by race and sex, leading to differences in jobs, responsibilities, pay, and exposure [8]. However, previous occupational cohort studies generally focused on white male industrial workers, with little empirical analyses of exposures among women and non-white

workers [8]. Further, no previous epidemiology studies examined disparate occupational exposures at Alcoa's Badin facility, or in the aluminum industry in general.

This dissertation aims to characterize differences in occupational exposures by race and gender, discuss the implications of these differences in shaping health disparities, and evaluate whether workers at the facility experienced excess mortality. It will serve as a starting point to addressing concerns about occupational disparities in this historical aluminum smelting cohort. It will further provide considerations for developing interventions to make departments uniformly safe for workers, regardless of race or gender. Work history and exposure information for Badin Alcoa workers employed between 1985 and 2007 was assembled from Alcoa's archives [9]; and work history and mortality information for hourly Badin Alcoa workers employed 1980-2001 was assembled from United Steel Workers (USW) records and the National Death Index (NDI).

Aim 1: Describe differences in job assignment and occupational exposures by race and gender. Using information on Badin Alcoa workers hired between 1985 and 2007, I:

Aim 1a. Assess whether baseline job assignment varies by race and gender.

Aim 1b. Given initial job assignment, assess whether expected job trajectory varies by race and gender.

Aim 1c. Characterize differences by race and gender in job characteristics across four domains—1) census-based prestige score, 2) worker-rated degree of danger, 3) job-exposure matrix-based particulate matter exposure, and 4) wage.

Aim 2: Characterize mortality among USW members at the Badin Alcoa facility relative to reference populations. Using information on Badin Alcoa workers hired between 1980 and 2007, I:

Aim 2a. Compare the age-, sex-, race-, and calendar period-standardized all-cause and cause-specific mortality rates among hourly, USW member, Badin Alcoa workers to reference rates for the general population of North Carolina using mortality ratios.

Aim 2b. Adjust for healthy worker survivor bias by comparing the age-, sex-, race-, and calendar period-standardized all-cancer, bladder cancer, respiratory cancer, and pleura/mesothelioma-specific mortality rates among hourly, USW member, Badin Alcoa workers to negative control reference rates in the same worker population using mortality ratios.

Aim 2c. Compare the age-, sex-, race-, and calendar period-standardized all-cause and cause-specific mortality rates of ever workers in the pot room to those of never workers in the pot room among hourly, USW member, Badin Alcoa workers using rate ratios.

Aim 3: Critically examine the use of race-based metrics in occupational epidemiology. Using a Critical Race Theory framework and simulation informed by North Carolina workers' compensation policies, I:

Aim 3a. Document and evaluate the discussion of race and gender differences in lung function and hearing loss in the occupational epidemiology scientific literature.

Aim 3b. Estimate the impact of race-based algorithm informed injury thresholds on workers' compensation for lung capacity impairment and hearing loss.

CHAPTER 1. BACKGROUND & SIGNIFICANCE

Theoretical and Conceptual Frameworks

Conceptual Model of Work and Health Disparities

While the literature examining determinants of health disparities is growing, it largely ignores the harms and benefits of work in its analyses [10]. Work is a source of income, social status, and access to healthcare, as jobs are the main source of health insurance in the United States (US) [11]. Similarly, despite the long history of job discrimination in the US [11–15], the large body of literature documenting the dangers of toxic work exposures in the aluminum smelting industry [2,16,17] has not included assessments of disparities by race and gender. I draw on Lipscomb et. al.'s "Conceptual Model of Work and Health Disparities" to inform my dissertation aims. Specifically, the aims focus on institutional interventions and policies rather than behaviors of individual workers. The aims assess how individuals are assigned to jobs with an awareness of how the community and broader economic structure influence the availability of jobs [11].

Ecosocial Theory

My approach is also informed by Nancy Krieger's Ecosocial Theory, from social epidemiology. Ecosocial Theory's core constructs include embodiment—noting that aluminum smelting workers, their families, and their communities biologically incorporate their social world into their bodies; pathways of embodiment—focusing on the increased toxic work hazards experienced by women and minority workers; the lifecourse—understanding the cumulative impact of such exposures and their influence on intergenerational embodiment of discriminatory

practices in and from the smelting facility; and accountability and agency—centering the questions and concerns of the Badin community. Ecosocial Theory also includes an explicit focus on the historical context shaping the current disparate conditions [10,18,19].

Critical Race Theory and Public Health Critical Race Praxis

I apply Critical Race Theory (CRT), a framework of anti-racist constructs and approaches to knowledge production developed by legal scholars of color [20], through Public Health Critical Race Practice (PHCRP), which is designed to relate CRT to health disparities research [21]. Linking with the aforementioned frameworks, I examine racism beyond the individual level, and measure its impacts at the institutional and policy levels [22].

The four foci of PHCRP inform my dissertation analyses. Focus 1 is on contemporary racialization and contemporary forms of racism, i.e. covert, ordinary, and systematic perpetuations of inequalities established through historic acts and policies of more overt racism (e.g. Jim Crow, redlining, etc.) [23–25]. I also consider the structural factors influencing the consideration of racism in existing occupational epidemiology research and literature (e.g. health research funding mechanisms, years of corporate control over research questions, etc.). Focus 2 is on knowledge production. I attempt to conduct analyses with an awareness that epidemiology's cumulative biases (including racial biases) are part of the evidence base. This drives an interest in the estimation of disparities rather than testing a hypothesis that racism had an impact on worker health. Focus 3 is about measurement. These dissertation aims attempt to operationalize racism-related variables and measure the impacts of racism in seemingly non-racial constructs. Focus 4 is action, which again is operationalized through the collaborative nature of this work and its objectives to directly benefit the affected community [21]. My primary collaborators on this project, the Concerned Citizens of West Badin (CCWB), first raised the

question motivating this research: were Black workers disproportionately exposed to job-related toxins and hazards that cause negative health outcomes [26]?

Environmental Justice

Finally, this dissertation draws on the work of Pavithra Vasudevan. She uses Cedric Robinson's term "racial capitalism," which places race centrally in the political, economic, and social system of capitalism [27], to describe the environmental justice concerns related to unequal burden of industrial toxicity in West Badin voiced by community members she interviewed. We are collaborating with the Concerned Citizens of West Badin (CCWB) and the North Carolina Environmental Justice Network (NCEJN) on a household survey to supplement my dissertation aims in an effort to validate community members' experiences, address their direct concerns in an open dialogue, and provide health research that is useful for environmental justice organizing.

We are also collaborating with the United Steel Workers (USW) for the third aim of this dissertation, with an appreciation for the historic and significant role of labor unions in the environmental justice movement [28]. Some CCWB members have expressed distrust of the USW local, and there is a dominant dialogue of a dying interest and effectiveness of unions in the US, starting in the 1980s. However, this dialogue ignores the aggressive tactics, including anti-union legislation, among southern states to appear more attractive to northern and international industries. It also ignores several substantial wins with respect to race and gender equity in wages and workplace safety, as well as continued, nearly unanimous worker support in more recent decades [11,15]. While maintaining a critical approach to assessing USW documentation, we value the partnership and its contributions to worker struggles in West Badin.

History of Aluminum Production in the United States

Aluminum is produced industrially in a three stage process from bauxite ore—mining, refining, and smelting. Each stage has vast energy input requirements and toxic outputs. Raw ore must usually be transported long distances (as over 60% of the world's bauxite is mined from four countries), and the cheapest method is often by ship. Alumina refining produces liquid waste which releases caustic soda, which has frequently been detected in the groundwater of surrounding facilities [29,30]. Finally, smelting releases dangerous heat as well as dusts and fumes, many of which are established carcinogens [2].

Because bauxite is very expensive to transport and smelting requires huge amounts of hydroelectric energy, most aluminum production has historically occurred in industrialized countries [29]. Aluminum's strength and light weight made it an attractive option for aviation, automobile, and weapon-related machinery and parts. The first major increase in its popularity and production occurred during World War I, and it peaked again during the Second World War to meet military demands. During both wars, Alcoa was the main producer of aluminum. Aluminum became a major driver of the United States' geopolitical dominance. The threat of German U-boat interference with the United States' bauxite supply influenced post-World War II policies to establish independence in aluminum production and expand the number of United States-based corporate producers [31].

The United States was the world's largest producer of aluminum for decades. In its peak, it produced over a third of the world's aluminum, with Alcoa acting as the United States' largest producer. The United States reached its highest absolute production level in 1980, when it produced 4.64 million tons of aluminum. Currently, the United States produces closer to 4% of the world's aluminum [32].

Existing Health Literature on Aluminum Smelting Work

Aluminum Smelting Occupational Exposures

Aluminum smelting is an electrolytic process on alumina, which is refined from bauxite ore. The alumina is dissolved in carbon-lined steel pots filled with molten baths using electric current from carbon anodes hanging above. The current maintains a temperature of 1,760-1,780° F. Once dissolved into a molten metal, the nearly pure aluminum is then formed into ingots or alloyed with other metal [29].

Aluminum smelting generates a group of airborne chemical vapors called coal tar pitch volatiles [1]. Coal tar pitch volatiles can be absorbed through inhalation or contact with the skin. Their chemical constituents are listed in Table 1.1 [2,30,33]. Polycyclic aromatic hydrocarbons (PAHs) have been most frequently studied in relation to cancer and most strictly monitored by industrial regulators [2]. Work exposure to coal tar pitch volatiles has also been quantified as the degree of exposure to benzene soluble materials, a marker that captures all particulate matter agents in the vapors [34,35]. More general measures of particulate matter have also been used [36–39].

Table 1.1 Potential Exposures in Aluminum Smelting Work

Alumina dust	Hydrogen chloride
Aluminum metal dust	Hydrogen fluoride
Aluminum fluoride	Polycyclic aromatic hydrocarbons
Ammonia	Magnesium dust/fume
Asbestos	Mercury
Beryllium dust	Nickel
Cadmium dust	Fluorides
Carbon monoxide	Lead
Chlorine gas	Ozone
Chromium	Phosgene
Coal tar pitch volatiles	Silica
Coke dust	Silica dust
Copper dust	Sulfur dioxide
Extreme heat	Trace elements (e.g. chromium, nickel)
Fibrous sodium aluminum tetrafluoride particles	Vanadium
High static magnetic fields	Welding fumes

Aluminum smelting workers experience a varying degree of toxic exposures and hazards. The job worked, and the tasks completed in each job, has a strong influence on workers' likelihood of exposure. For example, workers involved with pot room production are likely to have elevated exposure to coal tar pitch volatiles relative to maintenance workers who only enter pot rooms intermittently or supervisors [40]. Job exposure matrices are typically used to account for these variations in exposure [41].

Technological advances in smelting processes also lead to exposure variation over calendar time, as the magnitude of emissions produced by the smelting process depends on the approach. The two most common approaches are [1] the "Soderberg," method in which coke-pitch paste is fed into pots and baked, and [2] the "prebake" method, in which coke-pitch paste is baked into a solid in a separate carbon plant before use in the pots. Emissions are much higher when the Soderberg process is used [42], but the prebake method may increase risk of worker exposure to particulate matter [43]. Technological changes in production processes are sometimes evident in administrative records and included in occupational exposure modeling [44].

Changes in regulations, industrial hygiene practices, and screening requirements have also varied in aluminum smelting over the past several decades. In 1983, the Occupational Safety and Health Administration (OSHA) began requiring yearly audiometric surveillance among workers exposed to noise levels of 85 decibels (dB) or greater, with a threshold of a 10 dB decrease for reporting of work-related hearing loss [45]. In addition, the National Institute for Occupational Safety and Health (NIOSH), the United States Environmental Protection Agency (US EPA), and the United States Coast Guard (USCG) have established engineering (e.g. facility design, exhaust fans, etc.), workplace (e.g. personal protective equipment (PPE), isolation and cleaning of dusts, etc.), and administrative (e.g. designated work uniforms and shoes) controls to

limit the degree of worker and take-home exposure to specific agents, like beryllium and cadmium dusts, through inhalation, ingestion, and skin contact [46]. NIOSH also requires medical surveillance for intake of such agents. Some industrial hygiene practices and regulations were introduced as early as the 1970s [47].

Potential Impacts of Aluminum Smelting Work Exposures on Health

The International Agency for Research on Cancer (IARC) is an intergovernmental agency, a branch of the World Health Organization, which evaluates scientific evidence for agents' cancer risk for humans. They classify aluminum smelting occupational exposures in Group 1, indicating they find "*sufficient evidence of carcinogenicity* in humans" [48].

Documented evidence is strongest for aluminum smelting work exposures causing bladder cancer, followed by lung cancer [2]. Increased aluminum smelting occupational exposure has been correlated with several disease outcomes—including bladder cancer [16,33,44,49–51], lung cancer [33,52], central nervous system cancer [30,35,53], respiratory disease, cancer of the digestive system, Alzheimer disease, cerebrovascular disease, COPD [54], and other respiratory diseases [30,53,55,56]. Several studies have also reported associations between aluminum smelting work and cancer mortality [34,35,40,49,51,54,57,58]. Similar to cancer incidence studies, this literature provides the most support for an impact of aluminum smelting work on increased risk of bladder and lung cancer.

Aluminum smelting workers are also exposed to physical hazards, like heat and noise, and have been shown to experience a higher risk of injury [2,30,35,59–61]. Because of the potential for a broad range of hazards and toxic exposures, as well as limited chemical exposure measurement data, exposure is often characterized simply as employment in an aluminum smelting facility [36,62].

Lung function and hearing loss will be considered as health-related endpoints in Aim 2, as they have been identified in the scientific literature as key health concerns in relation to aluminum smelting work [55,56,59,60,62,63]. Respiratory illness (and compensation in relation to it) was mentioned by multiple former employees in conversations at Concerned Citizens of West Badin meetings. Further, hearing loss and lung function have been shown to vary by gender and class [56,64,65], are good approximations of the direct impacts of hazardous work environments [64,65], and have documented associations with further morbidity and declines in quality of life [52,60,66]. All-cause mortality, in addition to cancer mortality will be assessed in Aim 3, given the breadth of potential exposures and hazards. Further, mortality and years of life lost have been supported in conceptual frameworks for understanding the influence of work environment on health disparities [11,13].

Limitations of the Occupational Epidemiology on Aluminum Smelting

While occupational epidemiology of the aluminum industry has resulted in many successful, health promoting workplace interventions, it has limitations with regard to addressing health disparities. Nancy Krieger argues that dominant frameworks of epidemiology generally consider research on a smaller scale to be more rigorous (prioritizing internal validity), because of an implicit basis in biomedical frameworks. As a result, an inappropriate proportion of the research operates on the molecular scale without acknowledging processes at larger scales, like social and political contexts [10]. In this framework, race can be ignored by studying restricted, homogeneous samples—a method considered to increase scientific rigor by removing bias. Historically, occupational cohort studies have tended to focus on white male industrial workers, with little empirical analyses of exposures among women or non-white workers [8]. Additionally,

VanderWeele and Robinson point out that epidemiologists tend to include race in quantitative models while failing to acknowledge all aspects of the construct its quantified effect captures [67].

In the context of aluminum smelting occupational epidemiology, specifically, there are some inconsistencies between findings and community concerns. While some work is confirmatory (e.g. documentation that the potroom jobs are the most dangerous [56,58,68]), the bulk of the publications focus on company-initiated intervention effectiveness and methodological advances [37,62,63,69]. It does not address racial disparities in health, and it does not reflect the worker experience described by community members in West Badin.

Study Site: Alcoa Facility in Badin, North Carolina

The town of Badin is in Stanly County, rural western North Carolina, near Charlotte. It was established in 1913 and was the site of an aluminum smelting plant, operated by the Aluminum Company of America (Alcoa), for most of the 20th century. The smelter in Badin was a major employer in town for the entirety of its time of operation [70]. Over the years, community members have voiced concerns regarding several workplace injuries and a high prevalence of cancer. In interviews, former plant workers described segregation in both the town of Badin and their workplace, including worse working conditions for Black employees. Many workers suffered from high exposure to hazards and harmful chemicals. Figure 1.1 shows the location of Badin, NC and that of its "sister city," Alcoa, Tennessee, the site of another large facility, which is still in operation.

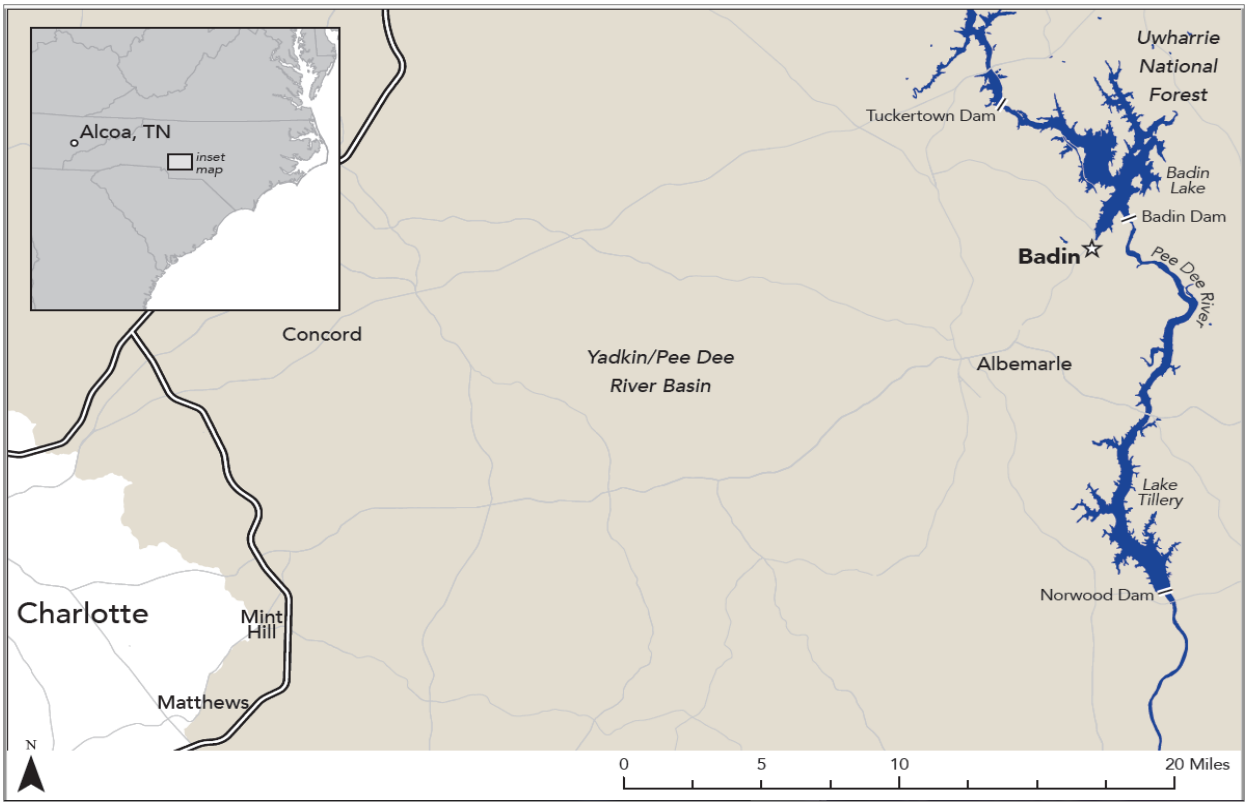


Figure 1.1 Badin, NC Location (Map: Tim Stallman)

Communities of color are disproportionately burdened by industrial pollution throughout the US [6,7]. The town of Badin is one case in which an organized group of citizens are currently fighting for environmental justice. The Concerned Citizens of West Badin formed in 2013 to advocate for remediation of contamination from the now closed Alcoa aluminum smelting facility in their community [5]. The town of Badin was founded on the Yadkin River by a French aluminum company that was quickly purchased by Alcoa [3]. It was strictly racially segregated, and Highway 740 remains a physical barrier between the communities, with East Badin being majority white and West Badin largely Black [4]. The aluminum smelting facility as well as its landfills and dumping sites are located in West Badin [5]. Figure 1.2 shows residential divide as well as sites of potential toxicity in Badin.

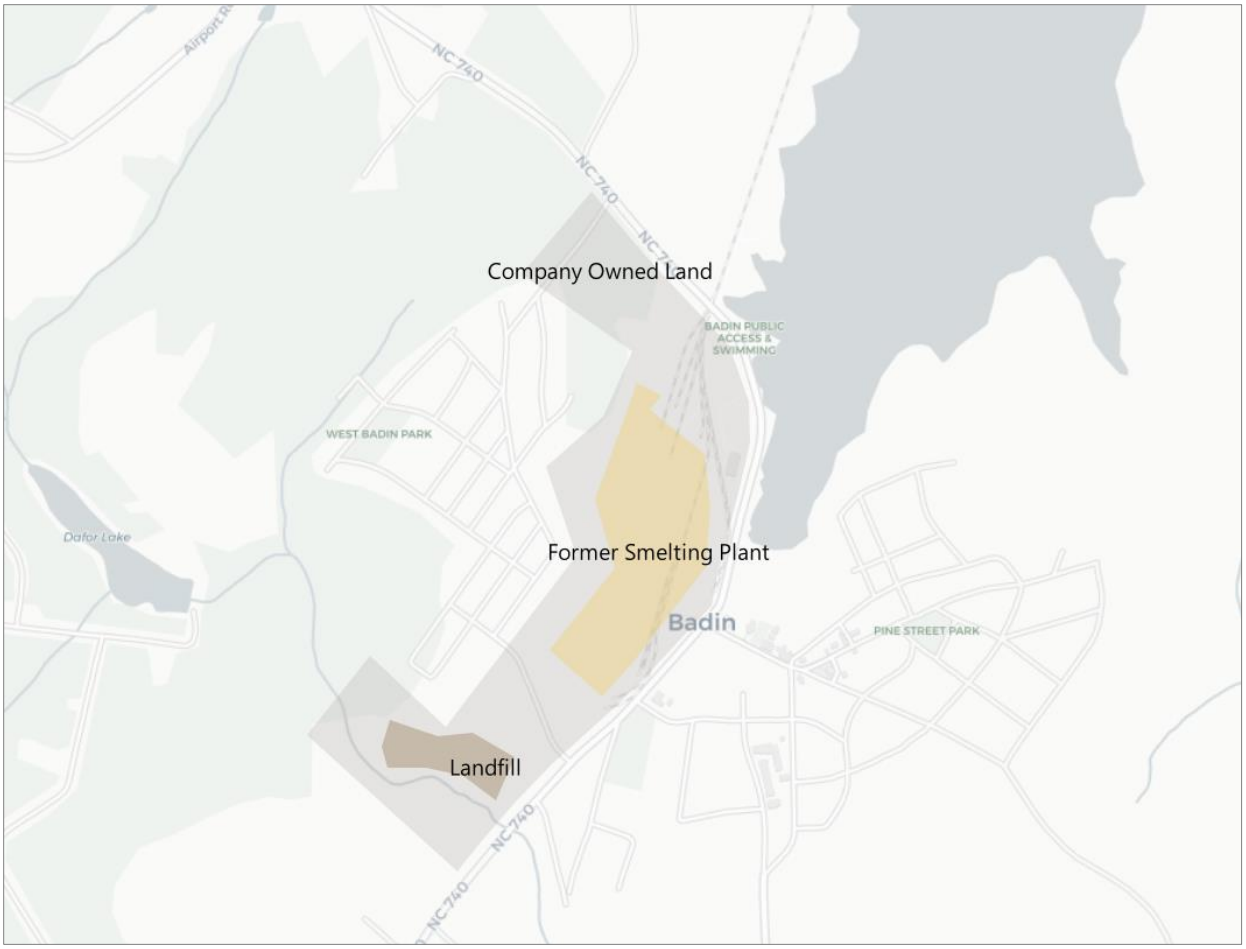


Figure 1.2 Alcoa Aluminum Smelting Facility and Dumping Site Locations; Badin Residential and Recreational Locations (Map: Elizabeth McClure)

Alcoa is the largest aluminum company in the world, with regard to revenue. Its headquarters are in Pittsburgh, and it operates facilities in 31 countries [70]. Alcoa purchased the Badin-located French aluminum smelting facility in 1917 and ceased operations in 2007. In the height of its operations, the plant produced over 100,000 tons of aluminum annually [70]. Despite being closed and employing no residents for a decade, the company's hazardous pollutants remain in West Badin. Residuals from the smelting process known to be toxic [71]—cyanide, fluoride, and polychlorinated biphenyls (PCBs)—leached from an unlined landfill have been identified in Badin Lake [72].

Badin's facility was the only of three Alcoa sites involved in a court ruling in 1992 not designated an EPA Superfund site. The other two sites have been extensively cleaned, while Alcoa maintains a "natural attenuation" cleanup plan for Badin, in which pollutants will be left in place until they dissipate [73]. A fish consumption advisory was established in 2009, and the state has required Alcoa to cover Badin Lake bed's contaminated sediment. However, the pollution remains in violation of the Clean Water Act and the disproportionate impact on the African American community is in violation of Title VI of the 1964 Civil Rights Act, while Alcoa continues to seek relaxed standards from the state of North Carolina [72]. Alcoa's smelting facility ceased operations in 2007, but the company maintains jurisdiction of the hydroelectric power generation and ownership of the dam near town on the Yadkin River [74].

In addition to contamination of Badin's residential water supply, numerous lawsuits in Badin have been filed against Alcoa with regard to work-related injuries and diseases. In collaboration with the North Carolina Environmental Justice Network and the Concerned Citizens of West Badin, Pavithra Vasudevan wrote a play based on in-depth interviews she conducted with West Badin residents entitled *Race and Waste in an Aluminum Town*. The play was performed in Badin, followed by an open discussion. In this discussion and the interviews, former workers report that the least desirable jobs in the plant involved laboring in rooms with combusting petroleum and inhaling black soot. They also voiced that these jobs were most frequently assigned to Black workers. The workers assigned to these tasks were informally known as "the bull gang," but their official job titles varied. Multiple former workers also mentioned the "25 year club," which came with some corporate benefits and was only opened to Black workers after the establishment of the Badin United Steel Workers Local 303 division [75],

was often referred to as “the graveyard,” because so many workers died after working in the plant for 25 years. Figure 1.3 shows a photo of the open discussion following the play in Badin.

