Eur Respir J, 1994, 7, 165–172
DOI: 10.1183/09031936.94.07010165
Printed in UK - all rights reserved

European Respiratory Journal
ISSN 0903 - 1936

REVIEW

Aluminium potroom asthma: the Norwegian experience

J. Kongerud*+, J. Boe*, V. Søyseth**, A. Naalsund*, P. Magnus+

Aluminium potroom asthma: the Norwegian experience. J. Kongerud, J. Boe, V. Søyseth, A. Naalsund, P. Magnus. ©ERS Journals Ltd 1994.

ABSTRACT: Work-related asthma in aluminium potroom workers, is reviewed and discussed, mainly on the basis of own investigations. The occurrence of work-related asthma has been shown to be associated with the duration of potroom employment, although the prevalence of asthmatic symptoms is not significantly different from that of the general population. Typical manifestations of occupational asthma are described in potroom workers, and a close relationship between the levels of fluoride exposure and work-related asthmatic symptoms has been observed.

The existence of occupational asthma in aluminium potroom workers has been confirmed by characteristic patterns of repeated peak flow measurements, supported by changes in methacholine responsiveness in workers with suspected work-related asthma. However, no immunological test is available to establish the diagnosis. Methacholine challenge appears to be inappropriate for screening aluminium potroom workers in order to detect work-related asthma.

Current smoking, but not self-reported allergy, is a risk factor for potroom asthma. A family history of asthma and previous occupational exposure may have some effect on the risk of developing symptoms.

The prognosis of potroom asthma seems to depend on early replacement to unexposed work. The pathogenetic mechanisms are unknown, although some studies indirectly imply a hypersensitivity reaction.

Future studies involving specific bronchial challenge appear to be necessary to find the causal agent(s) of aluminium potroom asthma.

Eur Respir J., 1994, 7, 165–172.

*Dept of Thoracic Medicine, Rikshospitalet, University of Oslo, Oslo, Norway. +Dept of Epidemiology, National Institute of Public Health, Oslo, Norway. **Health Department, Årdal aluminium plant, Årdalstangen, Norway.

Correspondence: J. Kongerud
Dept of Thoracic Medicine
Rikshospitalet
University of Oslo
N-0027 Oslo
Norway

Keywords: Aluminium
asthma
epidemiology
occupation

Received: February 8 1993
Accepted after revision July 20 1993

The electrolytic production of aluminium is accompanied by emissions of dust and gases, and asthma among potroom workers in this industry has been reported for the last 60 yrs [1]. Primary aluminium production is an important industry in Norway, producing 20% of the aluminium in Europe. Asthma-like symptoms ("potroom asthma") have been the most important health problem of the workforce. Thus, the occurrence and causes of potroom asthma have been of major concern to the industry and the health authorities. This has lead to considerable scientific activity, and several papers of Norwegian origin have appeared, supporting the existence of potroom asthma [2–10]. However, in other countries there are some studies which have not been able to detect occupational asthma in the primary aluminium industry [11–14].

So far, no specific agent in the potrooms has been shown to induce a hypersensitivity reaction [15]. Therefore, controversy as to whether potroom asthma is pre-existing asthma provoked by pollutants, or asthma that is induced by agents in the work environment still remains.

Disagreement with regard to the definition of occupational asthma and the use of inappropriate research methods may also explain some of the inconsistency in the published results.

The purpose of the present paper was to review the published literature and to discuss the evidence that asthma can be caused by aluminium potroom exposure.

Aluminium potroom exposure

Processes used in primary aluminium production

A knowledge of the potential hazards in the work atmosphere, both quantitatively and qualitatively, is a fundamental requirement in exploring health and exposure associations. Full accounts of the electrolytic processes have been published [16, 17].

Bauxite is the mineral from which aluminium is obtained. There are two stages in the process. Firstly, the separation of alumina (Al_2O_3) from silica, iron and other oxides, known as the Bayer process. Secondly, the transformation of alumina to aluminium by electrolysis, known as the Hall-Héroult process. It is the latter process which seems to be associated with development of asthma, and which will be discussed in detail.

Electrolytic technology

The reduction of alumina takes place in plants called smelters. The electrolytic baths or cells are usually called the pots, and the buildings where the pots are located are known as potrooms. The potrooms often extend several hundred

metres and contain 100–200 pots. A modern single pot operates at 4–5 V and more than 150,000 A, at a temperature of about 950°C. The pots are of two types, Søderberg and prebake. The main difference between them, is the way in which the anodes are supported (figs 1 and 2). In Søderberg pots, the anode is baked on site and carbon has to be added to the top of the pot. The anodes in prebake pots are produced outside the potroom in a special department called the carbon plant. Both technologies have a steel cradle, lined with insulating material, and a cathode bottom made of carbon connected to the negative polarity of the power source. The prebake technology permits for a more automated process, with hoods covering the pot. Although the hoods are closed and the collection efficiency of the hoods for fumes is better than that seen in Søderberg, the hoods have to be removed from time to time when aluminium is tapped or when the anode has to be changed. In these situations, large amounts of pollutants are emitted. Peak levels of exposure are, therefore, more likely to occur in prebake than in Søderberg potrooms.

