Community Health Risk Assessment of Primary Aluminum Smelter Emissions

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Objective: Primary aluminum production is an industrial process with high potential health risk for workers. We consider in this article how to assess community health risks associated with primary aluminum smelter emissions. **Methods:** We reviewed the literature on health effects, community exposure data, and dose–response relationships of the principal hazardous agents emitted. **Results:** On the basis of representative measured community exposure levels, we were able to make rough estimates on health risks associated with specific agents and categorize these as none, low, medium, or high. **Conclusions:** It is possible to undertake a rough-estimate community Health Risk Assessment for individual smelters on the basis of information available in the epidemiological literature and local community exposure data.

The production of primary aluminum metal is a well-established and vital industrial process. Aluminum metal has innumerable applications in modern society, which has become very dependent on its availability. Unfortunately, the (Hall–Héroult) smelting process is fraught with many well-documented risks to the health of the workers who run it. Over the century since its inception, questions have also been raised regarding the process emissions' potential impacts on the health of residents of adjacent neighborhoods. This article reviews the known toxic exposures that emanate from smelters and considers some of the factors that could render certain of those exposures a concern for community health. It concerns itself solely with smelters using the Hall-Héroult electrolytic process. It does not consider downstream manufacture of aluminum products or the secondary production of aluminum through recycling processes. Also not covered in this article are alumina refineries, which extract and calcine anhydrous, smelter-grade aluminum oxide (alumina) from the raw ore (bauxite) using the Bayer process.

There are two basic types of aluminum smelters:

1. Søderberg smelters: In the Søderberg process (Fig. 1), the anodes in the electrolysis vessels ("pots") are composed of a paste of petroleum coke and coal tar pitch. The process takes place at temperatures exceeding 900°C, generating copious coal tar pitch volatiles. These fumes are rich in carcinogenic polycyclic aromatic hydrocarbons (PAHs), which are released directly into the workplace during certain pot-tending tasks.

2. Prebake smelters: In this process (Fig. 2), anodes are "prebaked" (usually in a separate plant in ventilated anode-baking furnaces). The coal tar pitch volatiles have thus been driven off before the anode is introduced into the electrolytic "pot." Some PAH exposure still occurs in certain operations (pot start-ups, cathode-relining operations), but generally at *much lower concentration* than in Søderberg smelters.

Beyond the major differences in anode composition and worker exposures to PAH, the other components of the processes are similar, involving passage of high electrical current through a molten electrolytic bath of cryolite (Na_3AlF_6) and aluminum fluoride (AlF_3) into which alumina is dissolved. The principal occupational exposures are discussed hereafter.

OBJECTIVES

The goals of this article were to consider the emissions of primary aluminum smelters that may have potential for harm to the health of neighbors of aluminum smelters and, on the basis of the results of epidemiological studies and community exposure data, to describe a Health Risk Assessment (HRA) method to identify those exposures that may need higher priority for control.

METHODS

We collected 298 studies published in peer-reviewed journals by using keywords "aluminum smelter; Hall-Héroult process; fluoride; sulfur dioxide; PM; PM_{10}; $PM_{2.5}$; PAH; benzo[α]pyrene; occupational cancer; bladder cancer; lung cancer; health risk assessment; community health; noise" and others. We reviewed the following data:

- Epidemiological study results for health effects of aluminum production
- Known and suspected health hazards of aluminum smelters
- Studies of the health outcomes in communities with primary aluminum smelters
- Studies of health outcomes in communities (not specifically smelter towns) with exposure to the principal hazards identified earlier
- Smelter community exposure level data for the hazardous agents of interest

We then carried out an HRA using comparisons between actual or estimated community exposure levels and those associated with adverse outcomes in the smelter studies, nonsmelter communities, or both to assess risk in aluminum smelter communities. The final step was to assign each hazard to one of four risk categories: none, low, medium, or high (Table 1).

