PRIMARY ALUMINUM PRODUCTION & HEALTH

A Primer on the Key Health Issues Associated with Mining, Refining & Smelting

Yale University Occupational & Environmental Medicine Program for the International Aluminium Institute
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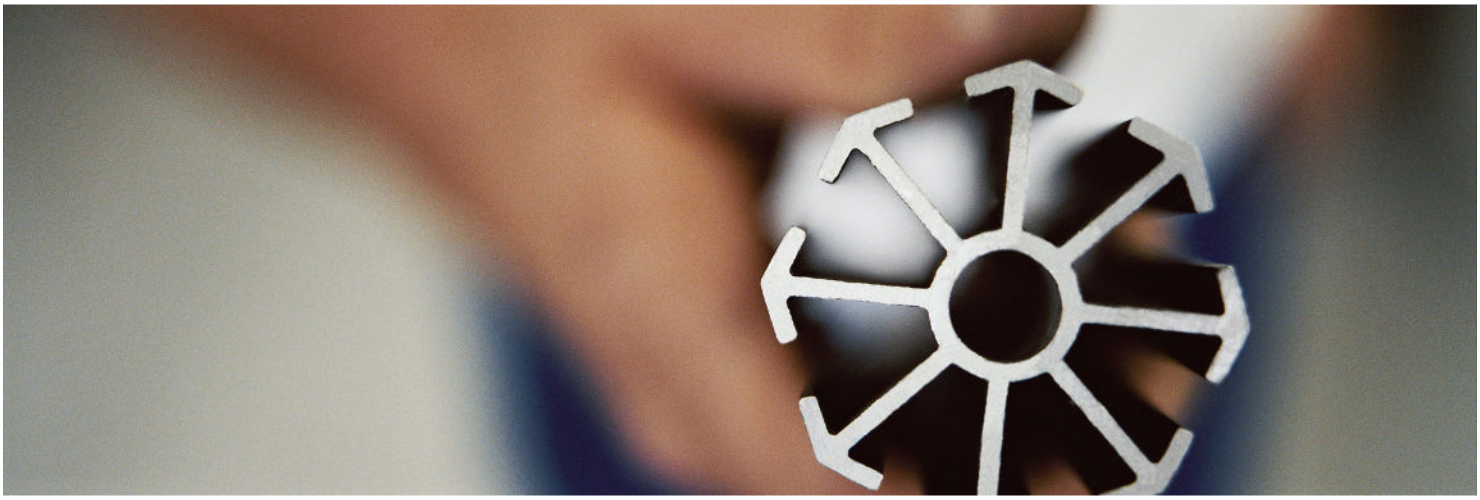


FOREWORD

Over the years, several health issues have been identified in relation to exposures incurred by workers during primary aluminum production. This document has been prepared for individuals both inside and outside of the aluminum industry, specifically for communications staff and managers, who wish to have a non-technical, factual explanation of the evolution of these health issues, their current status and what is being done in the aluminum industry to reduce the risk of undesirable health effects in the working population.

HEALTH RISKS IN ALUMINUM MANUFACTURING

Over the last several decades, the aluminum industry has been confronted with health issues that have raised concerns not only amongst the workers within the industry, but also in the communities that are home to the different production locations. Historically, three illnesses have been of particular concern: cancer, fluorosis and occupational asthma (which has been referred to as "potroom asthma") in aluminum workers.

Some of these "legacy" issues are still encountered in older and/or retired employees who encountered exposures to materials such as polyaromatic hydrocarbons (PAHs) and asbestos. These exposures were significantly higher than in today's modern plants where asbestos use has been eliminated and PAH exposure has been markedly reduced. Cancers (bladder, lung, mesothelioma) are seen less frequently as time goes by but, because of the lag time needed for them to develop, are still being diagnosed in those exposed to carcinogens in industry facilities many years ago.

It is important to note that while such health issues have been observed and documented, they were often most prevalent in workers employed by the primary aluminum industry in past eras when technologies were less well developed and when ambient chemical exposures were much greater. Today, in modern primary aluminum production facilities, exposures are generally lower than they were historically and, as a result, the incidence of many occupational illnesses associated with the aluminum industry has declined substantially. Currently:

- **To date, there is no evidence to suggest that bauxite mine workers are at an increased risk of respiratory illnesses, cancer, or other chronic diseases when compared to the general population.**
- **To date, there is no evidence to suggest that alumina refinery workers are at an increased risk of respiratory illnesses, cancer, or other chronic diseases when compared to the general population.**
- **While fluorosis, cancer, and asthma have been observed in aluminum smelter workers in the**

past, present day analyses show that the risk of developing any of these diseases as a result of working at an aluminum reduction facility has dramatically decreased over time, with fluorosis having been virtually eliminated amongst workers in modern facilities.

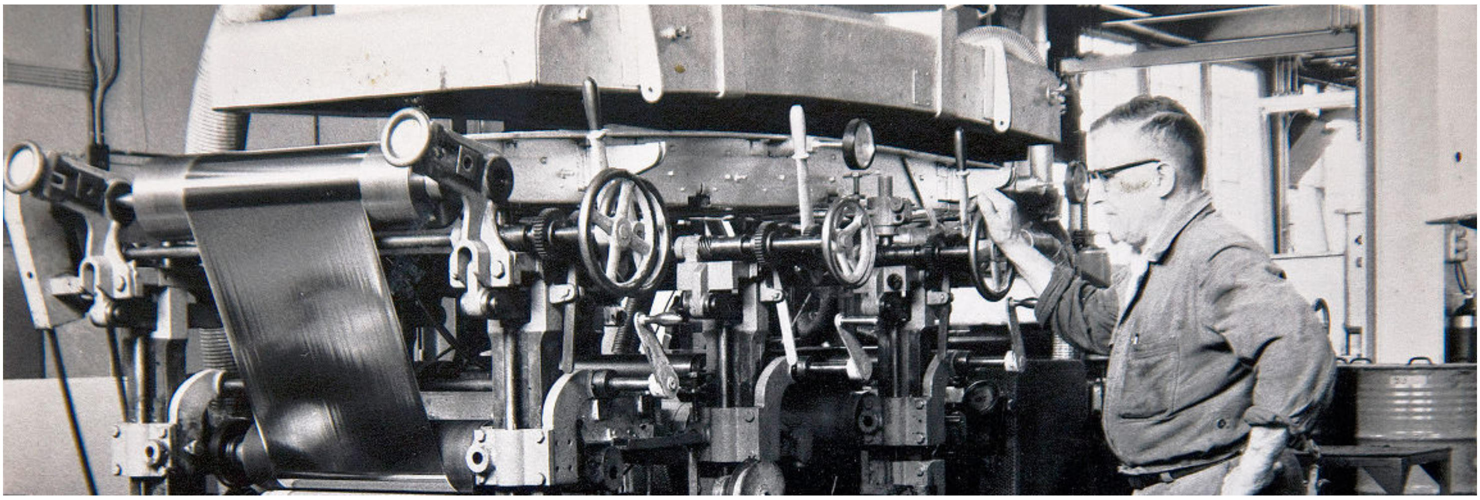
Within modern primary aluminum facilities, it is not cancer, fluorosis, and asthma that are the most common adverse health effects in aluminum production workers, but noise-induced hearing loss, heat strain, ergonomic injuries such as sprains and strains, and finally, psychological health impacts.

SUMMARY

Years of research and data collection have enabled occupational health professionals to have a much greater understanding today of the health effects associated with the three major aluminum production processes of mining, refining, and smelting than they did in the past.. As a result, various health & safety controls, including worker education and medical screening have been implemented, and the risk of experiencing an illness or injury while working at a well-run modern primary aluminum production facility has been reduced dramatically. In fact, the risk of developing some key health endpoints of interest (cancer, potroom asthma, fluorosis) is now approaching background levels with the risk of certain disease being similar to, if not less than that of the general public in many locations. Moreover, in recent years the aluminum industry has increased its role in promoting and maintaining worker health through the implementation of employee wellness programs.

INTRODUCTION

Aluminum is the most common metallic element in the earth's crust by mass, occurring as a metal ore throughout the world. It is unlikely, however, that most people would notice aluminum in its natural state. Aluminum is a highly reactive element, which means that it is typically found in nature chemically combined with other elements and minerals. As a result, ores that contain aluminum do not look anything like the silver, shiny material that most people typically associate with the metal. To produce the solid metallic form of aluminum, its ore must undergo chemical processing to separate the pure aluminum metal from the other elements and minerals to which it is bound. However, because aluminum compounds are relatively stable (due to the metal's reactivity), the aluminum metal isolation process requires a great deal of energy, delivered through both electricity and heat. The pure form of aluminum metal has several unique and important properties that make it a desirable material to be used in a wide variety of consumer products. Important aluminum-containing products include aircraft and automobiles, food packaging, building materials, and electronics. While the initial energy requirements to produce the metal are significant, aluminum can be easily recycled with minimal energy requirements – thus, in effect aluminum metal can be considered to constitute an "energy bank".



HISTORY OF ALUMINUM MANUFACTURING & HEALTH

Commercial aluminum production technology has been in place since the beginning of the 1800's when several different scientists worked to find a way to isolate aluminum from the materials that it is typically combined with in nature. Over the course of nearly two hundred years, the technologies have evolved and developed, although the basic processes have not changed.

