Chapter 7

Surviving 'Satan's Church'

Over more than a century and a half of production, aluminum plants around the world have earned a reputation for posing health hazards to neighbors and workers alike. In 1857, Henri Sainte-Claire Deville worked with the chemical company Debray, Morin and Rousseau Brothers in Glaciere, France, a suburb of Paris, to produce metallic aluminum through a chemical process using chlorides of sodium and aluminum. The plant's neighbors protested the presence of chlorine gas and salt fumes, and the operation was forced to move to Nanterre. [1] The hazards didn't disappear with the transition to the Hall-Heroult process. In early 1889, Charles Martin Hall and Arthur Vining Davis were working 12-hour shifts around the clock seven days a week at the Pittsburgh Reduction Co.'s Smallman Street smelter plant in Pittsburgh. The plant came to be called "Satan's Church" – not only because it kept them working on Sundays but because of the "dirt, soot and worse the fumes." [2]

The working environment at the Pittsburgh Reduction Co. and later Alcoa was neither safe nor secure from its earliest days. Health hazards were common, and workers could be arbitrarily hired and fired. Smelter workers daily faced the dangers of loud noise, extreme heat, explosions, electrocutions and exposure to chemical hazards, including fluorides, carcinogens, airborne alumina particulates and asbestos. Top management expressed concerns over worker safety in those early years, but the company lacked a strong policy on worker conditions, leaving local superintendents to deal with safety and health issues as they saw fit. Compared to other heavy industry jobs at the time, however, the hazards of aluminum smelters were not considered overly excessive, and the work was not mindless repetition as in mass-production assembly lines. Pushing for change was dampened by aluminum plants' locations in rural areas, where poverty was prevalent and union pressure was weak. [3]

A report by James Wesdock and Ian Arnold on the occupational and environmental health hazards in the aluminum industry published in the May 2014 Journal of Occupational and Environmental Medicine summarized the hazards facing workers in the aluminum industry. Wesdock was a full-time Alcoa employee, but the authors declared no conflicts of interest. Physical hazards for bauxite miners included noise, heat and humidity, ergonomics, vibration, naturally occurring radioactive material, and mosquito-borne illnesses. Chemical hazards were few because bauxite was considered "biologically inert." Physical hazards for workers at alumina refineries included noise, heat and humidity, vibration, ergonomics and traumatic injuries. Chemical hazards included alumina and bauxite dusts, caustic soda and diesel exhaust fumes. No clinically significant lung function decrements had been observed, the authors said. Cancer incidence and mortality studies were very limited. [4]

The number of serious physical and chemical hazards was much higher at aluminum smelters, Wesdock and Arnold reported. Physical hazards included heat, noise, ergonomics and strong electromagnetic fields produced by high-amperage buss bars connecting reduction pots. Studies at U.S. smelters had shown that heat stress levels might exceed defined occupational exposure limits, the authors said, but noise "is arguably the most prevalent occupational hazard within the aluminum industry." Wesdock and Arnold also found "a long history of academic study relative to respiratory disorders among aluminum smelter workers, particularly for those whose primary tasks occur in potrooms. Thus, the literature is replete." Much of the earlier literature originated from studies of Norwegian and Canadian smelter workers – primarily case reports and prevalence studies. More recently, Australian, European and U.S. researchers were contributing data that could help provide an overall understanding of respiratory issues, they noted. [5]

Potroom fumes and dust

Many aluminum plant health studies focused on what was called "potroom asthma," which had been linked to fluoride exposures as far back as the 1930s. But a definitive causative agent for potroom asthma had not yet been unequivocally determined, Wesdock and Arnold said. Several mortality cohort studies of aluminum production workers were continuing, and chronic obstructive pulmonary disease was a cause-specific respiratory disease of interest. Various forms of diffuse parenchymal lung disease, which could cause a dry cough or shortness of breath, had been associated with aluminum production, the authors said. Recognition that exposure to metallic aluminum powder and alumina could lead to lung diseases dated back to the 1930s. Epidemiological evidence was scant for linking interstitial lung disease to aluminum workers in mining, refining or smelting. It had been suggested that interstitial lung disease could result from co-existent exposure to asbestos or silica. [6] Asbestos products were commonly used in aluminum smelters, including the friable type used for insulating hot pipes or ductwork.

Epidemiological evidence existed showing a causal connection between exposures to certain chemicals in aluminum smelters and certain cancers, Wesdock and Arnold said. Most of the evidence related to workers at plants using open-topped Soderberg anodes, which had been linked to increased risks of lung and bladder cancer. The presumed exposure agent for the cancers was polycyclic aromatic hydrocarbons emitted by the open-top Soderberg anodes, such as used at the smelter in Columbia Falls, Mont. The release of polycyclic aromatic hydrocarbons at smelters with prebake anodes, on the other hand, was very low, Wesdock and Arnold said. Polycyclic aromatic hydrocarbons compounds primarily originated from the coal tar pitch binder used to make Soderberg carbon briquettes. Benzo(a)pyrene was typically used as a measure of polycyclic aromatic hydrocarbons exposure, and the incidence of lung and bladder cancer had been linked to cumulative exposure to this chemical. Wesdock and Arnold also cited a 2012 report by the International Agency for Research on Cancer. “There was sufficient evidence from epidemiological studies of a carcinogenic effect of occupational exposure in aluminium production based on a relatively large number of studies that showed a consistent excess of cancer of the bladder and a somewhat less consistent excess of lung cancer,” the 2012 report said. “Occupational exposures during aluminium production are carcinogenic to humans,” the report concluded. The focus of the agency’s report was polycyclic aromatic hydrocarbons chemicals, Wesdock and Arnold noted. [7]