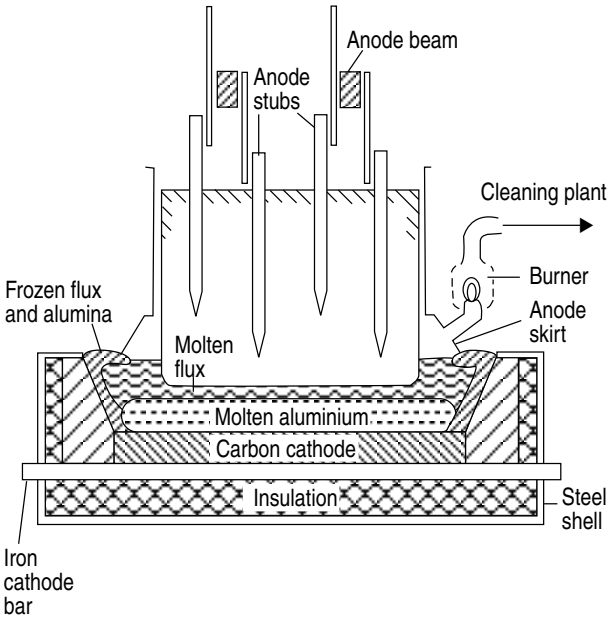

Fig. 1. – Aluminium smelter reduction with anodes baked on the spot (Søderberg cell) printed with permission [16].

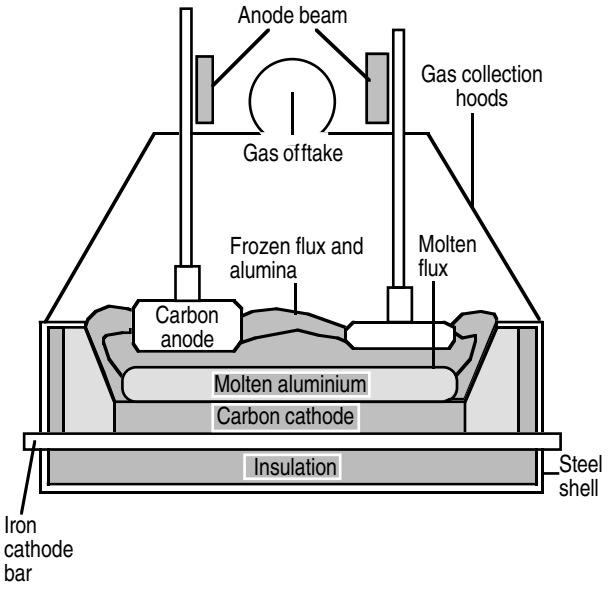

Fig. 2. – Aluminium smelter reduction cell with prebaked anodes (prebake cell) printed with permission [16].

Types of exposure

The pot fume emissions are complex, and 26 substances to which exposure may occur have been listed by WALKER [18]. In a Norwegian study, personal sampling of gaseous sulphur dioxide (SO_2) produced time-weighted average levels of 0.42 mg·m^{-3} [19], which is approximately one tenth of the Norwegian hygienic standard (8 h time-weighted average (TWA)) of 5 mg·m^{-3}. Gaseous SO_2 was also closely correlated to gaseous fluorides ($r=0.67$, $p<0.001$). The average levels of total dust and fluorides were lower than the hygienic standards of 5 and 1 mg·m^{-3}, respectively. In Norwegian aluminium plants, the levels of pollutants have decreased gradually, and in 1989 the average levels of exposure were approximately 50% of the hygienic standards [7].

An additional contamination with trace elements of vanadium, chromium and nickel occurs when the gases are treated by dry scrubbing to capture fluorides [20]. Routine measurements of these constituents are usually not made.

Polycyclic aromatic hydrocarbon (PAH) compounds are almost eliminated in prebake potrooms, and are not regularly measured.

Occurrence

The majority of studies of occupational asthma are single case reports, descriptions of a number of cases, and prevalence studies [21].

Workers leaving an industry because of symptoms will lower the prevalence of health problems in the work-force. A cross-sectional study may, therefore, fail to detect work-related health effect. This may be one explanation for the conflicting results in studies of respiratory symptoms among aluminium potroom workers. In an overview by ABRAMSON *et al.* [1], the prevalence of potroom asthma ranged 0–14%.