Primary aluminum production consists of three major stages – **mining**, **refining**, and **smelting**. During mining, bauxite, an aluminum-containing ore, is removed from the earth's crust. Refining is the process through which aluminum-oxide powder, or alumina, is extracted from bauxite. The extracted alumina is then transferred to an aluminum smelter, where it is reduced to pure aluminum metal through an electrochemical process.

As in any manufacturing environment, aluminum workers are exposed to a range of different chemical and physical agents during the production process. The extent of exposure that aluminum workers have had to each of these agents, however, has varied greatly over time, and is largely dependent on the era during which each aluminum worker was actively employed by the industry. For example, when the primary aluminum industry was first being developed in the 1800's, societal focus was on improving production processes with little focus on or understanding of health and safety.

In recent years, the safety of production processes has received much greater attention. In the aluminum production industry, modernization of both aluminum production technology and work practices has facilitated the creation of a safer work environment. Aluminum industry workers who were employed during the late-1800's to mid-1900's had greater exposures to both the physical and chemical agents involved in the production process than aluminum workers do today.

The higher exposures incurred by aluminum manufacturing workers during the first century that the primary aluminum production process existed resulted in certain adverse health effects being observed in the working population. Consequently, these health effects became associated with the aluminum industry. As societal interest turned towards occupational health and safety in the latter half of the 1900's, the vast majority of the exposure and health associations affecting the aluminum and other manufacturing industries began to be investigated.

Occupational health studies have since evaluated the extent to which many reported exposures in the aluminum industry have or have not influenced human health outcomes. Many of these research projects have specifically studied primary aluminum manufacturing workers. Some of the common health hazards in the modern aluminum industry facilities include **noise**, **heat**, **dust**, **gases**, and **particulates** from different chemical sources, and **ergonomic stressors**.

Health effects that have been associated with the aforementioned hazards include, but are not limited to, **legacy issues (cancers**, **fluorosis**, **and lung disease)**, **noise-induced hearing loss**, **heat stress**, **asthma**, and **injury**.

CONTROLS

Aluminum manufacturing environments are safer for workers today due to improved technology, hazard controls, and personal protective equipment. In other words, the increased awareness of health effects associated with aluminum manufacturing enabled controls to be developed and implemented in primary aluminum production facilities, greatly reducing a worker's exposure to various hazards. The end result of this is that an aluminum industry worker's risk of developing an undesirable health effect is much less today than it was 50 years ago. The industry is much safer.

Health-protective hazard controls in the aluminum industry fall into four main categories:

- Elimination controls
- Engineering controls
- Administrative controls
- Personal controls.

Elimination controls involve the removal or substitution of certain hazards for materials that pose less of a health risk to workers. While the **elimination or substitution of hazards** may be ideal, it is often impractical or impossible in an industrial setting, where a hazard may be integral to a process, or the safety of a substituted substance is unknown.

Engineering controls involve permanent structural or process modifications that reduce a worker's exposure to a hazard. Examples of engineering controls include ventilation systems and walls that confine a hazard to one location, or technology to remove operators from exposed areas.

Administrative controls are policies, procedures, or guidelines that govern the way with which work is done so that workers are best protected. Administrative controls include occupational exposure limits (OELs) and best practice guidelines. In addition, many companies will perform risk assessment analyses, so as to better characterize and understand the hazards that exist in the working environment. A component of risk assessment practices is often exposure sampling, in which different types of measurements are taken to quantify how much workers are being exposed to chemicals in their work environment. These measurements not only help ensure that chemical exposures in the work environment remain at safe levels, but also help to guide and inform the administrative decisions, best practices, and engineering controls needed to best protect worker health.

Finally, **personal controls** involve the use of a variety of different types of personal protective equipment (PPE). PPE provides a worker with a barrier between the hazard and their body, and includes equipment such as hearing protective devices, helmets, and heat shields. However, it is important to note that the protection afforded by PPE may vary considerably between workers, as individual working habits can greatly influence their effectiveness.

It should be noted that environmental emissions from primary aluminum production facilities are also controlled to ensure that the risks of any adverse health effects in the community and environment immediately surrounding the facilities are minimized.

Medical Screening & Surveillance

Another concept that is important to understand in regards to occupational health is that of **medical screening** and/or **surveillance**. Unlike exposure controls, which are designed to prevent or reduce exposure to various hazards, medical surveillance programs are designed to facilitate the early detection of various health endpoints after exposure to a hazard has already occurred. Medical screening can take many different forms, depending on the health outcome of interest. For example, screening can be as simple as a respiratory symptom questionnaire, or as complex as a blood test or X-ray. Some medical surveillance programs use a combination of several different types of screening tools together.

While medical surveillance is not preventative, it allows occupational health professionals to monitor disease rates amongst workers to ensure that the existing controls are adequately preventing disease. In addition, the early detection of an occupational illness afforded by routine screening enables a worker to begin treatment for their condition right away.

Wellness programs, on the other hand, are designed to be preventative, and have been introduced with increasing frequency in the aluminum industry. These programs allow employees to have access to a wide array of services that foster healthy behavior amongst employees and have the potential to identify and address chronic health issues at an early stage. The services offered to employees through a wellness program often include components such as smoking cessation programs, guidance on weight management and nutrition, screenings for chronic conditions such as high blood pressure, and encouraging an active lifestyle. In addition, many aluminum companies offer mental health services, such as employee assistance programs (EAPs), in which employees may receive anonymous assistance for mental illness, drug & alcohol dependency, and family and/or marriage counseling.

The following primer is a synopsis of pertinent occupational health issues in aluminum production. In particular, patterns in the occurrence of adverse health effects in aluminum workers will be discussed, as will causative factors. Finally, improvements to the industry’s technologies that have enhanced workplace safety will be covered. The health effects and exposures that are unique to each of the three major primary aluminium production process are addressed with each of their respective processes. Due to the commonality of the hazards of heat, noise, and ergonomic and psychological stressors across mining, refining, and smelting, they are addressed together at the beginning of this document.

Overall, it is important to understand that while certain health and safety risks do exist for workers in the primary aluminum industry, or in any heavy manufacturing field for that matter, a well-run modern primary aluminum production facility actively monitors and controls hazards so that the workforce can remain as safe and healthy as possible at all times.

HEALTH HAZARDS COMMON TO ALL PRIMARY ALUMINUM PRODUCTION OPERATIONS

What are they?

Heat, noise, and ergonomic and psychological stressors are health hazards that workers may be exposed to during all facets of primary aluminum production. They are also four commonplace factors that many people experience during their regular daily routines, both inside and outside of the workplace. In fact, heat, noise, ergonomic and psychological stressors are so familiar, that unless they are present in extreme quantities, they may often go unnoticed. It is precisely this familiarity that can make them dangerous to health in certain situations, as the familiarity leads to a tendency to perceive them as less of a risk to health than more unfamiliar hazards that one may not encounter with any regularity. These four hazards together account for some of the leading causes of injury and illness in the primary aluminum industry workforce today.

COMMON HAZARD 1: HEAT STRESS

What is it?

Simply stated, heat stress is the physiological impact of a hot environment on the human body. Hazardous heat can be generated both through natural and mechanical processes.

Occupational heat stress or heat load can be thought of as the combination of all of the heat-generating factors that a worker is exposed to, from environmental conditions to work demands and clothing requirements.

Exposure route(s)

Two major sources account for the majority of exposure to heat in the aluminum industry: industrial process and climate. Bauxite mining and alumina refining tend to occur in regions of the world with hotter climates because bauxite is mainly found in subtropical and tropical regions of the world. Smelting capacity, meanwhile, is growing predominantly in the Arabian Gulf and west China, both of which have hot climates.

Heat can also be encountered in aluminum manufacturing jobs that are in close proximity to radiant heat sources. Such jobs include working around hot caustics or the calciner in a refinery, or in the vicinity of anode production areas and the potroom in a smelter.

Smelting operations in particular require a great amount of heat, with certain chemical processes requiring temperatures of 1200ºC (2192°F). Accordingly, workers in the vicinity of furnaces and pots are subjected to extremely high temperatures, temperatures that may be even further compounded by a hot climate. In addition, workers often wear layers of PPE, which can further raise their core temperature, as can the physical demands of their job.

Health Effects

Heat stress can physiologically impact a worker in a variety of ways across a broad spectrum of severity. It is widely known that the optimal core temperature for the human body is somewhere around 37ºC (98.6ºF), and the body actively tries to maintain this temperature through several different mechanisms. Signs of a body working to eliminate excess heat and maintain normal temperature may include sweating, an elevated heart rate, and/or fatigue [1]. These symptoms can be referred to as heat strain.

Heat-related illnesses arise when external factors such as the ambient temperature, clothing, and exertion level make it more difficult for the body to maintain its optimal temperature, increasing heat strain. The body's temperature-regulating mechanisms no longer work effectively and, as a result, a person's internal temperature begins to rise.