Figure 1.3 Community Forum Discussion Following the Race and Waste in an Aluminum Town Performance in Badin, NC (Photo: Snehal Patel)

No research has been done to formally evaluate mortality or differences in occupational exposures at Alcoa’s Badin facility. Further no literature has examined disparate occupational exposures by race in the aluminum industry. This work is in partnership with the Concerned Citizens of West Badin (CCWB)—a group of former workers and their families at the segregated, now shuttered smelting facility in Badin, North Carolina who organize around environmental justice in their community [5] and the North Carolina Environmental Justice Network (NCEJN). The CCWB first raised the question motivating this research: were Black workers disproportionately exposed to job-related toxins and hazards that cause negative health outcomes [26]? Figure 1.4 is a photo of key collaborators involved in this research at a Quarterly Meeting of the NCEJN in July 2019, which the CCWB hosted.

Figure 1.4 Valerie Tyson (CCWB), Pavithra Vasudevan (University of Texas-Austin, NCEJN), Libby McClure (University of North Carolina-Chapel Hill, NCEJN), Macy Hinson (CCWB), Elizabeth Haddix (NCEJN), and Naeema Muhammad (NCEJN) at the NCEJN Quarterly Meeting in June 2018 (Photo: Courtney Woods)

CHAPTER 2. MATERIALS AND METHODS

Study Design

The dissertation aims were addressed in an aluminum smelting occupational cohort through retrospective, observational study. Data for the study were obtained from administrative data sources, supported and informed by findings from a household survey of West Badin residents. A novel occupational cohort using USW records was also assembled for the third aim. Statistical analyses were conducted to accomplish the three aims.

Data Sources

The study population was identified through two sources: contract data from Alcoa company records and seniority records provided by United Steel Workers (USW). No major exclusion criteria were applied. Work history and exposure information for Badin Alcoa workers ever employed between 1985 and 2007 were assembled from Alcoa's archives [9,76]; and work history and mortality information for hourly Badin Alcoa workers ever employed between 1981 and 2001 were assembled from USW records the North Carolina voter registry database, and the National Death Index (NDI).

Alcoa Contract Cohort Study

Alcoa contract data from all of its United States plants (both currently operating and closed) are maintained by the Alcoa Consortium at the Stanford Center for Population Health Studies. Alcoa company records from 1996 onward were made available to researchers through a partnership between Alcoa, Stanford University, and Yale University for the purposes of

workplace health research. The contract database includes records from all of Alcoa's facilities, which are located throughout the US and abroad. For some facilities, including Badin, data from as early as 1985 is available. Variables come from two administrative sources—human resources and industrial hygiene.

The data include all individuals (both salary and hourly) who were ever employed at the Badin, NC Alcoa aluminum smelting plant between 1985 and 2007. While the plant officially closed in 2007, the facility initiated cutbacks in smelting in 2002 and stopped production by 2004. Elizabeth McClure and David Richardson received access to Alcoa contract data in July 2018.

United Steel Workers Cohort

The USW data were first identified in historical seniority records collected by the USW, Local 303. The local office stored seniority records by department at the Badin smelter and the Yadkin River dam starting in 1969. Seniority records were collected irregularly but at least once per year to evaluate incidents, complaints, and payroll and membership changes. Name and social security number were available for workers ever employed between 1980 and 2001. Steve Burgess, current USW representative for the Local 303, gave access to the paper records with permission from the regional supervising team.

Elizabeth McClure, Pavithra Vasudevan, and Nathan DeBono scanned the seniority records on site over two days in March 2018. McClure then processed the images through text recognition software and converted them to text files. Elizabeth McClure, Jeff Yang, and Linnea Olsson manually cleaned the text files against the images for fidelity to printed name and social security number from May through August 2018.

The USW dataset includes identifying information for all union member, hourly workers ever employed at the Badin facility between 1980 and 2001. McClure then identified other key variables for this cohort through linkage with national driver's license and voter registry databases through LexisNexis, and the National Death Index (NDI). The final, enumerated USW study population dataset will work start date, work end date, date of birth, race, gender, vital status, and cause of death (among decedents).

Table 2.1 Data Sources and Relevant Characteristics by Dissertation Aim shows the data sources and relevant characteristics (including date ranges and variables used) to complete analyses for each of the three dissertation aims.

Table 2.1 Data Sources and Relevant Characteristics by Dissertation Aim

	Aim 1	**Aim 2**	**Aim 3**
Data Source	Alcoa Contract Cohort	United Steel Workers, National Death Index	Random Samples of Publicly Available Cohorts
Number of Workers	1,234	754	400
Dataset Year Range	1985-2007	1981-2001	N/A
Variables Used	Race, Sex, Date of Birth, Job, Job Date, Department, Department Date, Job Exposure Matrix Measures	Race, Sex, Date of Birth, Company Start Date, Vital Status, Date of Death, Cause of Death	Race, Hearing Threshold, Lung Function, Workers' Compensation Dollar Amount

Household Survey

To supplement this dissertation research, a household survey was conducted in collaboration with Dr. Pavithra Vasudevan, the Concerned Citizens of West Badin, and the North Carolina Environmental Justice Network. The Concerned Citizens of West Badin organized several former workers to participate in qualitative interviews, administered by Dr. Vasudevan and the North Carolina Environmental Justice Network, about their experiences living in Badin. Interview content specific to working at Alcoa both motivated this dissertation research and

informed questions for the survey. The open-ended survey involved younger folks from West Badin and other parts of North Carolina as administrators. It served to capture richer information, provide context to the dissertation aims [77], and better support the Concerned Citizens' organizing efforts than the traditional epidemiology methods described in the dissertation aims alone.

Study Population

Aim 1

The study population from the Alcoa contract data includes workers who were ever employed at the Badin facility (either the smelter and/or the dam) between 1985 and 2007. Human resources information includes demographic information that was used: date of birth; race; and, sex. The race variable may have been self-reported or assigned by workers' supervisors. The "sex" variable in the human resources data proxies worker gender in this analysis, as we are primarily interested in the social constructions of gendered work roles [78]. Similar to race, the sex variable may have been assigned or self-reported. This study population includes 1,234 workers, of whom 316 identify as Black, 917 identify as white, and 1,077 identify as male.

Aim 2

The study population from the USW data includes hourly workers who were ever employed and members of the union at the Badin facility (either the smelter and/or the dam) between 1980 and 2007. Former workers state that all hourly workers during this time period were union members as well. This study population includes 754 workers. Race, gender, and date of birth were determined through the data linkages with voter registration data and driver's

license records. The cohort was then searched in the National Death Index (NDI) for vital status and cause of death among decedents.

Aim 3

Aim 3 involves a random sample of 200 Black and 200 white workers' first spirometry measurements from the demonstration database in the NIOSH Spirometry Longitudinal Data Analysis Software [79] and a random sample of 200 Black and 200 white adults' audiometric measurements from the 1999-2000 NHANES [80].

Employment History

Aim 1

Alcoa contract data included detailed information from human resources. This includes titles and start dates of jobs and departments for all workers, active beginning in 1985.

Aim 2

The USW records include company start date and department start and end date.

Aim 3

As Aim 3 is an example analysis to investigate the impact of algorithms that use race-based clinical metrics, specifically, no work history was included in the study populations.

Exposure Assessment

Aim 1

Four metrics were used to characterize jobs in Aim 1. These were occupational prestige (based on sociologic rankings of prestige by job title [81,82]), occupational danger (based on former workers' assessments), annual wage (standardized to 1985 US dollar), and estimated total

particulate matter exposure (in mg/m^3, based on a job exposure matrix [39]). Job titles, annual wages, and start/end dates of jobs for all workers were updated at the time of each change in job. In addition to work history data, job exposure matrix-based estimates of exposure to a total particulate matter were used from industrial hygiene data.

Prestige: Job titles for workers in the aluminum manufacturing industry were coded to a standardized census classification through the National Institute of Occupational Safety and Health (NIOSH) Industry and Occupation Computerized Coding System (NIOCCS) single record coding tool [83]. Prestige ranks, on a 4-point scale from low to high, were assigned to census coded occupations based on scores from national sociology survey results [81,82].

Danger: A group of former workers from the smelting facility in Badin were given a list of every job title in the dataset (N=103), and they ranked each on a scale of 1 to 4, with 1 being the least dangerous and 4 being the most. Jobs with more than 2 discrepant rank levels (N=36) were brought to the full group for review and consensus was reached for all job titles.

Wage: Annual wages were standardized to the 1985 dollar, using annual conversion factors from the National Bureau of Labor Statistics' Consumer Price Index [84].

TPM Exposure: Alcoa contract data include job-exposure matrices (JEMs), which link department, job, task, and period to derive predicted exposure levels to specific agents (e.g. $PM_{2.5}$). These predictions are informed by direct measurements of agents and mapped to industrial hygiene "distinct exposure groups" (DEGs). The DEGs are linked with job titles from the human resources recording system. Department and job-specific estimated total particulate matter (TPM) exposure levels were available for the Badin facility [39]. I used the existing JEM to estimate individual worker levels of exposure.

Aim 2

The purpose of Aim 2 is to make characterize mortality rates among workers at the Badin facility relative to reference rates. Exposure in this aim is conceptualized as ever being employed as an hourly, union member worker at the Badin Alcoa facility between 1981 and 2001. It is a proxy for all job exposure to carcinogenic and otherwise hazardous agents and conditions, as specific job and task information is not available in this data source. Department-specific estimates may characterize exposures to hazards and hazard-levels that are unique to certain jobs (e.g. pot room work typically involves exposure to heat and higher levels of carcinogenic agents than janitorial work at aluminum smelting facilities). Therefore, we additionally characterize exposure as time worked in the pot room for stratified mortality rate comparisons.

Aim 3

The primary explanatory variable in Aim 3 is race, which is examined in relationship to interpretation of clinical metrics.

Outcome Assessment

Aim 1

The purpose of Aim 1 was to describe differences in job characteristics by race and gender. No health outcome information was included in this aim

Aim 2

Workers identified through USW records were followed from 1980 (or their company start date if later) through December 31, 2017 for vital status and cause of death. This information was obtained from the National Death Index (NDI). The NDI includes a record of all deaths occurring in the United States and is complete as of 1979. Individuals were linked using

their social security number, name, date of birth, race, and sex as available from the voter registry and driver's license records in the LexisNexis search. Deceased individuals' underlying cause of death was identified with death certificate ICD-9 or ICD-10 codes. Cause of death codes were grouped into cause-specific deaths according to the NIOSH-119 cause of death categories [85]. Reference mortality rates for the general population in North Carolina from 1981 until 2017 were obtained from the Department of Surveillance, Hazard Evaluations, and Field Studies at the National Institute for Occupational Safety and Health (NIOSH) with permission from the National Center for Health Statistics.

For Aim 2b, all-cancer, bladder cancer, respiratory cancer, and pleura/mesothelioma were identified *a priori* as causes of interest because of former workers' reports and known workplace exposures at the Badin smelter and other plants with similar processes [86]. Adjusted cause-specific SMRs were estimated for these causes using the worker cohort's mortality rates for causes not related to cancer, heart disease, and injury as negative control to remove potential "healthy worker survivor bias" (i.e. when the least healthy workers leave the work force early and healthier workers accumulate more occupational exposure time) [87,88]. To meet the assumptions required to reduce bias in the adjusted SMR, negative control causes of death were chosen that were 1) unlikely to be affected by smelting work exposures and 2) shared the theoretical sources and directions of healthy worker survivor bias as the causes of death of interest [88]. The negative control causes of death included: disorders of blood and blood forming organs, diabetes mellitus, mental and psychological disorders, nervous system disorders, diseases of the circulatory system (other than heart disease), diseases of the digestive system, diseases of the skin and subcutaneous system, diseases of the musculoskeletal and connective system, and diseases of the genito-urinary system.

Aim 3

Aim 3 estimated workers' injury compensation values on a sample of hypothetical manufacturing workers. North Carolina policy, recommends that clinical providers use the American Medical Association Guides [89] for evaluating workers' compensation claims for lung impairment [90]. The Guides define degree of lung function impairment across four classes using two of the worker's spirometry results, forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), relative to a predicted value. The predicted value comes from the Hankinson equation, which is a function of age, race, sex, and height [91]. Class 1 impairment is equivalent to normal lung capacity, Class 2 is defined as FVC or FEV_1 between 75 and 90% of the predicted value, Class 3 is between 50 and 74% or the predicted value, and Class 4 is lower than 50% of the predicted value. A typical case in North Carolina awards an average of $2,500 per each impairment class above 1 [92]. Hearing loss is evaluated using the average of decibel thresholds a worker demonstrates across four frequencies. If their average threshold is greater than 15 and not attributable to any degenerative or genetic disorder, workers are eligible to receive 70 weeks' pay for one ear and 150 weeks' pay for both ears [92]. For aluminum smelting production work, the national average for 70 weeks' pay is $42,700 and 150 is $101,140 [84].

The data in Aim 3 includes raw FVC, FEV_1, and hearing loss values the manufacturing cohorts represented.

Analytical Methods

Aim 1

Linear binomial regression models were used to predict average probability of being in a more desirable job each year since hire, across the four job domains (dichotomized for analyses) within race-sex strata. I assessed probability of being in a higher prestige job (any category but

lowest prestige); probability of being a less dangerous job (any category but highest danger); probability of being in a job that was not low-wage (above the bottom quartile of 1985 dollar-standardized wages for the entire study population); and probability of being in a lower TPM exposure job (any category but high exposure). Models were adjusted for an individual study-member fixed effect to control for time-invariant worker-level confounders as well as calendar year. To assess potential for healthy worker survivor bias, we conducted analyses restricted to incident hires.

Aim 2

Standardized Mortality Ratios (SMR) were used to compare mortality rates in the USW population to those in the general population of North Carolina. The SMR serves as a summary measure of the USW study population's mortality experience relative to that of the general population in North Carolina or the negative control within the worker population. I interpret it as the ratio of the observed to the expected number of deaths in the USW study population. The expected number of deaths is the number that would have been observed had the USW study population experienced the mortality rate of the general North Carolina population or the negative controls over the same time period, with the same race, sex, and age distribution [93]. The major assumptions required for this interpretation are 1) that the person-time distribution in the study population would have been the same in the absence of work exposures and 2) that the reference mortality rates represent the rates the cohort would have experienced in the absence of exposure [88,94].

SMRs for all-cause and cause-specific deaths were estimated using the reference rates for the calendar years 1980 through 2017 in North Carolina and among negative controls in the worker population. For age standardization, I used five-year age categories. Workers' person

time at risk of mortality in the USW study population began accumulating on January 1, 1980 or the first observed date of hire, if later. The accumulation ended on the date of death for decedents and on December 31, 2017 for workers presumed to be alive. SMRs were calculated for all-cause mortality and cause-specific mortality using the following formula:

$$SMR = \frac{\Sigma_i A_i}{\Sigma_i P_i R_i}$$

Where:

A = Observed number of cause-specific deaths in the USW study population

P = Person-years at risk of death in the USW study population

R = Cause-specific mortality rate in the North Carolina population

i = Index for strata of race, sex, 5-year calendar period (1980-1984 to 2016-2017), and 5-year age group (20-24 to ≥85)

Adjusted SMRs (aSMRs) for all-cancer, bladder cancer, respiratory cancer, and pleura/mesothelioma related deaths were estimated using negative control mortality rates from the USW population. The negative control causes were chosen to approximate equivalence in magnitude of the negative control's healthy worker survivor bias (ϵ_k) and that of the causes of interest (δ_k). The aSMR is the summary figure shown in the following formula:

$$aSMR = \frac{\frac{I_{1k}}{I_{Rk}}}{\frac{J_{1k}}{J_{Rk}}} = \exp(\alpha_k + \epsilon_k - \delta_k)$$

Where:

$\frac{I_{1k}}{I_{Rk}}$ = The rates of cause-specific deaths in the USW study population over the rates in the external, North Carolina population

$\frac{J_{1k}}{J_{Rk}}$ = The rates of negative control deaths in the USW study population over the rates in the external, North Carolina population

α_k= The log of the stratum-specific rate ratio, the target parameter of primary interest

ϵ_k= The degree of bias in the negative control

δ_k= The degree of bias in the cause-specific death of interest

k = Strata of race, sex, 5-year calendar period (1980-1984 to 2016-2017), and 5-year age group (20-24 to ≥85)

The aSMR is the weighted mean of stratum specific comparative statistics. It approximates the summary ratio of the observed counterfactual rates ($\frac{I_{1k}}{I_{0k}}$), because the reference rates for the negative control outcome J_R differ from the counterfactual rates J_0 by a factor ϵ_k that equals δ_k [88]. The overall, race and sex stratified, and age-group stratified SMRs were estimated using weighted Cox regression models in LTAS [85]. Adjusted all-cancer, bladder cancer, respiratory cancer, and pleura/mesothelioma-specific SMRs were estimated using SAS version 9.4 [88,95].

Standardized Rate Ratios (SRR) were used to compare all-cause, all cancer, bladder cancer, mesothelioma, respiratory cancer, and respiratory disease-specific mortality among individuals who ever worked in the pot room to that among those who never worked in the pot room. SRRs were calculated for all-cause mortality and cause-specific mortality using the following formula:

$$SRR_{a\ vs\ b} = \frac{\frac{\Sigma_i W_i A_{bi}}{T_{bi}}}{\frac{\Sigma_i W_i}{\frac{\Sigma_i W_i A_{ai}}{T_{ai}}}}$$

Where:

A = Observed number of cause-specific deaths in the USW study population

T = Person-years at risk of death in the in stratum i for the exposure group

W = Weight for the given stratum i

i = Index for strata of race, sex, 5-year calendar period (1980-1984 to 2016-2017), and 5-year age group (20-24 to ≥85)

a = Exposure group – never worked in the pot room

b = exposure group – ever worked in the pot room

Aim 3

Linear regression models were used to estimate the dollar amount of workers' injury compensation the example cohorts would have received under four conditions: 1) the workers' true races are known, 2) assuming the workers are all white, 3) assuming the workers are all Black, and 4) the workers' races are unknown. For lung function estimations, we used the Hankinson et al race-specific equations in conditions 1-3, and in condition 4, we used a prediction equation that did not correct for race. For hearing loss estimations, we applied race-specific equations in conditions 1-3, with a 7% decrement for white workers and a 7% increase for Black workers (informed by the race difference in the full 1999-2000 NHANES population), and in condition 4, we used audiometric output uncorrected for race. We applied the Guides

impairment class definitions and assumed $2,500 awards for each class above 1 for lung function, and $42,700 for one ear's hearing loss and $101,140 for two.

Household Survey

I began attending Concerned Citizens of West Badin (CCWB) meetings in May of 2017. Pavithra Vasudevan and I shared a one-page document about the benefits and limitations of doing a health study, as they relate to supporting organizing work (Appendix). At multiple meetings, members of the CCWB expressed that many former workers have not been able to tell their stories, and there has been excitement about the idea of conducting a household survey.

We researched examples of household surveys that have been used for environmental justice organizing, and drafted two versions of a survey for West Badin. One was largely prescriptive, with clear categories for exposures and health issues from which respondents could choose. The other had exposures prompts with some open-ended follow-up questions, and a health outcomes prompt, with more open-ended questions. We brought these two versions to a CCWB meeting in July of 2018, and there was consensus around preference for the more open-ended version.

After settling on a final version, with comments from the CCWB, we developed a training program for two members of the West Badin community to conduct the surveys door-to-door. The CCWB discussed the importance of this opportunity to involve younger community members in the organizing, and two young women were hired to conduct the surveys. We had the training in Badin with two members of the CCWB present. We brought maps of the nearly 200 homes in West Badin, printed surveys (Appendix), recorders, and consent forms. The CCWB members were able to give background on the importance of the surveys and act as

practice respondents for the research assistants. We ended the training with the research assistants' reflections on the survey and their town's history.

The two research assistants took other opportunities, and we hired two new research assistants from other parts of North Carolina to conduct the surveys. We continue to iteratively update the questions, as we get feedback from the research assistants on respondents' reactions to the questions. The CCWB are also developing a list of former workers and their family members who have moved outside of Badin to recruit for a phone survey.

Human Subjects

All components of this dissertation research have been described, and all study affiliates have been listed in the application to the University of North Carolina Institutional Review Board. The study IRB number is 17-1853, and the most recent modification was approved on August 15, 2019.

CHAPTER 3. DISPARITIES IN JOB CHARACTERISTICS BY RACE AND SEX IN A SOUTHERN ALUMINUM SMELTING FACILITY

Introduction

The study site is a southeastern United States town, was established in 1913, and hosted an aluminum smelting plant for most of the 20th century. The smelter was a major employer in town for the entirety of its time of operation [70]. Aluminum smelting is an electrolytic process on alumina, which is refined from bauxite ore. The alumina is dissolved in carbon-lined steel pots filled with molten baths using electric current from carbon anodes hanging above. The electric current maintains a temperature of 1,760-1,780° F [29]. Aluminum smelting generates a variety of airborne chemical contaminants including carcinogenic coal tar pitch volatiles (a measure of polycyclic aromatic hydrocarbons)[96] and fluorides, which are potent respiratory irritants [97]. At this smelting facility, some employees have reported that the least desirable jobs in the plant were most frequently assigned to Black workers [98]. Over the years, community members have voiced concerns regarding workplace injuries and a high incidence of cancer. In interviews, some former workers have also described segregation in both their residences and their workplace, including worse working conditions for Black employees. In this facility, many workers report having suffered from high exposure to hazards and harmful chemicals [99].

Little research has been done to formally examine occupational characteristics and exposures by gender and race in the aluminum industry. Historically, most occupational cohort studies have focused on white male industrial workers, with little empirical analyses of exposures among women or non-white workers [8]. Since most work has been done on white men,

the typical distributions of exposures that inform occupational safety guidelines may be biased. In this analysis, we estimate disparities in job characteristics and exposures by race and sex. Using information on aluminum workers employed at the plant between 1985 and 2007, we compared distributions by race and sex of census-based prestige rank, wage, worker-rated danger, and total particulate matter exposure categories.

Methods

Study Setting

The study site is a southeastern United States town. A company town, the site was established by the corporate owner of the smelter. Residences, churches, schools, and businesses were racially segregated, and a highway remains a physical barrier between two communities, with the east side being majority white and the west side largely Black [4]. The aluminum smelting facility, its landfills, and dumping sites are located in the west side of town [100]. It is well documented that residential communities of color are disproportionately burdened by industrial pollution throughout the US [6,101]; and, in this plant, employees report that the least desirable jobs in the plant were also most frequently assigned to Black workers [99].

Study Population

Study data are a subset of the American Manufacturing Cohort (AMC), maintained at the Stanford Center for Population Health Studies [102]. The study includes all individuals (both salaried and hourly) who were ever actively employed at the aluminum smelting plant between 1985 and 2007.

For the purposes of the current analyses, two study populations are defined: 1) the entire study population of workers; and, 2) the subset of the worker population limited to incident hires, defined only those workers with start dates on or after follow-up began on 1/1/1985.

Explanatory Variables of Primary Interest

The primary explanatory variables of interest in the current analysis are race and sex. Information on these variables was derived from human resources files that recorded demographic information including date of birth, race, and sex. In order to have adequate sample size in stratified populations by race and sex, we dichotomized the race variable (which was originally coded as a 7-level variable) as white versus non-white.

Outcome Variables of Interest

Four metrics were used to characterize outcomes of interest. These were occupational prestige (based on sociologic rankings of prestige by job title [81,82]), occupational danger (based on former workers' assessments), annual wage (standardized to 1985 US dollar), and estimated total particulate matter exposure (in mg/m^3, based on a job exposure matrix [103]). Information on these outcomes is derived from two administrative sources—human resources and industrial hygiene records [104]. These data include job titles, annual wages, and start/end dates of jobs for all workers; all were updated at the time of each change in job. In addition to work history data, job exposure matrix-based estimates of exposure to a total particulate matter were used from industrial hygiene data.

Occupational prestige: Occupational titles for workers in the aluminum manufacturing industry were coded to a standardized census classification through the National Institute of Occupational Safety and Health (NIOSH) Industry and Occupation Computerized Coding System (NIOCCS) single record coding tool [83]. Prestige ranks, on a 4-point scale from low to

high, were assigned to census coded occupations based on scores from national sociology survey results [81,82]. Supplemental Table 3.4 shows the mapping of job titles to prestige, danger, and total particulate matter exposure metrics. Some example high prestige job titles include "Plant Manager" and "Financial Manager." Examples of low prestige job titles include "Potliner" and "Pot Tender." Manufacturing jobs (in the pot room, dam, and other departments) in general are categorized as low prestige.

Worker-defined job danger: A group of former workers from the smelting facility scored each job title based on their perception of its danger. There is precedent for using worker perspective to characterize job hazards in the aluminum smelting industry; for example, Friesen et al. found good concordance between perceived and quantified exposure metrics as well as conceptual validity when using worker perspective to characterize less readily available measures of job danger [96] . Seven former workers were given a list of every job title in the dataset (N=103), and they ranked each on a scale of 1 to 4, with 1 being the least dangerous and 4 being the most. Jobs with more than 2 discrepant rank levels (N=36) were brought to the full group for review, and consensus was reached for all job titles. Some example low danger job titles include "Secretary" and "Accountant." Examples of high danger job titles include "Potliner" and "Pot Servicer." Workers stated that overall, the most dangerous jobs are in the pot room.

Annual wage: Annual wages were standardized to the 1985 dollar, using annual conversion factors from the National Bureau of Labor Statistics' Consumer Price Index [105]. Annual wages were obtained from human resources records.