During 1987, 205 cases of asthma and bronchitis were suspected as being of occupational origin and reported to the Norwegian Ministry of Labour [22]. Of these cases, 154 were cases of "potroom asthma" from the aluminium industry. However, in contrast to other industries, the health departments of the aluminium industry have probably overestimated the number of cases in recent years, as their report system is based only on symptoms reported by questionnaires. In 1981, 18 cases of "potroom asthma" were registered, whilst only 30 cases of work-related obstructive lung disease were notified from other industries [23]. The number of reported cases from non-aluminium industry increased between 1981 and 1987 by approximately 100%. In spite of this rather large increase in the number of cases, many cases from non-aluminium industry are probably still not diagnosed as occupational disease or have not been reported.

In a multicentre, cross-sectional study of 1,760 Norwegian potroom workers, 11% reported work-related asthmatic symptoms [5]. Among workers employed 10 yrs or more, the prevalence estimate was 15%. This is very similar to the results reported by KILBURN and WARSHAW [24], who found that 13% of aluminium workers exposed for 5 yrs or more reported a history of asthma.

Recently, BAKKE and co-workers [25] reported a population attributable risk of 19% for asthma due to airborne dust or gas exposure, and in the same population the adjusted odds ratio for obstructive lung disease was 2.7 (confidence interval (CI) 1.2–6.1) in aluminium workers [26]. These recent, cross-sectional studies suggest that asthma is two to three times more prevalent in the aluminium industry than in the general population. However, as the diagnosis of asthma in these epidemiological studies is based entirely on questionnaire-reported symptoms, a certain misclassification and overestimation of the true occurrence of asthma may be present. In a cross-sectional study, 26 subjects with normal spirometry reported symptoms suggestive of occupational asthma [9]. The diagnosis was clinically confirmed in 14 subjects, and further investigations by serial measurements of peak flow were carried out. Ten workers were assessed as having records meeting the criteria for occupational asthma. Thus, a 35–50% misclassification may be present when the diagnosis of occupational asthma is based only on questionnaire reported symptoms.

Longitudinal studies, which are the most reliable method of investigating risk factors and prognosis are, however, almost nonexistent in the aluminium industry. This type of study is the only method which can be used when the true incidence of a disease is to be estimated. We therefore conducted a 4 yr follow-up investigation of new employees [7]. All the subjects underwent a pre-employment examination, including spirometry and a standardized respiratory questionnaire. Similar examinations were then carried out each year, or the subjects were examined if they attended the plant's health departments with respiratory symptoms. They were also examined if they left the plant. As a result, the study was unbiased by the selection of symptomatic workers out of the potrooms. The study was also unbiased by previous potroom exposure, and only subjects with no symptoms of dyspnoea and wheezing during the last year prior to employment were included in the study. Of the total of 1,301 subjects examined, 8% developed dyspnoea and wheezing during a median time of observation of 145 (range 9–1,326) days. The probability of developing symptoms was 7% for people who had never smoked, and 23% for current smokers, during the first 2 yrs of employment. Adjusting for possible misclassification of disease, these figures are reduced to approximately 3 and 10%, respectively. No increase in the risk was found during the next 2 yrs. The adjusted probabilities for the development of asthmatic symptoms are higher than that anticipated from previously reported incidence estimates (0.06–4% of exposed workers per year) [1]. This discrepancy could be due to different diagnostic criteria and misclassification of the outcome variable, as discussed above, or to examination of a more vulnerable group, as it consisted of only new employees and not a "survivor group". It may also emphasize how important it is to examine all the workers leaving an industry in order to obtain reliable figures of a health problem.

Symptoms

The most characteristic symptoms of occupational asthma are episodic dyspnoea, chest tightness and wheezing, temporarily related to occupational exposure [27]. In a cross-sectional study, 189 aluminium potroom workers reported episodes of dyspnoea and wheezing, which improved during weekends or holidays (work-related asthmatic symptoms) [5]. As many as 42% of these workers had symptoms at least once weekly, and 21% reported that they had had to leave work because of symptoms. New workers developing dyspnoea and wheezing may also be severely affected [7]. Of 78 subjects who developed asthmatic symptoms during employment, 25 reported that they had had to take sick leave because of symptoms. These findings support the existence of potroom asthma.

Immunological tests

Skin and serological tests have been used to support the diagnosis of allergic occupational asthma [21]. MIDTTUN [3] found that eosinophil counts increased during asthmatic attacks in aluminium potroom workers. However, skin tests with potroom dust were negative. A decrease in serum eosinophils was found among subjects with potroom asthma during a three week unexposed period [9]. Atopy was not more common in workers with work-related, asthma-like symptoms than in the general smelter work-force [8]. This is in accordance with the findings of SARIC *et al.* [28]. In the latter study, skin patch tests to 2% sodium fluoride were performed, but the predictive power of the test with regard to potroom asthma was low.