According to the U.S. Agency for Toxic Substances and Disease Registry, asbestos materials could be found throughout older aluminum smelters – in roofing materials, floor tiles, electrical insulation and, most importantly, friable insulation for steam pipes and reduction pot exhaust flues. Asbestos fibers released from friable materials were sometimes transported across enormous potrooms by strong air currents – or wind, when the outer doors were opened. Asbestos fibers increased the hazards posed by carcinogens by providing a mechanism to insert these chemicals inside the human body – the fibers could be likened to a straw that sucked carcinogens into human cells. Some hazardous chemicals found in aluminum smelters were common to other heavy industrial facilities. Polychlorinated biphenyls (PCBs) were long used as a coolant for electrical transformers but were eliminated over time. PCBs were considered a “persistent and stable environmental contaminant.” When ingested, PCBs could cause damage to the liver, stomach and thyroid gland, and they were considered carcinogenic. Mercury was a naturally occurring metal in the environment but only could be absorbed by plants and animals in its organic form, methyl mercury. Exposure to high levels of mercury could damage the nervous system, the brain, kidneys and fetuses. Arsenic was a naturally occurring element also found in raw ores. Ingesting inorganic arsenic could cause cancer of the liver, bladder, kidney and lung. Incomplete studies indicated that organic arsenic was less toxic to humans than inorganic arsenic. [8]

For some health experts, the metal smelter workers were producing was potentially hazardous. According to a 1986 database on hazardous chemicals compiled by the National Library of Medicine, aluminum was considered a hazardous substance in certain forms, as cited by the Department of Transportation and the Environmental

Protection Agency. The workplace exposure limits for airborne aluminum or aluminum oxide (alumina) was 10 milligrams per cubic meter. The hazards posed by exposure to aluminum dust included irritation or scratching of eyes and lung scarring, with symptoms of coughing and shortness of breath. Various methods to reduce dust were discussed in the National Library of Medicine database, as well as different types of personal protective equipment that might help protect workers from the hazards, but the database stated in all capital letters that "workplace controls are better than personal protective equipment." A cancer hazard also existed, the database's authors said. "There is evidence of an increase in bladder, lung and other cancers among aluminum smelter workers," they said. "The increase appears to be due to exposure to polycyclic aromatic hydrocarbons, not to aluminum compounds." [9] Not everyone agreed about the dangers posed by aluminum. According to a 1997 public health assessment by the Agency for Toxic Substances and Disease Registry, "exposure to aluminum is usually not harmful" because "the bloodstream absorbs very little aluminum from the digestive tract and the kidney removes most of what the bloodstream does absorb." [10]

Coal tar pitch volatiles

Health experts increasingly focused on the hazards posed by polycyclic aromatic hydrocarbons or polycyclic organic matter in the latter decades of the 20th century, but knowledge about the risks from exposure to carbon materials can be traced back two and a half centuries. In 1775, Percivall Pott, a surgeon at St. Bartholomew's Hospital in London, England, observed that scrotal cancer was unusually common among chimney sweepers. Pott proposed that occupational exposure to soot was the cause. Near the end of the 19th century, Richard von Volkmann, a prominent German surgeon, reported finding an increased number of skin cancers among workers in the coal tar industry. By the early 1900s, the increased rate of cancer from exposure to soot and coal tar was widely known. [11]

In 1915, Katsusaburo Yamagiwa, a Japanese pathologist, and his assistant Koichi Ichikawa were the first to experimentally produce cancers, specifically in the skin, by applying coal tar to the ears of rabbits. In 1922, the British pathologist Sir Ernest Kennaway determined that the carcinogenic component of coal tar was an organic compound consisting only of carbon and hydrogen atoms. In the 1930s and later, Japanese, English and U.S. epidemiologists reported higher rates of death from lung cancer following occupational exposure to environments containing higher polycyclic aromatic hydrocarbon levels, including employees who worked around coke ovens, coal carbonization and gasification processes. By 2005, it was reported that some carcinogenic polycyclic aromatic hydrocarbon compounds were genotoxic and induced mutations that initiated cancer, while other polycyclic aromatic hydrocarbon compounds were not genotoxic and instead promoted the development of existing cancers. Polycyclic aromatic hydrocarbon compounds had also been linked to cardiovascular disease, such as increased development of plaques in arteries. [12]

Polycyclic aromatic hydrocarbon compounds are "a product of incomplete burning of fuels and wastes," and people are commonly exposed to polycyclic aromatic hydrocarbons from things as common as "grilled meats" and "cereals." As a category, polycyclic aromatic hydrocarbons include a large number of carcinogenic substances, including benzo(a)pyrene, benzo(a)anthracene and dibenzo(a,h)anthracene. [13] Polycyclic organic matter includes a combination of polycyclic aromatic hydrocarbons, such as anthracene, benzo(a)pyrene and naphthalene, among others. [14] By 2005, scientists were speculating on the abundance of polycyclic aromatic hydrocarbons in the universe. It was suggested that polycyclic aromatic hydrocarbons might have been created as early as several billion years after the Big Bang, and that more than 20% of the carbon in the universe might be associated with polycyclic aromatic hydrocarbons. Polycyclic aromatic hydrocarbons were also considered to be the possible raw materials for creating the earliest forms of life. [15] The source of both polycyclic aromatic hydrocarbons and polycyclic organic matter in aluminum smelters was fumes emitted by coal tar pitch used to bind petroleum coke into briquettes for Soderberg-type anodes. Briquettes from the carbon plant were loaded into the top of the steel anode shell, where heat from the reduction pot caused the briquettes to melt and then over time form rock-hard carbon anodes. Green sulfurous fumes could sometimes be seen hovering over Soderberg anodes, especially when the steel internal support pins were pulled during regular anode maintenance.