Particulate matter exposure: Job-title specific estimated total particulate matter exposure was quantified using a previously developed job exposure matrix. The job exposure matrix

provides an average plant, department, and job-specific total particulate matter exposure at the time of measurement, which was conducted by department between 1985 and 2000 [103]. Aluminum smelting workers experience a varying degree of toxic exposures and hazards. The job worked, and the tasks completed in each job, has a strong influence on workers' exposures. For example, workers involved with pot room production are likely to have elevated exposure to coal tar pitch volatiles relative to maintenance workers who only enter pot rooms intermittently [40]. The pot room at the study site had "prebake" pots, in which coke-pitch paste is baked into a solid in a separate carbon plant before use in the pots. Estimated exposure levels are based on industrial hygiene samplers worn by a random subset of workers intended to represent day-to-day total particulate matter exposures in each position at the facility. Administrative and management-style jobs that were considered by the facility industrial hygienist unlikely to experience particulate matter exposure in excess of 30% of the allowable limit more than 5% of the time did not have measurements and were assigned the "no exposure" category [103]. Those with measurements were divided into three categories (i.e. low, moderate, and high) that prioritized equal numbers of workers in each group. Some job titles with no exposure include "Secretary" and "Accountant," as well as some salaried employees. Examples job titles with high total particulate matter exposure include "Baghouse Fume and Control" and "Pot Servicer." Salaried jobs were not always in low exposure departments. For example, a "pot room supervisor" is a salaried worker with fairly high total particulate matter exposure. However, their exposure would be categorized as "no exposure" in this analysis because their salaried status precluded inclusion in the job exposure matrix.

Statistical Analysis

We examined the association between race and sex and changes in each job domain with time since hire. We aimed to characterize job mobility, conditional on continued employment, analogous to economic or class mobility often described in sociology literature [81]. Using linear binomial regression models, we compared each race-sex group's average probability of being in a more desirable job (e.g. less dangerous or lower exposure), each year since hire, across the four job domains, which were dichotomized for interpretability and sample size within race-sex strata. For the prestige domain, we assessed probability of being in a higher prestige job (any category but lowest prestige); probability of being a less dangerous job (any category but highest danger); for wage, we assessed probability of being in a job that was not low-wage (above the bottom quartile of 1985 dollar-standardized wages for the entire study population); and probability of being in a lower total particulate matter exposure job (any category but high exposure). Models were adjusted for an individual study-member fixed effect to control for any time-invariant worker characteristics and calendar year. Model-based predicted probability curves and confidence bands for each race-sex group were plotted in each job characteristic domain.

To assess potential for healthy worker survivor bias, we conducted analyses restricted to incident hires, as has been previously done in analyses of manufacturing workers [106]. Sample characteristics as well as distributions of each job domain (based on first job at hire) stratified by race-sex group were quantified.

This research was approved by the University of North Carolina Institutional Review Board.

Results

Table 3.1 shows the study population characteristics as well as those in the sub-population of incident hires. This full study population includes 1,234 workers, and the incident hire sub-population includes 534 workers. Of the full cohort, 1,077 (87%) were male and 917 (74%) were white. Consistent with the demographics of town residents, over 90% of workers identifying as non-white were Black or African-American. The total population was an average age of 28 years at hire and 38 years at the start of follow-up (1985). A similar proportion of incident hires were female and non-white, relative to that in the full study population. The incident hires were slightly older on the date they were hired than other workers in the full cohort, and they were younger at the start of follow-up (1985) in comparison to the full cohort. The cohort had minimal (<1%) missing demographic data.

Table 3.2 shows the characteristics of time accrued by workers in the full cohort and the incident hire sub-population. The full cohort accrued a total of 287,894 person-months of active work time, while the incident hires accrued 79,465. About half (49%) of the full cohort's person time, compared to 63% incident hire person-time, was spent working in jobs classified as low prestige. In 1985 dollars, the average annual wage over the study period was $42,632 in the full cohort and $46,950 in the incident hire population. While 22% of the person-months contributed by the full cohort was spent in jobs considered by former workers to be the most dangerous, 32% of the months contributed by the incident hires was spent in these jobs. 29% of the full cohort person time compared to 32% of the person time in the incident hires was spent in the jobs with the highest total particulate matter exposure. Similar proportions of the person-time were missing (person-time spent in jobs that did not have wages documented or under job titles that could not

be mapped onto a category in the three other job characteristic domains) in the full cohort and incident hire sub-population.

Figure 3.1 shows job trajectories (over time since hire) by race and sex across each of the job characteristics examined, predicted by the linear binomial regression models. The curves in the top left represent the proportion of workers in each year since hire in a higher-prestige job. At hire, non-white males had the highest proportion of workers in low prestige jobs (92%), followed by white males (74%), then non-white females (66%), then white females (44%). Over time since hire, non-white males had the slowest transition into higher prestige jobs, with 52% remaining in low prestige jobs after 20 years since hire. After 15 years since hire, white females were entirely working in higher prestige jobs and white males reached 100% prevalence of higher prestige jobs by 19 years since hire. Linear binomial regression model estimates and confidence intervals represented in the figure are shown in Supplemental Table 3.5.

The top right of Figure 3.1 shows race-sex group trajectories for worker-defined job danger. At hire, non-white males had the highest proportion of workers in the most dangerous jobs (50%), followed by non-white females (40%), then white males (28%), then white females (16%). White females and white males reached 100% prevalence of lower danger jobs by 15 years since hire, and non-white females reached 100% by 20 years since hire. However, 10% of non-white males were still in the most dangerous jobs after 20 years since hire.

The bottom left of Figure 3.1 shows probability of being in a higher wage job as time since hire accrues. At hire, non-white females had the highest proportion of workers in low wage jobs (53%), followed by white females (56%), then non-white males and white males (both 50%). Over time since hire, all male workers maintained a 50% prevalence in low wage jobs. Female workers' prevalence of individuals in low wage jobs increased as time since hire passed

for both race groups but more quickly for non-white females. After 20 years since hire, all non-white female workers were in low wage jobs.

The bottom right of Figure 3.1 shows probability of being in a lower total particulate matter exposure job. Non-white males were most likely to be hired into a job with high exposure (24%), and as time accrued since hire, prevalence of workers in lower exposure jobs decreased. While nearly all white females were hired into low exposure jobs, and 100% were in low exposure jobs by 2 years since hire, a large proportion of non-white males were in high exposure jobs, with 44% in high exposure jobs by 20 years since hire.

Sensitivity analysis results are shown in Table 3.3. Proportions of each race-sex group in the least desirable job characteristic category were fairly similar to those in the full cohort. Non-white males had the greatest prevalence of lowest prestige (89%), most dangerous (64%), and highest total particulate matter exposure (26%) jobs at hire. Non-white females followed with the second highest prevalence of low prestige (75%) and high danger jobs (54%), but white males had the second highest prevalence of high total particulate matter exposure jobs (14%). Meanwhile, white males had lower prevalence of low prestige (67%) and high danger (34%) jobs at hire; and white females had the lowest prevalence of low prestige (62%) and high danger jobs (23%). Non-white females had the highest prevalence of low wage jobs at hire (63%), followed by white females (54%), then non-white males (52%), with white males at the lowest prevalence (34%).

Discussion

We examined differences in job characteristics (both baseline and trajectories) by race and sex among workers who were actively employed between 1985 and 2007 at an aluminum

smelting facility in the southeastern United States. We found that non-white male workers were most likely to be hired into low prestige jobs and least likely to transition out of them. White male workers were the next most likely to be hired into low prestige jobs, but 100% of them were in higher prestige jobs by 19 years since hire. Non-white females were nearly as likely to be hired into low prestige jobs and less likely to move out of them, while white females were least likely to be hired into low prestige jobs. Non-white males and non-white females were the most likely to be hired into the most dangerous jobs, and white females and males moved out of the most dangerous jobs quickly and uniformly.

There is a large sex difference in prevalence of workers in low wage jobs in this cohort, with male workers having higher proportions of workers in higher wage jobs and the greatest burden of low wage work falling consistently on non-white females as time accrued since hire. Females were less likely to be hired into jobs with high total particulate matter exposure than male workers, and non-white males had the highest prevalence of high exposure jobs (24% at hire and 44% by 20 years since hire).

These findings are consistent with former workers' narratives, which document segregated hiring and mobility in the plant. At meetings of retired plant employees in the study site, former workers report that nearly all workers in the pot room—the most dangerous and least desirable positions—were Black men and Black women, after gender integration. More white workers were hired into these positions starting in the late 1970s because of mechanization of particular tasks associated with pot room production, specifically crust-breaking, but former workers report that white workers who were hired into the pot rooms were quickly moved into jobs in more desirable departments [98].

While our focus on one southeastern United States facility addressed former worker concerns and provided rich context for interpretation of quantitative findings, it limited the size of the study population and, thus, statistical power to detect estimated differences. The small stratified samples required us to dichotomize job characteristic and race categories. Additionally, because the data were collected for administrative purposes rather than for research, some of the constructs are mismeasured. For example, the race and sex variables may be self-reported or assigned by workers' supervisors. The "sex" variable in the human resources data proxy worker gender in this analysis, as documenting the social constructions of gendered work roles may be more practically informative for workplace policy than documenting the impact of biologic sex [78].

Third, there is both survivorship into the cohort, and truncation of follow-up at termination. Because the aluminum smelter was in operation for many years before follow-up began in the form of digital collection of administrative records, we are concerned about the influence of the healthy worker survivor effect. Healthy worker survivor effect generally creates bias in estimates of work exposure effects on disease risk when sicker workers leave the workforce and healthier workers continue to accumulate exposure. This results in attenuated effect estimates, and in some cases, make work exposures look protective [107,108]. We used sensitivity analyses similar to those used by Applebaum et al [106]—we assessed the extent of bias introduced by survival into the cohort through analyses using a sub-population of incident hires. The race and sex distributions of job characteristics at hire were similar across the four domains between the incident hire and full cohorts. However, these sensitivity tests do not fully address biases among early career workers, for whom health may be far less important than social factors such as alternative job opportunities, discrimination in hiring, etc. Previous research in the AMC

cohort shows that disability, absenteeism, and early termination varies by demographic factors including race, gender, and hourly/salaried wage scheduling [109,110].

The reported analyses only include information about actively-employed workers; once a worker terminated employment at the plant they were censored. The proportions of workers in the more desirable jobs 15 to 20 years since hire represent the members of each race-sex group still working at the plant. The trajectories shown demonstrate job mobility, conditional on staying employed at the plant. We know from former workers' reports that it was difficult to find work at the low prestige and high danger level of the pot room with pay as high, and it is likely that white male workers had more opportunities to leave the plant for other jobs than non-white and female workers [98].

Despite these limitations, this analysis responds to community concerns and is consistent with collective narratives of differential disease burden among non-white workers in the aluminum smelting facility. It additionally involved development, piloting, and demonstration of a novel, worker-generated scale for characterizing a salient job characteristic, perceived danger risk. No studies to date have assessed differences in aluminum smelting work exposures by race and gender. However, one study of coke oven steelworkers in the US found that 69% of those working jobs with the highest levels of toxic exposure were non-white, while 9% of those working jobs with the lowest exposure levels were non-white [111]. This analysis begins to address this gap and also responds to calls in the literature to combine health disparities and work hazard research [11,112,113].

Given that high exposure jobs in the aluminum smelting industry have established associations with many diseases [16,35–38,44,54,114], race and gender differences in job characteristics have implications for health equity. Based on our findings, job segregation and resulting race and

sex disparities in experiences of occupational hazards may contribute to differences in mortality and morbidity by race and sex. Our findings suggest that job segregation may contribute to greater disease risk for non-white men and women. Given the concerns voiced by former workers, disparities are of primary interest, and these findings are consistent with their reports. This analysis may inform policy development by giving some indication of the potential benefits and limitations of equity-focused job assignment interventions and regulations.

Table 3.1 Characteristics of the Full Cohort (n=1,234) and Incident Hire Sub-cohort (n=534) for Workers in the Badin NC Aluminum Smelting Facility at Start of Follow-up (1985, or date of hire if later).

Variable	**Full Cohort n=1,234** *n (%)*	**Incident Hire Sub-cohort n=534** *n (%)*
Sex[1]		
Female	156 (13)	75 (14)
Male	1,077 (87)	459 (86)
Race[1]		
Non-white	316 (26)	169 (32)
White	917 (74)	365 (68)
	Mean, Median (25^{th}-75^{th} percentile)	*Mean, Median (25^{th}-75^{th} percentile)*
Age at Start Date[2]	28, 25 (22-34)	30, 27 (20-40)
Age at Start of Follow-up[1]	38, 36 (27-47)	31, 27 (23-36)

[1]n=1 missing in full cohort, no missing in incident hire sub-cohort
[2]no missing

Table 3.2 Characteristics of the Person-Months Accrued by the Full Cohort (N=23,991) and Incident Hire Sub-cohort (N=6,622) for Workers in the Badin NC Aluminum Smelting Facility, 1985-2007

Variable	**Full Cohort N=23,991** *n (%)*	**Incident Hire Sub-cohort N=6,622** *n (%)*
Census-based Prestige Rank[1]		
High Prestige	3,371 (15)	726 (13)
Medium High Prestige	1,782 (8)	294 (5)
Medium Low Prestige	4,861 (22)	604 (10)
Low Prestige	11,794 (54)	4,141 (72)
Worker-rated Danger Rank[2]		
Least Dangerous	5,364 (24)	1,854 (29)
Not Very Dangerous	5,112 (22)	993 (15)
Dangerous	7,169 (31)	1,656 (26)
Most Dangerous	5,147 (23)	1,920 (30)
Total Particulate Matter Exposure Rank[3]	6,478 (28)	1,509 (23)
No Exposure	4,078 (18)	919 (14)
Low Exposure	5,758 (25)	1,963 (30)
Moderate Exposure	6,957 (30)	2,090 (32)
High Exposure		
	Mean, Median (25^{th}-75^{th} percentile)	*Mean, Median (25^{th}-75^{th} percentile)*
Active Person-Time by Worker (in years)[4]	20, 19 (10-26)	12, 14 (7-17)
Annual Compensation (in 1985 dollars)[5]	42632, 39213 (27,916-50,200)	46950, 42354 (35,701-58,084)

[1]9% missing in full cohort, 13% missing in incident hire sub-cohort
[2]5% missing in full cohort, 2% missing in incident hire sub-cohort
[3]3% missing in full cohort, 3% missing in incident hire sub-cohort
[4]no missing
[5]1% missing in full cohort, <1% missing in incident hire sub-cohort

Table 3.3 Distributions of Job Characteristics at Hire by Race and Sex in the Incident-Hire Badin Worker Cohort, 1985-2007 (N=534)

	% of Non-white Females N = 34 *n (%)*	**% of Non-white Males N = 135** *n (%)*	**% of White Females N = 41** *n (%)*	**% of White Males N = 324** *n (%)*	**% of all Females N = 75** *n (%)*	**% of all Males N = 459** *n (%)*
Prestige at Hire						
1 (highest prestige)	2 (5)	7 (5)	1 (3)	39 (12)	3 (4)	46 (10)
2	1 (2)	4 (3)	12 (29)	19 (6)	13 (17)	23 (5)
3	6 (18)	4 (3)	2 (5)	49 (15)	8 (11)	53 (11)
4 (lowest prestige)	26 (75)	120 (89)	25 (62)	217 (67)	51 (68)	337 (73)
Worker-defined Danger at Hire						
1 (least dangerous)	5 (15)	15 (11)	12 (29)	39 (12)	17 (23)	54 (12)
2	2 (4)	12 (9)	6 (15)	55 (17)	8 (10)	67 (15)
3	9 (27)	18 (13)	14 (33)	120 (37)	23 (30)	137 (30)
4 (most dangerous)	18 (54)	86 (64)	9 (23)	110 (34)	28 (37)	197 (43)
Wage at Hire						
1 (highest wage)	3 (9)	24 (18)	4 (9)	94 (29)	7 (9)	118 (26)
2	2 (7)	35 (26)	7 (17)	45 (14)	9 (12)	81 (18)
3	7 (21)	5 (4)	8 (20)	29 (9)	15 (20)	35 (8)
4 (lowest wage)	21 (63)	70 (52)	22 (54)	152 (47)	44 (58)	222 (48)
Total Particulate Matter Exposure at Hire						
1 (lowest exposure)	19 (55)	92 (68)	13 (31)	113 (35)	31 (42)	205 (45)
2	6 (18)	32 (24)	10 (25)	100 (31)	17 (22)	133 (29)
3	7 (21)	10 (7)	7 (18)	65 (20)	15 (19)	74 (16)
4 (highest exposure)	2 (5)	1 (1)	11 (26)	46 (14)	12 (16)	47(10)

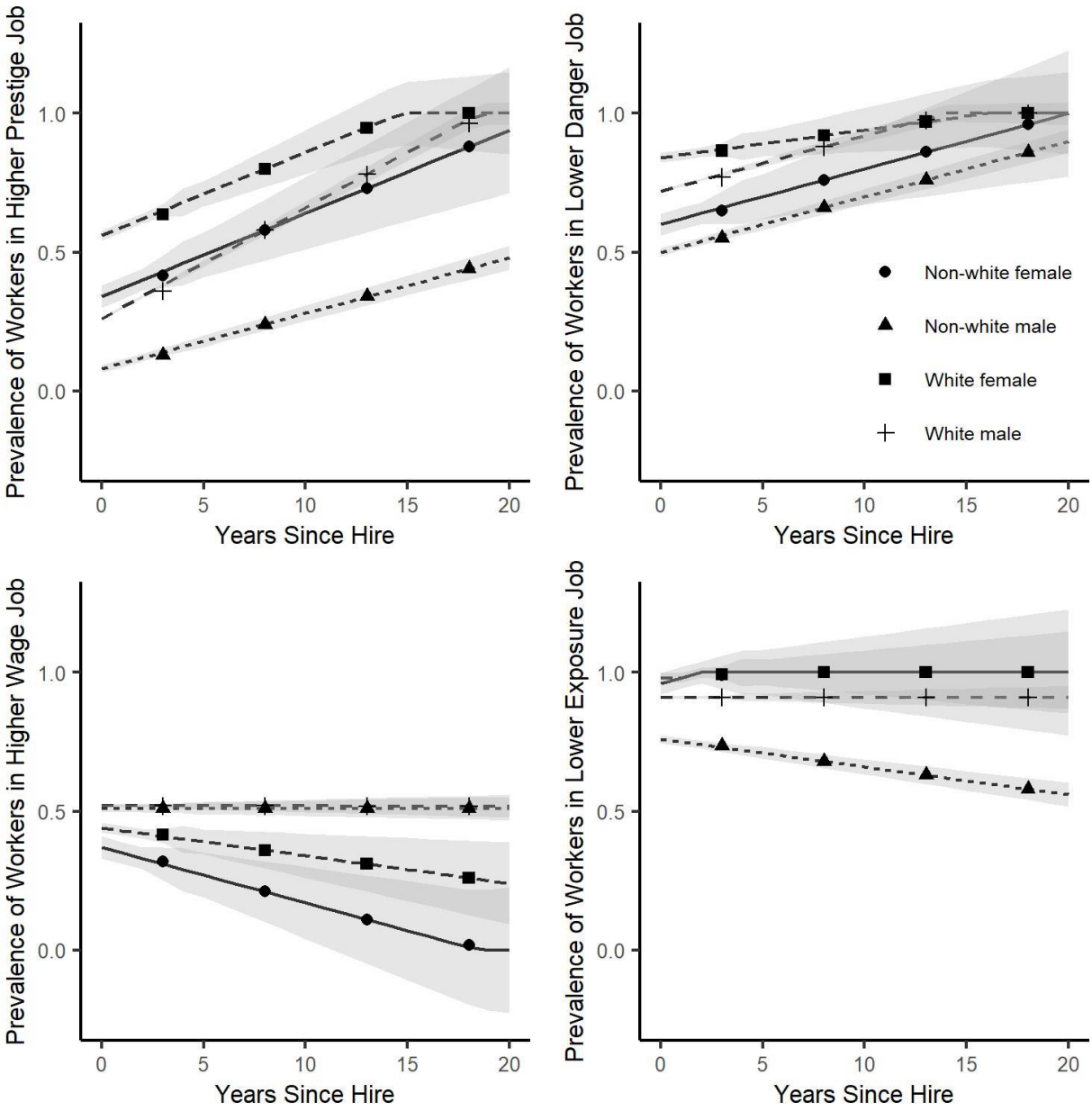


Figure 3.1 Prevalence Workers in More Desirable Jobs Over Years Since Hire by Race and Sex in the Full Badin Worker Cohort, 1985-2007 (N=1,234)

Points are five-year averages overlayed with linear binomial regression-fit trend curves. Non-white females are shown with circle point markers. Non-white males are shown with darker triangle point markers. White females are shown with square point markers. White males are shown with cross point markers.

Table 3.4 Supplemental - Job Title Categorizations for Prestige, Worker-Defined Danger, and Total Particulate Matter Exposure

Metric	1	2	3	4
Prestige	Accountant Administrative Assistant/Secretary Area Supervisor - Mechanical Engineering Business Analyst Casting Technican Electrical Engineer Engineer Engineering Manager Industrial Hygiene IT Specialist Manager Mechanical Engineer Medical Metallurgical Engineer Metallurgical Technician Metallurgist Plant Manager	Area Supervisor - Laboratory Chemist Electrician Environmental Specialist Human Resources Laboratory Public Relations	Area Supervisor - Anode Area Supervisor - Casting Area Supervisor - Cathode Area Supervisor - Construction Area Supervisor - Electrode Area Supervisor - Engineering & Maintenance Area Supervisor - Field Maintenance Area Supervisor - Ingot Area Supervisor - Labor Area Supervisor - Machinist Area Supervisor - Potlining Area Supervisor - Potroom Area Supervisor - Smelting Maintenance Cathode Foreman Cathode Technician Central Maintenance Dam Maintenance Mechanic	Anode Operator Anode Technician Bag House Repairer Bake Furnace Operator Brickmason Carpenter Caster Cathode Block Production Construction Construction Mechanic Crane Operator D C Operator Electrode Production Equipment Operator Filter Operator Furnace Operator Inspector Intern Janitor Lead Potliner Machinist Materials Processor Metal Furnace Operator Metal Processor Metal Trucker Millwright

			Electrical Maintenance Foreman Fume Control Technician Ingot Ingot Foreman Ingot Technician Labor Foreman Load Dispatcher Maintenance Foreman Mechanic Plant Clerk Pot Repair Foreman Potroom Foreman Rod-Chain Foreman Security Service Technician Shipping Foreman	Packer Loader Packer Puller Painter Pipefitter Pot Servicer Pot Tender Potline Technician Potliner Potlining Technician Potroom Potroom Technician Quanometer Operator Rod-Chain Handler Service Operator Smelting Operator Supply Attendant Tractor Loader Operator Truck Driver Welder
Worker-Defined Danger	Accountant Administrative Assistant/Secretary Area Supervisor - Laboratory Brickmason Business Analyst Human Resources Intern IT Specialist Labor Foreman Laboratory Painter Plant Clerk Plant Manager	Area Supervisor - Casting Area Supervisor - Construction Area Supervisor - Electrode Area Supervisor - Engineering & Maintenance Area Supervisor - Field Maintenance	Area Supervisor - Anode Area Supervisor - Cathode Area Supervisor - Mechanical Engineering Area Supervisor - Potlining Area Supervisor - Potroom Area Supervisor - Smelting Maintenance Caster	Anode Assembly Forman Anode Operator Anode Technician Bag House Repairer Bake Furnace Operator Cathode Block Production

	Public Relations Security	Area Supervisor – Ingot Area Supervisor - Labor Area Supervisor - Machinist Carpenter Chemist Construction Construction Mechanic Electrical Engineer Engineer Engineering Manager Industrial Hygiene Inspector Machinist Maintenance Foreman Manager Mechanical Engineer Medical Metallurgical Engineer Metallurgical Technician Metallurgist Shipping Foreman Supply Attendant Tractor Loader Operator Truck Driver Welder	Casting Technican Cathode Technician Central Maintenance Crane Operator D C Operator Dam Maintenance Mechanic Electrical Maintenance Foreman Electrician Environmental Specialist Equipment Operator Furnace Operator Ingot Ingot Foreman Ingot Technician Janitor Load Dispatcher Materials Processor Mechanic Metal Furnace Operator Metal Processor Metal Trucker Millwright Packer Loader Packer Puller Pipefitter Service Operator Service Technician	Cathode Foreman Cathode Technician Electrode Production Filter Operator Fume Control Technician Lead Potliner Pot Repair Foreman Pot Servicer Pot Servicer Pot Tender Pot Tender Pot Tender Potline Technician Potliner Potroom Potroom Foreman Potroom Technician Quanometer Operator Rod-Chain Foreman Rod-Chain Handler Smelting Operator
Total Particulate	Accountant Administrative Assistant/Secretary	Machinist Crane Operator D C Operator	Anode Operator Cathode Block Production	Anode Operator

Matter Exposure	Anode Assembly Forman Area Supervisor - Anode Area Supervisor - Casting Area Supervisor - Cathode Area Supervisor - Construction Area Supervisor - Electrode Area Supervisor - Engineering & Maintenance Area Supervisor - Field Maintenance Area Supervisor - Ingot Area Supervisor - Labor Area Supervisor - Laboratory Area Supervisor - Machinist Area Supervisor - Mechanical Engineering Area Supervisor - Potlining Area Supervisor - Potroom Area Supervisor - Smelting Maintenance Bag House Repairer Bake Furnace Operator Bake Furnace Repairer Brickmason Business Analyst Carpenter Caster Casting Technican Cathode Foreman Cathode Technician Central Maintenance Chemist Construction	Metal Processor	Crane Operator Equipment Operator Furnace Operator Lead Potliner Potliner Mechanic Supply Attendant Tractor Loader Operator Truck Driver	Anode Technician Packer Puller Pot Servicer Pot Tender Service Operator

	Construction Mechanic Dam Maintenance Mechanic Electrical Engineer Electrical Maintenance Foreman Electrician Electrode Production Engineer Engineering Manager Environmental Specialist Filter Operator Fume Control Technician Human Resources Industrial Hygiene Ingot Ingot Foreman Ingot Technician Inspector Intern IT Specialist Janitor Labor Foreman Laboratory Load Dispatcher Maintenance Foreman Manager Materials Processor Mechanical Engineer Medical Metal Furnace Operator Metal Trucker Metallurgical Engineer Metallurgical Technician Metallurgist Millwright Packer Loader Painter Pipefitter Plant Clerk Plant Manager Pot Repair Foreman Potline Technician			

	Potlining Technician Potroom Potroom Foreman Potroom Technician Public Relations Quanometer Operator Rod-Chain Foreman Rod-Chain Handler Security Service Operator Service Technician Shipping Foreman Smelting Operator Welder			

For all job characteristic metrics, 1 is best (high prestige, least dangerous, no exposure), and 4 is worst (low prestige, most dangerous, highest exposure)

Table 3.5 Supplemental - Linear Binomial Regression Model Estimates of Prevalence in More Desirable Jobs Over Years Since Hire by Race and Sex in the Full Badin Worker Cohort, 1985-2007 (N=1,234)

	Non-White Female *Estimate (95% CI)*	**Non-White Male** *Estimate (95% CI)*	**White Female** *Estimate (95% CI)*	**White Male** *Estimate (95% CI)*
Prestige Intercept	0.34 (0.30, 0.38)	0.08 (0.06, 0.09)	0.56 (0.54, 0.58)	0.26 (0.24, 0.25)
Prestige Slope	0.03 (0.01, 0.05)	0.02 (0.00, 0.04)	0.03 (0.01, 0.04)	0.04 (0.02, 0.06)
Danger Intercept	0.60 (0.56, 0.64)	0.50 (0.49, 0.51)	0.84 (0.82,0.87)	0.72 (0.71, 0.73)
Danger Slope	0.02 (0.00, 0.05)	0.02 (0.01, 0.03)	0.01 (0.00, 0.04)	0.01 (0.00, 0.02)
Wage Intercept	0.37 (0.33, 0.41)	0.51 (0.49, 0.52)	0.44 (0.42, 0.46)	0.52 (0.50, 0.53)
Wage Slope	-0.02 (-0.05, 0.02)	-0.01 (-0.03, 0.02)	0.00 (-0.03, 0.03)	0.00 (-0.01, 0.01)
Total Particulate Matter Exposure Intercept	0.96 (0.92, 1.00)	0.76 (0.74, 0.78)	0.98 (0.96, 1.01)	0.91 (0.90, 0.91)
Total Particulate Matter Exposure Slope	0.02 (-0.01, 0.05)	-0.01 (-0.03, 0.02)	0.00 (-0.02, 0.02)	0.00 (-0.01, 0.01)

Linear binomial models predicted probability of being in a more desirable job each year since hire for each of the job characteristic domains. Stratified models were run for each race-sex group. Models are adjusted for individual study-member fixed effect.