The severity of heat-related illness is thus directly related to an individual's ability to cope with the threat of overheating, rather than the heat stressors themselves. An example of this is how young children and elderly individuals are at greater risk of suffering from heat-related illnesses than young adults and middle-aged people because their bodies are not as efficient at cooling themselves and regulating body temperature. Naturally, the greater the duration and intensity of heat exposure, the greater the likelihood of experiencing a heat illness, regardless of a person's ability to cope with heat [1].

Heat-related conditions that may occur in the aluminum industry, from the least severe to most severe, include heat rash, heat cramps, heat exhaustion, and heat stroke. It should also be noted that heat-related abnormal heart rhythms can occur due to elevated heart rate, as well as the associated conditions of dehydration and electrolyte imbalances.

Symptoms of heat exhaustion can include those of heat strain, such as fatigue, sweating, cramps, and elevated heart rate, as well as dizziness, nausea, headache, and dehydration. Fortunately, heat exhaustion is generally easy to treat by removing an individual from exposure to heat sources, facilitating cool-down through removal of excess clothing and placement in a cooler environment, making sure that the affected individual is hydrated, and encouraging rest [1].

Heat stroke is the most severe form of heat illness and requires immediate medical attention. Heat stroke occurs when the body has lost its capacity to cool itself, and as a result body temperature rises rapidly to 40ºC (104ºF) or above. A heat stroke patient may be nauseous or vomiting, be flushed, have a very rapid heart rate, breathe shallowly, experience confusion and seizures, and/or be rendered unconscious. They must receive medical care right away in order to bring their temperature down such that their body tissues and organs do not sustain permanent damage. While heat stroke is severe and can be life-threatening, it is important to know that with proper attention to the symptoms of developing heat illness, it can easily be avoided [1].

Controls

In an environment where heat is unavoidable, the main objective to prevent a worker from becoming overheated is to implement practices that help support their normal physiologic ability to cool themselves. For the most part, such practices fall under the category of administrative controls and include correct nutrition, fluid replacement, adaptive work, and education. Fluid replacement and appropriate nutrition prevent dehydration, which helps an individual maintain their ideal body temperature.

Work practices designed to reduce heat strain include acclimatization programs, which allow an individual to become used to working in heat slowly over a period of time so that they can then cope better with the heat.

Another adaptive work practice is workload distribution, where the tasks and jobs that place people at the most risk of suffering a heat illness are distributed across multiple workers so that each person has time to recover from working the hottest tasks.

Education programs are used to inform workers about the symptoms of heat illness and to raise awareness about how to prevent it and to recognize the initial signs of sickness so that they may seek care for themselves or their coworkers while it is still at an early stage.

Finally, non-administrative controls for heat stress include cooling rooms and PPE such as heat shield when necessary.

COMMON HAZARD 2: NOISE

What is it?

From a health risk perspective, noise is technically defined as a loud or unpleasant sound. A major problem with noise in the workplace is that often people do not perceive it to be a hazard at all [2]. While it may be unpleasant at times, noise is a very familiar part of life and, as such, it is difficult for many to imagine it harming their health, at least immediately. This is important to understand, because noise-induced hearing loss (NIHL) typically occurs gradually, over a long period of time, and can be compounded by the normal hearing loss that accompanies aging.

As a result, a 20 year old worker may not worry about being exposed to noise at work because they cannot conceive an inability to hear in later life. Thus, noise is something to which almost every worker in aluminum manufacturing is exposed, at least periodically, that can impact their health and yet is not perceived to be risky. These parameters make noise exposure one of the highest risks in the aluminum industry, both historically and today, as well in every sector of manufacturing [3].

Exposure route(s)

In everyday life, noise can be generated by traffic, audiovisual equipment, and tools, among other things. In the aluminum industry, noise is often transmitted from different types of machinery, and is an occupational health issue in all facets of primary production.

Health Effects

Noise-induced hearing loss (NIHL) is the most important health effect associated with occupational noise exposure in the aluminum industry. As mentioned above, NIHL typically develops gradually, as chronic noise exposure begins to irreparably damage auditory cells in the inner ear.

NIHL develops the quickest during the first 10 years of chronic noise exposure [4], though it may continue at a slower rate for the entire duration of one's exposure to noise. The capacity to hear the sound frequencies that pertain to conversation are among the last to be lost. Because of this, a person may experience a considerable amount of hearing loss before they begin to realize that they have a problem hearing.

In addition to hearing loss, people with inner-ear damage due to noise exposure may experience tinnitus, which is a ringing or buzzing in the ears that can be intermittent or permanent. On the other hand, in some instances NIHL can develop instantly after a one-time exposure to a very loud noise such as an explosion, but this is not typical in the aluminum industry.

In most cases, hearing loss is permanent, as the components of the cells in the inner ear that facilitate hearing cannot grow back once damaged. As a result, prevention is the most important aspect of "treating" NIHL, and is especially important in manufacturing, where hearing loss can have a significant impact on worker safety, as a hearing impaired individual may not be able to recognize and respond to sound alerts as well as someone with no hearing loss.

Controls

There are several different methods to control noise in the workplace. First and foremost are engineering controls, in which machining equipment is designed to be quieter. While this is desirable, it is often impractical in the manufacturing environment. Instead, hearing loss can be effectively prevented and managed in the aluminum industry through the administrative controls of best practices and medical surveillance, as well as with an assortment of different types of personal hearing protective devices.

An all-encompassing approach to preventing and managing noise-induced hearing loss that can often be found in the aluminum industry is the hearing conservation program (HCP). HCPs have been implemented by several primary aluminum manufacturing companies and, in brief, require that workers who are exposed to high levels of noise (the cut-off level for each program varies depending on the managing company and location of each facility) have hearing tests (audiograms) at regular intervals. HCPs also encourage the use of hearing protection through both administrative policies and worker education [5-7].

Regular audiograms allow for hearing loss to be identified long before a worker is aware that it is occurring, which consequently allows a worker to take measures to safeguard themselves against additional loss. The mandated use of hearing protection helps to ensure that workers are actually using their hearing protection when the noise level is such that it may damage hearing. Finally, educating workers about hearing loss helps to overcome the obstacle presented by the workers who do not associate noise with any immediate threat to their health, and motivates them to take steps to prevent hearing loss. Well-established HCPs have the added benefit of motivating workers to adopt similar practices in their non-work activities, further improving the likelihood of preserving one's hearing acuity throughout life.

It should be noted that occupational hearing loss continues to be studied extensively in modern aluminum manufacturing. Of particular interest is the optimization of the comfort and effectiveness of hearing protective devices. In fact, there are certain locations in the primary aluminum industry that have begun to use cutting-edge hearing protection that allow researchers to analyze how much noise is actually reaching a worker's inner ear when it is being worn [8-10]. In time, researchers hope to use these data to continue to decrease the rates of hearing loss seen in both the aluminum industry, and occupational environments in general.

COMMON HAZARD 3: ERGONOMIC STRESSORS

What are they?

In broad terms, ergonomics can be thought of as the study of individuals' interactions with the world around them while they are working. In this sense, work can include a wide range of tasks in a wide variety of settings, such as sitting and typing on a computer in an office to lifting packages or operating machinery in a manufacturing environment. Thus, ergonomic stressors can be, in general terms, anything that places stress on a worker's physical form and cognitive function while they are performing the tasks required by their job.

Exposure route(s)

In aluminum production, and in manufacturing in general, ergonomic stressors include heavy lifting, the awkwardness of using equipment that is not developed for a certain person's individual size or capability, repetition, and vibration. Heat can also be classified as an ergonomic stressor, but is not discussed here as it is addressed in the preceding section on heat stress.

Health Effects

The most important health effects resulting from ergonomic stressors in the aluminum industry are musculoskeletal disorders (MSDs). MSDs involve a variety of different types of injuries to the musculoskeletal system, resulting in symptoms such as pain, numbness, stiffness, swelling, and tingling in the affected region of the body. They include sprains, strains, carpal tunnel, tarsal tunnel, and rotator cuff syndromes, tendonitis, and nerve pain such as sciatica. Of these, sprains, strains, and tendonitis tend to be the most prevalent type of ergonomic-related injuries in the aluminum industry.

A sprain results from stretching or tearing a ligament, the connective tissue surrounding joints. A strain is what is commonly referred to as "a pulled muscle", and is an overstretched or torn muscle. Finally, tendonitis is the inflammation of a tendon, which is the connective tissue that attaches a muscle to the bone. Symptoms of these specific conditions may include pain, swelling, and or bruising, and treatment often involves varying degrees of pain and inflammation management, as well as rest.

Controls

Controlling ergonomic hazards in all facets of a workplace is difficult, if not impossible to do. Workers come in all shapes and sizes, and consequently it is difficult to engineer machinery that can accommodate each individual's optimal ergonomic requirements. Despite this, a great deal of work has been done in the aluminum industry to identify and implement controls for ergonomic hazards and streamline the manufacturing process with the automation and machination of certain elements. While this has not eliminated risks from all ergonomic hazards, it has helped to reduce the amount of musculoskeletal injuries in modern aluminum production facilities.