In September 1978, the U.S. Occupational Safety and Health Administration (OSHA) published a guideline on coal tar pitch volatiles for employers, employees, physicians, industrial hygienists and other occupational health professionals. The five compounds referenced in the guidelines were anthracene, phenanthrene, pyrene, carbazole and benzo(a)pyrene. The OSHA standard at the time for coal tar pitch volatiles was 0.2 milligrams per cubic meter of air averaged over an eight-hour work shift. The U.S. National Institute for Occupational Safety and Health (NIOSH) had recommended changing the permissible exposure limit to 0.1 milligrams per cubic meter of air averaged over a 10-hour work shift, four days per week, and that coal tar products be regulated as occupational carcinogens. Coal tar pitch volatiles could affect the human body by inhalation or by skin or eye contact. Repeated exposure had been associated with an increased risk of developing bronchitis and cancer of the lungs, skin, bladder and kidneys. Repeated exposure could also cause sunlight to have a more severe effect on a person's skin or even cause an allergic skin rash. [16]

“Good industrial hygiene practices recommend that engineering controls be used to reduce environmental concentrations to the permissible exposure level,” the 1978 OSHA guidelines said. “However, there are some exceptions where respirators may be used to control exposure. Respirators may be used when engineering and work practice controls are not technically feasible, when such controls are in the process of being installed, or when they fail and need to be supplemented.” The only respirators permitted for use in aluminum smelters were those that had been approved by the Mine Safety and Health Administration or NIOSH. People who worked around coal tar pitch volatiles should also be provided and be required to use impervious clothing, face shields and other items to prevent skin contact, the guidelines said. “If employees’ clothing may have become contaminated with coal tar pitch volatiles, employees should change into uncontaminated clothing before leaving the work premises,” the guidelines said. “Clothing contaminated with coal tar pitch volatiles should be placed in closed containers for storage until it can be discarded.” [17] Personal protective clothing moved to a new level on Feb. 12, 1964, when workers at the Kaiser smelter in Chalmette, Louisiana began using an experimental portable one-man air-conditioning unit with a plastic hood and bib, a faceplate and compressed air supplied from a hose. Kaiser spent six years to develop the unit in response to the unbearably hot climate in Louisiana. A device called a “vortex tube” was worn at the waist which used supplied compressed air to provide cool and clean breathing air. [18]

According to a 1998 Columbia Falls Aluminum Co. (CFAC) Business, Safety & Health Newsletter, coal tar pitch was derived from distilling coal and was used in a variety of products, including roofing materials, pipe coverings and road paving. The three major hazards associated with coal tar pitch were fire, inhalation and skin exposure. Emissions from coal tar pitch included coal tar pitch volatiles, which were airborne solid particles released into the air when pitch was heated, and other gases and vapors. The main coal tar pitch volatiles of concern were polycyclic aromatic hydrocarbons, some of which were considered carcinogens. The coal tar pitch used to manufacture anode briquettes at the Northwest Montana aluminum smelter contained approximately 2.5% polycyclic aromatic hydrocarbons by weight. According to the newsletter, coal tar pitch volatiles were present in the plant in various concentrations and were regulated by OSHA, and the cartridge-type respirator supplied by CFAC was capable of filtering out coal tar pitch volatile emissions. Exposure to pitch dust and vapors could cause irritation to skin, eyes and the respiratory tract. Frequent or prolonged exposure could cause pitch burn to skin, similar to the symptoms of sunburn and made worse by sunlight. Continued or repeated exposures could cause skin disorders such as dermatitis, tar warts or rough skin. Over many years, continued or repeated exposures could lead to skin pigmentation, benign skin growths and possibly skin cancer. Inhaling coal tar pitch volatiles over a long period of time could cause lung cancer. The newsletter noted that

CFAC required long-sleeved shirts and barrier cream to minimize skin exposure. Employees who had been in areas with coal tar pitch fumes were encouraged to wash their hands and face prior to eating, drinking, smoking or using a restroom. [19]

Spent potliner hazards

Aluminum smelter workers also faced potential exposures to various hazardous chemicals when reduction pots were rebuilt. For Soderberg-type pots at CFAC, a 40-ton cathode shell was removed from its position in the potline, allowed to cool and then tipped upside down to remove the contents from the steel shell. Dust from the broken potliner remains sometimes was blown by wind through the North Crane Transfer Bay and even portions of the potrooms. Spent potliner mostly consisted of brick and cathode paste contaminated by various hazardous compounds created after years of pot use, including ammonia and cyanide. The amount of spent potliner created annually by a smelter plant depended on a number of factors, including how many reduction pots were in operation, how long a pot at that plant typically operated before needing to be replaced, and if pots were replaced ahead of schedule or need because of a process change. [20] Cyanide was created in reduction pots when the carbon lining in pot bottoms combined under high temperatures over several years with nitrogen from the atmosphere. [21] In one reaction, sodium from the electrolyte bath reacted with the carbon liner and nitrogen from the air to create sodium cyanide. Aluminum carbide, aluminum nitride and sodium fluoride could also be created. [22]

The EPA listed spent potliner as a hazardous waste in 1988. Coded K088, spent potliner contained fluoride and cyanide compounds that easily leached out when in contact with water. The International Aluminium Institute looked for ways to use the waste material as feedstock for other industries, including cement, steel, mineral wool and construction aggregate, and “to endeavor to store all spent pot-lining in secure, waterproof, ventilated buildings or containers.” The compounds found in spent potliner could be corrosive, toxic, reactive and even explosive. [23] At CFAC, each ton of waste carbon was estimated to contain four to six pounds of sodium cyanide. The typical lifespan of an aluminum smelting pot was only 3.2 years in 1983, but that increased to seven to eight years by 1995. Longer life spans for CFAC pots reduced the amount of carbon waste generated by the plant from 16,700 tons per year prior to 1979 to 5,400 tons per year in 1995. [24] In 1998, the EPA estimated that as much as 125,000 tons of spent potliner was produced in the U.S. every year. [25] But generally, spent potliner was not considered so much a worker’s health issue as it was a threat to groundwater and surface water following decades of dumping in unlined aluminum plant landfills. Dealing with spent potliner in landfills was often a dominating concern in Superfund cleanup projects.