Identification of Potential Health Hazards in Smelters

Occupational exposures in primary aluminum smelters are well identified by Jelinic et al[1] and the International Agency for Research on Cancer.[2] These are presented in Table 2, with their respective health effect(s) and an indication regarding presence or absence of evidence for adverse health outcomes in smelter workers.
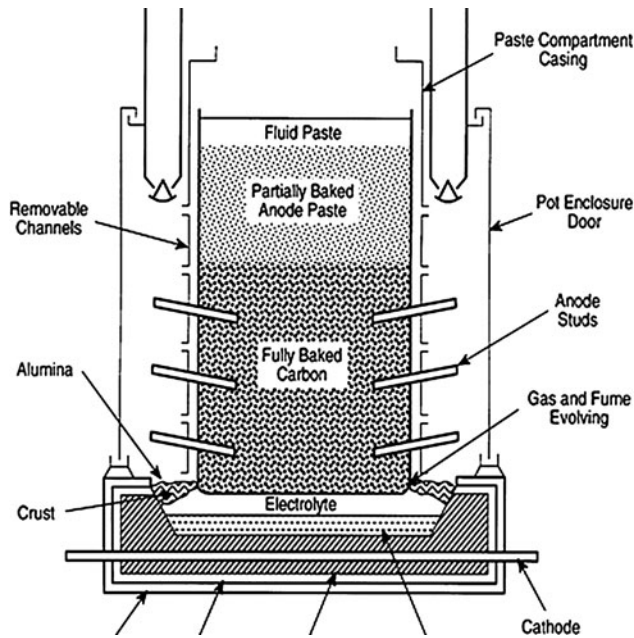
FIGURE 1. Horizontal stud Søderberg cell (pot). (From Primary Aluminum Industry: Technical Support Document for Proposed Maximum Achievable Compliance Technology Standards. US Environmental Protection Agency Office of Air Quality Planning and Standards Emission Standards Division, July 1996.)

Typical Workplace Exposure Levels

Occupational exposure levels have been reported in numerous publications.[1–3] Benke et al[3] reviewed reported time-weighted average exposure concentrations to the principal contaminants measured in primary aluminum smelters from the 1950s to 1996 in several countries, for both prebake and Søderberg processes. Table 3 summarizes their data, which can serve as a basis for comparison to the much lower-exposure levels found in neighboring communities.

Review of Epidemiological Studies That Examine Health Outcomes in Relation to Exposures to Those Hazards in the Workplace

Occupational Cancers

The earliest reports of suspected increased cancer rates in primary aluminum smelter workers were from Russia.[4] Both lung and stomach cancers appeared in higher than expected numbers, but smoking histories were unavailable. Subsequent studies in Canadian and Norwegian smelters confirmed increased incidence rates of lung cancer[5–7] and bladder cancer.[7–10] Dose–response relationships were clearly demonstrated between these effects and cumulative exposure dose to benzene-soluble matter and benzo[α]pyrene (BaP) after controlling for smoking. These studies and others[11,12] have also found frustratingly inconsistent evidence for increased incidence rates for lymphomas as well as stomach and pancreatic cancers.

Occupational Lung Diseases

Asthma

Data for an association between the Hall-Héroult process and asthma have been suspected for over 70 years. Scandinavian[13] and Australian studies tend to conclude in its existence and call the disease "pot-room asthma," even though North American studies have usually failed to confirm an excess incidence. Putative candidate causal agents include fluorides (HF and particulate), sulfur
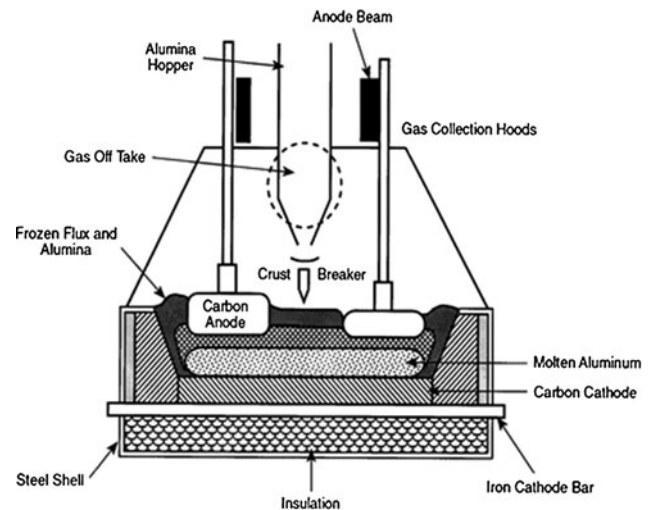