Administrative controls also play an important role in minimizing ergonomic stressors in the aluminum industry. These include reducing the overall job demand and reducing repetition of tasks by allowing for rest breaks and distributing certain demanding tasks across the workforce with job rotation. Worker education and training programs are also important in encouraging proper form and in increasing awareness of certain ergonomic hazards. As a last resort, padded PPE can be used to minimize the impact of ergonomic stressors on areas of the body that are vulnerable to musculoskeletal injury, such as joints and the hands. Again, such practices do not eliminate MSDs, but they do help to ensure that no one worker bears the full brunt of a physically demanding job.

COMMON HAZARD 4: PSYCHOLOGICAL STRESSORS

What are they?
Psychological stressors are human, organizational, or environmental factors that can cause mental distress in an individual, both inside and outside of the workplace.

Exposure route(s)

Psychological stressors in primary aluminum manufacturing can originate from many different things. Psychological demands, such as the pressure to meet deadlines, work fast, work precisely and the extent of control a worker has l over their job can significantly impact a worker's mental health. Additional factors that can influence mental health include work-life balance, supervisor-employee and co-worker dynamics, and worker morale.

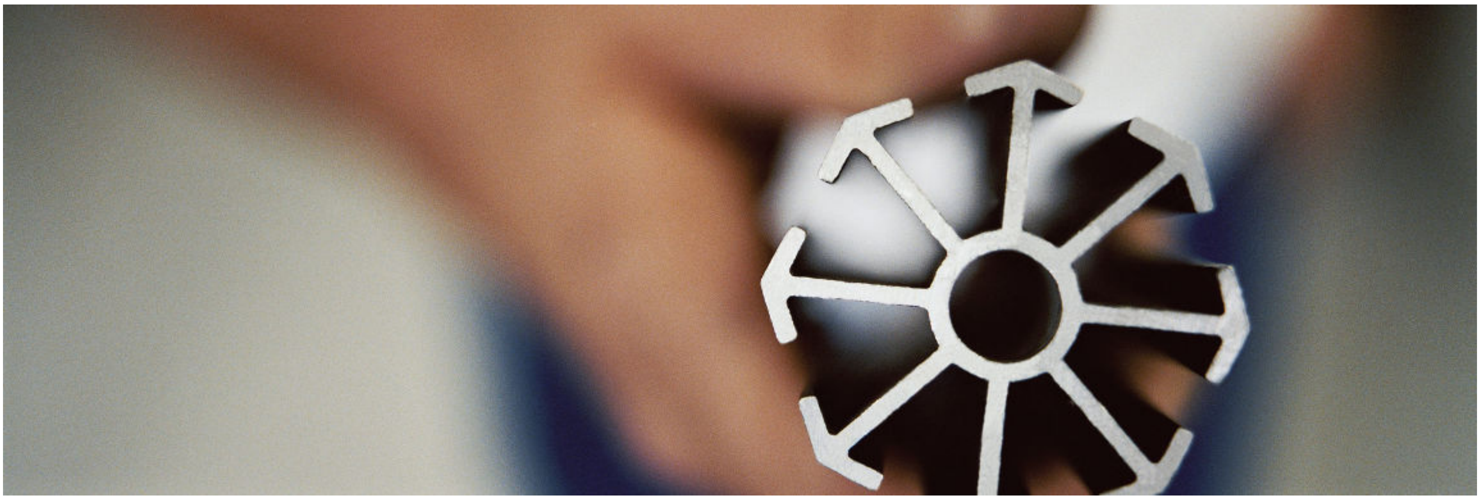
Health Effects

The most common health effects resulting from psychological stressors in the workplace are stress, depression, and anxiety. As none of these effects, nor their causative factors are unique to aluminum manufacturing, they will not be discussed in depth here.

Controls

The aluminum industry has recognized the importance of psychological health both inside and outside of the workplace and is taking steps to promote psychological and physical wellbeing through implementation of workplace wellness and employee assistance programs.

Employee assistance programs allow workers to anonymously seek help for stress-related conditions as well as alcohol or drug dependency. In offering discrete avenues through which employees can seek care, the aluminum industry is striving to improve overall worker health and morale, in turn reducing absenteeism and enhancing productivity. New approaches to managing workplace psychological health and, including emerging and recently developed governmental guidelines and standards [11-13] will, in the future, assist organizations to better manage the hazards and risks that lead to psychological health and safety issues.



BAUXITE MINING

What is bauxite?

Aluminum appears with a wide variety of elements and minerals in the environment, and is often combined with oxygen, silicon, other metals, as well as with compounds such as hydroxides, sulfates, and phosphates.

Bauxite ore, a type of aluminum-containing rock, is the primary raw material used to produce commercial aluminum. Bauxite generally contains anywhere from 30-60% aluminum oxide, or alumina. Silica, iron, and titanium are also commonly found in the ore, along with trace amounts of naturally occurring radioactive materials (NORM) such as uranium, thorium, and potassium.

The process

Bauxite deposits are most often found within 3-5 meters of the earth's surface in tropical and subtropical regions of the world, such as parts of South America, Africa, and Asia. As a result, bauxite ores are typically extracted through open surface mining. Surface mining requires the mechanical clearance of vegetation in the area to be mined and the removal of any rock, or overburden, covering the bauxite deposit. Finally, the bauxite ore is removed from the mine site through digging, blasting, or ripping. The raw, removed bauxite is then crushed and sorted, and subsequently transported to a refining facility for processing.

Associated Hazards

Because bauxite mines are an outdoors, open-air environment, workers can be exposed to heat and ultraviolet radiation (UVR) from direct sunlight. Noise from machinery is also common. Ergonomic stressors may exist, but are less frequent in an open mining environment than they are in a closed mining environment due to the highly mechanized approach to ore extraction. The principal hazards of interest in the bauxite mining process are bauxite dust and diesel exhaust from excavating equipment.

The majority of tasks in bauxite mining are conducted from within the well-ventilated and controlled cabs of mining machinery. This greatly reduces a bauxite mine worker's exposure to both the chemical and physical hazards associated with their jobs.

MINING HAZARD 1: BAUXITE DUST

Bauxite dust is largely comprised of particles of bauxite, alumina, silica, iron oxide, and titanium oxide, though the exact composition can vary depending on the geographic location of the mine and other environmental factors.

In general, the hazard that any dust poses to an individual's health largely depends on the size of the particle to which an individual is exposed; inhalation is the primary route of exposure and particle size determines where a material is deposited in the respiratory tract. Accordingly, jobs that entail breaking down or crushing bauxite from larger to smaller pieces generate more hazardous particles than the removal of large pieces of bauxite from the earth.

Workers are also more likely to be exposed to bauxite dust when the ground and rock beds on the mine site are dry. Dry particles do not adhere to each other or the ground as strongly as wet particles and thus become aerosolized more easily.

Health Effects

To date, there is no evidence that bauxite dust exposure results in any serious adverse health effects in bauxite miners [14-16], and in general bauxite dust is considered to be innocuous. As a result, outside of some possible mouth, nose, and eye irritation, bauxite dust should not pose a threat to bauxite miners' health, especially with modern controls. It should be noted that lung disease attributable to silica exposure has not been observed in bauxite mine workers [17, 18], and thus is not considered to be an important health risk for such workers.

Controls

The principal control for dust exposure in mining is the enclosure of workers within well-ventilated cabins on mining equipment. This greatly reduces dust exposure. In addition, the mine area and adjacent roads may be periodically wet down to suppress dust that is generated from particles settled on the ground. Finally, personal respiratory protection may be used when warranted by a specific dust-exposed job or task.

MINING HAZARD 2: DIESEL EXHAUST

What is it?

Diesel exhaust (DE) is a complex mixture of different gases and particulates that is produced by the combustion of diesel fuel. Both the composition and particle size of the chemicals in DE are dependent on a variety of factors such as the type of machine, type of fuel and the extent to which the diesel engine is being operated. However, several chemicals that are known to be toxic to humans are consistently found in the exhaust mixture. These chemicals include polycyclic organic compounds, benzene and formaldehyde, each of which are listed cancer causing substances, as well as respiratory irritants such as carbon dioxide, carbon monoxide, and nitrogen and sulfur compounds. Overall, IARC, the International Agency on Cancer Research, has classified inhalational exposure to diesel exhaust as "carcinogenic to humans" [19].

In addition, despite the range of particle sizes that may be found in DE, it is typical for the chemical mixture to contain a large amount of very tiny, sub-microscopic fine and ultrafine particles, which have the ability to travel deep into the lungs upon inhalation.

Exposure route(s)

Diesel exhaust is an exposure that is inherent to almost every manufacturing industry, to one extent or another. In primary aluminum production, diesel exposure primarily occurs during the use of mining equipment and when using diesel-powered tools to clean reaction vessels at a refinery.

Health Effects

The immediate effects from DE exposure can cause some of the same symptoms as regular nuisance dust exposure, such as irritation of the respiratory system and eyes. In addition, DE exposures can trigger asthma-like symptoms as well as nausea and light-headedness [20, 21]. Long-term exposure to DE is believed to cause inflammation of the lungs [20]. Also, as noted, DE is classified as a carcinogen, and as such has been associated with lung cancer across many different studies [22-24] in people who have been chronically exposed to it. DE exposure has never been studied specifically in bauxite mine workers, but the possible health effects are not expected to be any different in this population. In fact, the risk of adverse health effects from DE in bauxite mine workers can reasonably be expected to be less than the risk in underground miners, due to the ability of the fumes to disperse in the open air, and as we note above, the use of ventilated cabs, both of which reduce exposure.