Fluoride and smeltermen

For much of the 20th century, when it came to the health of workers at aluminum smelters and similar industries, the focus was on fluoride. The effects of fluoride on farm plants and animals first drew the attention of governments and scientists, but as the aluminum industry grew attention turned to worker exposure inside aluminum plants, including cryolite processing plants. In 1932, P.F. Moller and S.V. Gudjonsson published their findings on the physiological impacts of exposure to fluoride on Danish cryolite workers in a report titled "Massive fluorosis of bones and ligaments." The most severe problems were found in the vertebral column and pelvis, and they noted stiffness of backs and complaints of rheumatic pains. [26] In the January 1985 American Journal of Epidemiology, P. Grandjean, K. Juel and O.M. Jensen reported on their study of 431 male workers who were employed at a cryolite processing plant in Copenhagen, Denmark, for at least six months between 1924 and 1961. The authors looked at mortality and cancer morbidity after heavy occupational fluoride exposure. They found at least 74 cases of skeletal fluorosis, and 206 workers had died when only 149.3 were statistically expected to die during a specified time period. Violent deaths and deaths from respiratory cancer were significantly higher, the authors reported. In the Dec. 16, 1992 Journal of the National Cancer Institute, P. Grandjean, J.H. Olsen, O.M. Jensen and K. Juel followed up with a study of 425 men and 97 women who were employed for at least six months at a Copenhagen cryolite processing plant between 1924 and 1961. The cryolite ore contained about 50% fluoride. An increased incidence of respiratory cancer was linked to smoking, but "the disproportionate increase in the incidence of bladder cancer is difficult to explain by smoking habits alone." The exposure to high concentrations of fluoride by respiration was thought to have contributed to the increased cancer risk. The authors recommended further studies of bladder cancers. [27]

Much of the research into fluoride impacts on aluminum plant workers focused on smelters. In 1937, K. Roholm published "Fluorine intoxication: A clinical-hygienic study with a review of the literature and some experimental investigations." The work was referred to as a "classic treatise on fluoride intoxication" by Bertram Carnow and Shirley Conibear in 1981. Roholm also noted stiffness of backs and complaints of rheumatic pains. [28] In 1969, R.Y. Eagers published a book on the toxic properties of inorganic fluorine compounds. The use of fluorine compounds, particularly in industry, had increased significantly since the beginning of the 20th century. Fluorine was estimated to be the 13th most abundant element in the Earth's crust, but it rarely existed in a pure gaseous form in nature. Just prior to 1935, a study of injuries to animals and vegetation by dusts or gases emitted by industrial plants identified the sources as six phosphate works, six chemical works, five aluminum works and one brick plant. Another study found 71 cases of injury to humans and livestock between 1935 and 1957, of which 22 related to aluminum works and 18 to chemical works. Chronic fluorosis was the term used for injuries to animals or plants caused by exposure through inhalation or surface exposure over a long period of time. Chronic fluorosis developed slowly as fluorine was retained in the skeletal system, Eagers said. It was possible for animals to tolerate for short periods of time levels of fluorine that would be hazardous over a longer period of time. Typically animals exposed to fluorides over a long period of time developed mottled and stained teeth with excessive wearing, and eventually they showed signs of lameness and loss of appetite. In 1955, a committee of the National Research Council proposed safe fluoride ranges for various farm animals. By 1969, most investigators concluded that animals were not injured directly by fluoride in the atmosphere but by fluoride that had deposited on herbage and then was eaten by the animals. [29]

In an article titled "Occupational Skeletal Fluorosis" in the April 1969 issue of Fluoride Quarterly Reports, an official journal of the International Society for Fluoride Research, the Czech authors J. Lezovic and L. Arnost noted that many reports had been written about fluorosis in industry in general, but rarely on fluorosis that originated in aluminum smelters. The report described four cases of skeletal fluorosis in patients who had worked in aluminum smelters for up to 12 years, concluding, "All patients exhibited backache, pains in arms, legs and paresthesias." The Hungry Horse News, the newspaper for CFAC's home town of Columbia Falls, published portions of this report in a September 1969 editorial but noted that smelter conditions in Czechoslovakia and Columbia Falls were very different. Comparing the two was "like trying to impress someone by using six syllable words." Furthermore, the editorial continued, the union representing hourly workers at the Columbia Falls plant provided for the workers' "wages, benefits and working conditions." The real problem, the editorial concluded, was air pollution and the effects of fluoride emissions on trees around the town. [30]
During an Aug. 23, 1972 deposition in the Dehlbom v Anaconda Aluminum Company air pollution case, Charles E. Taylor, AAC's assistant division manager, stated that the company began collecting urine samples from employees at the smelter in Columbia Falls on an annual basis since it began operating to determine how much fluoride had been ingested by the workers. The samples were tested in the AAC laboratory. [31]

Smelter health studies after 1970

Fluoride studies continued to be published – both overseas and in the U.S. In 1970, T.L. Vischer, C. Bernheim and C. Guerdjikoff published the results of their study of the physiological impacts of fluoride on aluminum plant workers in Switzerland in the book "Fluoride in medicine." They found that 17 heavily exposed aluminum plant potroom workers had seriously ossified spinal ligaments and outgrowths of bony spurs on their vertebrae. All except one complained about pain and stiffness of extremities, shoulder, neck and lower back. In 1971, D.M. Zislin and E. Girskaya published the findings of their study of the physiological impacts of fluoride on 2,738 aluminum smelter workers in "The classification of skeletal fluorosis." They tracked the workers from the time they first began working at a smelter and compared them to 1,700 workers in industrial plants with no fluoride exposure. They reported finding nonspecific bone changes, musculoskeletal symptoms and other changes that occurred five to seven years prior to detection by X-rays, which was the classical approach to discovering fluorosis. They concluded that Roholm's 1937 studies represented late stages of fluorosis. In 1972, N.L. Kaltreider, M.J. Elder, L.V. Cralley and M.O. Colwell published their findings of a study of aluminum workers in "Health survey of aluminum workers with special reference to fluoride exposure" in the Journal of Metals of the Minerals, Metals and Materials Society. They reported that 96% of the 79 potroom workers they examined had varying degrees of skeletal fluorosis. [32]