FIGURE 2. Center-worked prebake cell (pot). (From Primary Aluminum Industry: Technical Support Document for Proposed Maximum Achievable Compliance Technology Standards. US Environmental Protection Agency Office of Air Quality Planning and Standards Emission Standards Division, July 1996.)

dioxide, and smelter dust (inhalable, total, respirable, ultrafine, or nanoparticulates). One US study did document an excess asthma incidence[14] and found an association with gaseous fluoride. On the contrary, a recent Australian study[15] found a stronger association with sulfur dioxide exposure. By far, the largest study ever undertaken of pulmonary health in the primary aluminum industry (personal communication; Richard Martin; Quebec smelter studies of 1982 and 1995–1998) involved more than 5000 Quebec smelter workers. Posthire asthma incidence rates were similar in exposed and nonexposed employees. Unfortunately, this study has not yet been submitted to a peer-reviewed journal.

Chronic Obstructive Pulmonary Disease

There is good consistency from morbidity–mortality studies for increased prevalence and mortality rates for this disease among electrolysis workers in aluminum production.[16] The above-mentioned unpublished Quebec study showed a significant association between work with exposure to the electrolytic process and reduced forced expiratory volume in the first second of expiration (FEV-1) values. This was true for *both* types of smelter: Søderberg and Prebake, suggesting that PAHs are not a major influence in the generation of obstructive lung disease.

Lung Cancer

See Occupational Cancers section.

Beryllium Sensitization

Although there is significant exposure to beryllium-containing dust in certain smelters, beryllium sensitization in aluminum smelter workers appears to be rare in two studies performed in North America and Norway (prevalence of 0.47% and 0.28%, respectively).[17,18]

Noise-Induced Health Effects

Noise-induced hearing loss is well-documented in aluminum smelters where exposures in certain similar exposure groups or jobs can exceed 85 dBA for 8-hour shifts or 82 dBA for 12-hour shifts. The contribution of aluminum production operations to community sound pressure levels remains well below these levels and hence

TABLE 1. Risk Categorization of the Most Significant Community Health Hazards Related to Primary Aluminum Production

Hazard	Community Exposure Data*	Community Exposure Levels That Showed Harm in EPI Studies/Exposure Limits	Plausibilty of Community Health Effect	Proposed Risk Category†
Benzo[α]pyrene ηg/m^3	0.5–90‡	Insufficient data/0.9§	Yes	None: for Prebake smelter communities
				Low to medium: for Søderberg smelter communities
Beryllium,¶ μg/m^3	0.000031–0.00012	No community cases/0.01 (US EPA)	No	None
PM$_{10}$, μg/m^3	11.6–31.9‡ 8.0–10.9‖	Inconsistent data/150§/(20 annual mean 50 μg/m^3 24-hr mean) (WHO)	Yes	Low
PM$_{2.5}$, μg/m^3	7.1–15.1#; 3.7–16.6‡; 1.7–5.6‖; 0.08–335.0[32] (daily mean)	RR = 1.09 per 10-μg increase[28] /25 (WHO)/35§	Yes	Medium
SO$_2$ ppb	0.75–30[37]; 1–12.3‡; 0.2–1.9‖; 0–168 (32 − daily mean)	200 [28,37] /75 (US EPA)	Yes	Medium
Total fluorides (as F), μg/m^3	0.06–0.25** <2–3††	2.8[37]/13.0 (Calif chronic REL)	Yes	None to low
Gaseous fluorides (as HF), μg/m^3	0.8–2.80[37] 0.16–0.26‖	14.0 μg/m^3 (Calif chronic REL)		
Noise dBA	44–48	>45[41]; ≥60[42]/L_{eq24} < 45 indoor, <55 outdoor (US EPA); ‡‡	Yes	Low

*Not necessarily typical or representative; annual mean unless otherwise stated; smelter contribution unknown unless stated. The reader will note that the units used for community air measurements for benzo[α]pyrene, fluorides, and sulfur dioxide are two to three orders of magnitude lower than for worker exposures (ηg, μg, mg, and ppb as compared with μg, mg, and ppm, respectively).