EKLUND *et al.* [29] found that concentrations of albumin and fibronectin in bronchoalveolar lavage (BAL) fluid were significantly higher in 14 nonsmoking, exposed workers than in 28 controls, reflecting an increased alveolar capillary permeability and an activation of alveolar macrophages. In an Australian smelter, 33 asthmatic workers had significantly lower mean serum levels of immunoglobulin (Ig) M. However, mean levels of IgG, IgA and IgE, levels of immunocomplexes, and frequency of antinuclear or other autoantibodies did not differ from the values for 127 non-asthmatic potroom workers [30].

In summary, no immunological test has so far been designed to support the hypothesis of an immunological pathogenesis for potroom asthma.

Lung function tests

Spirometry

Lung function measurement may be normal when a subject with occupational asthma is examined [31]. Spirometry

before and after the work-shift may also fail to demonstrate airflow limitation in occupational asthma [32]. Many workers with occupational asthma have the lowest airflow in the morning, and their airflow increases during the shift, unless there is an immediate reaction. As a result, across-shift spirometry will often fail to record the airflow limitation induced by pollutants in the work environment. Across-shift spirometry among potroom workers has, thus, produced conflicting results. Some authors have failed to demonstrate any spirometric changes in the course of a shift [1], while other investigators [33, 34] found significant variations in forced expiratory volume in one second (FEV_1) during a shift among potroom workers. DURAND *et al.* [35] found that the maximum expiratory flow varied significantly more in potroom workers than in unexposed controls. Thus, no final conclusions of the relationship between variable airflow limitation and potroom exposure can be drawn on the basis of across-shift lung function measurements.

Peak flow measurements

Some case reports of potroom asthma have shown a decline in peak flow measurements during exposed periods, and recovery on days off [1]. In one study, 14 asthmatic workers were investigated with serial measurements of peak flow at home and work. The peak flow measurements showed the characteristic changes in occupational asthma in 10 out of 13 workers with interpretable records [9]. These findings argue in favour of potroom asthma as an occupational disease.

Nonspecific bronchial challenge

The sensitivity of nonspecific bronchial reactivity (NSBR) as a test for asthma has been claimed to be good [36–38]. However, in occupational asthma, NSBR may vary with the degree and duration of exposure, and the sensitivity of the test is generally lower than that seen in asthmatics whose illness has other causes [39]. In a Norwegian study of 370 potroom workers [6], the prevalence of bronchial hyperresponsiveness (provocative concentration producing 20% fall in FEV_1 (PC_{20}) ≤ 8 mg·ml^{-1}) was 5%, which is similar to that seen in a general Norwegian population (6%) [40]. This might indicate that the most severely affected workers have left, or have been transferred to unexposed jobs within the aluminium plant. The sensitivity for work-related asthmatic symptoms was 35% (PC_{20} ≤ 32 mg·ml^{-1}), although the degree of symptoms was positively correlated with the degree of methacholine responsiveness. BURGE [41] found that the sensitivity of PC_{20} ≤ 8 mg·ml^{-1} methacholine was 42% in subjects with isocyanate asthma, diagnosed by specific inhalation tests. Other authors have reported occupational asthma without bronchial hyperresponsiveness [42, 43].

In summary, NSBR could be a valuable supplement in the diagnosis of potroom asthma, but it is of limited value as a screening tool for the condition.

In a study of new employees, only one out of 58 subjects had bronchial hyperresponsiveness (BHR) [6]. This subject left the plant after only one working day in the potrooms. It seems that the majority of workers with BHR have developed the condition after starting to work in the potrooms. No single episode of extreme exposure has been reported as a cause of BHR or asthma in potroom workers. The plant physicians claim that the risk of developing asthmatic disease is probably well-known in the community. Consequently, subjects with respiratory disorders will generally not apply for employment in the potrooms, and this may be the reason for the low prevalence of NSBH in new employees.

Bronchial responsiveness which increases on return to work and decreases when away from work, together with appropriate changes in lung function, supports a relationship between symptoms and work exposure. Methacholine reactivity, measured on a working day, was within the normal range in 8 out of 13 aluminium potroom workers, who could be evaluated and were included in an investigation with serial peak flow measurements [9]. Following a three week holiday, the PC_{20} improved in 5 out of 9 subjects with occupational asthma in whom repeated estimations were possible. LARSSON *et al.* [44] found that none of 38 aluminium potroom workers without airway symptoms had bronchial hyperreactivity. In a group of 12 subjects transferred to unexposed jobs, SØYSETH *et al.* [10] found that eight subjects had bronchial hyperreactivity at the time of relocation.

The degree of bronchial reactivity in aluminium workers seems to be associated with potroom exposure and the disease intensity. Accordingly, low prevalence estimates of bronchial hyperreactivity are probably due to the fact that the most severely affected workers have left the potrooms.