In March 1976, the Aluminiumindustriens Miljosekretariat employee health organization was formed in Oslo, Norway to study the environmental and health impacts of 10 primary aluminum smelters run by five companies. Among the issues studied in depth were cancer and mortality in the Norwegian aluminum industry, musculoskeletal health in the aluminum industry, respiratory symptoms, bronchial provocation, epidemiological evidence of cancer in aluminum smelters, fiber handling, risk assessment in the working environment, and the effects of polycyclic aromatic hydrocarbons on workers and the environment. [33] One year later in the U.S., the Organization for Economic Cooperation and Development (OECD) stated in a 1977 report on air pollution in the primary aluminum industry that fluoride emissions did not pose a significant human health hazard. The report was written for the National Academy of Sciences. Severe effects had only been observed in humans after long-term occupational exposure to high levels, such as in the mining of cryolite or phosphate. The OECD found that community airborne fluoride had caused an adverse effect on humans in the very few instances where humans were in the immediate vicinity of fluoride-emitting industries. The threshold limits for adverse human effects by hydrogen fluoride was 2.45 milligrams per cubic meter and for particulate fluoride was 2.5 milligrams per cubic meter. [34]

In 1977, E. Czerwinski and W. Lankosz presented their findings of a study of 105 aluminum smelter workers who had exhibited skeletal changes resulting from exposure to fluoride. Skeletal changes were "an inseparable feature of chronic fluoride intoxication," they reported, as a result of "the specific affinity of fluoride for hydroxyapatite, the basic substance of bone tissue." Factors that affected skeletal changes by fluoride exposure included mechanical overstrain, high heat and high humidity. The workers ranged in age from 37 to 69 and had been exposed to fluoride for 8 to 24 years, for an average of 18.2 years. The aluminum workers tended to complain about pains in the lumbar region of the spine and less often about pains in the larger joints, forearms or lower legs. The researchers reported finding exostoses and ossification of the ligaments in the spine area. [35]

Czerwinski and Lankosz followed up with a report in the July 1977 issue of Fluoride: Journal of the International Society for Fluoride Research that studied 60 retired, disabled aluminum smelter plant workers who had been exposed to fluoride. The average age of the workers was 49.6 years and the average duration of exposure was 16.9 years, with 88.3% having worked in the potrooms. The researchers reported finding exostoses and ossification of the interosseous membranes and muscle attachments. About 60% of the fluoride taken in by the workers was excreted in urine, they reported, "but almost 90% of what remains accumulates in bones due to the affinity of fluoride for hydroxyapatite, the basic mineral substance of bone." Fluoride changed the hydroxyl ion of hydroxyapatite to fluoroapatite, which was much less soluble and could build up over time. Many of the workers complained of pains in the lower back, shoulders, elbows, forearms and lower legs. Upon radiological examination, the researchers found limited mobility in the joints of the spine and extremities. [36]

In 1981, Carnow and Conibear published their findings from a study of the physiological impacts of fluoride on 1,242 aluminum workers who belonged to the Canadian Association of Smelter and Allied Workers. The union had cooperated with the study. The Canadian smelter where the study took place began production in 1954 with vertical-stud Soderberg pots. The plant produced more than 800 tons of aluminum per day and emitted 4 to 5 kilograms of fluoride per ton of aluminum produced – about 6,720 to 8,400 pounds per day. The workers were initially described as "apparently healthy and actively employed" – the authors referred to them as the "survival" population. Each worker filled out a questionnaire about their health and was given X-rays. The results were tabulated by age group and by the amount of exposure to fluoride. Carnow and Conibear found a significant relationship between workers who had back and neck surgery to their employment and exposure to fluoride. The authors also found a correlation between exposure and fractures. [37]

Carnow and Conibear had also been involved in a study of the effects of fluoride emissions on residents living downwind of an aluminum smelter on Cornwall Island in the St. Lawrence River. Between 1969 and 1971, two Canadian government agencies first became concerned about a potential link between ecological impacts on the St. Regis Akwesasne Indian Reserve and fluoride emissions by the Reynolds Metals plant in Massena, N.Y. The smelter began operating in the 1950s and the Indian reserve was downwind about 60% of the time. The Indians claimed increased livestock losses, dying crops and trees, and even dead bees shortly after the smelter began operating. In 1973, Reynolds spent $17.8 million installing pollution control equipment and reduced their fluoride emissions from more than 7,200 pounds per day to 2,688 pounds. They were later reduced to 1,776 pounds. Conditions on Cornwall Island improved but did not disappear. [38]

A two-day survey of the Cornwall Island residents by Carnow and Conibear in 1978, commissioned by the Indian tribe, found evidence of muscular, skeletal, nervous and blood abnormalities, and school children who were irritable and hyperactive. Two years later, an epidemiological study on the impacts was begun by the Mount Sinai School of Medicine in New York City. In February 1980, the Indian tribe filed a $150 million lawsuit against Reynolds and Alcoa, which also operated a smelter in Massena. [39] P. Ernst, D. Thomas and M.R. Becklake followed up with a report in the February 1986 journal American Review of Respiratory Disease. They reported on a study of the respiratory symptoms and lung functions of 253 Indian children from 11 to 17 years old who lived on Cornwall Island. The children were exposed to the particulate and gaseous fluorides from the aluminum smelters. Children living closest to the smelters had the worst symptoms, the authors concluded. [40]