CHAPTER 4. CANCER AND NON-CANCER MORTALITY AMONG ALUMINUM SMELTING WORKERS IN BADIN, NORTH CAROLINA

Introduction

Production jobs at aluminum smelters involve demanding and difficult work under adverse environmental conditions. [2,48]. Aluminum smelting poses a wide range of occupational hazards, including extreme heat, airborne metal dusts, asbestos, polycyclic aromatic hydrocarbons, silica, and other chemical vapors which can be absorbed through inhalation or contact with the skin [1,2,30,58]. Toxic work exposure constituents include asbestos, beryllium, coal tar pitch volatiles, lead, polycyclic aromatic hydrocarbons and others [2,30,58]. Aluminum smelting workers have also been shown to experience a higher risk of injury due to exposure to physical hazards, such as heat and noise. [2,30,35,59–61]. Exposures in the aluminum production industry cause bladder [33,44,49–52,54,114] and lung cancer [33,52] as classified by the International Agency for Research on Cancer (IARC) [2], in addition to being positively associated with other cancer sites, including central nervous system cancer [30,35,53] and cancer of the digestive system [30,53,55,56].

The Concerned Citizens of West Badin, a group of former aluminum smelter workers and their families in Badin, North Carolina have voiced concerns about excess mortality among plant employees in oral histories, at state conferences, and before panels of government officials [26,115]. The aluminum smelting plant in Badin was established in 1913 and continued operations until 2007. During its peak of operations, the plant produced over 100,000 tons of aluminum annually [70]. Workers reported that the least desirable jobs in the plant involved work in the pot room, and that these jobs were most frequently assigned to Black workers [26]. Specifically, community

members have voiced concerns regarding a high prevalence of cancer in relation to work exposures at the plant [26].

A group of former workers, in collaboration with the United Steelworkers (USW) union, requested epidemiologic support to investigate these concerns. While some previous research is consistent with workers' reports (e.g. pot room jobs being the most dangerous [56,58,68]), most epidemiological publications focus on company-initiated health and safety intervention effectiveness and advances in statistical methodologies [37,62,63,69]. Existing studies do not address racial disparities in worker mortality nor the health concerns described by workers and community members in Badin.

The purpose of this study was to investigate concerns regarding excess and disparities in mortality among union members employed at the Badin aluminum smelting plant. Cause-specific mortality rates in the study cohort were compared with North Carolina general population rates, quantified as standardized mortality ratios (SMR). We also estimated cancer-specific adjusted standardized mortality ratios using non cancer, heart disease, or injury-related mortality as a negative control, to adjust for unmeasured differences between the occupational cohort and the reference population related to "healthy worker effects" [88]. Finally, we estimated associations between time worked in the pot room and mortality rates overall and according to race and sex using standardized rate ratios (SRR). This investigation involves de novo enumeration of a cohort with vital status and cause of death ascertainment.

Methods

Study Setting

The town of Badin is located in Stanly County, rural western North Carolina, near Charlotte, North Carolina. Badin was the site of an aluminum smelting plant, operated by the

Aluminum Company of America (now, Alcoa Inc.), for most of the 20th century. The smelter in Badin was the major employer in the town for the entirety of its time of operation [70]. The workforce at the plant was unionized with the USW through the plant shutdown in 2007 [116]. Despite being closed and employing no residents for over a decade, hazardous pollutants remain at the plant site and throughout the town as of 2020. Residuals from the smelting process known to be toxic—cyanide, fluoride, and polychlorinated biphenyls (PCBs)—leached from an unlined landfill and have been identified in Badin Lake [72,74], a central recreational feature of the town. These environmental exposures also are of concern to these former workers, as Badin is a company town where many workers and their families lived and continue to live after operations at the smelter ceased.

Study Population

The study cohort includes 754 hourly USW members employed for any duration (1 day or more) at the Badin smelting plant. The cohort was enumerated for this study from seniority records collected and stored by the USW, Local 303; due to limitations of available union records the study cohort is restricted to workers employed between 1980 and 2007 only. Seniority records were collected at least once per year to evaluate incidents, complaints, and payroll and membership changes. Full name, department, and social security number (SSN) were available for workers ever-employed between 1980 and 2007. Records also included work histories with month and year start dates for the company and department, including the 'pot room'. Gaps in employment were deduced by a worker's absence on subsequent records.

The current USW president for the Local 303 gave access to paper seniority records with permission from the regional supervising team. Three members of the study team scanned the seniority records on site over two days in March 2018. The images were then processed through

text recognition software and converted to text files. Three study team members manually cleaned the text files for fidelity based on the scanned images to ascertain each individual's name and SSN from May through August 2018.

A commercial database (LexisNexis Accurint) was used to obtain information on birth date, sex, and race for workers in the cohort. The search included driver's license and US voter registration databases and was conducted using complete name and SSN. The search provided birth date and sex for all individuals in the cohort and provided information on race for 93% of individuals. Of those missing race data who were deceased, race was obtained from the death certificate, leaving 30 workers with missing race information (4%). LexisNexis searches and worker reports indicate that the vast majority of non-white workers at the Badin plant identified racially as Black and are therefore referred to as Black throughout [26]. There were no exclusions applied to the study cohort due to missing data. The study protocol was approved by the University of North Carolina Institutional Review Board.

Exposure Characterization

The USW data include department histories for workers in the cohort. However, no agent-specific exposure information, industrial hygiene monitoring data, or job-specific work histories were available for this study. Therefore, we conducted analyses based on comparisons of those ever employed as hourly, USW members at the Badin Alcoa plant between 1980 and 2007 to an external reference population. Because of the potential for a broad range of hazards and toxic exposures, as well as limited chemical exposure measurement data, this approach is similar to several prior studies on aluminum smelting work and health have characterized exposure simply as ever-employment in an aluminum smelting plant [36,62].

In addition, we conducted internal analyses using employment in the pot room as a proxy for potential exposure to hazards associated with pot-room processes. This proxy was informed by both worker testimony and previous studies. Two of the authors (PV and EM) participated in several Concerned Citizens of West Badin meetings and interviews with former workers. In these conversations, former workers in Badin report that the least desirable jobs in the plant involved laboring in the pot rooms with combusting petroleum and inhalation of black soot, and that these jobs were most frequently assigned to Black workers. The workers assigned to these tasks were informally known as "the bull gang," although their official job titles were varied [26]. Workers describe exposure to extreme heat as well as concerns about asbestos and toxic chemicals involved in repair of and waste management related to spent pots at the plant [98]. Scientific literature also suggests that jobs in the pot room are the most hazardous at an aluminum smelting plant. Workers involved in pot room production are likely to have elevated exposure to carcinogens, heat, and other agent classes of concern here (e.g. PAHs including benzo-a-pyrene, sulfur dioxide, and trace metals including chromium and nickel), relative to those working in other departments [40,56,58,68]. The two most common pot room technologies are [1] the "Soderberg," method in which coke-pitch paste is fed into pots and baked, and [2] the "prebake" method, in which coke-pitch paste is baked into a solid in a separate carbon plant before use in the pots. Emissions are much higher when the Soderberg process is used [42], but the prebake method may increase risk of worker exposure to particulate matter [43]. The Badin plant used the prebake method during the entire study period.

Mortality and Cause of Death Ascertainment

Vital status of the study cohort was ascertained through December 31, 2017 using the National Death Index (NDI). All 754 workers were searched in the NDI from 1980 through

2017, using name, SSN, date of birth, sex, and race. The NDI provided the date of death and underlying cause of death codes listed on the death certificate of decedents. The NDI probabilistically identified decedents, and we included all those designated as "likely matches," with probabilities above the threshold imposed by the NDI [117]. The underlying cause of death code was classified according to the International Classification of Diseases (ICD) revision that was in effect at the time of death [117]. Individuals not identified as deceased in the NDI as of December 31, 2017 were presumed to be alive.

Statistical Analysis

We estimated all-cause and cause-specific Standardized Mortality Ratios (SMR) using the National Institute of Occupational Safety and Health's Life Table Analysis System (NIOSH LTAS) [118]. The SMR serves as a summary measure of the USW study population's mortality experience relative to that of the general population in North Carolina. It is the ratio of observed to expected number of deaths in the USW study population. The expected number of deaths is the number that would have been observed had the study population experienced the mortality rate of the general North Carolina population over the same time period. Expected deaths are estimated within strata of age, race, and sex distribution to remove any confounding effect of these factors [93]. Assumptions required for this interpretation are 1) that the person-time distribution in the study population would have been the same in the absence of work exposures and 2) that the reference mortality rates represent the rates the cohort would have experienced in the absence of exposure [88,94]. For all SMRs, cause of death categories are based on the NIOSH-119 underlying cause of death classification scheme [117].

Workers' person-time at risk of mortality in the study cohort began accumulating on the first observed date of hire or on January 1, 1980 if hire occurred before that date. Follow-up

ended on December 31, 2017 for those presumed alive and on the date of death for decedents. Person-time at risk was stratified by years of work in the pot room (never, ever, 0 to 5 years, 5 to 10 years, and 10+ years), attained age (5-year groups), calendar period of hire (5-year intervals), sex (male, female), and binary race (white, Black). Referent rates were based on North Carolina mortality rates in the general population from 1980 through 2017. All-cause and cause-specific SMRs were stratified by race and sex to assess disparities in mortality patterns. We calculated confidence limit ratios for cause-specific SMRs by taking the absolute value of the ratio of upper to lower confidence bounds to provide a readily comparable indication of precision for each SMR.

We used a negative control to adjust for "healthy worker effects," a known limitation of SMRs wherein the SMR may be biased in worker populations, because working populations tend to be healthier (and therefore tend to have lower mortality rates) than the general population [119,120]. A negative control adjusted estimate of the SMR may reduce bias related to healthy worker effects by reproducing a condition that involves the same healthy worker selection effect but does not involve the causal effect of work exposure. The adjusted SMR (aSMR) is estimated by comparing the observed cause-specific mortality rates in the worker population to cause-specific mortality rates in the worker population that satisfy these bias reduction conditions [88].

All cancer, bladder cancer, mesothelioma, respiratory cancer, and non-malignant respiratory disease (COPD and asthma)-specific aSMRs were estimated using negative control mortality rates from the worker cohort. These causes were identified as outcomes of interest *a priori* because they have been associated with known workplace exposures at the Badin smelter and other plants with similar processes in previous studies [2,40,44,56,64,69,97,121–125] and/or were of specific concern among former workers [98]. To meet the assumptions required to reduce healthy

worker bias in the aSMR, negative control causes of death were chosen that were 1) unlikely to be affected by smelting work exposures and 2) shared the sources and directions of healthy worker survivor bias as the causes of death of interest [88]. The negative control causes of death included: non-malignant disorders of blood and blood forming organs, diabetes mellitus, mental and psychological disorders, nervous system disorders, diseases of the circulatory system (other than heart disease), diseases of the digestive system, diseases of the skin and subcutaneous system, diseases of the musculoskeletal and connective system, and diseases of the genito-urinary system. For adjusted estimates, the negative control mortality rates are used in place of the referent rates when estimating the SMR. Adjusted SMRs were estimated using SAS [88,95].

We used SRRs to compare all-cause, all cancer, bladder cancer, mesothelioma, respiratory cancer, and respiratory disease-specific mortality among individuals who ever worked in the pot room to that among those who never worked in the pot room. Comparisons were also made according to duration of employment in the pot room. SRRs were used rather than SMRs, because SMRs for two different groups are not readily comparable due to the use of different standards of age and demographic characteristics in each group. SRRs are mutually standardized to the covariate distribution of the total cohort. Distributions of person-time worked in the pot room by race and gender, alongside the pot room SRRs, were estimated to assess disparities in mortality related to work in the pot room and workplace segregation. SRRs were estimated using LTAS [118].

Results

Table 4.1 shows characteristics of the study cohort. The cohort of 754 workers had a median age of 33 (Interquartile range, IQR: 28-40) at the beginning of follow up and was mostly

male (94%). 493 (65%) of the workers were white, with 35% identifying as Black or other (96% Black, 4% other). At the end of follow-up, December 31, 2017, 507 (67%) of the cohort was presumed to be alive, while 247 (33%) were deceased. The cohort had a median of 31 (IQR: 26-36) years of follow-up and a median attained age of 67 (IQR: 60-74) at the end of follow-up. The oldest presumed alive worker at the end of follow-up was 95. Black males spent a disproportionate amount of time working in pot rooms compared to their White counterparts. Black males spent 38.5% of their total employed person-time in pot rooms compared to 19.9% among White males, 7.6% among White females, and 15.6% among Black females. The full cohort spent 25.5% of employed person-years in the pot room.

Standardized Mortality Ratios

Table 4.2 shows all-cause and cause-specific mortality relative to the North Carolina general population. After standardizing for age, race, sex and calendar period, the all-cause mortality rate in the overall worker population was lower than that in the general population of North Carolina (SMR: 0.81, 95% CI: 0.71-0.92, CLR: 1.30). However, there was imprecise evidence of excess mortality due to mesothelioma (SMR: 15.00, 95% CI: 3.82-40.82, CLR: 10.69), bladder cancer (SMR: 2.27, 95% CI: 0.62-5.82, CLR: 9.39), urinary cancer (SMR: 1.52; 95% CI: 0.56-3.30, 5.89) cancer of male genital organs (SMR: 1.42, 95% CI: 0.71-2.55, CLR: 3.59), multiple myeloma (SMR: 1.65; 95%: 0.34-4.81, CLR: 14.15) and leukemia (SMR: 1.93, 95% CI: 0.63-4.49, CLR: 7.13). Combining urinary tract and bladder cancer (both are predominantly transitional cell carcinomas [126]), the SMR is 1.72 (95% CI: 0.88-3.07, CLR: 3.49). There were relatively fewer deaths than expected due to heart disease (SMR: 0.84 95% CI: 0.65-1.07, CLR: 1.65) and other diseases of the circulatory system (SMR: 0.49, 95 CI: 0.25-0.86, CLR: 3.44).

There was relatively lower mortality among both Black men (SMR: 0.80, 95% CI: 0.65-0.96) and among white men (SMR: 0.82, 95% CI: 0.69-0.97) than expected based on reference population rates. Black females in the study cohort experienced more deaths than would have been expected based on North Carolina reference rates (SMR: 1.23, 95% CI: 0.40-2.86), and Black males experienced more deaths due to cancer than would have been expected (SMR: 1.11, 95% CI: 0.79-1.51). Only two deaths occurred among the 29 white females in the study cohort, whereas n were expected. Because of the small cohort size and sparse numbers in stratified estimates, detailed race and sex stratified SMRs are not shown.

Table 4.3 reports all cancer, bladder cancer, mesothelioma, respiratory cancer, and respiratory disease mortality in the study cohort relative to negative control mortality in the study cohort. The SMR for the negative control outcomes in study cohort was 0.65 (95%CI: 0.50-0.87). The adjusted all cancer SMR is 1.55 (95% CI: 1.10-2.21) after correcting for healthy worker bias, suggesting excess cancer mortality among USW-member workers at the Badin aluminum plant. The adjusted SMRs also indicated excesses of bladder cancer and mesothelioma mortality (aSMR: 3.47, 95%CI: 1.25-9.62 and aSMR: 17.33, 95%CI: 5.40-55.59, respectively).

Standardized Rate Ratios

Table 4.4 shows SRRs comparing rates of all-cause and cause-specific mortality among ever pot room workers to those among workers in the cohort who never worked in the pot room. Ever workers in the pot room had higher all-cause mortality than never pot room workers (SRR: 2.83, 95% CI: 0.88-9.10). Ever workers in the pot room also had higher cancer mortality than never pot room workers (SRR: 1.48, 95% CI: 0.92-2.39). Workers who ever worked in the pot room had higher rates of respiratory cancer mortality than never pot room workers (SRR: 2.99, 95% CI: 1.23-7.26). Relative to never pot room workers, those who worked 0-5 years in the pot

room had elevated respiratory cancer mortality rates (SRR: 2.28, 95% CI: 0.66-7.81), and the excess was more extreme among workers who spent 5-10 years in the pot room (SRR: 4.27, 95% CI: 1.17-15.62). Those with over 10 years in the pot room had lower respiratory cancer mortality than the never pot room workers (SRR: 0.71, 95% CI: 0.19-2.69).

Discussion

All-cause mortality in the study population of USW members working at the Badin smelter was lower than that of the general North Carolina population, adjusted for age, sex, race, and calendar year. This is consistent with other studies of SMRs comparing aluminum smelting workers' mortality patterns to those in general populations [123,124]. However, the cohort experienced excess mortality due to bladder cancer and mesothelioma, causes identified *a priori* to be of concern based on exposure to asbestos in production processes [98] and the IARC classification of exposures in this industry as carcinogenic to the bladder [2]. These findings are based on only 4 and 3 deaths, respectively. Elevated rates for other causes of interest were indicated, including cancers of the urinary tract, male reproductive cancer and leukemia/lymphoma mortality [127]. While the numbers of deaths due to these causes are small, the patterns are consistent with observations in prior studies of smelters. Cancer, and specifically bladder cancer and mesothelioma, have documented associations with smelting work [2,26,40,44,69,124] Soot is a known cause of scrotal cancer [128]. Benzene and other polycyclic aromatic hydrocarbons as well as polychlorinated biphenyls (which are potential occupational hazards in the aluminum smelting industry, and also may be environmental hazards in Badin as these agents have been detected in Badin site wastewater evaluations [72,74]) have been associated with lymphatic and hematopoietic cancers [129–132].

Black workers spent a greater proportion of their employed person-years in the pot room than white workers. Black female workers at the Badin smelter experienced excess mortality overall, relative to the general population of North Carolina, and Black male workers experienced excess death due to cancer. These findings support the narratives of former workers [26]. Standardized rate ratios comparing mortality among workers with more time in the pot room to that among those who never worked in the pot room provide support for former workers' concerns related to long term employment in dangerous conditions at the plant. Workers ever-employed in the pot room had 1.5 times the rate of cancer mortality as never pot room workers. They reference that the "25 year club," which came with some corporate benefits and was only opened to Black workers after establishment of the Badin United Steel Workers (USW) Local 303 division in the 1960s [75], was often referred to as "the graveyard," because so many workers died after working in the plant for 25 years. Our findings are consistent with previous studies suggesting that the pot room process entails greater worker exposure to carcinogens than others at the plant [40,56,58,68]. Much of the literature distinguishes between the two most common smelting approaches with regard to carcinogenicity. Workers' exposure to emissions are higher when using the "Soderberg" method [42], but the pre-bake method (which was used at the Badin plant during the study period) is associated with higher risk of particulate matter exposure [43]. Our study provides evidence of elevated cancer risk among pot room workers despite use of a smelting method that is generally presumed to be safer with regard to carcinogenic exposures [30,133].

The reduced all-cause mortality in this study cohort relative to the general population may be due to healthy worker biases, as this has been documented in similar occupational cohort studies [88]. Further, the rates of mortality and poverty were high in North Carolina, relative to the

general US population during the study period [134,135]. Individuals in the study cohort were able to obtain employment in a unionized plant, where they likely gained access to better health and retirement benefits as well as higher income than the general population. This is likely to have conferred mortality advantages within the study population that limit their comparability to general population reference rates. Adjusted SMR estimates attempt to mitigate biases related to unmeasured differences between the study cohort and the general population of North Carolina.

If the assumptions of our negative control choice are met, i.e., 1) the negative control causes are not influenced by work exposures, 2) the same healthy worker survivor bias affects the negative control causes as the causes of interest, and 3) the bias is in the same direction and of similar magnitude for the negative control and causes of interest, then the adjusted SMRs represent less biased estimates than the SMRs using the external population reference rates. Our adjusted SMR results suggest occupationally-associated excesses of mortality due to all cancer, bladder cancer, and mesothelioma, and they also provide support for excess respiratory cancer and other respiratory disease-related mortality. Previous studies have documented excess respiratory disease and cancer incidence among aluminum smelting workers [56,64,68,123]. Moreover, the results are consistent with the general conclusions of IARC, which classifies aluminum smelting occupational exposures as a Group 1 carcinogen indicating "*sufficient evidence of carcinogenicity* in humans" [2,48].

The mortality deficit we find among Black men relative to the general population may be due to a greater difference in mortality between workers and the general population among Black than white men and a higher all-cause mortality rate among Black men than white men in the general population. A similar property of these disparities has been observed in previous southern occupational cohort studies in the US south during similar time periods to this study [136].

Our findings are consistent with "inverse hazard law," as described by Krieger et al. The inverse hazard law states that "the accumulation of health hazards tends to vary inversely with the power and resources of the populations affected [137,138]." This structural bias manifests in epidemiologic study in the form of limited and biased data, and affects who is counted in the study population. For example, salaried workers, who were more often white, likely had lower average exposure to many dangerous conditions compared to their hourly counterparts at the Badin plant, who were more often Black. Because salaried employees were not unionized, their records and vital status are not included in this analysis. Workers also expressed concerns about take-home exposures related to laundering of clothing worn in the pot room. However, we do not have mortality follow-up on family members of the workers in the study.

This study has several limitations, the first of which is the lack of specific exposure quantification. There is consistency in former workers' reports about specific agents of concern, but the prevalence and intensity of exposures in the cohort over time has not been quantified. This limited our ability to make mortality comparisons within the Badin workforce with respect to exposure. However, we were able to characterize mortality relative to work time in the pot room, a department known to be more dangerous than other smelting departments [26,40,56,58,68,98].

Second, the small numbers of some cancer outcomes reduced statistical precision and limited our ability to make reliable inference from stratified estimates. A large proportion of the cohort was younger at the end of follow-up than the typical age at which some causes of disease result in fatality. For example, the median attained age at the end of follow up is 67 while the national median age at lung cancer diagnosis is 70 [139]. We plan to update this cohort in the future to improve the statistical precision of estimates.

The imprecision in the all-cause SRR is likely related to the divergent age distributions in the ever and never pot room worker populations. Both groups accrued similar amounts of person-time before attained age 40, but the ever pot room group experienced greater mortality. Between attained ages 40 and 64, both strata experienced less mortality than would have been expected in the general population of North Carolina. At attained age 65 and older, the never pot room group accrued substantially more person time than the ever pot room stratum, while the ever pot room workers experienced excess mortality in this attained age group. The 65 and older age group is up-weighted in the summary ever pot room SRR because both groups are standardized to the total cohort age distribution. This may be due to changing demographics in the worker population that represents a gradual decay of the healthy worker hire effect over time. People are healthiest relative to the general population when they are first employed, and this advantage gradually reduces as they age. This has been observed in occupational cohort studies and can lead to underestimations of work exposure-related mortality risk in SMRs [140].

A third limitation of this study is that information on cause of death does not reflect the true burden of disease in the cohort, especially non-fatal conditions and diseases with long periods of morbidity. Under registration of some causes of death is known to affect several diseases of interest to former workers, including lung and bladder cancer [141]. Death certificate coding also has documented misclassification of disease diagnoses associated with the cause of mortality [142,143]. Diseases of interest were captured in our analyses only if they were reported as underlying causes on the death certificate.

Strengths of this study include that it used available data to address the concerns of former workers at the Badin aluminum smelting plant. It involved the enumeration of a novel cohort and preliminary analysis of mortality with the potential for further follow-up in the future.

The work history records ranged 27 years, covering a relevant period of exposure for concerned former workers. The cohort was followed for a median of 31 years—adequate time to ascertain mortality related to most causes of interest.