†At smelter community exposure levels cited in this table —column 2. Qualitative judgment that considers the *number* of persons at risk, *gravity* of effect, and *probability* of effect.

‡Quebec Ministry of Sustainable Development, Environment, Wildlife and Parks (data from four Quebec smelter towns).

§National ambient air quality standard, United States.

¶Shawinigan QC 2002 arithmetic mean July and August.

‖Rio Tinto Alcan (RTA) BC Operations Annual Environmental Report 2012 Chapter 6 Air Quality Monitoring and Web page of RTA Alma Works, section Environment and Community.

#GM exposure 2012: range for four Quebec smelter towns. Estimated smelter contribution = 3%.[43]

**Estimate based on the assumption that fluorides represent 50% of a modern smelter air emissions. Furthermore, from the work of Boullemant,[43] PM$_{2.5}$ emission from a modern primary aluminum smelter represents 3% of the total concentration of PM$_{2.5}$ in urban air.

††Level reported by the WHO (environmental criteria 227) as typical levels of SO$_2$ usually encountered in the vicinity of emission sources.

‡‡This noise level is often used as a design criterion for new plants.

EPA, Environmental Protection Agency; REL, Recommended Exposure Limit; WHO, World Health Organization.

noise-induced hearing loss from smelter noise would not be expected in smelter towns.

Asbestosis, Mesothelioma, and Silicosis

These are diseases that have been identified in aluminum production facilities, but because their causal agents are not significant components of smelter emissions into the environment, they will not be discussed here. Electromagnetic fields will not be considered either, because the exposures within the smelters do not represent an "emission" to which residents can be significantly exposed. Even though electrical transmission lines do run through smelter communities, fields generated by them do not represent smelter-originating exposures and are hence beyond the scope of our topic.

Studies of Community Health Effects of Hazards Relevant to Primary Aluminum Smelter Emissions

Benzo[α]pyrene

Extrapolating from the dose–response relationships seen in the smelter employees, Gibbs[19] estimates a risk of an additional 4.4 cases of lung cancer per 100,000 persons exposed for 50 years to 1 ηg/m^3 BaP. Armstrong and Gibbs[20] later revisited the dose–response relationship for smelter workers and found that a linear relation-

ship model predicted a relative risk of 1.35 per 100 μg/m^3-yrs cumulative BaP exposure and a multiplicative power curve model (the best fitting) predicted a RR of 2.68. Vyskocil et al[21] looked at lifetime lung cancer risks in smelter and nonsmelter towns on the basis of available BaP exposure data. When performing quantitative risk assessment by using epidemiological data based on BaP exposures, they found (upper bound) lifetime excess lung cancer risks between 0.02 and 89 cancers per 100,000 residents in smelter towns. Occupational exposures in the smelter towns studied are almost exclusively in males, which would tend to confound the relationship between community exposure levels and cancer risk in men in those communities. Nevertheless, there was a linear relationship between community BaP exposure and lung cancer rates in women with a correlation coefficient (R) near 0.8. In addition, a study of lung cancer rates and regional BaP exposure in the same geographic region (Saguenay-Lac Saint Jean region of the Province of Quebec) did reveal an excess of lung cancer in women in the most highly exposed district of one smelter town.[22]

Beryllium

Neighborhood levels of airborne beryllium were 100- to 300-fold lower than EPA–recommended exposure limit of 0.01 μg/m^3 at air quality–sampling stations near a smelter using

TABLE 2. Potential Health Hazards With the Basis for Their Respective Exposure Limit