Personal protection and plant equipment

In June 1983, the U.S. Department of Health and Human Services published a report on occupational health control technology for the primary aluminum industry as part of a series of NIOSH technical reports. Over the years, aluminum producers had developed and installed engineering controls for the protection of workers health, but in some situations exposure to hazardous agents continued. The NIOSH study's investigations included exposures to fluorides in the potrooms, hydrocarbon vapors in carbon paste plants and airborne particulates in ore-handling operations. The report looked at 12 U.S. aluminum plants and two Japanese plants, including those using prebake or Soderberg anodes. According to the NIOSH report, "The Hall-Heroult process (whether prebake or Soderberg) is a heavy industrial process and involves the release of various chemicals, some hazardous, into the workplace atmosphere, presenting a potential worker health problem." Because of this, the aluminum industry was subject to OSHA's occupational health regulations. Most of the occupational exposures in aluminum reduction plants occurred through inhalation. The major hazards included carbon dust, benzene-soluble hydrocarbons, sulfur dioxide, fluorides, alumina, and metal dust and fumes. Emissions from reduction cells in potrooms included gaseous or particulate fluorides and hydrocarbons. Hydrocarbon vapors were also emitted in the paste plant during the heating of coal tar pitch in the production of anode briquettes. [41]

According to the 1983 NIOSH report, control technologies utilized by aluminum companies included technical innovations with less hazardous processes and equipment, use of automation to isolate workers from hazards, room ventilation and better work practices. Respirators were worn by workers at some plants during ore unloading operations, in paste plants and around reduction pots. Nearly all 12 aluminum plants required workers in production areas to wear safety glasses with side shields, safety shoes and hard hats. Potroom workers were often required to wear long-sleeved shirts and safety shoes with nonconducting soles. In some plants, workers were required to wear safety shoes with metatarsal guards. Hearing protection was used by workers at several plants when performing certain kinds of operations. Specialized safety equipment included aluminized jackets, face shields, goggles, gloves, spats, air-supplied respirators, self-contained breathing respirators and safety belts. The NIOSH report pointed out that all the surveyed aluminum plants provided medical assistance by physicians, registered nurses or medical technicians. Generally a physician was onsite for four to 20 hours per week, and one to six registered nurses or medical technicians were employed full-time. Pre-employment examinations were required at all U.S. aluminum plants, and most plants held monthly safety meetings. Most of the plants surveyed in the report routinely measured pre-shift and post-shift urinary fluoride levels. [42]

With government agencies looking more and more into worker safety at aluminum plants, it was not surprising that aluminum companies began to make their positions on the matter public. In October 1987, newly appointed Alcoa CEO Paul O'Neill gave his first speech to the company's investors. At the time, investors were nervous because of failed product lines, but O'Neill didn't talk about profit margins or revenue projections. "I want to talk to you about worker safety," he began. "Every year, numerous Alcoa workers are injured so badly that they miss a day of work," he continued. "Our safety record is better than the general American workforce, especially considering that our employees work with metals that are 1,500 degrees and machines that can rip a man's arm off. But it's not good enough. I intend to make Alcoa the safest company in America. I intend to go for zero injuries." Investors were reportedly bewildered by O'Neill's words. Following the meeting, one investor called his 20 largest clients and said, "The board put a crazy hippie in charge, and he's going to kill the company." But according to one business writer, O'Neill's emphasis on safety made a positive safety and financial impact. During his tenure, lost work days due to injury at Alcoa dropped from 1.86 per 100 workers to 0.2, and one year after his speech Alcoa's profits hit a record high. Business pundits later suggested that the focus on worker safety had created a cultural change that rippled through the company and improved several processes in the organization. "I knew I had to transform Alcoa," O'Neill later said. "But you can't order people to change. So I decided I was going to start by focusing on one thing. If I could start disrupting the habits around one thing, it would spread throughout the entire company." [43]

Plant fluoride studies continue

Meanwhile, the studies continued and journal reports were published – many about Norwegian workers. In the 1986 American Journal of Industrial Medicine, M. Saric, J. Godnic-Cvar, M. Gonzi and L. Stilinovic reported on the role of atopy in potroom asthma after examining 227 workers. The authors concluded that "the results support our previous findings that acute respiratory impairment in some workers is most probably based on bronchial hyper-reactivity and not on an allergic mechanism." In the February 1992 British Journal of Industrial Medicine, V. Soyseth and J. Kongerud reported on the prevalence of respiratory disorders among aluminum potroom workers in relation to exposure to fluoride. They surveyed 370 workers at the Hydro Aluminium smelter in Ardal, Norway, and found that "work-related asthmatic symptoms in potroom workers may be related to exposure to fluorides." In the September-October 1992 journal Med Lav, Kongerud reported that "epidemiological studies of aluminium potroom workers have been in progress in Norway since 1986." He also reported, "Work-related asthmatic symptoms and airflow limitations were closely associated with duration of potroom employment." [44]

Incidences of potroom asthma attracted further research. In the January 1994 European Respiration Journal, J. Kongerud, J. Boe, V. Soyseth, A. Naaslund and P. Magnus reported on work-related asthma among Norwegian potroom workers. "The occurrence of work-related asthma has been shown to be associated with the duration of potroom employment, although the prevalence of asthmatic symptoms is not significantly different from that of the general population," they reported. "Current smoking, but not self-reported allergy, is a risk factor for potroom asthma." In the October 1994 journal Thorax, V. Soyseth, J. Kongerud, J. Ekstrand and J. Boe reported on the relationship between "plasma fluoride levels and bronchial responsiveness" for 26 selected aluminum plant potroom workers at the Hydro Aluminium smelter in Ardal. In the Feb. 24, 1995 journal Science Total Environment, T.V. O'Donnell reported that "occupational asthma is the principal respiratory health problem within the primary aluminum industry." He recommended respiratory protection and screening of potroom workers. "Particle size limits smelter grade primary alumina reaching the alveoli of the lung," he reported. In the Sept. 8, 1995 European Respiratory Journal, B. Sorgdrager, T.M. Pal, A.J. De Looff, A.E. Dubois and J.G. Monchy reported on "occupational asthma in aluminum potroom workers related to pre-employment eosinophil count." They reported that "occupational asthma still occurs in aluminum potroom workers despite pre-employment medical selection." They studied 364 potroom workers, of which half were cases and half were controls. The cases were unable to work because of respiratory diseases. [45]