Controls

The reduction of DE exposures in bauxite mining is achieved primarily through engineering controls such as ventilated cabins on the diesel equipment and regular engine maintenance to ensure cleaner combustion of the fuel. Along with these measures, steps have been taken to replace older machines with newer equipment that generate less hazardous exhaust, as well as to improve diesel fuel itself so that it produces less hazardous exhaust when burned. Because diesel-fuelled machines are used in enclosed spaces in refineries, additional measures of protection may be taken such as the use of personal respiratory equipment and ventilation.

MINING HAZARD 3: ULTRAVIOLET RADIATION

What is it?

Ultraviolet Radiation is one of the two types of physical hazards that are unique to the mining stage of primary aluminum production. Sunlight, or solar radiation, is a form of ultraviolet radiation (UVR). The International Agency for Research on Cancer (IARC) has classified sun UVR exposure as a Group 1 Carcinogen, meaning that it is carcinogenic to humans [25].

Exposure route(s)

Any individual working outside may be exposed to the sun; the most intense sun exposure occurs during midday and in tropical and subtropical regions.

Health Effects

The most common health effect associated with prolonged sun exposure is sunburn, which can be painful and damages the skin. In addition, direct sun exposure can cause damage to the eyes. The greatest health risk associated with long-term sun exposure is skin cancer, a risk that is increased amongst workers with light or fair skin, freckles, and light-colored eyes [26, 27]. The risk of developing skin cancer also increases with the number and severity of sunburns that an individual has had, and can be increased if a person has family members that have had the disease [26]. While there have been no studies specifically of skin cancer in bauxite workers, the most common skin cancers found in outdoor workers are basal cell and squamous cell carcinomas [26, 28]. The vast majority of studies of outdoors workers have not found an increased risk of melanoma, the most severe form of skin cancer [28].

Controls

The controls for reducing bauxite mine workers' exposure to UVR are generally the same as controls for reducing sun exposure in any environment. Engineering controls include the enclosure of the cabs of mining equipment to block the sun; administrative controls include the reduction of outdoor work during the middle of the day, when sunlight is at its greatest intensity. Finally, personal protective equipment is used to shield a worker's skin and eyes from the sun. PPE to reduce UVR exposure can include UVR- resistant long-sleeved clothing and pants, helmets, sunglasses and sunscreen.

MINING HAZARD 4: NATURALLY OCCURRING RADIOACTIVE MATERIAL

What is it?

Naturally occurring radioactive material (NORM) is the second type of physical hazard in the mining stage of primary aluminum production, and is a term that describes natural compounds that contain radionuclides. When mining bauxite, the most commonly encountered NORMs are uranium and thorium.

Exposure route(s)

Bauxite mine workers can be occupationally exposed to NORMs during the extraction, transportation, and processing of minerals. However, to date, there is no evidence to suggest that bauxite mine workers receive any more NORM exposure than the general population living in the same geographic area [29]. The radioactivity of bauxite may vary considerably, however, depending on the location of the deposit.

Health Effects

Radioactive materials have been associated with a variety of types of cancer and yet there have been no published studies that have evaluated cancer risk in open-pit bauxite mine workers due to NORM exposure. Regardless, because a bauxite mine worker's NORM exposure is unlikely to be above that of people inhabiting the same geographic region of the mine [29], NORM exposure at the levels typical of a bauxite mine are not expected to cause any adverse health effects in the workforce, as NORM assessments to date have not shown exposures to exceed the 1mSv/year above-background recommended for the general public [29].

Controls

Control strategies to reduce workers' exposure to bauxite dust and diesel fuel also lower exposure to NORM. Many bauxite mines also have regular exposure assessment programs that monitor both the workers and the mining locations to ensure that workers are not being excessively exposed to NORM.

MINING HAZARD 5: MOSQUITOES

What are they?

Mosquitoes are small, flying insects that are prevalent in most regions of the world and feed on the blood of other animals. In the tropical and subtropical regions where bauxite mines are typically found, mosquitoes are generally active all year long.

Exposure route(s)

Mosquitoes can transmit certain blood-borne diseases by taking blood from an infected person and then exposing a healthy individual to the infected blood when they go to feed again. An individual can only develop a mosquito-borne disease if they are bitten by an infected mosquito.

Health Effects

Three diseases that are transmitted by mosquitoes and are of relevance in the regions that generally have bauxite mines are malaria, yellow fever, and dengue fever. All three of these diseases generally begin to affect a person within a week or so of being bitten by an infected mosquito. Flu-like symptoms such as fever, nausea, chills, and body aches are common. Each of the three diseases ranges in severity, with mild cases making a full recovery, and more severe cases needing more care and possibly hospitalization.

Controls

The most important control is the prevention of mosquito bites. This may involve the use of insecticides, insect repellant, protective clothing and/or the removal of stagnant pools of water, which is where mosquitoes breed. While there are no other preventive strategies for dengue fever, preventive medications including doxycycline, chloroquine, and mefloquine, exist for malaria and a preventative vaccine is available for yellow fever.

ALUMINA REFINING

What is alumina?

Alumina, or aluminum oxide, is the intermediate product between aluminum ore and aluminum metal and is used as the feed material for the aluminum reduction process that occurs at smelters. It is produced during the refining process, when it is chemically extracted from bauxite ore.

The process

The Bayer Process is the most common method for alumina refining, accounting for over 95% of production worldwide. It involves a series of physical processes and chemical reactions that progressively strip away extraneous elements and minerals from bauxite, ideally leaving behind alumina that is 99% aluminum oxide, with a maximum of 1% impurities.

Milling is the first step in refining, and involves crushing and cleaning the source bauxite so that it is a desirable consistency for the next step, which is digestion.

Digestion involves the addition of hot sodium hydroxide, or caustic soda, to the crushed bauxite slurry. The resulting chemical mixture is green liquor.

Green liquor then undergoes a process called clarification in which heavy waste solids are precipitated, sink to the bottom of the tank and removed, leaving a solution of sodium aluminate behind.
Aluminium hydroxide is precipitated out from the sodium aluminate solution after several cooling and evaporation steps and filtered out. The aluminium hydroxide is calcined at high temperature and transformed to alumina crystals.

An important aspect of refining is that some of the chemicals involved in the process, such as the green liquor, are recycled. As a result, they are cleaned and prepared for re-use, resulting in exposures that are not necessarily limited to one area of the refinery.

In addition, the solid bauxite residue that precipitates out during the digestion process can be highly alkaline, due to the addition of the caustic soda. This residue, often referred to as “Red Mud” due to its color, the result of the presence of iron compounds, may also contain residual natural radioactive materials (NORMs). In order to ensure that the bauxite residue does not negatively impact the health of workers, the surrounding community, and the environment, it is stored in carefully engineered disposal areas that are adjacent to the refinery, referred to as bauxite residue storage areas (BRSAs). It is in the BRSAs that bauxite residue typically undergoes a gradual dehydration process and is partially or fully neutralized. A great deal of research is currently underway to determine both the best practices for bauxite residue disposal, as well as avenues for its possible re-use[30].

Associated hazards

Workers at an alumina refinery are predominately exposed to chemical and physical hazards. Of these, the most important hazards that will be addressed here are caustic soda and alumina dust. Some refinery workers may be exposed to diesel exhaust in confined spaces as they are using certain equipment to clean the reaction vessels. We will not discuss diesel here, however, since we have already addressed it in the mining section. Regardless, workers cleaning the reaction vessels use respiratory protection, which reduces their exposures not only to diesel, but also to other relevant chemicals. The primary physical hazards at a refinery are heat, noise and ergonomic stressors, explored at the beginning of this document.

REFINING HAZARD 1: CAUSTIC SODA

What is it?

Caustic soda is a white, odorless solid that is dissolved in a water-based solution to facilitate the removal of undesired materials in bauxite, leaving behind aluminum oxide. As an extremely strong base, it is corrosive to any tissue with which it comes into contact, causing severe chemical burns.

Exposure route(s)

The most likely routes of exposure to liquid caustic soda in refinery workers are through the skin, as the result of accidental chemical splashes, and inhalational exposures, from breathing in the proximity of caustic mist.

Health Effects

Caustic mist is known to cause a variety of health effects in exposed workers. Common symptoms of inhaling low to moderate levels of caustic mist include wheezing, chest tightness, and nasal congestion. In addition, caustic mist can cause eye, skin, and throat irritation. For people who have inhaled or swallowed large amounts of, or highly concentrated, caustic soda, extensive scarring of the mouth, throat, and the digestive and respiratory organs may occur. However, such exposure in a refinery is extremely rare.

In health studies specific to the effects of inhaled caustic mist by alumina refinery workers, the most common respiratory complaints of those exposed were wheezing and congestion. Upon further analysis, no change in lung function was found, indicating that while exposure to caustic mist in alumina refinery workers can cause irritation and needs to be carefully monitored and controlled, it does not result in permanent lung damage [15].

In addition, as mentioned above, caustic soda exposure can cause severe burns to any skin or tissue that it comes in contact with. As such, in the event of a chemical splash that results in skin exposure, immediate medical attention is required.