Exposure-effect associations

In spite of their limitations, cross-sectional investigations have been useful when examining the association between work exposure and the occurrence of asthmatic symptoms. Among 1,760 Norwegian potroom workers [5], the odds ratio for the development of work-related asthmatic symptoms increased as the number of years employed in the potrooms rose. The adjusted odds ratio for work-related asthmatic symptoms among workers employed for 10 yrs or more was 3.4 (95% CI 2.1–5.8) as compared to workers exposed for less than 5 yrs. In another cross-sectional study, which included a detailed exposure classification, a significant association between current fluoride exposure and work-related asthmatic symptoms was found [8]. The adjusted odds ratio for work-related asthmatic symptoms was 3.7 (95% CI 1.4–9.6) for subjects exposed to total fluorides above 0.5 mg·m^{-3}, as compared to subjects exposed below this level.

A longitudinal study of 1,301 new workers revealed a similar association between total fluoride exposure and asthmatic symptoms [7]. A dose-effect relationship between current fluoride exposure and asthmatic symptoms was also observed. Subjects exposed to a current fluoride level of 0.41–0.80 and >0.80 mg·m^{-3} had a relative risk (RR) of 3.4 (95% CI 1.5–7.4) and 5.2 (95% CI 2.0–13.3), respectively, as compared to subjects exposed to fluoride levels of <0.41

mg·m^{-3}. In this longitudinal study, a multiplicative interaction was found between smoking and fluoride exposure. Based on the data from this study, the relative risk of developing asthmatic symptoms is estimated to be 10.5 for smokers exposed to an average fluoride level of >0.5 mg·m^{-3}, as compared to people who had never smoked and were exposed to levels of <0.5 mg·m^{-3} (fig. 3).

The importance of a precise exposure classification is shown in table 1. In the longitudinal study, the "detailed classification" was based on exposure measurements from personal samplers in specific jobs. When the exposure classifications were manipulated in the direction of a greater misclassification ("crude classification") by including mean exposure measurements for different jobs, the estimates of associations decrease towards the null value. Thus, even though a relationship between fluorides and asthmatic symptoms in potroom workers is found, the associations are probably underestimated.

Predisposing host factors

As only a proportion of exposed workers acquire work-related asthmatic symptoms, the presence of some predisposing condition is likely. Suggested predisposing factors for potroom asthma include smoking, allergies, childhood bronchitis, pertussis, pleurisy and previous occupation [1].

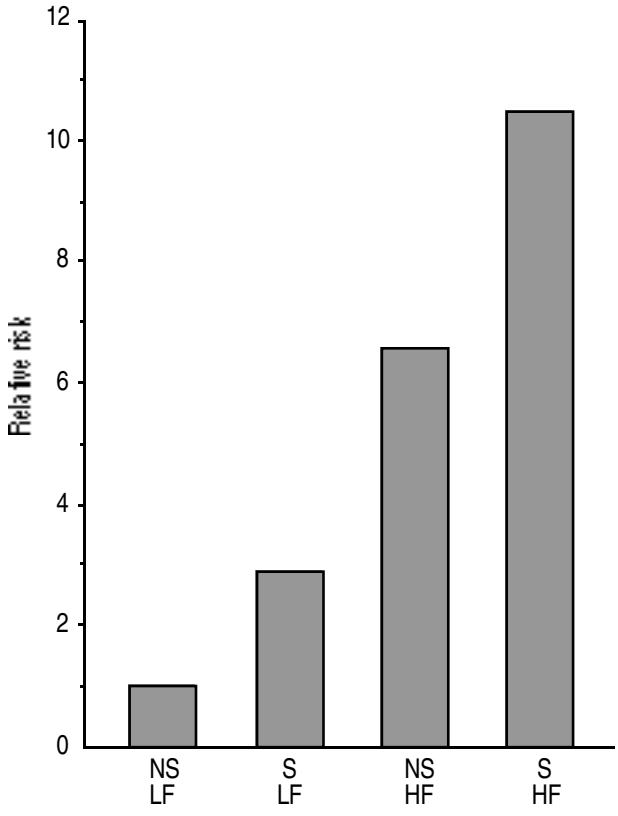

Fig. 3. – Cox's regression analysis of longitudinal data for new employees was used to estimate the relative risk of asthma-like symptoms between different groups of smokers and lifetime nonsmokers, according to exposure levels. NS: lifetime nonsmokers; S: current smokers; LF: fluoride level <0.5 mg·m^{-3}; HF: fluoride level >0.5 mg·m^{-3}.