Health Hazard	Health Effect(s) for Which Exposure Limits Were Set by ACGIH or Other Exposure Limit Authority; *Other Suspected or Plausible Effect(s)*	Evidence for Adverse Effects in Aluminum Smelter Workers
Aluminum oxide (Al_2O_3)	Irritation of the respiratory tract *Aluminum toxicity*	No
Beryllium	Beryllium sensitization *Chronic beryllium diseases*	Yes (rare)
Carbon monoxide (CO)	Headache Nausea Chemical asphyxia	No
Carbon dioxide (CO_2)	Headache Nausea Hypercapnea, acidosis, asphyxia	No
Dust Respirable and inhalable	Irritation of the respiratory tract *Arrhythmia; other cardiovascular effects* *Exacerbation asthma; bronchitis;* *COPD*	Yes
Fluorides Particulates and gaseous	Irritation of the respiratory tract, eyes and skin *Asthma: de novo and exacerbation* *COPD*	Yes (relative contributions of fluoride, SO_2, and particulates to these effects is uncertain)
Electromagnetic fields Alternating and Direct Currents (AC and DC)	*Leukemia* *Lymphoma* *Brain cancer*	No
Nitrogen dioxide (NO_2)	Upper and lower respiratory tract irritation Lung inflammation Asthma Increase of respiratory symptoms Decrease in pulmonary function	No
Noise	Noise-induced hearing loss *Sleep disturbance* *Stress* *Hypertension*	Yes
PAHs (as benzene-soluble matter and Benzo[α]pyrene)	Cancer: bladder and lung *Other cancers: stomach, pancreas, lymphoma?*	Yes (Søderberg smelters)
Sulfur dioxide (SO_2)	Irritation respiratory tract Exacerbation of asthma and chronic bronchitis; COPD Increased susceptibility to lung infections *Cardiovascular effects*	Yes (relative contributions of fluorides, SO_2, and particulate matter to these effects is uncertain)

AC, alternating current; ACGIH, American Conference of Governmental Industrial Hygienists; COPD, chronic obstructive pulmonary disease; DC, direct current; PAHs, polycyclic aromatic hydrocarbons.

beryllium-containing alumina (personal communication; Rio Tinto Alcan). Workers exposed to beryllium at or above an arbitrary action level below the American Conference of Governmental Industrial Hygienists new Threshold Limit Value were tested and found not to be sensitized to beryllium (Beryllium Lymphocyte Proliferation Test). Hence, it is reasonable to assume that community exposures are not causing beryllium-related sensitization or disease in residents living near that smelter.

Particulate Matter

There is now an impressive body of scientific literature concerning the health effects of community exposures to airborne particulates. The studies are shared between evaluation of the health effects of finer particulates with an aerodynamic diameter less than 2.5 μm ($PM_{2.5}$) and evaluation of the effects of particles with less than 10-μm diameter (PM_{10}).

Particulate Matter With Diameter Less Than 10 μm (PM_{10})

Studies abound on the potential health effects of exposure to particulate matter aerosols. Exposure to PM_{10} has been linked to respiratory symptoms of cough and wheeze, onset and exacerbation of asthma in adults and children, hospitalizations for respiratory and cardiovascular diseases, death rates in vulnerable groups (in the elderly and in late neonates), and low birth weight. A study of Swedish children showed a significant association between PM_{10} exposure in the first year of life and the onset of asthma before the age of 12 years.[23] A meta-analysis of 36 European studies of PM_{10} levels (24-hour mean PM_{10} concentrations ranging from 10 to 167 μg/m^3) and asthma symptoms in children showed a significant association.[24] In a review of five European studies, an association between long-term PM_{10} and mortality rates (total deaths and cardiovascular and respiratory deaths) was confirmed, with statistically significant dose–response relationships.[25] In a prospective cohort study[26] of women in

TABLE 3.   Usual Ranges of TWA Exposures to Principal Workplace Contaminants in Primary Aluminum Smelters

Contaminant	Typical Workplace TWA Exposure Levels
Benzo[α]pyrene	Prebake smelters: 0.02–0.20 $\mu g/m^3$
	Søderberg smelters: 0.5–5 $\mu g/m^3$
Fluorides (Total − HF + particulate F$^-$) −	0.2–3.1 mg/m^3 (both smelter types)
Sulfur dioxide	0.4–3 mg/m^3 (both smelter types)
Total dust	2.4–7.6 mg/m^3 (both smelter types)
	0.2–6.0 mg/m^3 (data for 2009–2010 from four modern prebake smelters*)

*Center-worked prebake cell smelter with current flux density greater than 180 kA and local exhaust ventilation rate greater than 1.5 m^3/s and equipped with dry scrubbing.