This study also included an exposure assessment process involving input from the USW and Concerned Citizens of West Badin. The research addresses a concern with direct public health need, substantiates and documents workplace injustices in the pot room that are consistent with worker complaints [98], involves an application of community-based participatory methods which are underused in occupational epidemiology [144,145], and uses advanced statistical methodological techniques for dealing with healthy worker biases. While SMR analyses are vulnerable to a form of healthy worker bias, we attempt to indirectly address this bias through calculation of adjusted SMRs, and we also calculated SRRs which are internal comparisons of rates.

Our study suggests that this study cohort of hourly, union-member aluminum workers experienced higher rates of bladder cancer and mesothelioma mortality than the general population of North Carolina, standardized by sex, age, race, and calendar period. However, the SMRs for these outcomes are based on small numbers. Black females experienced excess all-cause mortality, and Black males experienced excess cancer mortality relative to the general population. Workers in the pot room experienced more all-cause and cancer mortality than those who never worked in the pot room. After adjusting for healthy worker survivor bias, we found that the study population had elevated rates of all cancer, bladder cancer, and mesothelioma mortality—all causes of *a priori* interest due to worker concern and previous scientific findings [2,26,40,44,69,98,124]. Former workers at the plant and their families have expressed concerns related to cancers, as well as race and gender disparities in harmful work exposures [26]. These

preliminary findings provide foundation for future mortality follow-up of this cohort and potential follow-up of broader worker and family cohorts at risk of aluminum smelting work exposures.

Table 4.1 Descriptive characteristics of 754 hourly USW members ever-employed [a] at the aluminum smelting facility from 1980-2007 in Badin, North Carolina

Characteristic	Black Female	Black Male	White Female	White Male	Total
Total number of workers, N	19	238	29	468	754
Presumed alive at end of follow-up, n (%)	14 (74)	134 (56)	27 (93)	332 (71)	507 (67)
Deceased at end of follow-up, n (%)	5 (26)	104 (44)	2 (7)	136 (29)	247 (33)
Age beginning of follow-up, median (25^{th}, 75^{th})	33 (30, 35)	35 (28, 41)	30 (25, 37)	33 (27, 40)	33 (28, 40)
Attained age at end of follow-up, median (25^{th}, 75^{th})	66 (57, 69)	68 (61, 75)	63 (59, 69)	67 (60, 74)	67 (60, 74)
Median duration of follow-up, (25^{th}, 75^{th})	34 (28, 36)	29 (23, 36)	34 (26, 36)	33 (27, 36)	31 (26, 36)
Person-years of active employment, n	218	2,791	225	5,456	8,690
Person-years of active employment in the pot room, n (%)	34 (15.6)	1,075 (38.5)	17 (7.6)	1,087 (19.9)	2,213 (25.5)
Person-years of active employment not in the pot room, n (%)	184 (84.4)	1,716 (61.5)	208 (92.4)	4,369 (80.1)	6,477 (74.5)

[a] One day or more of continuous employment in the plant.

Table 4.2 Standardized mortality ratios comparing cause-specific mortality among 754 USW members ever-employed from 1980-2007 to North Carolina referent rates [a]

Cause of death	Obs	SMR	95% CI	CLR
All Causes	247	0.81	0.71, 0.92	1.30
All Cancers	86	1.02	0.81, 1.26	1.56
Buccal & pharynx	2	1.00	0.12, 3.61	30.08
Digestive & peritoneum	19	0.94	0.57, 1.47	2.58
Esophagus	3	0.97	0.20, 2.82	14.10
Liver, biliary passages, gall bladder	2	0.67	0.08, 2.42	30.25
Respiratory	24	0.75	0.48, 1.12	2.33
Trachea, bronchus, lung	23	0.75	0.48, 1.13	2.35
Mesothelioma [b]	3	15.00	3.82, 40.82	10.69
Male genital organs	11	1.42	0.71, 2.55	3.59
Urinary	6	1.52	0.56, 3.30	5.89
Kidney	2	0.91	0.11, 3.29	29.91
Bladder & other urinary site	4	2.27	0.62, 5.82	9.39
Lymphatic & hematopoietic	9	1.28	0.58, 2.43	4.19
Non-Hodgkin's lymphoma	1	0.41	0.01, 2.28	228.00
Multiple myeloma	3	1.65	0.34, 4.81	14.15
Leukemia	5	1.93	0.63, 4.49	7.13
Other & unspecified	7	1.14	0.46, 2.34	5.09
Diseases of the respiratory system	17	0.69	0.40, 1.10	2.75
Chronic Obstructive Pulmonary Disease	10	0.74	0.35, 1.36	3.89
Asthma	1	2.33	0.06, 13.01	216.83
Heart diseases	66	0.84	0.65, 1.07	1.65
Hypertension with heart disease	4	0.94	0.25, 2.40	9.60
Ischemic heart disease	49	0.84	0.62, 1.11	1.79
Conduction disorder	3	0.68	0.14, 1.98	14.14
Other heart diseases	3	0.61	0.12, 1.77	14.75
Other diseases of the circulatory system	12	0.49	0.25, 0.86	3.44
Cerebrovascular disease	11	0.69	0.34, 1.23	3.62
Diseases of the arteries, veins, lymph	1	0.17	0.00, 1.47	147.00
Diseases of the genito-urinary system	4	0.55	0.15, 1.40	9.33
Acute glomerulonephritis & renal failure	1	1.05	0.03, 5.84	194.67
Chronic nephritis & renal failure	2	0.43	0.05, 1.57	31.40
Diseases of the digestive system	10	0.77	0.37, 1.41	3.81
Cirrhosis & other liver diseases	6	0.97	0.36, 2.11	5.86
Other diseases of the digestive system	4	0.73	0.20, 1.86	9.30
Nervous system disorders	9	1.09	0.50, 2.07	4.14
Other nervous system diseases	9	1.13	0.52, 2.15	4.13
Mental & psychiatric disorders	1	0.11	0.00, 0.64	64.00
Diabetes mellitus	7	0.70	0.28, 1.45	5.18
Diseases of skin & subcutaneous tissue	2	4.33	0.52, 15.66	30.12
Diseases of blood & blood forming organs	4	2.72	0.74, 6.97	9.42

Transportation injuries	3	0.42	0.09, 1.24	13.78
Falls	1	0.47	0.01, 2.64	264.00
Other injury	5	0.72	0.23, 1.67	7.26
Violence	7	0.83	0.33, 1.70	5.15
Intentional self-harm	6	1.17	0.43, 2.55	5.93
Symptoms & ill-defined conditions	3	1.53	0.32, 4.48	14.00
Other & unspecified causes	10	0.93	0.44, 1.71	3.89

Obs: Observed number of deaths in study cohort; SMR: Standardized Mortality Ratio; CI, Confidence Interval; CLR, Confidence Limit Ratio (the absolute value of the ratio of upper to lower confidence bounds).

[a] SMRs standardized by age, sex, race, and calendar year.

[b] Pleural cancer and mesothelioma deaths are combined.

Table 4.3 Standardized mortality ratios for deaths due to select causes of death among USW members ever-employed from 1980-2007 adjusted using negative control outcomes observed in the same cohort [a]

Cause of death	Obs	Adjusted SMR (95% CI)
Negative Control Outcomes [b]	58	1.0 (ref)
All Cancers	86	1.55 (1.10, 2.21)
Bladder & other urinary site	4	3.47 (1.25, 9.62)
Mesothelioma [c]	3	17.33 (5.40, 55.59)
Respiratory	24	1.24 (0.77, 1.99)
Diseases of the respiratory system	17	1.05 (0.61, 1.82)

Obs: Observed number of deaths in study cohort; SMR: Standardized Mortality Ratio; CI, Confidence Interval.

[a] SMRs standardized by age, sex, race, and calendar year.

[b] Negative Control Outcomes were: non-malignant disorders of blood and blood forming organs, diabetes mellitus, mental and psychological disorders, nervous system disorders, diseases of the circulatory system (other than heart disease), diseases of the digestive system, diseases of the skin and subcutaneous system, diseases of the musculoskeletal and connective system, and diseases of the genito-urinary system. Standard SMR for the combined outcomes: 0.65 (95% CI 0.50-0.87).

[c] Pleural cancer and mesothelioma deaths are combined.

Table 4.4 Standardized rate ratios comparing mortality due to select causes of death among USW members ever-employed from 1980-2007 who worked in the pot room to workers who never worked in the pot room [a]

	Pot Room SRR (95% CI) [Obs]	
Cause of death	Never	Ever
All cause	1.0 (ref) [158]	2.83 (0.88, 9.10) [89]
All cancer	1.0 (ref) [51]	1.48 (0.92, 2.39) [35]
MN bladder & other urinary site	1.0 (ref) [3]	1.58 (0.15, 15.28) [1]
Mesothelioma	1.0 (ref) [2]	3.36 (0.21, 53.78) [1]
MN respiratory	1.0 (ref) [11]	2.99 (1.23, 7.26) [13]
Non-malignant respiratory disease	1.0 (ref) [15]	0.33(0.07, 1.71) [2]

Obs: Observed number of deaths in study cohort; SRR: Standardized Rate Ratio; CI, Confidence Interval.

[a] Estimates are standardized by age, sex, race, and calendar.

CHAPTER 5. RACE-BASED METRICS IN OCCUPATIONAL EPIDEMIOLOGY: PROBLEMS AND IMPLICATIONS FOR WORKERS' COMPENSATION

Introduction

Scientific racism is a term that has been proposed to describe the misuse of science in medicine that perpetuates arguments used to justify slavery and conflates race with genetics [146–151]. In this chapter, we examine the uses of two representative race-based metrics in occupational epidemiology, lung function and hearing, and discuss how they may exemplify scientific racism. Our inquiry is informed by critical race theory, which leads us to focus on the role of racism in analyses of race differences, challenge the overt or implicit claims of objectivity in the race-based medicine scientific literature, center the experiences (as assets) of People of Color, and inform practice through interdisciplinary, contextually and historically aware inquiry [152,153]. This work is in partnership with the Concerned Citizens of West Badin—a group of former workers and their families at the segregated, now shuttered smelting facility in Badin, North Carolina who organize around environmental justice in their community [5].

We are considering lung function and hearing loss in this chapter, because both metrics are commonly monitored in manufacturing industries in response to decades of Occupational Safety and Health Administration (OSHA) regulation related to each measure [154,155]. Further, hearing loss and lung function vary by socioeconomic status [56,64,65], are good approximations of the direct impacts of hazardous work environments [64,65], have documented associations with further morbidity and declines in quality of life [52,60,66], and are frequently used measures in workers' compensation claims [156]. Importantly, clinical measurements of lung function 'correct'

for race [157–162], while those of hearing loss do not. In the United States population, Black people have better average hearing and worse average lung function than white people [91,147,163–165]. We critically evaluate how race differences in the two metrics are examined in the literature and compare how they are measured in the context of regulations and clinical practice. We also provide an empirical example, in which we estimate the impacts of race corrections on workers' compensation.

Lung Function: A clinical measure that 'corrects' for race

Lung function injury and disability thresholds are made relative to a sex and race-corrected predicted capacity [91,166]. The American Thoracic Society-recommended lung function prediction equations for the United States population are based on a study by Hankinson et al, conducted on data from the National Health and Nutrition Examination Survey (NHANES) [91,166,167]. Typically, the predicted score is generated by the spirometer using the Hankinson et al equations [91]. The spirometer is usually operated by an occupational medical staff person. The clinician—not the patient—enters the patient's race and sex into the spirometer [155]. Workers' compensation claims are evaluated based on workers' spirometric performances relative to the predicted lung capacity, and the literature says that race-specific predictions can be accurately replicated with a standard 15% decrement for Black patients [91]. This means Black workers must experience more lung function loss than white workers to qualify for compensation because their baseline is set lower by the algorithm.

Proposed mechanisms for race differences

There is repeated documentation of Black/white differences in lung function. White study participants and clinical patients have better lung function than their Black counterparts [91,147,163–

[165]. The biological mechanisms for baseline differences in lung function are seldom discussed in the literature, but the most common explanations are physiological and behavioral. Separate standard prediction equations exist for "African American, Caucasian, and Mexican-American" race groups, and they are used to define respiratory disability both clinically and legally [166,167]. Hankinson et al state that the Black/white difference in lung function "may be due to in part a difference in body build: African-Americans having on average a smaller trunk:leg ratio than do Caucasians" [91]. This is the main referenced explanation for the difference [91,165,168] despite repeated failed attempts to quantitatively explain the Black/white difference in lung function using chest and torso measurements [169–171]. Other studies more vaguely attribute the difference to genetic ancestry [163–165].

Much of the occupational epidemiology on lung function controls for smoking or restricts samples to non-smokers. This is problematic for causal identification of the impacts of work exposures, because smoking is likely to be correlated with the downstream effects of a person's job (e.g. targeted marketing, leisure tradeoffs, stress relief, social reinforcement, etc.) [172]. Despite a general lack of empirical investigation of the role of smoking in Black/white differences in lung function, it is frequently offered as a conceptual consideration. This requires some logical acrobatics, as Black Americans are less likely to be smokers than whites [173]. To avoid this obstacle, multiple studies have argued that smoking plays a role in the Black/white difference in lung function by proposing that Black smokers absorb more nicotine than white smokers [164,174,175]. While it is standard to adjust for sex in lung function prediction equations [91], we could find no proposed physiological or behavioral mechanisms to support this practice.

Impact on regulations

Most states, including North Carolina, recommend that clinical providers use the American Medical Association Guides [89] for determining disability in lung capacity when evaluating workers' compensation claims [90]. The Guides define degree of lung function impairment across four classes using two of the worker's spirometry results, forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), relative to a predicted value. The predicted value comes from the Hankinson equations, which are functions of age, sex, and height, with race-specific parameters [91]. Class 1 impairment is equivalent to no reduced lung capacity, Class 2 is defined as FVC or FEV_1 between 75 and 90% of the predicted value, Class 3 is between 50 and 74% or the predicted value, and Class 4 is lower than 50% of the predicted value. The impairment class in which a worker's results fall corresponds to the compensation they are awarded—a typical case in North Carolina might award $2,500 per each impairment class above 1 [92].

Hearing Loss: A clinical measure that does not 'correct' for race

Hearing loss is evaluated using the average of decibel thresholds a worker demonstrates across four frequencies. Black individuals have better hearing than whites [157–162], while females have better hearing than males [176]. Studies of hearing loss include some critical evaluation of whether race, sex, and/or age should be used to identify control groups [160,177], while race, age, and sex correction seems to be uncontested, standard practice in lung function research. The hearing loss literature examines the role of occupational exposures in population averages [158,178], while the lung function literature adjusts for baseline risk before examining role of occupational

exposures [91,147]. More generally, there is minimal focus on the roles of race and genetics in population distributions of hearing loss, relative to that in lung function.

Proposed mechanisms for race differences

There are multiple physiological explanations proposed in relation to the Black/white difference in hearing. The most frequently referenced theory is that melanin provides a protective function for hearing [157–159,161,162,179,180]. Others, like Helzner et al, offer "poorer cognitive function" as a risk factor for hearing loss among Black women while listing cardiovascular disease as the main risk factor among white men [158]. Additional behavioral mechanisms in the literature include nonuse of hearing protection, lack of exercise, and poor diet [178]. Helzner et al also offer different behavioral explanations by race-gender group. Occupational noise exposure is proposed as a major risk factor for white men only, moderate alcohol use is proposed for Black women only, and salicylate use for Black men only [158]. Smoking more easily fits the narrative with regard to Black/white differences in hearing relative to lung function differences, and it is referenced as a theoretical mechanism in multiple studies [158,177,178].

Impact on regulations

Lung function and hearing loss metrics are also treated differently when it comes to regulations. For hearing loss-related injuries, no race-based decrement is applied. Hearing loss injury and disability thresholds are made based on absolute decibel ranges (regardless of a worker's race or sex) [92,181,182]. If their average threshold is greater than 15 and not attributable to any degenerative or genetic disorder, workers are eligible for compensation of 70 weeks' pay for one ear and 150 weeks' pay for both ears [92].

Empirical Example: Workers' Compensation Awards

First, we analyzed a random sample of 200 Black and 200 white workers' first spirometry measurements from the demonstration database in the NIOSH Spirometry Longitudinal Data Analysis Software [79]. We then estimated the amount of workers' compensation the cohort would have received under four conditions: 1) the workers' true races are known, 2) assuming the workers are all white, 3) assuming the workers are all Black, and 4) the workers' races are unknown. For lung function estimations, we used the Hankinson et al race-specific equations in conditions 1-3, and in condition 4, we used a prediction equation that did not correct for race. We applied the Guides impairment class definitions and assumed $2,500 awards for each class above 1.

Next, we analyzed a random sample of 200 Black and 200 white adults' audiometric measurements from the 1999-2000 NHANES [80]. For hearing loss estimations, we applied race-specific equations in conditions 1-3, with a 7% decrement for white workers and a 7% increase for Black workers (informed by the race difference in the full 1999-2000 NHANES population), and in condition 4, we used audiometric output uncorrected for race. For aluminum smelting production work, the national average for 70 weeks' pay is $42,700 and 150 is $101,140 [84], so we assumed awards of $42,700 for one ear's hearing loss and $101,140 for two.

Figure 5.1 shows Black workers' and white workers' distributions of lung capacity as they would be measured to evaluate compensation—percent of predicted FVC for lung function—under two of the race specification conditions. The curve in yellow is condition 1, the percent of predicted capacities using the equations corresponding to the race of the workers (Black for Black workers and white for white workers), the purple curve is condition 2, using the white worker algorithm, and the blue curve is condition 3, using the Black worker algorithm. The

vertical line shows threshold for initial compensation, below 90% of predicted capacity. Using the Black worker algorithms, 81% of Black workers' spirometry results qualify for compensation. When applying the white worker algorithm to the Black workers, 94% of the results qualify for compensation. Among white workers, 60% qualify for compensation when using the white algorithms and 30% qualify when using the Black algorithm.

Figure 5.2 shows distributions of left ear hearing loss in decibels. The yellow curve is condition 1, the decrement or increase corresponding to the race of the workers (7% increase for Black workers and 7% decrease for white workers), the purple curve is condition 2, using the white worker decrement, and the blue curve is condition 3, using the Black worker increase. The vertical line shows threshold for initial compensation, above 15 decibels. Using the white worker decrement, 47% of workers qualify for compensation, and 63% qualify when using the Black worker increase.

Table 5.1 shows the total amount of compensation estimated for the worker cohorts under each condition. The total compensation for lung function impairment that would have been received by the 400 workers varies by up to $422,500 when changing only their assumed race—the absolute values for FVC remained constant in each condition. Among only 400 workers, removing the race correction from the prediction equation resulted in 34 additional worker impairment designations, as the total award value under condition 4 was $85,000 greater than that under the current standards (condition 1). Total compensation for hearing loss is substantially higher than for lung function impairment. Additionally, there were no changes in total compensation when applying the white decrement but a substantial rise in compensation in when applying the Black hearing increase.

Race-Based Metrics in Occupational Epidemiology Reflect Scientific Racism

The field of occupational epidemiology has roots in supporting worker organizing [183], and much of it is currently motivated by social and environmental justice efforts [28,184,185]. Despite this, scientific racism in the form of race-based metrics is especially pervasive in the field. We argue there are three main reasons for its prominence. First, discussions of race and racism are largely absent in occupational epidemiology literature. A relatively small body of literature examines differences in occupational characteristics and exposures by gender and race [144]. Historically, most occupational cohort studies have focused on white male industrial workers, with little empirical analyses of exposures among non-male or non-white workers [8]. Since most work has been done on white males, the typical distributions of exposures and outcomes that inform occupational safety guidelines and compensation thresholds may be biased. Further, the validity of clinician-assigned race categories is problematic [186] and is becoming increasingly so as patient and worker populations in the United States grow and change.

Second, we use Cedric Robinson's terminology, "racial capitalism," to frame our understanding of how scientific racism operates within occupational epidemiology. Robinson describes racial capitalism as a structure in which race is a central operating logic of the political, economic, and social system of capitalism. He discusses how racism against Black communities is the engine that allows United States capitalism to grow, not only in slavery, but also in 20th and 21st century industrialization [27]. Industry's reliance on fundamentally unequal races may perpetuate use of race-based metrics to describe—and avoid social, environmental, and occupational explanations for—differences in health by race.

As Lundy Braun highlights in her work on the history of spirometry, the main measurement improvements in the literature have focused on identifying specific genetic

influences on outcomes [164,187]. This reinforces a narrative of biologic determinism by adding measurements of ancestry to improve algorithmic prediction while further burying social, environmental, and occupational measures as relevant predictors of lung function [147,188]. More material resources are required to measure these markers of genetic ancestry than to measure social factors, but literature conflicting with genetic explanations remains largely uncited [188–190]. Examining this phenomenon through the lens of racial capitalism would suggest this demonstrates a vested interest in maintaining a biological explanation for Black/white differences in lung function. As one former worker in Badin put it, "[the company] would spend a million dollars to keep from giving me a dime." [26,98]

Finally, while it is established in the literature that toxins are unevenly distributed by racial capitalist logics [191], molecular level alterations are mostly imperceptible to people's senses and difficult to prove. This leads to dependence on forms of knowledge production that are limited in their articulation of race and have complicated histories of denying, erasing, and reiterating racism [192].

Conclusions

In this chapter, we discussed conceptual, historical, and practical issues with race-based metrics in occupational epidemiology. We then estimated one of several (e.g. job loss, displacement, psychological impacts, etc.) potential material consequences of using race-based metrics in occupational epidemiologic practice. Our empirical example demonstrated substantial differences in typical compensation for hearing loss and lung capacity impairment, with hearing loss being compensated at a much higher dollar value. Further, it showed the potential impacts of using race-based metrics in occupational injury compensation determination—current evaluation

standards under compensate workers for lung disease because of their assumed race alone. This aspect of our science is based in racist logic with origins in eugenics used to reify racial differences for capital gains [153,193]. Through use of race-based metrics, occupational epidemiology research is facilitating structural racism in the form of job segregation, thereby undermining core values of the discipline whose primary purpose is to support workers [183].

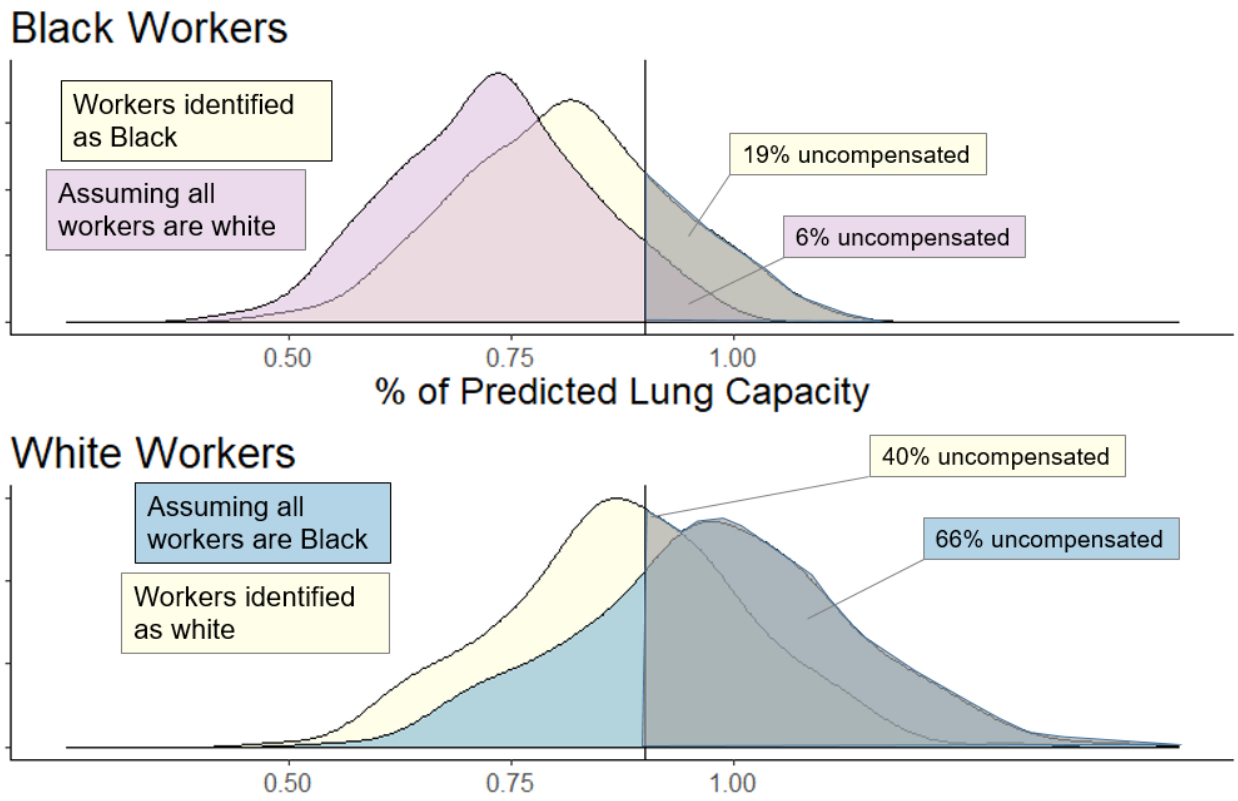


Figure 5.1 Distributions of percent of predicted value for forced vital capacity (FVC) under different race-based correction conditions

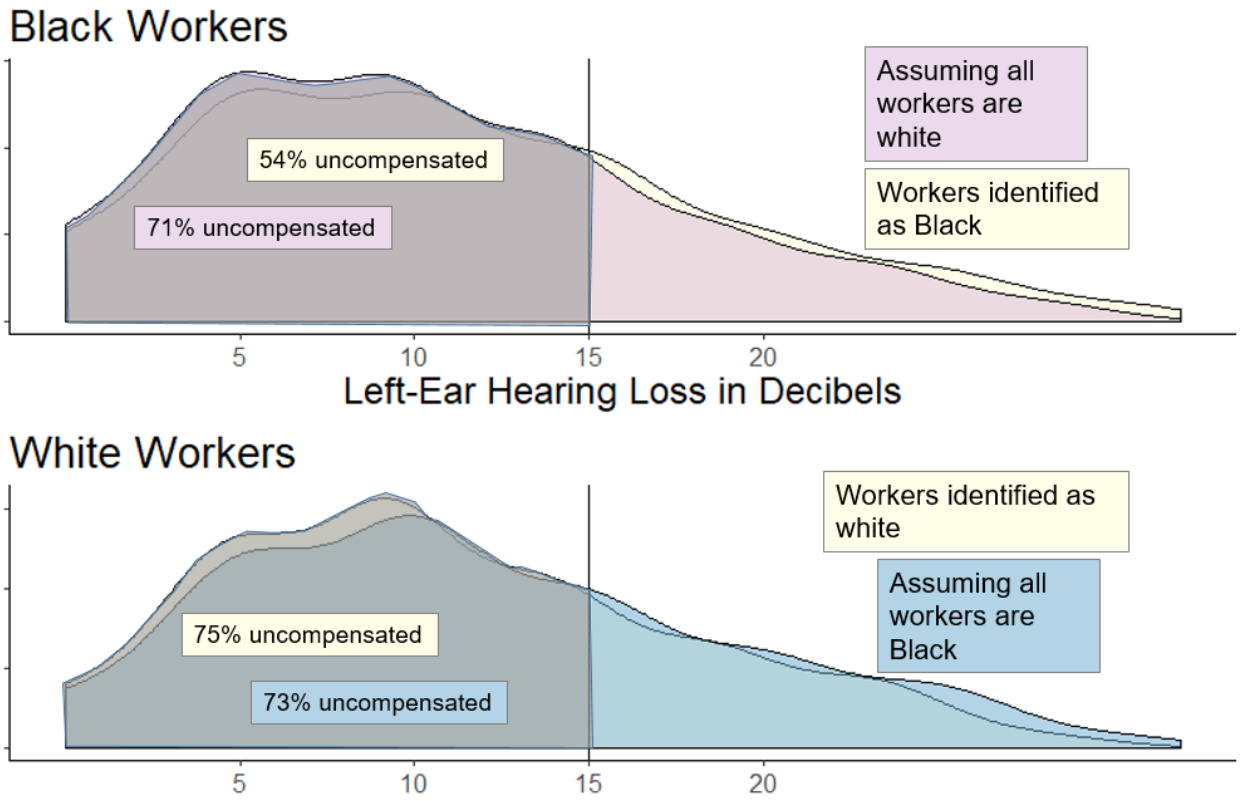


Figure 5.2 Distributions of left ear hearing loss under different race-based correction conditions

Table 5.1 Condition descriptions and total compensation awards for lung function impairment and hearing loss in the example cohorts N=400, N=400.