Table 1. – Associations (relative risk (RR)) between work-related asthmatic symptoms and fluoride exposure (mg·m^{-3}) in new potroom workers, according to a detailed and a crude exposure classification

Current fluoride exposure	Classification: Detailed RR	Detailed 95% CI	Crude RR	Crude 95% CI
0–0.40	1.00	-	1.00	
0.41–0.80	3.35	1.52–7.36	1.92	0.57–6.51
>0.80	5.20	2.03–13.29	1.12	0.20–6.23

95% CI: 95% confidence interval.

Smoking

The prevalence of current smokers in the Norwegian aluminium industry is as high as 60–70% [5]. This is approximately 50% higher than the figure reported by the population in a Norwegian community [40]. In the Norwegian aluminium industry, smoking was a strong risk factor for work-related asthmatic symptoms [7], and a dose-response gradient was proposed. An association between work-related asthmatic symptoms and smoking was also found in a cross-sectional study of 1,760 potroom workers [5], but to a lesser degree than that observed in the longitudinal study [7].

MACKAY *et al*. [30] found that cigarette smoking had independent effects on immunological function in 33 asthmatic potroom workers [30].

This finding could imply that smoking is involved in some immunological reaction related to potroom asthma.

Allergy

Allergy is usually recognized as a risk factor for occupational asthma caused by some agents, notably those of biological origin [21, 45]. No other study of low molecular weight induced asthma has noted a strong association with atopy [46]. The failure to detect any significant association between work-related asthmatic symptoms or nonspecific bronchial responsiveness and atopy in cross-sectional studies [6, 8] may be due to such a selection of the workforce; allergic individuals refraining from work in the potrooms.

In the study by MACKAY *et al*. [30], it appeared that 64% of the asthmatic potroom workers had atopy. In the dynamic population study of new employees in Norway, no significant association was noted between allergy and development of asthmatic symptoms [7]. The prevalence of childhood allergy was 9.5 and 7.2% in the new employees and the "old" work-force, respectively. The difference was not statistically different and, if the selection criteria for employment have remained unchanged over the years, it is unlikely that subjects with allergy have been removed from exposure to a greater extent than subjects without allergy. Although some self-selection may take place, *i.e*. that the most severely affected allergic subjects do not apply for a job in the potrooms, it seems unlikely that allergy is an important risk factor for potroom asthma.

Family history of asthma

A slightly higher risk of work-related asthmatic symptoms has been found in potroom workers reporting a family history of asthma [5]. It is likely that subjects who have developed symptoms are more aware of the existence of similar symptoms among other family members. In a longitudinal study, such bias was eliminated. A nonsignificant relationship was found between development of work-related asthmatic symptoms and a family history of asthma [7]. Consequently, this characteristic probably plays a minor role in the development of asthma in potroom workers.

Others factors

Some studies have indicated that females are at greater risk, when it comes to nonspecific bronchial hyperresponsiveness and potroom-related asthmatic symptoms, than males. However, the associations have been small and have only reached statistical significance for NSBH [6]. The estimates were generally very unstable, and no final conclusions can be drawn on the basis of the latter investigation.

Apart from work-related symptoms associated with chronic cough [5], age has not been noted as a risk factor for work-related asthmatic symptoms, when potential confounders such as the duration of potroom employment and smoking have been controlled for.

A predisposition for potroom asthma caused by previous occupational exposure to irritating vapours, gases or dust may exist, as such exposure appeared to be a risk factor [7, 47].

Prognosis

Several longitudinal studies of subjects suffering from occupational asthma have shown that, even though their condition improves, many of the patients do not recover completely after the cessation of exposure [48–52]. In a follow-up study of 35 potroom workers 1–43 months after cessation of exposure, 10 subjects reported persisting asthma, dyspnoea at night or dyspnoea on exertion [4]. In a New Zealand smelter, 47 subjects with potroom asthma, diagnosed and transferred to other jobs between 1971 and 1986, were re-examined in 1986 [53]. Twelve had frequent or persistent symptoms of asthma, and a further 11 were taking some regular medication for intermittent, milder symptoms. In a recent study, SARIC and MARELJA [54] found that 67% retained their bronchial hyperreactivity after cessation of exposure, even though symptoms improved or disappeared in 60% of the workers. In a Norwegian study of 12 subjects relocated because of potroom asthma, a twofold increase in PC_{20} was observed in 7 of the 8 subjects who were hyperreactive at the time of relocation [10]. Symptoms improved or disappeared in seven workers during 2 yrs of follow-up, whilst no improvement in FEV_1 was observed.

It is suggested that patients with occupational asthma should be diagnosed at an early stage, and removed from exposure as soon as possible in order to improve their prognosis. The same recommendations would appear to be valid for potroom asthma.

Provokers and/or inducers

Different pathogenetic mechanisms in aluminium potroom asthma have been proposed. It has been a dogma that occupational asthma should be caused by a specific, as opposed to an irritant, agent present in the workplace.