In the August 1999 Scandinavian Journal of Workplace Environment and Health, K. Lund, M. Refsnes, T. Sandstrom, P. Sostrand, P. Schwarze, J. Boe and J. Kongerud reported on their study of the physiological impacts of fluoride emissions on aluminum plant workers. They concluded that "hydrogen fluoride may induce an inflammatory reaction in the airways at concentrations that can occur in the ambient air in the primary aluminum industry." In the December 2000 Scandinavian Journal of Workplace Environment and Health, P. Romundstad, A. Andersen and T. Haldorsen reported on the nonmalignant mortality of workers at six Norwegian aluminum smelters. They studied the impact of exposure to fluoride and polycyclic aromatic hydrocarbons on workers who were employed for more than three years from 1962 to 1996. The study showed an association between exposures to potroom emissions measured by fluorides and mortality from asthma, emphysema and chronic bronchitis combined. No association was observed between cumulative fluoride exposures or PAH exposure and circulatory mortality. [46]

A number of studies looked at the health impacts on children who lived near the Hydro Aluminium smelter in Ardal, Norway. In the January 1995 journal Lancet, V. Soyseth, J. Kongerud, D. Haarr, O. Strand, R. Bolle and J. Boe reported on the prevalence of bronchial hyper-responsiveness among schoolchildren living near the Ardal smelter. In the November 1995 journal Arch Dis Child, V. Soyseth, J. Kongerud, J. Boe, P. Lilleng and P. Broen reported on the prevalence of hyper-responsiveness among the schoolchildren. In the October 1996 journal Allergy, V. Soyseth, J. Kongerud and J. Boe reported on the prevalence of atopy in schoolchildren 7-13 years old who were impacted by sulfur dioxide and fluoride emissions from the smelter. They reported that exposure to low levels of the chemicals increases allergen sensitization in children. [47]

Studies were also conducted in Australia, where five bauxite mines, seven alumina refineries and six aluminum smelters operated. In 2003, the Journal of Occupational and Environmental Medicine published a report by M. Sim and G. Benke on the hazards faced by aluminum workers at three Australian smelters. The authors reported finding the typical hazards found in heavy industry – noise, radiant energy and burns from hot metal, along with strong magnetic fields, a hazard particular to potlines. Chemical hazards of concern included coal tar pitch volatiles, emitted by Soderberg anodes and by furnaces that produced prebaked anodes. The volatiles emitted into the potroom air included many lower molecular weight polycyclic aromatic hydrocarbons. Fluorides in both gas and dust form escaped from the electrolyte bath. Other dusts included alumina and calcined coke, and other gases included carbon monoxide and sulfur dioxide. [48]

Sim and Benke noted that epidemiological studies "have implicated these exposures as causal agents for excess cancers and/or respiratory disease." The concentrations found inside aluminum smelters varied by the age of the plant and the technology chosen. The authors noted that "typically, in many of the jobs and tasks, the worker can be simultaneously exposed to all of these dusts and fumes." The authors noted that early studies of the aluminum industry focused on fluorosis as a major health concern, "but with the reduction in fluoride exposures through effective fume extraction and environmental controls, this is no longer of concern in most modern potrooms." [49]

Sim and Benke cited the International Agency for Research on Cancer, which concluded in 1984 that "certain exposures in the aluminum industry are probably carcinogenic to humans." Working in potrooms using Soderberg anodes "has been associated with increased risk of lung and bladder cancer," the authors said. Sim and Benke noted that respiratory diseases such as potroom asthma had been the main focus of more than 50 epidemiological studies since the 1960s. "The mechanism is not clear, but may involve a mix of irritancy and sensitization, and asthma can continue after a worker is removed from exposure," the authors said. They also noted that an association between plasma fluorides and bronchial hyper-responsiveness had been shown, and it had been reported that potroom workers were at an increased risk of mortality from chronic obstructive lung disease. Measures to protect workers included engineering controls, administrative or work practices, and personal protective equipment – including respiratory protection, ear protection and special clothing. [50]

Studies were also conducted in the Mideast. In April 2016, the Egyptian Journal of Chest Diseases and Tuberculosis published a report by Lamiaa Shaaban, Hussein Zayet, Hala Aboufaddan and Shimaa Elghazally on respiratory hazards for workers at the Nag Hammadi aluminum smelter. The case study included 320 workers who were subdivided into two groups according to the duration of daily exposure to aluminum gases and exhausts. The study found that the more exposed workers "had more chronic and acute work-related respiratory symptoms," including a higher occurrence of asthma and reticular, nodular and reticulo-nodular patterns found through chest X-rays. "The aluminum industry is hazardous to both the workers and the community," the study concluded, adding that "the free radicals of silica and polycyclic aromatic hydrocarbons may have a direct relationship with the recorded changes in diaphragmatic and pulmonary functions and may be precancerous." [51]

As the U.S. aluminum industry shrunk after 2001 and large modern smelters were built around the world – particularly in China – reporting on worker hazards began to move to the forefront of health reporting. The May 2014 Journal of Occupational and Environmental Medicine included a special supplement focused on the health impacts of the aluminum industry. The supplement included 10 papers from leading experts reporting on the current status of occupational health, environmental and sustainability issues related to aluminum production. Hazards typically found in heavy industry included noise and accidental injuries. Health hazards included possible increases in lung and bladder cancers related to benzo(a)pyrene exposure, a specific type of asthma that was in decline in recent years, an increased risk of chronic obstructive pulmonary disease, and the unsupported "aluminum hypothesis" that aluminum use in the world increased the prevalence of Alzheimer's disease. [52]