Condition	Assumed Race Distribution	Total Compensation Awarded for Lung Function Impairment	% change from Condition 1	Total Compensation Awarded for Hearing Loss	% change from Condition 1
1	200 Black workers, 200 white workers	$967,500		$5,998,420	
2	400 white workers	$1,190,000	+23%	$5,998,420	-0%
3	400 Black workers	$772,500	-20%	$7,875,040	+31%
4	Races unspecified	$1,037,500	+8%	$5,998,420	-0%

CHAPTER 6. DISCUSSION

In this dissertation research, we found that Black males were most likely to be hired into low prestige, high danger, and high exposure jobs at the aluminum smelting plant in Badin, North Carolina. Black females were next most likely to be hired into the most dangerous jobs, and women received lower paying jobs than men. Over time since hire, white workers tended to transition out of undesirable jobs while a larger proportion of Black workers remained in dangerous and low prestige jobs even after accruing 20 years' tenure. These findings provide quantitative support for the histories former worker in West Badin have shared.

We also found that there was excess all-cancer, bladder cancer, and mesothelioma among hourly workers who were members of the United Steel Workers, Local 303 in Badin, after adjusting for healthy worker survivor bias. Consistent with findings in the first aim, we found that Black males and females experienced more active work time in the pot room, the most dangerous department, than their white counterparts. Standardized rate ratios comparing mortality rates among ever to that among never pot room workers indicated excess all-cause and cancer mortality among workers employed in the pot room.

The empirical work inspired a critical assessment of how occupational diseases are recognized and compensated by race and sex. We discussed how race-based metrics in occupational epidemiology recreate structural racism, and we demonstrated potential implications for practice through workers' compensation. Our example analyses imply that there is substantial under compensation of Black workers for lung function impairment.

Strengths of this Research

This dissertation involves major innovations in the conduct of interdisciplinary and collaborative occupational epidemiology in support organizing of efforts and yielding policy implications. It provides novel contributions to the aluminum occupational epidemiology literature.

Interdisciplinary and Collaborative Occupational Epidemiology

This dissertation research brings together theory, methods, and constructs from different disciplines within epidemiology (social, environmental, cancer, and occupational), as well as those from outside of public health (geography, sociology, medicine, industrial hygiene, and activist scholarship). The work is collaborative, and the questions, methods, and outputs are developed in partnership with the Concerned Citizens of West Badin, the North Carolina Environmental Justice Network, and the United Steel Workers as well as with academic associates from the University of North Carolina at Chapel Hill, the University of Texas at Austin, and Stanford University.

The household survey will also provide novel contributions. We conducted a review of studies that addressed occupational and residential exposures, particularly through surveys conducted at a community level, and specifically with input and direction from the communities most affected. While community-based research is becoming more accepted as a legitimate form of knowledge production [21,194], it was difficult to find instruments and survey tools used for data collection. There were three notable mentions of development of the survey tool [195–197]. Similar to the limited previous studies, our survey tool is site-specific, and has involved community members in the survey development.

Organizing and Policy Implications

This research can support workplace safety regulations, with a focus on equity [198,199]. Occupational epidemiology is a key informant for current workplace hazard standards. The novel data and methodological combinations may support these policies for aluminum production, as well as similar industrial settings. It highlights un-representative pieces of existing toxic exposure and health information with regard to women and Black workers. This may inform better policy to ameliorate disparate work exposure impacts on disease, injury, and mortality outcomes. The evidence of disparities in work exposures and illness provided by this dissertation may improve regulations development to make industrial sites safer for all workers.

This research also aims to support the Concerned Citizens of West Badin's organizing efforts. Collaborative involvement in this research has strengthened connections between the Concerned Citizens and similar groups in the state through the North Carolina Environmental Justice Network.

Novel Contributions to Aluminum Occupational Epidemiology Literature

This dissertation responds to calls in the literature to combine health disparities and work hazard research [11,113,144]. The majority of cohorts supporting occupational epidemiology studies have been white men [8]. No studies to date have measured or assessed distributions of aluminum occupational exposure or related disease outcomes by race or gender. However, one study of coke oven steelworkers in the US found that 69% of those working jobs with the highest levels of toxic exposure were non-white, while 9% of those working jobs with the lowest exposure levels were non-white [111]. Given the concerns voiced by West Badin community members, disparities such as these are of primary interest. This dissertation uses methods for characterizing racial inequality in workplace exposures, disease, and mortality among workers.

Epidemiology studies are typically conducted to assess the association between exposure to one job-related hazard and one specific disease outcome in a population of workers. The isolation of exposures and specific (typically very rare) disease outcomes makes it difficult to establish causal relationships [56]. Further, focusing on the rarest outcomes and specific agents that may be causing them ignores the cumulative exposures that many communities like those in West Badin experience [11,200]. For example, residents of West Badin were systematically and historically disadvantaged, then economically constrained and exposed to toxins and hazards through their work environment while their residential areas were simultaneously polluted by the same industry [26,72]. Epidemiologic studies of the health impacts of individual constituents ignore these compounding factors.

Job exposure matrices are often used to proxy direct measurement of toxin exposure. Traditionally, the concentration of an agent or physical hazard affiliated with each job title, on average, is quantified and assigned to all workers with that title in the epidemiologic analysis. Job exposure matrices have been generated within the Alcoa contract data [39]. Qualitative validation of aluminum job exposure matrices with expert testimony (from occupational hygienists and union specialists) suggested that job exposure matrices do not adequately capture worker experience [1] and cost epidemiology studies statistical power due to exposure misclassification [201]. The worker testimony in this study can inform future research on the influence of factors unmeasured in the typical occupational exposure measurement process. For example, former workers highlighted that protective uniforms were only introduced in the 1990s at the Badin plant [26].

The findings of this research have broad public health implications. This novel exposure measurement process may inform future occupational epidemiologic studies in the aluminum

industry assessing the impacts of aluminum work exposures on other disease or injury outcomes, or in different geographic contexts. This dissertation provides a rich, NC-specific analysis. Additionally, the cohort I enumerated from USW records is available for easy use in future studies.

Limitations of this Research

There are a several limitations of the aims fulfilled in this dissertation. The first is that we are unable to directly incorporate into quantitative analyses the historical processes leading to the inequitable race and gender distributions in applicant pools. This is relevant to our treatment of socioeconomic status (SES) in the dissertation aims. We believe that worker SES is on the pathway between race/gender and job placement, and therefore will not adjust for it in quantitative models. We do, however, need to execute and interpret findings from the dissertation aims with an awareness that historical discrimination changes the race and gender distribution of the applicant pool for each job [81].

Another concern is loss of information from early years and selective survival into both the USW and Alcoa contract cohorts, given the cohorts are made up of prevalent workers with follow-up start dates of 1980 and 1985, respectively. We used sensitivity tests to assess the degree of potential bias from selective survival in analyses using each cohort. The administrative censoring at the end of follow-up may have led to missed cases of disease with long latency periods. Both the USW and Alcoa contract cohort for the Badin facility are relatively small samples. This limits our ability to make inference on stratified, cause-specific analyses of mortality and changes in endpoints.

Another limitation is construct measurement for key variables. Non-fatal conditions that ended in job termination may have measurement limitations, as these conditions were assessed for administrative surveillance purposes, not research. Additionally, there is restricted exposure classification data. Some hazards of interest have been captured and precisely measured [39], but we have limited ability to classify workers with respect to the intensity of specific agents. There are similarly limitations to the measurement of race and gender. Both come from administrative sources, and we cannot discern whether their values were self-reported or assigned. We were not be able to precisely attribute exposure and health differences to individual constructs within the range of concepts captured by the race and gender measures we model [67]. Similarly, the cause of death was obtained from diagnoses on death certificates, which are known to have systemic over and under reporting of certain causes [142]. Further, former workers in West Badin have expressed concerns that coroners had incentive to under report cancer diagnoses [98].

Finally, we must be cautious when interpreting race and sex-stratified SMRs in Aim 2, noting that, for example, work exposures may look protective among Black men relative to the general population. Rather than indicating that the workplace is less harmful for Black men, this may result from the mortality risk in the general population being much higher for Black men than other groups (and work, even dangerous work, may reduce that risk on the whole through financial mobility, etc.) [11].

Report Back

This research is being developed with former workers, and findings will be delivered back to former workers, regardless of their participation. We are planning results report back in two forms—written summaries and discussion topics at scheduled Concerned Citizens meetings.

The main content of the report back will come from the household surveys, but we will additionally include the findings of the three dissertation aims described. An example of a report back document provided at the February Concerned Citizens meeting is included in the Appendix. In previous interviews, residents expressed concerns about information necessary for effective interactions with their healthcare providers, as well as those of their children in the context of take-home work exposures [98]. These exposure summaries and associations may help Badin residents access better tailored clinical care.

Funding

Data collection and linkage for the proposed dissertation is supported by a pilot award from the North Carolina Occupational Safety and Health Education Research Center (NC OSHERC). Libby McClure is supported by a training grant from the National Institute of Environmental Health Sciences (T32 ES007018).

Conclusions

This research has potential impact for former workers in Badin, North Carolina, who have been active partners in sharing their experiences and documenting the history of the plant and the surrounding community. The main goals of this health research, in collaboration with former workers, are to validate experiences and support organizing efforts. Epidemiology findings may be used to support West Badin residents' ongoing efforts to secure reparations. Former workers also expressed interest in relevant information for their healthcare providers, and the exposure summaries we are developing aim to reduce uncertainty and facilitate better clinical care [98]. We are working to get much of this information through the household survey, because

most of the epidemiology literature about the aluminum industry does not reflect the concerns expressed by former workers. The survey is bringing new voices to the Concerned Citizens' organizing conversations, including younger members of the community.

We are developing this collaborative research by centering an effort to maintain the Concerned Citizens of West Badin and the North Carolina Environmental Justice Network as full partners. We have iteratively developed the household survey and health study research questions together, and we are planning results report back in two forms. Additionally, I scanned and digitized the paper records we obtained from the United Steel Workers, Local 303, and linked them with data from the National Death Index. This cohort may now easily be used for research to address future questions identified by the Concerned Citizens.

This study may further serve as an avenue through which the Concerned Citizens of West Badin's efforts and the experiences of Badin's workers can help prevent future industrial harms from being inflicted upon communities with newly developed or still functioning aluminum smelting, like Badin's "sister city," Alcoa, Tennessee. We will draw from the work of Black Workers for Justice in a case with a lock manufacturer in Rocky Mount, NC. Black Workers for Justice both obtained reparations for Rocky Mount workers after the plant closed and moved operations to Mexico, and also developed a partnership between Rocky Mount workers and workers in the new facility to prevent future injustices [202].

This research may also support broader workplace equity efforts [198,199]. While it is historical research, epidemiology findings from occupational cohorts continue to play important roles in current workplace hazard evaluations. The novel combination of data and approaches will support future studies of the aluminum industry. It shows how representative (or non-representative) the existing toxic exposure information is for women and Black workers, which

can inform broader assessments of disparate work exposure impacts on other diseases/injuries or in other geographic contexts. Evidence of disparities in work exposures and illness can improve regulations development to make industrial sites safer for all workers.

APPENDIX

West Badin Household Survey

Research Assistant Name: _____

Date: _____ **Recorder 1 File #: _____**

Start time: _____ **Recorder 2 File #: _____**

Alcoa BadinWorks Occupational Health Survey

Introduction

Thank you for participating in this research. I will ask you questions about you and your family's work and health history. You do not have to answer any questions that you are not comfortable answering, and you may ask me to stop asking questions at any time. To improve the accuracy of the study and our understanding about toxic exposures from the plant and health, it is very important that you answer the questions as accurately and honestly as possible.

Please wait until I have read all the answer choices for a question before you respond. Do you have any questions before we begin?

First we'll talk about basic demographic info.

Demographics

1. How long have you lived at this residence? _____
2. Which age group describes you?
   - □ 18-24
   - □ 25-34
   - □ 35-44
   - □ 45-54
   - □ 55-64
   - □ 65+
   - □ Don't know/prefer not to answer
3. How do you describe your race (check all that apply)?
   - □ American Indian or Alaska Native
   - □ Black or African American
   - □ Native Hawaiian or other Pacific Islander
   - □ Asian
   - □ White or Caucasian
   - □ Multiracial
   - □ Other:_____
   - □ Don't know/prefer not to answer
4. Are you Hispanic, Latino, Latina, or Spanish origin?
   - □ Yes

- No
- Don’t know/prefer not to answer

5. How do you describe your sex?
   - Male
   - Female
   - Other
6. What is the highest level of schooling that you have completed?
   - Less than high-school diploma
   - High-school diploma
   - Some college, no degree
   - Associate degree
   - College degree
   - More than college degree
   - Other:_____
   - Don’t know/prefer not to answer

Research Assistant Notes:

Now I'll ask about you and your family's toxic work exposures and work experiences

Work Exposure History

7. Did you work at Alcoa's smelting plant? Y / N

   If so, when and for how long? _____

8. Did you have family members who worked at the smelting plant? Y / N

   If so, when and for how long?

   a. _____

   b. _____

   c. _____

9. When you/your family member worked at Alcoa, were you exposed to any of the following?

   - ☐ Asbestos
   - ☐ PCBs
   - ☐ Extreme heat
   - ☐ Inhalation of dust
   - ☐ Direct skin contact w/ known toxins
   - ☐ Dust/chemicals on your clothes or body that you carried home

   Open-ended probes:

   - Tell me more about that
   - How long did your body carry it?
   - Can you describe the job or situation where you experienced that?

10. When you/your family member worked at Alcoa, did you experience any of the following?

    - ☐ Intimidation
    - ☐ Physical violence
    - ☐ Overt racism
    - ☐ Threat of losing your job
    - ☐ Anything else not mentioned?

      If so, what_____

    Open-ended probes:

    - Tell me more about that
    - How did you address the situation?
    - Can you describe where you experienced that?

Research Assistant Notes:

Next is the health history section about you and your family members

Health History

11. Have you or anyone in your family/household ever experienced (been diagnosed with) any of the following? (checkbox)

    - ☐ Cancer
        - If so, type_____
    - ☐ Liver Damage
    - ☐ Ischemic Heart Disease
    - ☐ Hearing loss
    - ☐ Carpal tunnel
    - ☐ Injury on the job
    - ☐ COPD
    - ☐ Bronchitis
    - ☐ Asthma
    - ☐ Asbestosis
    - ☐ Thyroid problems
    - ☐ Anything else not mentioned?
        - If so, what_____

    Open-ended probes:

    - Tell me more about that
    - When did you/they get sick?
    - How did you/they get diagnosed? [Alcoa doctor, health department]
    - What did you/they do about it?

- Where did you/they get health care?
- How severe was the disease/injury?

Research Assistant Notes:

Last we'll talk about your broader observations.

Impacts

12. What are your concerns or observations about work at the Alcoa facility?

    Open-ended probes:

    - When did you notice that?
    - How have your concerns/observations changed over time?
    - How has working there and/or having a family member work there impacted your life?
    - How did it impact the community?
    - Do you have concerns about future generations living in Badin? Other families who might be connected to aluminum work?

Research Assistant Notes:

Those are all of my questions. I just want to follow up to see if you have anything to add, and ask if you're interested in seeing results of this research study.

Comment

13. Do you have other concerns we did not ask about?

Results Sharing

14. Do you want to receive results of this study?

    If so, where should we send them? (Email or mailing address)

    _____

    _____

15. If we host a report back meeting where we present the results of the study, would you like to attend?

    If so, where can we contact you for scheduling? (Phone number)

    _____

Sample Report Back Materials

Concerned Citizens of West Badin & Libby McClure

Libby's Dissertation: *Disparities in Work Exposures, Health, and Mortality at the Alcoa Aluminum Smelting Facility in West Badin, North Carolina*

Defense: **April 7, 2020** at 2pm Room 2020 Bondurant Hall (321 S Columbia St, Chapel Hill, NC 27514)

Collaboration Timeline

- **2015-2016** – Naeema Muhammad and Pavithra Vasudevan (North Carolina Environmental Justice Network) conduct oral histories in collaboration with the Concerned Citizens of West Badin

- **April 2016** – Pavithra writes play based on interviews, *Race and Waste in an Aluminum Town*

  Race and Waste in an Aluminum Town was performed near Badin, followed by an open discussion. Community members reported:

  - The least desirable jobs in the plant involved work in the pot rooms
  - These jobs were most frequently assigned to Black workers
  - Former workers also mentioned the "25 year club," which came with some corporate benefits and was only opened to Black workers after the establishment of the Badin United Steel Workers Local 303 division, was often referred to as "the graveyard," because so many workers died after working in the plant for 25 years
- **February 2017 –** Macy Hinson, Richard Leak, and Valerie Tyson visit the Environmental Justice Class at UNC-Chapel Hill

← Valerie, Richard, and Macy shared their stories about working at the Alcoa plant with public health students at UNC-Chapel Hill. Valerie brought her scrap book of the Black community in Badin—25 year club inductees, graduation and wedding announcements, and obituaries.

The CCWB first raised the question **motivating Libby's dissertation research**:

Were Black workers disproportionately exposed to job-related toxins and hazards that cause disease and death?

No research has been done on mortality or differences in work exposures at Alcoa's Badin facility.
No research has examined disparate work exposures by race in the aluminum industry.

- **July – October 2017** – Pavithra, Nate DeBono, and Libby scan seniority records from USW

  We collected name, age, race, sex, and work history for all union members between 1980 and 2002. Then, we linked these with the National Death Index to analyze differences in mortality and cancer mortality by race, sex, and time in the pot room.

- **March 2018** – Pavithra and Libby draft household surveys

- **May 2018** – Concerned Citizens choose survey and give feedback on questions

- **June 2018** – Survey trainings begin

  Macy Hinson and Richard Leak helped train two young members of the West Badin community, Chelsea Cagle and Lee-Lee Allen, on survey administration and told them about the history of the Concerned Citizens.

- **September 2018** – Libby gains access to company records

  We analyzed jobs at hire by race and sex at the Badin plant between 1985 and 2002.

- **October 2018** – Libby and members of the Concerned Citizens review all of the job titles in the company data to identify which ones were most dangerous

- **November 2018** – Chelsea and Lee-Lee get opportunities outside of Badin, Jonitka Hall and Priya Sadagopan begin conducting household surveys

  We developed this flyer describing the survey research, which we distributed at meetings:

Research Collaboration – Health Risks and Alcoa Work Environment in Badin

What this Research Is

This research project is a collaboration between the Concerned Citizens of West Badin, the North Carolina Environmental Justice Network (NCEJN), and researchers from UNC, Chapel Hill. It is a health study about illness and death as well as toxic exposures among former Alcoa workers and their families in Badin, North Carolina.

In this health study, we will document disease and toxic exposures associated with work at Alcoa's Badin plant. We are also interested in tracing the health impacts of discriminate exposure by race and gender, based on information from Badin residents and former employees.

Why Do a Health Study

We plan to share anything we learn about exposure and health concerns. We *may* also be able to demonstrate a relationship between these exposures and disease.
A study like this could be an opportunity to get community members involved and may be useful in efforts to protect the health of future generations.

Why Not Do a Health Study

It is possible that we may *not* be able to prove a direct connection between exposures and diseases experienced by community members. In the past, this type of finding has been used by industry as evidence that no problem exists.

How We Plan to Do This Health Study

We can will assess associations between occupational exposures and disease outcomes by matching union or pension records to injury, cancer, or death records.

We are also conducting a survey to:
1) document the experiences of workers and their families, and
2) find out what is missing from the existing research on aluminum smelting work and health.

How You Can Help with This Health Study

We are doing a household survey, door-to-door, in West Badin. One of two surveyors may come to your home to ask about your and/or your family members' experience working at the Badin Alcoa plant. The surveyors are named Jo and Priya, and their photos are shown on the back of this sheet. We can also administer the survey over the phone. Feel free to contact us if you or someone you know is interested in participating.

We welcome community members to share any relevant information with us. Please contact us to learn more about this study.

Who We Are
Surveyors

Jonitka Hall (Jo) is a student at the University of North Carolina-Greensboro. She is interested in community health and environmental justice.

Supriya Sadagopan (Priya) is a student at the University of North Carolina-Chapel Hill. She is interested in research on race-related health disparities.

Study Leaders

Libby McClure is a student in Epidemiology at the University of North Carolina-Chapel Hill. She is interested in environmental justice research that supports social change.

Phone: 785-865-8212
Email: emcclure@unc.edu

Naeema Muhmmad is the organizing co-director for the NCEJN. She is married to Saladin Muhammad and together they have 3 children, 10 grandchildren, and 7 great grandchildren. They have been married 52 years and reside in Rocky Mount, NC.

Phone: 252-314-0703
Email: naeema1951@gmail.com

Pavithra Vasudevan is an assistant professor at the University of Texas-Austin. Pavithra did her dissertation research in Badin and wrote a play based on West Badin residents' experiences.

Phone: 214-796-6458
Email: pavithra@austin.utexas.edu

- **June 2019** – The Concerned Citizens of West Badin host the NCEJN Quarterly Meeting

Valerie Tyson, Pavithra Vasudevan, Libby McClure, Macy Hinson, Elizabeth Haddix, and Naeema Muhammad at the NCEJN Quarterly Meeting

Communities with similar struggles came from all over the state in solidarity. Valerie, Richard, and Macy shared their stories and answered questions.

- **October 2019** – Macy Hinson, Richard Leak, and Libby McClure present at the annual Environmental Justice Summit

  We talked about motivation and methods for the household survey.

- **December 2019** – Concerned Citizens organizes public hearing around clean-up of the Alcoa dumping sites

Community members discussed a history of neglect of toxic waste in Badin.