Specific mechanisms may be involved in aluminium potroom asthma, but, for the time being, only indirect evidence is present. Peak flow patterns in asthmatic potroom workers are similar to those seen in occupational asthma caused by a hypersensitivity reaction [9]. Smoking enhances the development of asthmatic symptoms in potroom workers as it does in platinum refinery workers [55].

Many case reports of potroom workers describe how they wake up during the night following work with symptoms of wheezing and chest tightness [15]. Delayed asthmatic reactions are seen in occupational asthma involving immunological processes, and have so far not been described after irritant-induced bronchoconstriction [21].

Asthma has been reported in workers exposed to potassium aluminium tetrafluoride ($KAlF_4$) and other metals [56, 57]. Potroom pollutants include compounds such as AlF_3 and $NaAlF_4$, as well as trace elements, such as vanadium, chromium and nickel, which could be responsible for a hypersensitivity mechanism.

Specific provocation tests have not yet been carried out in aluminium potroom workers. SIMONSSON *et al.* [58] tested three out of 19 subjects with asthma due to exposure in aluminium fluoride and sulphate factories; an exposure quite different from that in the potrooms of the primary aluminium industry. Two subjects were tested with aluminium fluoride dust (also found in primary aluminium industry) and one was tested with aluminium sulphate dust. Specific bronchial hyperreactivity could not be shown. Nevertheless, aluminium fluoride may be responsible for potroom asthma. The failure of SIMONSSON *et al.* [58] to achieve a positive test may be due to too low concentrations of AlF_3 or the lack of a necessary co-factor, such as hydrogen fluoride (HF), also appearing in the primary aluminium industry.

NSBH induced by low-grade exposure to irritants, perhaps adsorbed onto respirable dust, may vary with the degree of exposure and may represent a relevant pathogenetic mechanism of occupational asthma. This mechanism has been proposed by other investigators as a cause of occupationally-induced asthma [59].

Consequently, work-related asthmatic symptoms in potroom workers may involve both specific and nonspecific mechanisms. However, the offending agent be may even the same for the different disorders, *i.e.* acting both as an irritant and as a sensitizer.

Future research

One of the most important issues in the future, is to find the agent(s) responsible for occupational asthma in

potroom workers. Are there inducers or only provokers of asthma responsible for the bronchoconstrictive episodes in aluminium potroom workers? Provokers, such as SO_2 and HF, are intermittently present in concentrations known to cause exacerbation in asthmatics. Also, known asthma inducers (vanadium, chromium, nickel) and agents acting theoretically as potential inducers (AlF_3, $NaAlF_4$) are present, but not yet shown to cause potroom asthma. The many agents and complex compounds present are often closely correlated in the work environment. Therefore, experimental, rather than epidemiological studies may be needed to find the causal agent(s). Specific bronchial challenge (SBC) is regarded as the "gold standard" for confirming a diagnosis of occupational asthma in an individual [60], and should be carried out in the future studies of potroom asthma. If potroom asthma is caused by an irritant effect alone, no experimental procedure or test is currently available to verify this mechanism. Airway pathology induced by the combination of agents in the potroom may also be difficult to demonstrate by SBC.

Another approach is the use of bronchial lavage and bronchial biopsy, to study the morphological changes in the bronchial mucosa and submucosa and the release of mediators, as well as the functional activity of the cells involved in the asthmatic reaction. Such studies will enhance our understanding of the basic mechanism of potroom asthma and, perhaps, enable us to differentiate, to some extent, between immunological and irritant reactions.

Further analyses of cohort data are also of interest, in order to investigate the prognosis of potroom asthma, as well as the possibility of an increased lung function impairment which is not related to the development of occupational asthma.

Prolonged longitudinal studies are necessary, in order to determine whether exposure to potroom pollutants may be a risk factor for the development of chronic obstructive lung disease.

The technical equipment for exposure measurements has been improved in the past few years, and future epidemiological studies may be supported by exposure data measured by continuous, individual registrations.

Conclusions

There is substantial evidence in Norway and elsewhere of a work-related asthmatic condition developing in potroom workers in the primary aluminium industry. The occurrence of the respiratory problems is associated with fluoride exposure, but a causal relationship is still uncertain. Smoking is the dominant personal risk factor, whilst allergy seems to be of minor importance. Experimental studies of specific bronchial provocation should be carried out to find the causal agent.