Controls

Proper ventilation is important, to remove caustic fumes and mist from the work area. As with other hazards, administrative controls such as occupational exposure limits and best practice guidelines can further reduce worker exposure.

In addition, employees working with caustic materials use several types of personal protection. This PPE should include clothing, gloves and face shields that are impervious to sodium hydroxide. Perhaps most importantly, respirators are used, especially in situations that require a worker to go into one of the chemical reaction vessels for maintenance, cleaning, or other tasks. In the aluminum industry, fitting an employee with the proper respirator is often part of a larger respiratory protection program, in which employees receive medical evaluations, respiratory fitting and training at regular intervals, in order to monitor respiratory health while working amongst respiratory irritants.

REFINING HAZARD 2: ALUMINA DUST

What is it?

Alumina is the end product of refining; also known as aluminum oxide, it is an odorless, fine white crystalline powder.

Exposure route(s)

The main route of exposure to alumina dust is inhalation.

Health Effects

The few studies that have been conducted looking at the health of refinery workers in relation to alumina exposures have not established any significant issues [15-17]. Alumina has been associated with mild increases in wheezing and congestion, but never a decrease in lung function [15, 16]. It is important to note that alumina exposure has never been associated with cancer, and is not considered carcinogenic.

Controls

The controls for mitigating alumina exposure are similar to those for caustic mist. Engineering controls can limit the amount of dust in the environment. Administrative controls, such as exposure limits and best practices, ensure that workers are not receiving excessive exposures to the particles. Finally, respiratory and eye protection can be used to reduce the risk of any irritation associated with alumina dust.

REFINING HAZARD 3: BAUXITE RESIDUE (RED MUD)

What is it?

Bauxite residue is the material that remains after alumina is extracted from bauxite ore. There are two distinct components of the residue: sand, which mostly contains coarse grains of quartz, and red mud, which is comprised of very fine particles of both metallic and non-metallic oxides. Because of the caustic chemicals used during the digestion process, bauxite residue can be highly alkaline, sometimes with a pH exceeding 11, and may also contain natural radioactive materials (NORMs).

Exposure route(s)

Occupational exposure to bauxite residue occurs via the inhalation of respirable particles of dust, which can be lifted off and carried away from the bauxite residue storage area (BRSA) by the wind.

Health Effects

Bauxite residue does not pose a serious health risk to refinery workers when it is properly contained and stored, thereby limiting exposures to fugitive bauxite residue dust, and preventing spills that can result in chemical burns upon contact with skin. To date, there is no evidence that inhaling respirable bauxite residue causes any significant health effects. Due to the caustic nature of the dust, however, some mild respiratory irritation is possible[31].

Controls

As stated above, bauxite residue does not pose a serious health threat to workers or the communities surrounding BRSAs when properly stored. Thus, the controls instituted to reduce exposure to bauxite residue are focused on maintaining the integrity of the BRSA. As a result, engineering controls are very important, with special consideration given to the climate, geological, and meteorlogical events in the design of the containment unit, as well as water flow and the proximity of plant, animal, and human habitation. Administrative controls also play an important role, with careful monitoring and daily inspection of key components of the BRSA. In addition, regular preventative maintenance ensures that all engineering controls are functioning properly. Finally, refineries should have emergency-action plans in place, which dictate the actions to be taken in the unlikely event of a breach of the containment unit. This ensures that the human and environmental impact of a spill is minimized in both the refinery site and the surrounding community[30].

ALUMINUM SMELTING

What is smelting?

Smelting is the mechanism through which alumina, produced in the refining process, is chemically reduced to create aluminum metal through an electrolysis process. The modern method for aluminum smelting, also known as aluminum reduction or as the Hall-Héroult process, was invented in 1886.

The process

During smelting, alumina is dissolved in a molten cryolite "bath", which contains sodium, aluminum, and fluoride. Aluminum fluoride is added to the cryolite to lower the bath temperature. The bath mixture is contained in a large carbon-lined steel container known as a pot. An electric current flows between a carbon anode, made of petroleum coke and pitch, and a cathode, formed by the carbon lining of the pot. The electric current results in the generation of static and extremely-low frequency electromagnetic fields (ELF-EMF) and the heat generated by the electrolytic reduction process makes the potroom environment a hot one.

The final product of reduction is pure molten aluminum that is deposited at the bottom of the pot and later removed for casting into solid aluminum blocks in various forms, used to create aluminum products.

There are two main types of aluminum smelting facilities, Søderberg and prebake. Søderberg technology involves the continuous, direct addition of carbon paste to the pots, which is then baked in place to create the carbon anode described above. Prebake smelting technology uses anodes that are manufactured in a separate facility before being added to the pot. The most significant occupational exposures at an aluminum smelter occur in two main locations - the potrooms of both Søderberg and prebake facilities and the carbon anode production plants at prebake smelters. In the potroom, tasks involving noteworthy exposures include crust tapping or breaking, anode changing, and molten metal removal.

Other important tasks include pot tending, which involves ensuring that the pots are running properly, and potlining, which involves dismantling and rebuilding of the pot superstructure. Potroom workers may operate cranes and other mobile equipment, as well as perform mechanical and electrical maintenance.

Carbon plants are where the carbon anodes are created for prebake technology. They consist of three main processes known as green milling, carbon or anode baking and, finally, anode assembly. Through these three processes, the chemicals needed to create the anodes are combined and preheated, baked at very high temperatures, cooled and finally attached to steel rods before they are ready to be placed in pots.

Associated hazards & health effects

Cancers, fluoroses, and respiratory diseases are the health issues which have historically caused concern due to exposures during the smelting processes. In general, these health effects are associated with chemical aerosols and dusts generated in the potroom and in carbon plants. While certain health endpoints are more strongly associated with certain exposures than others (for example, fluorides & fluorosis), there remains some ambiguity as to which chemical or chemicals are causative agents for cancers and respiratory diseases. It is due to this uncertainty that IARC lists occupational exposures in aluminum manufacturing as carcinogenic to humans [32, 33], as opposed to certain individual chemicals. Having said that, most of the research that has led to that decision is based on the carcinogenicity of some polycyclic aromatic hydrocarbons, present in coal tar pitch and emitted during the anode production or Søderberg reduction processes.

A similar causative ambiguity exists for respiratory diseases, such as asthma. Accordingly, for the purpose of this primer, we will deal with the chemicals in the ambient potroom environment collectively. These chemicals include **coal tar pitch volatiles (CTPVs)**, **fluorides**, **beryllium**, **sulfur dioxide (SO2)**, **carbon dioxide (CO2)**, and **carbon monoxide (CO)**.

As mentioned above, **EMF** is another important exposure, but we will address it separately.

SMELTER HAZARD 1: AMBIENT POTROOM & ANODE PLANT CHEMICALS

What are they?

As stated in the introduction to this section, there are multiple chemical exposures in smelter operations that may or may not play a role in the three major heath endpoints associated with aluminum reduction: cancer, fluorosis, and asthma. All of the relevant chemicals are profiled here to illustrate the nature of the mixture. In addition, it should be noted that exposures to each of these chemicals will vary depending on technology employed, the location in the smelter, the job or task being completed at any given time and the composition of the input materials. Moreover, some of these chemicals can exist in particulate form, creating dust mixtures of different particle sizes in the potroom, while others only exist as gas. Again, the smaller or finer the dust particles, the more likely they are to travel deep into the lungs.

Coal Tar Pitch Volatiles (CTPVs)
Coal tar pitch is a major component of the carbon anodes necessary to the aluminum reduction process. Due to the chemical nature of coal tar pitch, it is volatile, or prone to evaporation, when heated, creating coal tar pitch volatiles (CTPV). Of primary interest to health is the component of CTPV mixtures known as polycyclic aromatic hydrocarbons (PAHs). PAHs are a group of chemicals formed during the incomplete combustion of almost any fuel. PAHs are distributed widely in the human environment at low concentrations. They are produced through chemical reactions associated with domestic heating, vehicle exhaust, waste incinerators, certain industrial activities, as well as with cigarette smoking and charring or overcooking foods. PAHs travel through the atmosphere while in the vapor phase and are absorbed onto particulate matter. Consequently, human exposure to PAHs generally occurs through inhalation and dietary intake.

However, in industrial environments, the levels of PAHs present, and subsequent exposures to them, may be greater. Workplaces where carbon-containing materials such as coke, coal tar, pitch, creosote and heavy oils are handled yield the highest exposure. These include aluminum smelters, as well as coke plants, gas works, and iron and steel plants. PAHs are found in the coal tar used to bind the carbon anodes together and emitted predominantly prior to and during their baking. Thus, the greatest likelihood of exposure to PAHs occurs in Søderberg potrooms and in prebake anode production areas, where workers are exposed to CTPVs, of which they are a part.

Many PAHs are known carcinogens[33]. However, because they usually occur in mixtures, it is nearly impossible for scientists to determine which of the individual chemicals in the mixture are carcinogenic. Because benzo(a)pyrene (BaP), a particular type of PAH, is consistently found in such mixtures, it is used as an indicator compound for the presence of hazardous PAHs in occupational and other environments. In other words, safety and health professionals will assume that carcinogenic PAHs are present if measurements for BaP are positive. Benzene soluble matter (BSM) is also used as a PAH indicator compound.