TWA, time-weighted average.

Germany, PM$_{10}$ exposure was significantly associated with increased all-cause cardiopulmonary and lung cancer mortality rates.

Particulate Matter With Diameter Less Than 2.5 μm (PM$_{2.5}$)

Similar results have been found for exposures to these finer particles; yet some studies have found the latter to be more strongly associated with adverse cardiovascular outcomes. In the elderly in Madrid,[27] both PM$_{10}$ and PM$_{2.5}$ were associated with increased mortality from respiratory causes, while cardiovascular deaths were associated significantly only with PM$_{2.5}$ exposure. In New York City[28] over a 5-year period, out-of-hospital cardiac arrests were associated significantly with PM$_{2.5}$ (RR more than 1.06 per increase in PM$_{2.5}$ exposure of 10 $\mu g/m^3$) during warm seasons but not with CO, ozone, SO$_2$, or NO$_2$. A similar investigation in Melbourne[29] yielded almost identical results. A prospective cohort study of 125,000 female California teachers and former teachers followed over 10 years[30] showed an association between PM$_{10}$, PM$_{2.5}$, and nitrogen oxides exposures and ischemic heart disease mortality and stroke incidence that was stronger for the PM$_{2.5}$ exposure. That these effects are predominantly important in the more elderly is suggested by the failure to detect an association between PM$_{2.5}$ and PM$_{10}$ exposures and any adverse cardiopulmonary health effects in a cohort of 2800 young (mean age 32 years) US military personnel over an 18-month period in Southwest Asia.[31] A recent study of asthmatic children living within a 7.5-km radius of a Søderberg smelter in the province of Quebec[32] showed a significant association with time exposed downwind from the smelter emission source and hospitalizations for asthma and bronchiolitis. The PM$_{2.5}$ and SO$_2$ peak concentrations were 967 $\mu g/m^3$ and 434 ppb, respectively.

Sulfur Dioxide

Sulfur dioxide is a well-known respiratory irritant and has been shown to reliably produce bronchoconstriction in persons with asthma in a dose-related manner, beginning at about 200 ppb in persons with mild to moderate asthma.[33] A Montreal study[34] of children living in proximity to a petroleum refinery revealed a dose-related association between increasing SO$_2$ exposure and active asthma, which became statistically significant for poor asthma control. Another investigation[35] in the same city found that short-term increases in SO$_2$ were significantly associated with increased numbers of asthma episodes, emergency department visits, and hospitalizations for asthma (also in children). Although the emissions composition of oil refineries is quite different from aluminum smelters, these findings lend plausibility to a role for SO$_2$ in exacerbation of asthma in community residents. Sulfur dioxide exposure was found

in Shanghai to have independent linear association with total mortality even after controlling for PM$_{10}$ exposure.[36] The previously cited Quebec study[32] of asthmatic children living near a Søderberg smelter revealed mean daily SO$_2$ concentrations downwind of the smelter ranging up to 168 ppb and mean hourly concentrations up to 434 ppb.

Fluorides

Primary aluminum smelters emit fluorides in gaseous and particulate forms. The role of fluorides in community health has been less studied than PMs, SO$_2$, and NO$_x$. In aluminum smelter towns, their role is difficult to sort out, because they are invariably accompanied by significant amounts of particulate matter and SO$_2$. A study of children in the Norwegian smelter town of Årdal[37] did show a significant association between bronchial hyperresponsiveness and recent exposure to peak levels of *both* SO$_2$ *and fluorides*. In aboriginal children living near an aluminum smelter in upstate New York, respiratory obstruction was associated with increased urinary fluoride.[38] The previously mentioned study by Abramson et al[15] on pot-room asthma may shed some light on the relative importance of fluoride versus SO$_2$ on respiratory impact in the communities neighboring smelters. Median fluoride levels in the Årdal region over a 30-day period were 1.6 $\mu g/m^3$ with a 10th percentile of 0.08 $\mu g/m^3$ and 90th percentile of 2.8 $\mu g/m^3$.