Anecdotes and politics

Concerns about fluoride impacts on human health also were raised as municipal water departments in the U.S. – small and large – began to fluoridate public water supplies for dental health reasons. A grassroots opposition movement emerged, sometimes with the backing of reputable scientists. George Waldbott's renowned 1978 book, "Fluoridation: The Great Dilemma," employed primary and secondary information sources from around the U.S. to make the controversial case that Andrew and Richard Mellon and the Alcoa and Reynolds Metals companies had promoted the use of fluoride in drinking water as a way to market sodium fluoride – an unwanted byproduct of aluminum smelting. The book claimed that the Mellon Institute and the Kettering Laboratory helped support the companies' claims about the benefits of fluoridating drinking water by using proxies at the U.S. Public Health Service and other U.S. agencies. The book also claimed that Andrew Mellon influenced the government's support for fluoridation as Secretary of the Treasury from 1921 to 1931 – long before the fluoridation effort began. [53] Opposition to fluoride matured over the years. In May 2000, a group of environmental activists joined to create the Fluoride Action Network (FAN). In August 2003, the directors included David Brower, founder of Friends of the Earth and the Earth Island Institute; Anna Maria Caldara, editor of Coyote Nation; the Green Party of England and Wales; and Vicki and Bill Smedley, founders of GreenWatch. Nine scientists were on the directors list, including seven dentists opposed to water fluoridation who cited the chemical's toxicity. [54]

The aluminum industry's notoriety for health impacts – both to workers inside plants and nearby residents – provided fodder for political groups. Oftentimes, institutions or government agencies went to bat for aluminum companies in an attempt to set the story straight – including in Third World countries. On April 5, 2005, the Agencia de Informacao de Mozambique issued an article refuting numerous folk claims about safety and environmental hazards posed by the new Mozal aluminum smelter in Mozambique. Among the claims – that anyone who worked at the plant would not live more than five more years, based on the lifespan of the aluminum reduction pots; that the Mozal plant polluted the river, when the plant's fluoride wastewater emissions averaged about 15 ppm and the legal limit was 20 ppm; that fluoride was polluting Richards Bay, where the older less efficient Bayside smelter in South Africa was operating, but with no evidence to support the claim; that the Mozal smelter caused a drought which was ravaging the countryside, based on the idea that extremely high temperatures in the smelter affected weather; that workers at the smelter actually endured temperatures reaching 960 degrees centigrade, the temperature inside the reduction pots; and that the alumina shipped to the smelter somehow escaped into the atmosphere and caused fevers and other health problems. [55]

A feel for the hazardous work conditions in U.S. aluminum plants in the 1950s can be gleaned from an autobiographical blog site by Richard Ginnold, who worked at Kaiser's Mead aluminum smelter in Spokane, Wash., from 1956-1958 – the plant's "golden age," he called it. About 1,000 workers worked around the clock at $2.20 to $3 per hour for straight time. "Most important, because demand for aluminum was rising fast, there was always overtime, paid at double or triple time," he said. The work was "tough, dirty and sometimes dangerous, but there was a strong union relationship between our union, the Steelworkers, and Kaiser, and workers were treated very fairly," he said. Sometimes, particularly during graveyard shift, it felt like the union ran the plant, he said. Ginnold started out as a potroom spare. "The potman had to be very skilled and sensitive to his mixture," he said, continually raising and lowering carbon anodes, skimming off the slag and dumping in cryolite as needed. But the potman was the worker most exposed to all the dangerous chemicals emitted by the pot, including fluoride and heavy metals. [56]

"In those days, there was no federal safety law, little concern for safety and health or much knowledge," Ginnold said. "There was little ventilation. The coming of OSHA probably hastened the move of Kaiser and other countries overseas." Most of the workers wore ragged clothing with burn holes from molten metal spatter. Some wore a bandanna over their face, and everyone wore safety glasses with side screens and long-sleeved shirts – even if the temperature in the potroom reached 120 degrees. "Carbon setters got so carboned up they had a special shower but could not get all the carbon off," Ginnold said. "You could usually tell a carbon setter on the street by his carbon-streaked face and shadows of carbon around his face. Some of the carbon setters were proud cowboys, and if no supervision was around, they would ride their blocks in on the crane, and there were a couple of bad injury accidents while I worked there when a carbon setter stuck his foot in the opening left by the removed carbon." [57]

The hot metal trucks were dangerous, especially if the driver was "highballing" down the alley, which often happened on graveyard shift. Ginnold said he was rushing once and a 50-pound crane hook hit him in the head, knocking him about 10 feet and leaving him stunned. "Another worker took me to the infirmary, and I got some stitches and bandaged up and went back to work," he said. "Luckily my head was hard. I took the lesson seriously and didn't get hit again." One of the dirtiest jobs at the plant was unloading box cars carrying alumina or cryolite. The workers used a big vacuum hose with a two-foot diameter spout and climbed into the rail cars. "However, the hose continually plugged, and we sunk into the car," Ginnold said. "Sometimes the exiting cryolite missed the conveyor, creating another mess to clean up. The dust created was incredible. The hose was very heavy to manipulate, like wrestling a 50-foot anaconda. Going into the corners to clean the last of the load was very bad because it was zero visibility. Even with T-shirts tied over our faces, we sucked in a lot of the grains and other dust." Ginnold said unloading took a whole day and was the most tiring work at the plant. "For weeks afterwards, I would be coughing up black phlegm and tasting the fluoride. Luckily, I have always been pretty impervious to dust in my later life, and this experience might have helped." Ginnold eventually landed a job loading 50-pound pigs in the casting house, and he liked working on graveyard shift. "We would hustle like mad and come 5 a.m. or so, we would frequently be done," Ginnold said. "Some of the guys would play cards, read or talk in the 'waterholes,' the lunchrooms near every area. The other guys would sleep, usually including me." Ginnold said he got laid off in 1958 because of his low seniority. [58]

Harsh and hazardous working conditions were at least one of the driving forces behind efforts to organize workers in the aluminum industry. Workers at aluminum smelters were paid more than at other heavy industries because labor costs were a relatively small part of the overall cost of smelting and because managers knew they needed more skilled and reliable workers. But keeping that kind of talent on a long-term basis when working conditions were so hellish helped open the industry up to labor organizing.

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