Fluorides

As we describe in the introduction to smelting, the molten bath in which aluminum reduction occurs contains fluoride compounds. Because of this, and as a consequence of the heat and ongoing chemical reactions in the bath, many different fluoride-containing compounds are emitted from the pots during the reduction process. The emitted compounds include both particulate and gaseous fluorides such as hydrogen fluoride (HF), which is a very strong acid, and small amounts of other fluoride compounds. While it is possible for a worker's skin to be exposed to fluorides, inhalational exposures to particulate fluorides and fluoride anion are the most relevant to health in aluminum smelters.

Fluoride compounds are rapidly absorbed into the upper airways when they are inhaled. About 50% of the absorbed fluoride is retained in the body, with approximately 99% of absorbed fluorides being deposited in the skeleton and 1% deposited in soft tissues. The remaining 50% of absorbed fluoride is excreted in urine. As stated above, aluminum smelter workers may be subject to high fluoride exposures. Such chronic exposure to high levels of fluorides can result in both dental fluorosis, the mottling of teeth, and skeletal fluorosis, in which bone tissue is damaged. In addition, exposure to fluorides is known to cause varying degrees of respiratory irritation and congestion. It is because of this respiratory irritation that fluorides are thought to play a role in the development of a condition known as "potroom asthma"[34-37].

Beryllium

Beryllium is a metal that can be found in combination with a variety of different rocks and minerals, including bauxite. As a result, workers in the primary aluminum industry can be exposed to beryllium, though the amount of exposure that they receive is highly dependent on the amount of beryllium contained within the source bauxite being processed at any given time. Some regions of the world have bauxite that contains a high amount of beryllium, while other regions have bauxite that contains considerably less beryllium. During the refining process, the beryllium in the bauxite is concentrated within the alumina and subsequently, during the smelting process, is further concentrated in the cryolite bath. Thus, smelter workers may be exposed to beryllium contained in the pot emissions or fumes. The most important route of beryllium exposure in the aluminum industry is through inhalation. IARC, the International Agency for Research on Cancer, classifies beryllium as carcinogenic (lung) to humans. However, to date, occupational exposure to beryllium has not been found to cause cancer [38, 39].

Sulfur Dioxide

Sulfur is a component, to varying degrees, of the coke used in the production of the carbon anodes and, as a result, gaseous sulfur dioxide can be produced during the reduction process. Sulfur dioxide is a very reactive chemical and may have an unpleasant odor. When dissolved in water it can form sulfuric acid, a strong oxidizing agent that can result in acid burns if it comes in contact with human tissue.

In a smelter, the main route of exposure to sulfur dioxide is via inhalation.

Sulfur dioxide is not classified as a carcinogen [40], but it has been implicated as a possible causal agent of potroom asthma, due to its ability to cause respiratory irritation [34] when it reacts with water in the upper respiratory tract of exposed individuals.

Carbon Oxides

Both carbon dioxide and carbon monoxide are produced in significant volumes during the reduction process, although extraction through pot ventilation systems minimizes occupational exposure. Both are odorless, colorless gases that can displace oxygen in the lungs when inhaled, making it difficult to breathe. The subsequent lack of oxygen can result in dizziness, headaches, and nausea. As with other potroom chemicals, the most important route of exposure to these gases is through inhalation.

Health Effects

We state in our introduction to this section that there are several health effects that have been or currently are associated with aluminum smelting – in particular, cancer, asthma, and fluorosis. We will profile each of these diseases in relation to potroom exposures here. Again, while some health effects are more closely associated with certain chemicals than others, there remains a great deal of uncertainty over whether or not one chemical is solely responsible in the development of cancer and respiratory illness, or if several chemicals interact and influence each other in the development of these diseases.

Cancer

One of the most important health effects observed in primary aluminum production workers is cancer, particular of the lung and bladder. In the 1980s, a few landmark studies were published that found populations of Søderberg aluminum smelter workers in Canada to be at a higher risk of developing bladder and/or lung cancer than similar individuals who did not work in a smelter [41-44]. Subsequent epidemiologic studies of both Søderberg and prebake smelter workers in Europe have supported these associations [45, 46]. In some cases, the excess risk of cancer observed in aluminum smelter workers was linked to the amount of exposure the workers had to coal tar pitch volatiles (CTPVs) [41, 44-49], and the risk remained elevated even when researchers accounted for the non-occupational carcinogenic effects of smoking and other exposures such as fish smoking. Other cancers, such as oesophageal, stomach, pancreatic, kidney, and cancers of the blood have also been linked to CTPV exposure, but insufficient evidence exists to conclude that CTPVs are a causal factor in their development [46, 49-51]

While the aforementioned studies did find elevated cancer risks in aluminum smelter workers, it is important to note that they were retrospective, meaning that they used exposure and health data on workers from the past. In addition, most of the associations between aluminum industry CTPV exposures and cancer were found in men who had worked in smelters for twenty or more years. Thus, investigators looked backwards through a worker's occupational exposure history to determine if there were exposures that may have played a role in initiating disease in the cancer patients. The end result was that the studies correlated exposures from working conditions in the 1940's to the1960's to cancer incidence in the 1970's and beyond.

More recently, studies published on cancer and aluminum smelter workers have been prospective, meaning that instead of looking backwards, the studies have followed groups of workers and their average chemical exposures from working in a smelter going forward from their date of hire, tracking cancer diagnoses. Some of these studies have shown lung cancer mortality to be lower than expected in the group of workers given their CTPV exposure history and/or found no elevated risk of lung and bladder cancer in smelter workers [52, 53].

Other studies have continued to show a moderately increased risk of lung cancer, as well as kidney and stomach cancers, though the agent(s) most responsible for the increased kidney and stomach cancers remains unknown, as cancer incidence did not always correlate with CTPV exposure [50, 52, 54-57].

Overall, exposures in aluminum smelting have been associated with the occurrence of certain cancers, particularly cancers of the lung and bladder. It is these two cancers that have generally been most consistently associated with CTPV exposure, though other factors may play a role in their development. Increased incidence of cancers of other body regions, such as the kidney, pancreas, and stomach have been observed in some groups of smelter workers, but there is much less certainty about what agent, if any, is responsible for causing the diseases, as well as whether or not the cancers are related to occupational exposures at all.

Regardless, the risk of developing cancer as a result of working at an aluminum smelter is very small, and substantially less than it was in the past, with the reduction of hazardous chemical exposures over time and improved control systems[58]. This trend is expected to continue, as analyses in both aluminum and general manufacturing have shown that chemical exposures have been decreasing over time [59].

Potroom Asthma & Respiratory Disease

After case reports of aluminum smelter workers with respiratory issues emerged during the early to mid-1900's, the possible relationship between potroom exposures and respiratory function began to receive greater attention [58]. Historic studies of potroom workers from Europe, Australia, and New Zealand lent support to this suspicion, with the annual incidence of a condition that had come to be known as "potroom asthma" estimated to be approximately 2%. Moreover, historically, up to 10% of long-term potroom workers were shown to have asthma diagnoses [60].

While asthma is a disease that can be caused by many different factors, both environmental and genetic, "potroom asthma" is believed to occur in large part as a result of irritant exposures incurred in the potroom. Potroom asthma is generally diagnosed in workers based on symptoms, which include chest tightness, cough, wheezing, and breathlessness, and lung function. Occasionally measurements of breathing ability and lung capacity are used [58].

Many studies have looked at all potroom emissions as possible catalysts of this condition. Dust, sulfur dioxide, carbon monoxide, carbon dioxide, coal tar pitch volatiles, and finally fluorides have all been suspected as causal agents, but there remains uncertainty as to which, if any, of the above chemicals carries the greatest role in the development of the condition [35, 60, 61]. Some European studies conducted during the 1980's and 1990's found that reports of asthma-like symptoms were closely related to the duration of a worker's potroom employment, as well as the concentration of fluorides to which a worker was exposed [62]. Thus, the longer a person worked in a potroom, and/or the greater the concentration of fluorides to which they were exposed, the more likely they were to develop symptoms of potroom asthma. Despite this evidence that fluorides may play a role in the genesis of potroom asthma, other chemicals in the ambient potroom environment cannot be ruled out as causal agents.

Further evidence supporting a relationship between potroom emissions and asthma came from studies that followed symptomatic potroom workers and found that those who were removed from the potroom environment experienced symptom improvement [36, 37, 63, 64]. However, workers who continued to have exposure to potroom emissions after the onset of symptoms had less improvement after removal from the potroom than those who did not continue to work in a potroom after symptom onset [60]. It has also been hypothesized that workers diagnosed with potroom asthma may be at a higher risk of developing chronic obstructive pulmonary disease (COPD) [65], but there has not been enough research to date to validate this presumption. It is still unknown.

Overall, cases of "potroom asthma" continue to be recognized in modern aluminum smelters, albeit at a much reduced incidence than in the past [66]. However, as we discussed in the preceding section, exposures to potroom emissions are less today than they were in the past and should continue to decrease. As always, personal protective equipment is available to further reduce workers' exposure to the irritant chemicals that remain despite engineering controls, and medical surveillance can help to identify and treat workers with asthma symptoms quickly, so that the condition does not progress.