- **April 2020** – Libby defends dissertation

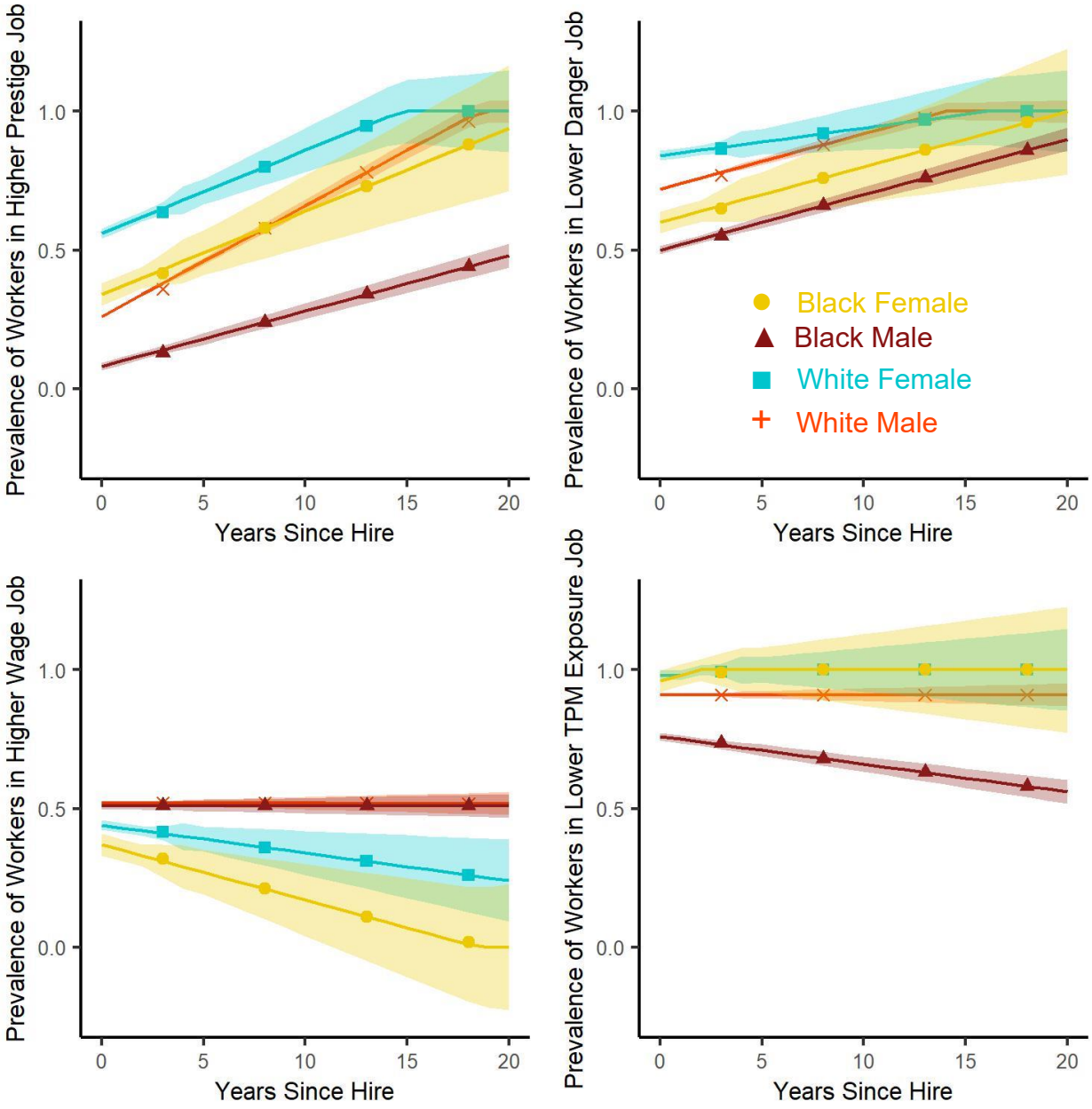
  Key Findings:
  1. Black workers were most likely to be hired into most dangerous jobs and least likely to transition out of them.
  2. There has been excess cancer mortality among Black workers and pot room workers relative to the general North Carolina population.
  3. Race-based clinical metrics result in Black workers being under compensated for lung function impairment related to work exposures.

- **May 2020** – Complete survey transcription

  Pavithra and Libby to share findings at Concerned Citizens meeting.

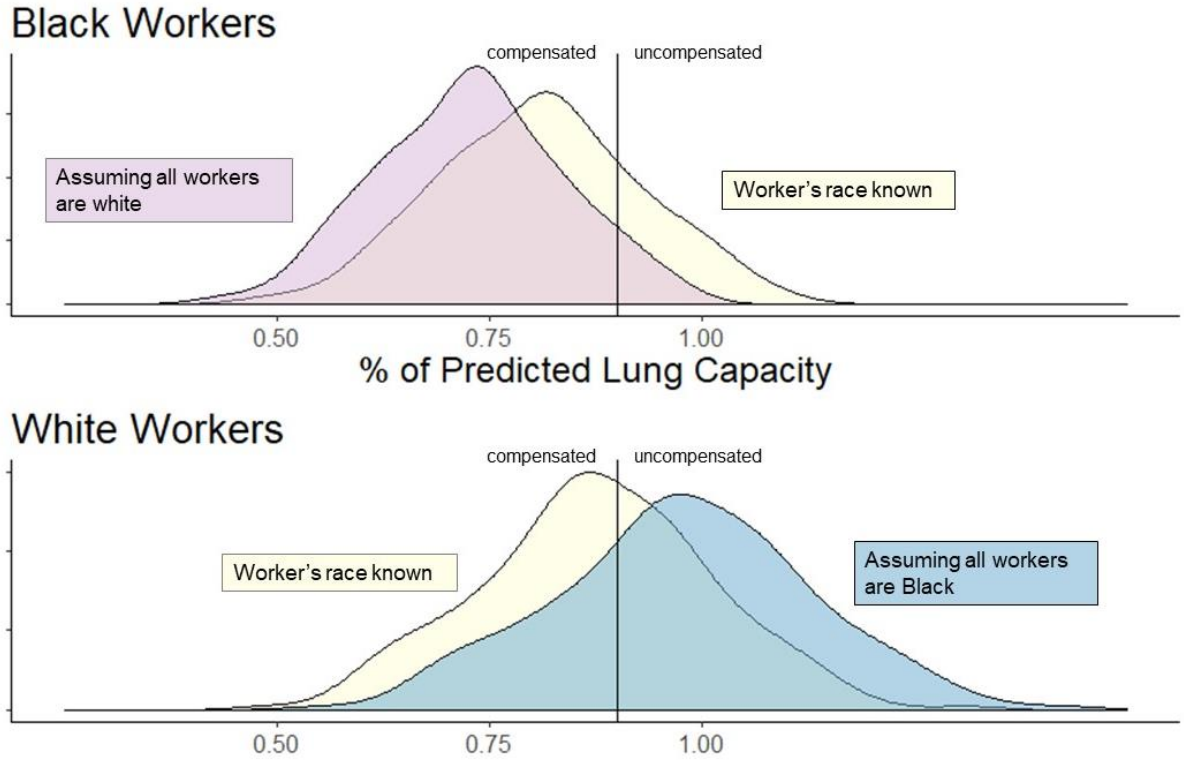
Libby's Dissertation

Key Finding 1: Black workers were most likely to be hired into least desirable jobs and least likely to transition out of them.



Prevalence Workers in More Desirable Jobs Over Years Since Hire by Race and Sex in the Full Badin Worker Cohort, 1985-2007 (N=1,234)

Key Finding 2: Race-based clinical metrics result in workers being under compensated for lung function impairment related to work exposures.



Distributions of percent of predicted value for forced vital capacity (FVC) under different race-based correction conditions

Workers' compensation for respiratory injury is determined by evaluating percent of predicted lung capacity, a comparison of a worker's lung capacity to an algorithmically predicted race-specific lung capacity. The algorithm sets predicted lung capacity to be 15% worse for Black workers than White workers. This means Black workers must experience more lung function loss than white workers to qualify for compensation because their baseline is set lower by the algorithm.

Widespread and unquestioning belief in the inherent physiological inferiority of Black Americans perpetuates systems that limit the size of industry payouts for workplace injuries.

Key Finding 3: There has been excess cancer mortality among Black workers and pot room workers relative to the general North Carolina population.

Among USW-member workers at the Badin Alcoa facility between 1985 and 2002, relative to the general North Carolina population in the same years of similar age, race, and sex:

- There was excess death due to **all cancer** (about **1.6 times** as much as expected)
- There was excess death due to **mesothelioma** (about **17 times** as much as expected)
- There was excess death due to **bladder cancer** (about **3.5 times** as much as expected)
- **Black females** had more **all-cause deaths** than would be expected
- **Black males** had more **cancer deaths** than would be expected

Among USW-member workers at the Badin Alcoa facility between 1985 and 2002 who **ever worked in the pot room**, relative to those who **never worked in the pot room**:

- There was a higher proportion of Black male and Black female workers than white male and white female workers working in the pot room
- There was excess death all causes (about **3 times** as much)
- There was excess death due to cancer (about **1.6 times** as much)

Status of Household Survey

- **25 former workers** and/or family members of workers have completed the survey
- Still collecting phone numbers to contact for the **phone survey**
- Nearly everyone we have talked to experienced **toxic work exposures**, overt **racism** at work, and **cancer** in their family

REFERENCES

1. Friesen MC, Demers PA, Spinelli JJ, LE ND. Validation of a Semi-quantitative Job Exposure Matrix at a Söderberg Aluminum Smelter. *The Annals of Occupational Hygiene*. 2003;i(6):947–. doi:10.1093/annhyg/meg059

2. IARC. Occupational Exposures During Aluminium Production. *IARC Monographs*. 2012;2005(100F):215–224.

3. Otterbourg K. Alcoa and the great North Carolina power grab | Fortune.com. Fortune. http://fortune.com/2010/11/30/alcoa-and-the-great-north-carolina-power-grab/. Published 2010. Accessed April 15, 2017.

4. Franklin JH. *The Rich History of African Americans in North Carolina*.; 2000.

5. NCEJN. *NCEJN Congratulates the Concerned Citizens of West Badin Community | North Carolina Environmental Justice Network*.; 2013. https://ncejn.wordpress.com/2013/09/18/ncejn-congratulates-the-concerned-citizens-of-west-badin-community/. Accessed February 21, 2017.

6. Wing S. Whose epidemiology, whose health? *International journal of health services : planning, administration, evaluation*. 1998;28(2):241-252. doi:Doi 10.2190/Y3ge-Nqck-0lnr-T126

7. Delegates to the First National People of Color Environmental Leadership Summit. *The Principles of Environmental Justice*. Washington Office of Environmental Justice; 1991.

8. Murray LR. Sick and tired of being sick and tired: scientific evidence, methods, and research implications for racial and ethnic disparities in occupational health. *American journal of public health*. 2003;93(2):221-226.

9. Cullen MR. The Alcoa Study: 1997-present. 2013.

10. Krieger N. *Epidemiology and the People's Health*. Oxford University Press; 2011. doi:10.1093/acprof:oso/9780195383874.001.0001

11. Lipscomb HJ, Loomis D, McDonald MA, Argue RA, Wing S. A Conceptual Model of Work and Health Disparities in the United States. *International Journal of Health Services*. 2006;36(1):25-50. doi:10.2190/BRED-NRJ7-3LV7-2QCG

12. Green JR. *Workers' Struggles, Past and Present : A "Radical America" Reader*. Temple University Press; 1983.

13. Loomis D, Richardson D. Race and the risk of fatal injury at work. *American journal of public health*. 1998;88(1):40-44.

14. Robinson JC. Trends in racial inequality and exposure to work-related hazards, 1968-1986. *AAOHN journal : official journal of the American Association of Occupational Health Nurses*. 1989;37(2):56-63.

15. Windham L. *Knocking on Labor's Door : Union Organizing in the 1970s and the Roots of a New Economic Divide*. Chapel Hill, NC: University of North Carolina Press; 2017.

16. Gibbs GW, Labrèche F. Cancer Risks in Aluminum Reduction Plant Workers. *Journal of Occupational and Environmental Medicine*. 2014;56. doi:10.1097/JOM.0000000000000003

17. Nayak P. REVIEW: Aluminum: Impacts and Disease. *Environmental Research Section A*. 2002;89:101-115. doi:10.1006/enrs.2002.4352

18. Krieger N. Got Theory? On the 21st c. CE Rise of Explicit use of Epidemiologic Theories of Disease Distribution: A Review and Ecosocial Analysis. *Current Epidemiology Reports*. 2013;1(1). doi:10.1007/s40471-013-0001-1

19. Krieger N. Living and Dying at the Crossroads: Racism, Embodiment, and Why Theory Is Essential for a Public Health of Consequence. *American Journal of Public Health*. 2016;106(5). doi:10.2105/AJPH.2016.303100

20. West C, Crenshaw K, Gotanda N, Peller G, Thomas K, Crenshaw K. *Critical Race Theory : The Key Writings That Formed the Movement*.

21. Ford CL, Airhihenbuwa CO. Commentary: Just What is Critical Race Theory and What's it Doing in a Progressive Field like Public Health? *Ethnicity & Disease*. 2018;28(Supp 1):223. doi:10.18865/ed.28.S1.223

22. Jones CP. Invited Commentary: "Race," Racism, and the Practice of Epidemiology. *American Journal of Epidemiology*. 2001;154(4):299-304. doi:10.1093/aje/154.4.299

23. Muhammad M, De Loney EH, Brooks CL, Assari S, Robinson D, Caldwell CH. "I think that's all a lie…I think It's genocide": Applying a Critical Race Praxis to Youth Perceptions of Flint Water Contamination. *Ethnicity & Disease*. 2018;28(Supp 1):241. doi:10.18865/ed.28.S1.241

24. Coates RD. *Covert Racism : Theories, Institutions, and Experiences.* BRILL; 2011.

25. Sewell AA. The Racism-Race Reification Process. *Sociology of Race and Ethnicity*. 2016;2(4):402-432. doi:10.1177/2332649215626936

26. Vasudevan P. An Intimate Inventory of Race and Waste. *Antipode*. January 2019. doi:10.1111/anti.12501

27. Robinson CJ. *Black Marxism : The Making of the Black Radical Tradition*. University of North Carolina Press; 2000.

28. Rector J. Environmental Justice at Work: The UAW, the War on Cancer, and the Right to Equal Protection from Toxic Hazards in Postwar America. *Journal of American History*. 2014;101(2):480–502. doi:10.1093/jahist/jau380

29. Barham Brad, Bunker SG, O'Hearn D. *States, Firms, and Raw Materials : The World Economy and Ecology of Aluminum*. University of Wisconsin Press; 1994.

30. Benke G, Abramson M, Sim M. Exposures in the Alumina and Primary Aluminium Industry: an Historical Review. *The Annals of Occupational Hygiene*. 1998;42(3):173-189. doi:10.1093/annhyg/42.3.173

31. Gendron R, Ingulstad M, Storli E, eds. *Aluminum Ore : The Political Economy of the Global Bauxite Industry.* Univ Of Brit Columbia Pr; 2014.

32. Bray E. *USGS Minerals Information: Aluminum*.; 2015.

33. Rønneberg A, Andersen A. *Mortality and Cancer Morbidity in Workers from an Aluminium Smelter with Prebaked Carbon Anodes–Part II: Cancer Morbidity.*; 1995:250–4. http://www.ncbi.nlm.nih.gov/pubmed/7795740 http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=PMC1128203.

34. Armstrong B, Tremblay C, Baris D, Thériault G. Lung Cancer Mortality and Polynuclear Aromatic Hydrocarbons: A Case-Cohort Study of Aluminum Production Workers in Arvida, Quebec, Canada. *American Journal of Epidemiology*. 1994;139(3):250-262. doi:10.1093/oxfordjournals.aje.a116992

35. Björ O, Damber L, Edström C, Nilsson T. Long-term follow-up study of mortality and the incidence of cancer in a cohort of workers at a primary aluminum smelter in Sweden. *Scandinavian journal of work, environment & health*. 2008;34(6):463–70.

36. Costello S, Neophytou AM, Brown DM, et al. Incident Ischemic Heart Disease After Long-Term Occupational Exposure to Fine Particulate Matter: Accounting for 2 Forms of Survivor Bias. *American Journal of Epidemiology*. 2016;183(9):861–868. doi:10.1093/aje/kwv218

37. Neophytou AM, Costello S, Brown DM, et al. Marginal structural models in occupational epidemiology: Application in a study of ischemic heart disease incidence and PM2.5 in the US aluminum industry. *American Journal of Epidemiology*. 2014;180(6). doi:10.1093/aje/kwu175

38. Neophytou AM, Noth EM, Liu S, et al. Ischemic heart disease incidence in relation to fine versus total particulate matter exposure in a U.S. aluminum industry cohort. *PLoS ONE*. 2016;11(6). doi:10.1371/journal.pone.0156613

39. Noth EM, Dixon-Ernst C, Liu S, et al. Development of a job-exposure matrix for exposure to total and fine particulate matter in the aluminum industry. *Journal of exposure science & environmental epidemiology*. 2014;24(1):89–99. doi:10.1038/jes.2013.53

40. Lavoue J, Gerin M, Cote J, Lapointe R. Mortality and Cancer Experience of Quebec Aluminum Reduction Plant Workers. Part I: The Reduction Plants and Coal Tar Pitch Volatile (CTPV) Exposure Assessment. *Journal of Occupational and Environmental Medicine*. 2007;49(9):997-1008. doi:10.1097/JOM.0b013e3181484cf3

41. Benke G, Sim M, Fritschi L, Aldred G. Beyond the Job Exposure Matrix (JEM): the Task Exposure Matrix (TEM). *The Annals of Occupational Hygiene*. 2000;44(6):475-482. doi:10.1093/annhyg/44.6.475

42. International Aluminum Institute. *The Aluminum Sector Greenhouse Gas Protocol*.; 2006.

43. Debia M, Weichenthal S, Tardif R, Dufresne A. Ultrafine Particle (UFP) Exposures in an Aluminium Smelter: Soderberg vs. Prebake Potrooms. *Environment and Pollution*. 2012;1(1). doi:10.5539/ep.v1n1p2

44. Armstrong BG, Tremblay CG, Cyr D, Thériault GP. Estimating the relationship between exposure to tar volatiles and the incidence of bladder cancer in aluminum smelter workers. *Scandinavian journal of work, environment & health*. 1986;12(5):486–93. doi:10.5271/sjweh.2109

45. Rabinowitz PM, Slade M, Dixon-Ernst C, Sircar K, Cullen M. Impact of OSHA final rule--recording hearing loss: an analysis of an industrial audiometric dataset. *Journal of occupational and environmental medicine*. 2003;45(12):1274-1280. doi:10.1097/01.jom.0000100040.45929.42

46. NIOSH, OSHA, US Coast Guard, US EPA. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities*.; 1985.

47. US Department of Health and Human Services, NIOSH. *Work Related Lung Disease Surviellance Report*. Washington DC; 1991.

48. World Health Organization. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans PREAMBLE*.; 2006.

49. Romundstad P, Haldorsen T, Andersen A. Cancer incidence and cause specific mortality among workers in two Norwegian aluminum reduction plants. *American journal of industrial medicine*. 2000;37(2):175-183.

50. Rønneberg A, Langmark F. Epidemiologic evidence of cancer in aluminum reduction plant workers. *American journal of industrial medicine*. 1992;22(4):573-590.

51. Spinelli JJ, Band PR, Svirchev LM, Gallagher RP. Mortality and cancer incidence in aluminum reduction plant workers. *Journal of occupational medicine : official publication of the Industrial Medical Association*. 1991;33(11):1150-1155.

52. Rønneberg A. *Mortality and Cancer Morbidity in Workers from an Aluminium Smelter with Prebaked Carbon Anodes-Part III: Mortality from Circulatory and Respiratory*

Diseases.; 1995:255–261. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1128204/pdf/oenvmed00064-0039.pdf.

53. Martin SC, Larivière C. Community health risk assessment of primary aluminum smelter emissions. *Journal of occupational and environmental medicine*. 2014;56(5 Suppl):S33-9. doi:10.1097/JOM.0000000000000135

54. Gibbs GW, Labrèche F, Busque M-A, Duguay P. Mortality and Cancer Incidence in Aluminum Smelter Workers. *Journal of Occupational and Environmental Medicine*. 2014;56(7):739–764. doi:10.1097/JOM.0000000000000175

55. Donoghue AM, Frisch N, Ison M, et al. Occupational asthma in the aluminum smelters of Australia and New Zealand: 1991-2006. *American Journal of Industrial Medicine*. 2011;54(3):224-231. doi:10.1002/ajim.20925

56. Radon K, Nowak D, Heinrich-Ramm R, Szadkowski D. Respiratory health and fluoride exposure in different parts of the modern primary aluminum industry. *International archives of occupational and environmental health*. 1999;72(5):297–303.

57. Milham S. Mortality in aluminum reduction plant workers. *Journal of occupational medicine : official publication of the Industrial Medical Association*. 1979;21(7):475-480.

58. Rønneberg A. *Mortality and Cancer Morbidity in Workers from an Aluminium Smelter with Prebaked Carbon Anodes-Part I: Exposure Assessment*.; 1995:242–249. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1128202/pdf/oenvmed00064-0026.pdf.

59. Donoghue AM, Frisch N, Dixon-Ernst C, Chesson BJ, Cullen MR. Hearing conservation in the primary aluminium industry. *Occupational Medicine*. 2016;66(3):208-214. doi:10.1093/occmed/kqv168

60. Rabinowitz P, Galusha D, McTague M, Slade M, Wesdock J, Dixon-Ernst C. Tracking occupational hearing loss across global industries: A comparative analysis of metrics. *Noise and Health*. 2012;14(56):21. doi:10.4103/1463-1741.93326

61. Taiwo O, Galusha D, Tessier-Sherman B, et al. Acoustic neuroma: potential risk factors and audiometric surveillance in the aluminium industry. *Occupational and Environmental Medicine*. 2014;71(9):624-628. doi:10.1136/oemed-2014-102094

62. Wesdock JC, Arnold IMF. Occupational and environmental health in the aluminum industry: key points for health practitioners. *Journal of occupational and environmental medicine*. 2014;56(5 Suppl):S5-11. doi:10.1097/JOM.0000000000000071

63. Mosites E, Neitzel R, Galusha D, Trufan S, Dixon-Ernst C, Rabinowitz P. A comparison of an audiometric screening survey with an in-depth research questionnaire for hearing loss and hearing loss risk factors. *International Journal of Audiology*. 2016;55(12):782-786. doi:10.1080/14992027.2016.1226520

64. Kongerud J, Grønnesby JK, Magnus P. *Respiratory Symptoms and Lung Function of Aluminum Potroom Workers*. Vol 16. Scandinavian Journal of Work, Environment & HealthFinnish Institute of Occupational HealthDanish National Research Centre for the Working EnvironmentNorwegian National Institute of Occupational Health; 1990. doi:10.2307/40965803

65. Rabinowitz PM, Galusha D, Dixon-Ernst C, Slade MD, Cullen MR. Do ambient noise exposure levels predict hearing loss in a modern industrial cohort? *Occupational and environmental medicine*. 2007;64(1):53-59. doi:10.1136/oem.2005.025924

66. Verine Sabia S, Shipley M, Elbaz A, et al. Original Contribution Why Does Lung Function Predict Mortality? Results From the Whitehall II Cohort Study. *Am J Epidemiol*. 2010;172(12):1415-1423. doi:10.1093/aje/kwq294

67. VanderWeele TJ, Robinson WR. On causal interpretation of race in regressions adjusting for confounding and mediating variables. *Epidemiology*. 2014;25(4):473.

68. Kongerud J, Søyseth V. Respiratory disorders in aluminum smelter workers. *Journal of occupational and environmental medicine*. 2014;56(5 Suppl):S60-70. doi:10.1097/JOM.0000000000000105

69. Taiwo OA, Slade MD, Cantley LF, et al. Bladder Cancer Screening in Aluminum Smelter Workers. *Journal of Occupational and Environmental Medicine*. 2015;57(4):421-427. doi:10.1097/JOM.0000000000000377

70. ALCOA. *Our History*.; 2016. http://www.alcoa.com/global/en/who-we-are/history/default.asp. Accessed April 15, 2017.

71. Colombo A, Benfenati E, Bugatti SG, et al. Concentrations of PCDD/PCDF in soil close to a secondary aluminum smelter. *Chemosphere*. 2011;85(11):1719-1724. doi:10.1016/j.chemosphere.2011.09.018

72. Southern Environmental Law Center. *Shuttered Alcoa Plant Threatens North Carolina Community | Southern Environmental Law Center*.; 2015. https://www.southernenvironment.org/news-and-press/news-feed/shuttered-alcoa-plant-threatens-north-carolina-community. Accessed April 15, 2017.

73. Henderson B. Alcoa wins federal case over ownership of Yadkin River bed | Charlotte Observer. Charlotte Observer. http://www.charlotteobserver.com/news/local/article36922374.html. Published 2015. Accessed April 28, 2017.

74. Sorg L. PW special report: Residents of NC town long treated as a massive waste dump demand action. NC Policy Watch. http://www.ncpolicywatch.com/2019/12/16/pw-special-report-residents-of-nc-town-long-treated-as-a-massive-waste-dump-demand-action/. Published December 16, 2019. Accessed February 29, 2020.

75. Allen CJ, Hester R. Documenting the American South: Oral History of the American South. 1986.

76. Elser H, Neophytou AM, Tribett E, et al. Cohort Profile: The American Manufacturing Cohort (AMC) study. 2019;48(5):1412-1422. doi:10.1093/ije/dyz059

77. Wing S. Limits of epidemiology. *Medicine and global survival*. 1994;1(2):74-86.

78. Johnson JL, Greaves L, Repta R. Better science with sex and gender: Facilitating the use of a sex and gender-based analysis in health research. *International Journal for Equity in Health*. 2009;8(1):14. doi:10.1186/1475-9276-8-14

79. CDC. *SPIROLA Software - NIOSH Workplace Safety and Health Topic*.; 2019. https://www.cdc.gov/niosh/topics/spirometry/spirola-software.html. Accessed February 14, 2020.

80. CDC, National Center for Health Statistics. National Health and Nutrition Examination Survey Data: Audiometry Data. 2000 1999. https://wwwn.cdc.gov/Nchs/Nhanes/1999-2000/AUX1.htm#AUXU500L. Accessed February 19, 2020.

81. Treiman DJ. *Occupational Prestige in Comparative Perspective*. Elsevier Inc.; 1977.

82. Treiman DJ. A Standard Occupational Prestige Scale for Use with Historical Data. *The Journal of Interdisciplinary History*. 1976;7(2):283–304.

83. NIOSH. NIOSH Industry and Occupation Computerized Coding System (NIOCCS). U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Surveillance, Hazard Evaluation and Field Studies, Surveillance Branch. https://www.cdc.gov/niosh/topics/coding/overview.html. Published 2018. Accessed March 1, 2019.

84. U.S. Bureau of Labor Statistics. CPI Home. https://www.bls.gov/cpi/. Published 2020. Accessed August 21, 2019.

85. Robinson CF, Schnorr TM, Ii RTC, et al. Tenth Revision U.S. Mortality Rates for Use With the NIOSH Life Table Analysis System. 2006. doi:10.1097/01.jom.0000229968.74906.8f

86. IARC. *Occupational Exposures During Aluminum Production*.; 2010. https://monographs.iarc.fr/ENG/Monographs/vol100F/mono100F-22.pdf.