Noise

As mentioned under the "Review of Epidemiological Studies That Examine Health Outcomes in Relation to Exposures to Those Hazards in the Workplace" section earlier, the contribution of aluminum production operations to community levels does not reach the high levels required to cause hearing loss, and hence noise-induced hearing loss from smelter noise would not be expected in smelter towns. Nevertheless, smelter contribution to community noise can result in environmental levels close to 50 dBA (personal communication; Rio Tinto Alcan's Laterrière Works in Quebec). Background noise levels in the smelter community ranged from 35 to 38 dBA in the absence of smelter operations, and 44 to 48 dBA during operations (24 hours per day). The latter levels were well below those that have been associated with an increased risk of myocardial infarction in one study,[39] but did fall in the range of "noisy area" (L_{eq} more than 45 dBA) for which another study[40] found a significant adjusted odds ratio of 1.58 in males for hypertension. Road traffic noise was also associated with hypertension in a Swedish town[41] in both males and females. Another Swedish study[42] showed a significant odds ratio of 1.27 for hypertension in 40- to 59-year-old subjects exposed to 60 to 64 dBA. Each 5-dB increase in L_{eq24} beyond 45 dBA was accompanied by an increased odds ratio of 1.38 for hypertension. The Laterrière smelter reduced community noise levels in 1999 by installing a muffling system into the emission stacks, resulting in exposures in the range of 33 to 40 dBA, hardly more than the preconstruction background ambient noise.

RESULTS AND DISCUSSION

The HRA for aluminum smelter emissions is a daunting task that requires specific knowledge of industrial processes and their by-products, results of research into potential occupational and community health effects, regional exposure measurement results, the relative contributions of the smelter to those results, the demographic characteristics of the community, and the local community health outcomes data.

We encountered much uncertainty at several levels. One of the most difficult tasks is estimating the contribution of a given smelter to the concentration of airborne contaminants in the surrounding community. The more urban the setting and the more densely inhabited and industrialized, the more difficult that task will be. Some,

like Boullemant,[43] have been able to use novel approaches using isotope tracing to calculate the proportion of community $PM_{2.5}$ that originated from the anodes of the local smelter, but such technical aids are the exception.

Much of the information available on community health impacts involves relative risks with increasing concentrations but is not as helpful in providing information about exposure thresholds below which harm is improbable. Care must be taken in extrapolating dose–response relationships from studies on workers to community residents, whose characteristics differ (eg, the latter include vulnerable groups like children, the elderly, pregnant women, higher numbers of persons with respiratory disorders, and other chronic illnesses and disabilities).

In estimating risk, we took a worst-case scenario approach and used highest measured community exposures, highest risk estimates from other sources,[19–21] and considered studies that showed plausible community health impacts from the agents under consideration.

The useful life of modern primary aluminum smelters is usually 50 years or more. The design criteria for these industrial settings are determined to ensure their long-term compliance with local and international regulations on health, safety, and environment. Nevertheless, a serious threat is emerging; given the significant and sustained growth in global aluminum demand, the industry is facing a shortage of raw materials with low sulfur content, such as petroleum coke. Several sites are currently considering the use of petroleum coke at higher sulfur content, which could result in a significant increase in sulfur dioxide emissions and, in turn, the concentration of this pollutant in urban air of communities located in their vicinity, thus representing an increased risk to the health of general public.

CONCLUSIONS

We conclude that a community HRA can be carried out for an aluminum smelter by comparing representative community exposure levels to known health hazards present in emissions from primary aluminum production with the exposure levels that have been established as harmful in community health studies or in other health effect studies. Where community health data are lacking, the occupational health literature may provide insights into dose–response relationships, which could be used in risk assessment. It is important in such assessments to consider historical exposure levels because some of the health effects of interest involve long latency periods. The authors consider, depending on technology, proximity, and other factors, that risk is not zero for adverse community health effects from BaP (from Søderberg smelters only), fluoride, noise, particulate matter, and sulfur dioxide. Continuous improvement in emissions controls hence remains a high priority for all primary aluminum producers.

ACKNOWLEDGMENTS

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