Fluorosis

Fluorosis is a disease that was much more prevalent in aluminum workers in the past than it is today, though it still merits discussion here. Fluorosis is a disease that can occur when excess fluoride from prolonged, elevated exposures is deposited in hard tissue. There are two forms of the disease – skeletal and dental fluorosis, which are characterized by bone changes associated with joint and muscle pains and mottled teeth, respectively.

Fluorosis was first described in an industrial setting in 1932 in cryolite workers in Copenhagen, Denmark [67]. Following the initial reports, cases were identified in other industries with high levels of occupational fluoride exposure, such as aluminum and superphosphate fertilizer production. In addition, cases of fluorosis have been documented in animals living in the vicinity of aluminum smelters [68, 69].

As with any of the health effects observed in workers in the aluminum industry, researchers began to investigate patterns of exposure that could result in disease. Several historical studies were conducted that tracked the health status of former or current aluminum industry workers who had worked in potrooms anywhere from the mid-1900's to the 1980's. The majority of the studies found evidence of a dose-response association between potroom fluoride exposure and the incidence of fluorosis [70]. Other studies did not find any fluorosis in potroom workers [71], though some evidence of early skeletal fluorosis was found in workers who had been on the potlines for more than 10 years [72]. In general, fluorosis was only observed in workers who had been exposed to high levels of fluorides for 10 or more years, as fluorides slowly accumulate in the body over time. More recently, however, a significant reduction in urinary fluoride excretion was documented in aluminum smelter workers employed between 1976 and 1986. This reduction was correlated with the introduction of technical measures designed to reduce fluoride exposures. This observation led investigators to conclude that the risk of industrial fluorosis was eliminated in newly engaged workers and significantly lowered in other workers employed in the Swiss aluminum industry [73]. Further research has confirmed this observation, with the last documented case of fluorosis in aluminum workers in the Czech Republic in 2001 [74]. As a result, while fluorosis was certainly an issue for aluminum smelter workers in the past, it is much less of an issue today, due to increased exposure controls.

Chronic Beryllium Disease

We previously discussed how beryllium, an element that can be found with bauxite in nature, may be present in smelter potrooms. The most important possible health effect from chronic beryllium exposure in the aluminum industry is the development of chronic beryllium disease (CBD). Chronic beryllium disease is an illness in which exposure to inhaled beryllium causes chronic inflammation of the lung tissue, ultimately leading to scarring of the lungs. Symptoms of CBD range from fatigue, weakness and lack of an appetite, to respiratory symptoms such as a cough, shortness of breath or difficulty breathing. In the early stages of the disease, a worker may have no obvious symptoms, with a positive blood test the only indication that they are sensitive to beryllium exposure.

Beryllium sensitization is similar to an allergy, and occurs when an individual's immune system identifies beryllium in the body as a foreign substance. This in turn results in the sensitized person having a greater negative reaction to the chemical than a non-sensitized person. Beryllium sensitization can be thought of as a marker of susceptibility to adverse health effects from prolonged beryllium exposure, meaning that sensitized workers are more likely to go on and develop CBD than workers who are not sensitized to the metal.

In addition, certain genetic traits, known as host factors, have been shown to increase significantly the risk of beryllium-related disease in beryllium exposed workers. The prevalence of these specific genetic traits have been estimated to be 30-40% in the general population [75-77], and while genetic distribution of the aluminum smelter workers has not been studied, there is no reason to believe that predisposing personal factors associated with the risk of developing beryllium related diseases will be under-represented among aluminum smelter workers.

It is important to understand that while beryllium may be present in smelter potrooms, and while there remains a risk of aluminum workers developing beryllium sensitization, the risk is very, very small. Recent studies of aluminum industry workers have shown the beryllium sensitization rates in the workforce to be less than 1% [78, 79]. Further, only a small percentage of the fraction of workers that do become sensitized to beryllium will ever go on to develop CBD. Because of this, beryllium is an important exposure to be aware of, but not one that poses any significant risk of adverse health effects in the primary aluminum industry workforce.

Controls

To reduce a smelter worker's exposure to ambient particulate and gaseous chemicals, engineered ventilation and fume hoods are the first line of defense. Ventilation systems conduct fumes collected in the hood away from smelter personnel and into locations where they can be treated so that they no longer pose a threat to human health. Administrative controls include occupational exposure limits (OELs), which vary depending on the location and institution governing each smelter, and best practice guidelines.

Personal protective equipment is also mandated at most facilities and is provided primarily for safety hazards arising from working in the vicinity of molten bath and metal, as well as from chemical aerosols, gases and particulates. There are multiple types of PPE used by workers in a smelter, and particularly a potroom. These personal controls include covering exposed skin with long pants, long-sleeved shirts, gloves, work boots, a helmet, goggles, and a respirator.

Because of the risk of health effects from inhaling potroom chemicals, many primary aluminum companies have introduced respiratory protection programs to their workforce. These programs are designed to ensure that workers are not only using the correct respiratory protection for their job, but that each worker's respirator fits properly. In addition, many respiratory protection programs include various levels of medical surveillance in order to identify and treat respiratory health issues in the workforce at an early stage. Depending again on the location and company instituting a particular program, medical surveillance may include symptom questionnaires, medical histories, spirometry, and/or chest imaging studies.

SMELTER HAZARD 2: ELECTROMAGNETIC FIELDS (EMF)

What are they?

Electromagnetic fields (EMF) can be thought of as waves or packets of energy in space that are made up of both electric and magnetic components. EMF are generated by any electrically charged particle and are one of the four fundamental forces in nature. The electromagnetic spectrum is classified by the frequency of the waves, using the metric of cycles per second or Hertz (Hz). At the higher frequency end of the spectrum are the sources of “ionizing” radiation (since electromagnetic radiation at these high frequencies has the energy to break a chemical bond in a molecule), which include gamma rays and x-rays. At the lower end of the spectrum (at or below the visible light frequencies), are the “non-ionizing” types of radiation, including, in descending order of frequency, microwaves, radio waves, and finally, at the lowest end of the EMF spectrum, the “extremely low frequency” (ELF) magnetic fields, generated by electrical current and the magnetic field of the earth.

In addition to variation in frequency, EMF can be classified in terms of the current of the generating particles, which can be direct (DC), or alternating (AC). Direct current generates a magnetic field that is related in intensity to the strength of the electric field. Examples of DC EMF are the magnetic field of the earth and those generated by household batteries.

Alternating current is characterized by periodic reversal in the direction of electrical charge through a system, such as the electricity running through household electrical appliances. Household appliances and household wiring generate much of the background AC EMF exposure for the general population. Greater AC EMF exposures can occur close to overhead electrical transmission lines and electric distribution lines.

Exposure route(s)

The U.S population is generally exposed to AC fields at a frequency of 60 cycles per second (Hertz or Hz) and a voltage of 110-120 Volts, whereas Europe and many other locations use 50Hz and 220-240V AC electrical systems. In contrast to this AC exposure range, exposures to DC EMF from the earth's magnetic field may be of a higher magnitude, depending on distance from the poles. However, AC fields and DC fields act differently on body tissues, so the biological importance of the two types and strengths of exposures cannot be directly compared.

Workers in aluminum smelters, especially in potrooms, are primarily exposed to DC EMF, which results from the electrical current running to, through and away from the electrolytic pots, creating static magnetic fields. Other workers in an aluminum plant, such as electrical workers, may be exposed to high levels of AC EMF fields through their work on power lines and transformers, as high levels of electricity are required to facilitate the reduction process.

Health Effects

Concern about health risks from EMF arise from the fact that such fields, in particular AC EMF, are capable of inducing electric fields and associated electric currents in body tissue. At the forefront of this worry is the risk of cancer, which has been associated with AC EMF in non-aluminum industry health studies, and has been reported at times in the media. Reports of childhood leukemia in children living near power lines prompted this unease, with the first study on the issue published in 1979[80]. Subsequently, several studies followed, some of which supported the association, while others did not[81]. In all cases, the mechanism for such an effect remains unclear. Regardless of this uncertainty, IARC classifies EMF as a possible human carcinogen[82], leading both aluminum smelter workers and communities located near smelters to be concerned about how such exposure might influence their health.

As stated above, aluminum potroom workers are exposed to high levels of DC EMF. In regards to such exposure, IARC states that "there is inadequate evidence in humans for the carcinogenicity of static electric or magnetic fields and extremely low-frequency electric fields"[82]. Unlike alternating current, there is no body of epidemiological evidence suggesting that DC EMF fields are associated with cancer risks, and studies of aluminum smelter workers have not found a relationship between EMF and cancer[83, 84]. Thus, based on current medical knowledge, there is very little evidence for chronic disease health risks related to chronic DC EMF exposures at the levels currently found in aluminum potrooms or acute risks in the normal occupational population. Short-term high exposures to EMF fields, however, can cause problems for users of medical devices such as pacemakers.

Controls

Occupational exposure limits that vary by location and company may be employed to limit a worker's exposure to EMF. In addition, individuals with medical devices should avoid EMF fields so that they do not disrupt the device's function.

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