87. Applebaum KM, Malloy EJ, Eisen EA. Reducing healthy worker survivor bias by restricting date of hire in a cohort study of Vermont granite workers. *Occupational and environmental medicine*. 2007;64(10):681–7. doi:10.1136/oem.2006.031369

88. Richardson D, Keil A, Tchetgen TE, Cooper G. Negative Control Outcomes and the Analysis of Standardized Mortality Ratios. *Epidemiology*. 2015;26(5):727-732. doi:10.1097/EDE.0000000000000353

89. Rondinelli R. *AMA Guides to the Evaluation of Permanent Impairment*. Sixth. Chicago: American Medical Association; 2007. https://catalog.lib.unc.edu/catalog/UNCb1446960. Accessed January 9, 2020.

90. U.S. Department of Labor. A.M.A. Guides to the Evaluation of Permanent Impairment, 6th Edition - Division of Federal Employees' Compensation (DFEC) - Office of Workers' Compensation Programs (OWCP) - U.S. Department of Labor. https://www.dol.gov/owcp/dfec/AMAGuideEvalPermImpair6thEd.htm. Published 2009. Accessed January 9, 2020.

91. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric Reference Values from a Sample of the General U.S. Population. *American Journal of Respiratory and Critical Care Medicine*. 1999;159(1):179–187. doi:10.1164/ajrccm.159.1.9712108

92. NC Industrial Commission. N.C. Industrial Commission Rating Guide (February 15, 2000 Update). July 2016. http://www.ic.nc.gov/ncic/pages/ratinggd.htm. Accessed January 9, 2020.

93. Rothman KJ, Greenland S, Lash TL. *Modern Epidemiology*.

94. Richardson DB, Keil AP, Cole SR, MacLehose RF. Observed and Expected Mortality in Cohort Studies. *American Journal of Epidemiology*. 2017;185(6):479-486. doi:10.1093/aje/kww205

95. SAS Institute Inc. *SAS*. Cary, NC, USA; 2013.

96. Friesen MC, Demers PA, Spinelli JJ, LE ND. Validation of a Semi-quantitative Job Exposure Matrix at a Söderberg Aluminum Smelter. *The Annals of Occupational Hygiene*. 2003;i(6):947–. doi:10.1093/annhyg/meg059

97. Friesen MC, Benke G, Del Monaco A, et al. Relationship between cardiopulmonary mortality and cancer risk and quantitative exposure to polycyclic aromatic hydrocarbons, fluorides, and dust in two prebake aluminum smelters. *Cancer Causes and Control*. 2009. doi:10.1007/s10552-009-9329-8

98. Concerned Citizens of West Badin. Concerned Citizens of West Badin Meetings. March 2018.

99. Vasudevan P. An Intimate Inventory of Race and Waste. doi:10.1111/anti.12501

100. NCEJN. NCEJN Congratulates the Concerned Citizens of West Badin Community | North Carolina Environmental Justice Network. https://ncejn.wordpress.com/2013/09/18/ncejn-congratulates-the-concerned-citizens-of-west-badin-community/. Published 2013. Accessed February 21, 2017.

101. Washington Office of Environmental Justice D to the FNP of CELS. The Principles of Environmental Justice. 1991.

102. Elser H, Neophytou AM, Tribett E, et al. Cohort Profile: The American Manufacturing Cohort (AMC) study. doi:10.1093/ije/dyz059

103. Noth EM, Dixon-Ernst C, Liu S, et al. Development of a job-exposure matrix for exposure to total and fine particulate matter in the aluminum industry. *Journal of exposure science & environmental epidemiology*. 2014;24(1):89-99. doi:10.1038/jes.2013.53

104. Pollack KM, Agnew J, Slade MD, et al. Use of Employer Administrative Databases to Identify Systematic Causes of Injury in Aluminum Manufacturing. *AMERICAN JOURNAL OF INDUSTRIAL MEDICINE*. 2007;50:676-686. doi:10.1002/ajim.20493

105. CPI Home : U.S. Bureau of Labor Statistics. https://www.bls.gov/cpi/. Accessed August 21, 2019.

106. Applebaum KM, Malloy EJ, Eisen EA. Reducing healthy worker survivor bias by restricting date of hire in a cohort study of Vermont granite workers. *Occupational and environmental medicine*. 2007;64(10):681-687. doi:10.1136/oem.2006.031369

107. Arrighi HM, Hertz-Picciotto I. Controlling the healthy worker survivor effect: an example of arsenic exposure and respiratory cancer. *Occupational and environmental medicine*. 1996;53(7):455-462.

108. Checkoway H, Pearce N, Dement JM. Design and conduct of occupational epidemiology studies: II. Analysis of cohort data. *American Journal of Industrial Medicine*. 1989;15(4):375-394. doi:10.1002/ajim.4700150403

109. Harrati A, Hepburn P, Meausoone V, Cullen MR. Characterizing Long-Term Trajectories of Work and Disability Leave: The Role of Occupational Exposures, Health, and Personal Demographics. *Journal of Occupational and Environmental Medicine*. 2019;61(11):936–943. doi:10.1097/JOM.0000000000001705

110. Harrati A, Modrek S, Cullen MR. Absenteeism, Health, and Disability in a Large Working Cohort. In: Washington D.C.; 2017:8.

111. Costantino JP, Redmond CK, Bearden A. Occupationally related cancer risk among coke oven workers: 30 years of follow-up. *Journal of occupational and environmental medicine*. 1995;37(5):597-604.

112. Ahonen EQ, Fujishiro K, Cunningham T, Flynn M. Work as an Inclusive Part of Population Health Inequities Research and Prevention. *American journal of public health*. 2018;108(3):306-311. doi:10.2105/AJPH.2017.304214

113. Artazcoz L, Borrell C, Cortès I, Escribà-Agüir V, Cascant L. Occupational epidemiology and work related inequalities in health: a gender perspective for two complementary

approaches to work and health research. *Journal of epidemiology and community health*. 2007;61 Suppl 2(Suppl 2):ii39-45. doi:10.1136/jech.2007.059774

114. Rønneberg A, Haldorsen T, Romundstad P, Andersen A. Occupational exposure and cancer incidence among workers from an aluminum smelter in western Norway. *Scandinavian journal of work, environment & health*. 1999;25(3):207–14.

115. Vasudevan P, Smith S. The domestic geopolitics of racial capitalism. *Environment and Planning C: Politics and Space*. January 2020:2399654420901567. doi:10.1177/2399654420901567

116. Hufnagel R. *USW Members Vote to Ratify Five-Year Contract with Alcoa | United Steelworkers*.; 2014. http://www.usw.org/news/media-center/releases/2014/usw-members-vote-to-ratify-five-year-contract-with-alcoa. Accessed April 28, 2017.

117. National Center for Health Statistics. National Death Index User's Guide. 2013. https://www.cdc.gov/nchs/ndi/index.htm. Accessed January 13, 2020.

118. NIOSH. *CDC - Life Table Analysis System*.; 2019. https://www.cdc.gov/niosh/ltas/default.html. Accessed January 13, 2020.

119. Checkoway H, Pearce N, Dement JM. Design and conduct of occupational epidemiology studies: II. Analysis of cohort data. *American Journal of Industrial Medicine*. 1989;15(4):375–394. doi:10.1002/ajim.4700150403

120. McMichael A. Standardized mortality ratios and the "healthy worker effect": Scratching beneath the surface. *J Occup Med*. 1976;18(3):165-168. doi:10.1097/00043764-197603000-00009

121. Carreón T, Hein MJ, Hanley KW, Viet SM, Ruder AM. Bladder cancer incidence among workers exposed to o-toluidine, aniline and nitrobenzene at a rubber chemical manufacturing plant. *Occupational and environmental medicine*. 2014. doi:10.1136/oemed-2013-101873

122. Cassidy LD, Marsh GM, Talbott EO, Kelsey SF. Initial and continued adherence with bladder cancer screening in an occupationally exposed cohort. *Journal of occupational and environmental medicine / American College of Occupational and Environmental Medicine*. 2011. doi:10.1097/JOM.0b013e3182135841

123. Friesen MC, Demers PA, Spinelli JJ, Eisen EA, Lorenzi MF, Le ND. Chronic and Acute Effects of Coal Tar Pitch Exposure and Cardiopulmonary Mortality Among Aluminum Smelter Workers. *Am J Epidemiol*. 2010;172(7):790-799. doi:10.1093/aje/kwq208

124. Maltseva A, Serra C, Kogevinas M. Cancer risk among workers of a secondary aluminium smelter. *Occup Med (Lond)*. 2016;66(5):412-414. doi:10.1093/occmed/kqw054

125. Mamtani R, Haynes K, Boursi B, et al. Validation of a coding algorithm to identify bladder cancer and distinguish stage in an electronic medical records database. *Cancer Epidemiology Biomarkers and Prevention*. 2015. doi:10.1158/1055-9965.EPI-14-0677

126. Yaxley J. Urinary tract cancers: An overview for general practice. *J Family Med Prim Care*. 2016;5(3):533-538.

127. IARC. Agents Classified by the IARC Monographs, Volumes 1–125 – IARC Monographs on the Identification of Carcinogenic Hazards to Humans. https://monographs.iarc.fr/agents-classified-by-the-iarc/. Published 2020. Accessed February 29, 2020.

128. IARC. Overall evaluations of carcinogenicity: an updating of IARC Monographs volumes 1 to 42. *IARC Monogr Eval Carcinog Risks Hum Suppl*. 1987;7:1-440.

129. Guénel P, Imbernon E, Chevalier A, Crinquand-Calastreng A, Goldberg M. Leukemia in relation to occupational exposures to benzene and other agents: A case-control study nested in a cohort of gas and electric utility workers. *American Journal of Industrial Medicine*. 2002;42(2):87-97. doi:10.1002/ajim.10090

130. Ward Mary H., Colt Joanne S., Metayer Catherine, et al. Residential Exposure to Polychlorinated Biphenyls and Organochlorine Pesticides and Risk of Childhood Leukemia. *Environmental Health Perspectives*. 2009;117(6):1007-1013. doi:10.1289/ehp.0900583

131. IARC. IARC Monographs Volume 107: Polychlorinated Biphenyls and Polybrominated Biphenyls – IARC. https://www.iarc.fr/news-events/iarc-monographs-volume-107-polychlorinated-biphenyls-and-polybrominated-biphenyls/. Accessed March 19, 2020.

132. IARC. IARC Monographs Volume 120: Benzene – IARC. https://www.iarc.fr/news-events/iarc-monographs-volume-120-benzene/. Accessed March 19, 2020.

133. International Aluminum Institute. *The Aluminum Sector Greenhouse Gas Protocol*.; 2006. https://ghgprotocol.org/sites/default/files/aluminium_1.pdf.

134. CDC. CDC WONDER. https://wonder.cdc.gov/. Published November 2019. Accessed January 29, 2020.

135. US Census Bureau. American Community Survey (ACS). The United States Census Bureau. https://www.census.gov/programs-surveys/acs. Published 2013. Accessed January 29, 2020.

136. DeBono N, Kelly-Reif K, Richardson D, et al. Mortality among autoworkers manufacturing electronics in Huntsville, Alabama. *American Journal of Industrial Medicine*. 2019;62(4):282–295. doi:10.1002/ajim.22933

137. Krieger N, Chen JT, Waterman PD, et al. The inverse hazard law: Blood pressure, sexual harassment, racial discrimination, workplace abuse and occupational exposures in US low-income black, white and Latino workers. 2008. doi:10.1016/j.socscimed.2008.09.039

138. Krieger N, Kaddour A, Koenen K, et al. Occupational, social, and relationship hazards and psychological distress among low-income workers: implications of the "inverse hazard law." *J Epidemiol Community Health*. 2011;65(3):260-272. doi:10.1136/jech.2009.087387

139. NIH. Risk Factors: Age. National Cancer Institute. https://www.cancer.gov/about-cancer/causes-prevention/risk/age. Published April 29, 2015. Accessed February 29, 2020.

140. Pearce N, Checkoway H, Kriebel D. Bias in occupational epidemiology studies. *Occup Environ Med*. 2007;64(8):562-568. doi:10.1136/oem.2006.026690

141. Jacquez GM, Meliker J, Kaufmann A. In search of induction and latency periods: Space-time interaction accounting for residential mobility, risk factors and covariates. *International Journal of Health Geographics*. 2007;6(1):35. doi:10.1186/1476-072X-6-35

142. Percy C, Stanek E, Gloeckler L. Accuracy of cancer death certificates and its effect on cancer mortality statistics. *American journal of public health*. 1981;71(3):242–50. doi:10.2105/AJPH.71.3.242

143. Richardson DB, Loomis D, Bena J, Bailer AJ. Fatal Occupational Injury Rates in Southern and Non-Southern States, by Race and Hispanic Ethnicity. *American Journal of Public Health*. 2004;94(10). http://www.unc.edu/ davidr/trends.

144. Ahonen EQ, Fujishiro K, Cunningham T, Flynn M. Work as an Inclusive Part of Population Health Inequities Research and Prevention. *American journal of public health*. 2018;108(3):306–311. doi:10.2105/AJPH.2017.304214

145. Murray LR. Sick and tired of being sick and tired: scientific evidence, methods, and research implications for racial and ethnic disparities in occupational health. *American journal of public health*. 2003;93(2):221–6.

146. Roberts DE. *Articles What's Wrong with Race-Based Medicine?: Genes, Drugs, and Health Disparities*.; 2011. http://www.bidil.com/pnt/questions.php#1.

147. Braun L. *Breathing Race into the Machine : The Surprising Career of the Spirometer from Plantation to Genetics*. Minneapolis, MN: University of Minnesota Press; 2014.

148. Braun L. Theorizing race and racism: Preliminary reflections on the medical curriculum. *American Journal of Law and Medicine*. 2017;43(2-3). doi:10.1177/0098858817723662

149. Mansfield B. Race and the new epigenetic biopolitics of environmental health. *BioSocieties*. 2012;7(4):352–372. doi:10.1057/biosoc.2012.22

150. Obermeyer Z, Powers B, Vogeli C, Mullainathan S. Dissecting racial bias in an algorithm used to manage the health of populations. *Science*. 2019;366(6464):447-453. doi:10.1126/science.aax2342

151. Hogarth RA. *Medicalizing Blackness: Making Racial Difference in the Atlantic World, 1780-1840*. Chapel Hill: University of North Carolina Press; 2017.

152. Solorzano DG. Critical race theory, race and gender microaggressions, and the experience of Chicana and Chicano scholars. *International Journal of Qualitative Studies in Education*. 1998;11(1):121-136. doi:10.1080/095183998236926

153. Ford CL, Griffith DM, Bruce MA, Gilbert KL. *Racism: Science & Tools for the Public Health Professional*. 1 edition. (Ford CL, ed.). Washington, DC: American Public Health Association; 2019.

154. OSHA. Safety and Health Topics | Occupational Noise Exposure | Occupational Safety and Health Administration. https://www.osha.gov/SLTC/noisehearingconservation/. Published 1990. Accessed January 7, 2020.

155. OSHA. Pulmonary function testing training requirements and spirometer transmission of disease. | Occupational Safety and Health Administration. https://www.osha.gov/laws-regs/standardinterpretations/1993-06-17-0. Published 1993. Accessed January 7, 2020.

156. Sengupta I, Reno VP, Burton J, Baldwin ML. *Workers' Compensation: Benefits, Coverage, and Costs, 2010*. Rochester, NY: Social Science Research Network; 2012. https://papers.ssrn.com/abstract=2131336. Accessed January 7, 2020.

157. Jerger J, Jerger S, Pepe P, Miller R. Race difference in susceptibility to noise-induced hearing loss. *The American journal of otology*. 1986;7(6):425–9.

158. Helzner EP, Cauley JA, Pratt SR, et al. Race and Sex Differences in Age-Related Hearing Loss: The Health, Aging and Body Composition Study. *Journal of the American Geriatrics Society*. 2005;53(12):2119–2127. doi:10.1111/j.1532-5415.2005.00525.x

159. Lin FR, Maas P, Chien W, Carey JP, Ferrucci L, Thorpe R. Association of skin color, race/ethnicity, and hearing loss among adults in the USA. *JARO - Journal of the Association for Research in Otolaryngology*. 2012;13(1):109–117. doi:10.1007/s10162-011-0298-8

160. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US adults: Data from the National Health and Nutrition Examination Survey, 1999-2004. *Archives of Internal Medicine*. 2008;168(14):1522–1530. doi:10.1001/archinte.168.14.1522

161. Dement J, Ringen K, Welch L, Bingham E, Quinn P. Surveillance of hearing loss among older construction and trade workers at Department of Energy nuclear sites. *American Journal of Industrial Medicine*. 2005;48(5):348–358. doi:10.1002/ajim.20217

162. Ishii EK, Talbott EO. Race/ethnicity differences in the prevalence of noise-induced heating loss in a group of metal fabricating workers. *Journal of Occupational and Environmental Medicine*. 1998;40(8):661–666. doi:10.1097/00043764-199808000-00001

163. Hessel PA, Sluis-Cremer GK. Prediction equations for lung function in black industrial workers at Palabora Mining Company. *South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde*. 1989;76(10):548–9.

164. Kumar R, Seibold MA, Aldrich MC, et al. Genetic Ancestry in Lung-Function Predictions. *N Engl J Med*. 2010;363(4):321-330. doi:10.1056/NEJMoa0907897

165. Dement JM, Welch L, Bingham E, et al. Surveillance of respiratory diseases among construction and trade workers at Department of Energy nuclear sites. *American Journal of Industrial Medicine*. 2003;43(6):559–573. doi:10.1002/ajim.10226

166. American Thoracic Society. Lung Function Testing: Selection of Reference Values and Interpretative Strategies. *Am Rev Respir Dis*. 1991;144(5):1202-1218. doi:10.1164/ajrccm/144.5.1202

167. American Lung Association. Guidelines for the evaluation of impairment/disability in patients with asthma. American Thoracic Society. Medical Section of the American Lung Ass... - PubMed - NCBI. *Am Rev Respir Dis*. 1993;147(4). https://www.ncbi.nlm.nih.gov/pubmed/?term=8466106. Accessed January 9, 2020.

168. Scanlon PD, Shriver MD. "Race Correction" in Pulmonary-Function Testing. *New England Journal of Medicine*. 2010;363(4):385–386. doi:10.1056/NEJMe1005902

169. McDonnell WF, Seal E. Relationships between lung function and physical characteristics in young adult black and white males and females. *Eur Respir J*. 1991;4(3):279-289.

170. Jacobs DR, Nelson ET, Dontas AS, Keller J, Slattery ML, Higgins M. Are race and sex differences in lung function explained by frame size? The CARDIA Study. *Am Rev Respir Dis*. 1992;146(3):644-649. doi:10.1164/ajrccm/146.3.644

171. Whittaker AL, Sutton AJ, Beardsmore CS. Are ethnic differences in lung function explained by chest size? *Archives of Disease in Childhood - Fetal and Neonatal Edition*. 2005;90(5):F423-F428. doi:10.1136/adc.2004.062497

172. Lee JO, Horwood LJ, Lee WJ, Hackman DA, McLeod GFH, Boden JM. Social causation, social selection, or common determinants? examining competing explanations for the link between young adult unemployment and nicotine dependence. *Nicotine Tob Res*. August 2019. doi:10.1093/ntr/ntz131

173. CDC. Tobacco use among U.S. racial/ethnic minority groups--African Americans, American Indians and Alaska Natives, Asian Americans and Pacific Islanders, Hispanics. A Report of the Surgeon General. Executive summary. *MMWR Recomm Rep*. 1998;47(RR-18):v-xv, 1-16.

174. Pérez-Stable EJ, Herrera B, Jacob P, Benowitz NL. Nicotine metabolism and intake in black and white smokers. *JAMA*. 1998;280(2):152-156. doi:10.1001/jama.280.2.152

175. Aldrich MC, Kumar R, Colangelo LA, et al. Genetic Ancestry-Smoking Interactions and Lung Function in African Americans: A Cohort Study. *PLoS One*. 2012;7(6). doi:10.1371/journal.pone.0039541

176. Pearson JD, Morrell CH, Gordon-Salant S, et al. Gender differences in a longitudinal study of age-associated hearing loss. *The Journal of the Acoustical Society of America*. 1995;97(2):1196-1205. doi:10.1121/1.412231

177. Agrawal Y, Niparko JK, Dobie RA. Estimating the effect of occupational noise exposure on hearing thresholds: The importance of adjusting for confounding variables. *Ear and Hearing*. 2010;31(2):234–237. doi:10.1097/AUD.0b013e3181c6b9fd

178. Daniel E. Noise and Hearing Loss: A Review. *Journal of School Health*. 2007;77(5):225–231. doi:10.1111/j.1746-1561.2007.00197.x

179. Carter NL. Eye Colour and Susceptibility to Noise-Induced Permanent Threshold Shift. *Audiology*. 1980;19(1):86-93. doi:10.3109/00206098009072651

180. Carlin MF, McCroskey RL. Is eye color a predictor of noise-induced hearing loss? *Ear Hear*. 1980;1(4):191-196. doi:10.1097/00003446-198007000-00003

181. Ryan AF, Kujawa SG, Hammill T, Le Prell C, Kil J. Temporary and Permanent Noise-Induced Threshold Shifts: A Review of Basic and Clinical Observations. *Otol Neurotol*. 2016;37(8):e271-e275. doi:10.1097/MAO.0000000000001071

182. Kryter KD. Evaluation of Hearing Handicap. In: ; 2004.

183. Halpern W, Howard J. *Occupational Epidemiology and the National Institute for Occupational Safety and Health*. Centers for Disease Control and Prevention; 2011. https://www.cdc.gov/mmwr/preview/mmwrhtml/su6004a15.htm. Accessed February 17, 2020.

184. DeMatteo R, DeMatteo D. Workers' Fight for Justice: A Retrospective Exposure Profile Study of the GE Factory in Peterborough, Ontario. *NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy*. 2019;29(2):138–166. doi:10.1177/1048291119850779

185. Fujishiro K, Heaney CA. Justice at Work, Job Stress, and Employee Health. *Health Educ Behav*. 2009;36(3):487-504. doi:10.1177/1090198107306435

186. Braun L, Fausto-Sterling A, Fullwiley D, et al. Racial Categories in Medical Practice: How Useful Are They? *PLoS Med*. 2007;4(9):e271. doi:10.1371/journal.pmed.0040271

187. Ortega VE, Kumar R. *The Effect of Ancestry and Genetic Variation on Lung Function Predictions: What Is "Normal" Lung Function in Diverse Human Populations?* Vol 15. Current Medicine Group LLC 1; 2015. doi:10.1007/s11882-015-0516-2

188. Braun L. Race, ethnicity and lung function: A brief history. *Can J Respir Ther*. 2015;51(4):99-101.

189. Myers JE. Differential ethnic standards for lung functions, or one standard for all? *South African medical journal = Suid-Afrikaanse tydskrif vir geneeskunde*. 1984;65(19):768–72.

190. White NW. "Ethic discounting" and spirometry. *Respir Med*. 1995;89(4):312-313. doi:10.1016/0954-6111(95)90097-7

191. Pulido L. Geographies of race and ethnicity II: Environmental racism, racial capitalism and state-sanctioned violence. *Progress in Human Geography*. 2017;41(4):524-533. doi:10.1177/0309132516646495

192. Mansfield B, Guthman J. Epigenetic life: biological plasticity, abnormality, and new configurations of race and reproduction. *cultural geographies*. 2015;22(1):3-20. doi:10.1177/1474474014555659

193. Morning A. *The Nature of Race: How Scientists Think and Teach about Human Difference on JSTOR*. University of California Press; 2011. https://www.jstor.org/stable/10.1525/j.ctt1pnrht. Accessed November 26, 2019.

194. Minkler M, Victoria D, Vásquez B, Tajik M, Petersen D, Breckwich Vásquez V. Promoting Environmental Justice Through Community-Based Participatory Research: The Role of Community and Partnership Capacity. *Health Education & Behavior*. 2008;35(1):119-137. doi:10.1177/1090198106287692

195. Grossman CM, Nussbaum RH, Nussbaum FD. Cancers among Residents Downwind of the Hanford, Washington, Plutonium Production Site. *Archives of Environmental Health: An International Journal*. 2003;58(5):267-274. doi:10.3200/AEOH.58.5.267-274

196. Heaney C, Wilson S, Wilson O, Cooper J, Bumpass N, Snipes M. Use of Community-Owned and -Managed Research to Assess the Vulnerability of Water and Sewer Services in Marginalized and Underserved Environmental Justice Communities. *Journal of Environmental Health*. 2011;74(1):8-17. doi:10.2307/26329247

197. Nussbaum RH, Hoover PP, Grossman CM, Nussbaum FD. Community-Based Participatory Health Survey of Hanford, WA, Downwinders: A Model for Citizen Empowerment. *Society & Natural Resources*. 2004;17(6):547–559. doi:10.1080/08941920490452526

198. Landsbergis PA, Choi B, Dobson M, et al. The Key Role of Work in Population Health Inequities. *American journal of public health*. 2018;108(3):296-297. doi:10.2105/AJPH.2017.304288

199. Krieger N, Chen JT, Waterman PD, et al. The inverse hazard law: Blood pressure, sexual harassment, racial discrimination, workplace abuse and occupational exposures in US low-income black, white and Latino workers. *Social Science & Medicine*. 2008;67(12):1970-1981. doi:10.1016/j.socscimed.2008.09.039

200. Wing S. Environmental Justice, Science, and Public Health. *Essays on the Future of Environmental Health Research*. 2002:54-63.

201. Dewar R, Siemiatycki J, Gérin M. Loss of Statistical Power Associated with the Use of a Job-Exposure Matrix in Occupational Case-Control Studies. *Applied Occupational and Environmental Hygiene*. 1991;6(6):508-515. doi:10.1080/1047322X.1991.10387920

202. Diehl K. Black Belt Justice. Color Lines. http://www.colorlines.com/articles/black-belt-justice. Published 2000. Accessed April 28, 2017.