References

1. Abramson MJ, Wlodarczyk JH, Saunders NA, *et al*. – Does aluminum smelting cause lung disease? *Am Rev Respir Dis* 1989; 139: 1042–1057.
2. Frostad EW. – Fluorine intoxication in Norwegian aluminium plant workers. *Tidsskr Nor Laegefor* 1936; 56: 179–182, (in Norwegian).
3. Midttun O. – Bronchial asthma in the aluminium industry. *Acta Allergol* 1960; 15: 208–221.
4. Wergeland E, Lund E, Waage JE. – Respiratory dysfunction after potroom asthma. *Am J Ind Med* 1987; 11: 627–636.
5. Kongerud J, Grønnesby JK, Magnus P. – Respiratory symptoms and lung function of aluminum potroom workers. *Scand J Work Environ Health* 1990; 16: 270–277.
6. Kongerud J, Søyseth V. – Methacholine responsiveness, respiratory symptoms and pulmonary function in aluminium potroom workers. *Eur Respir J* 1991; 4: 159–166.
7. Kongerud J, Samuelsen SO. – A longitudinal study of respiratory symptoms in aluminum potroom workers. *Am Rev Respir Dis* 1991; 144: 10–16.
8. Søyseth V, Kongerud, J. – Prevalence of respiratory disorders among aluminium potroom workers in relation to exposure to fluoride. *Br J Ind Med* 1992; 49: 125–130.
9. Kongerud J, Søyseth V, Burge PS. – Occupational asthma due to aluminium potroom exposure, validation with serial peak flow measurements and methacholine reactivity. *Thorax* 1992; 47: 292–297.
10. Søyseth V, Kongerud J, Boe J, Fonneland T. – Bronchial responsiveness and work-related asthma in aluminium potroom workers: effect of removal from exposure. *Eur Respir J* 1992; 5: 829–833.
11. Chan-Yeung M, Wong R, Maclean L, *et al*. – Epidemiologic health study of workers in an aluminium smelter in British Columbia. *Am Rev Respir Dis* 1983; 127: 465–469.
12. Tourangeau FJ. – The health of workers in the aluminium extraction industry. *Laval Med* 1944; 9: 548, (in French).
13. Kaltreider NL, Elder MJ, Cralley LV, *et al*. – Health survey of aluminium workers with special reference to fluoride exposure. *J Occup Med* 1972; 14: 531–541.
14. Discher DP, Breitenstein BD. – Prevalence of chronic pulmonary disease in aluminium potroom workers. *J Occup Med* 1976; 18: 379–386.
15. Kongerud J. - Occupational exposure and asthma. An epidemiologic study of aluminium potroom workers. *Nor J Occup Med* 1991; (Suppl. 2): (Doctoral thesis).
16. Ravier EF. – Technology of alumina reduction. *In*: Hughes JP, ed. Health Protection in Primary Aluminium Production. London, International Primary Aluminium Institute, 1977; pp. 17–21.
17. Stobart PD. – Centenary of the Hall-Héroult process, 1886–1986. London, International Primary Aluminium Institute, 1986.
18. Walker TJ. – Hygienic aspects of aluminium reduction. *In*: Hughes JP, ed. Health Protection in Primary Aluminium Production. London, International Primary Aluminium Institute, 1977; pp. 23–29.
19. Kongerud J, Rambjør M. – The influence of the helmet respirator on peak flow rate in aluminum potroom workers. *Am Ind Hyg Assoc J* 1991; 52: 243–248.
20. Eduard W, Lie A. – Influence of fluoride recovery alumina on the work environment and the health of aluminum potroom workers. *Scand J Work Environ Health* 1981; 7: 214–222.
21. Chan-Yeung M, Lam S. – Occupational asthma. *Am Rev Respir Dis* 1986; 133: 686–703.
22. The Norwegian Ministry of Labour. – Occupational diseases, 1987. Oslo 1989, September, (in Norwegian).
23. The Norwegian Ministry of Labour. – Occupational diseases, 1981. Oslo 1982, October, (in Norwegian).
24. Kilburn KH, Warshaw RH. – Irregular opacities in the

lung, ocupational asthma and airways dysfunction in aluminum workers. *Am J Ind Med* 1992; 21: 845–853.
25. Bakke P, Eide GE, Hanoa R, Gulsvik A. – Occupational dust or gas exposure and prevalences of respiratory symptoms and asthma in a general population. *Eur Respir J* 1991; 4: 273–278.
26. Bakke P, Baste V, Hanoa R, Gulsvik A. – Prevalence of obstructive lung disease in a general population: relation to occupational title and exposure to some airborne agents. *Thorax* 1991; 46: 863–709.
27. Newman Taylor AJ. – Occupational asthma. *Thorax* 1980; 3: 241–245.
28. Saric M, Godnic-Cvar J, Stilinovic L. – The role of atopy in potroom workers asthma. *Am J Ind Med* 1986; 9: 239–242.
29. Eklund A, Arns R, Blaschke E, *et al.* – Characteristics of alveolar cells and soluble components in bronchoalveolar lavage fluid from nonsmoking aluminium potroom workers. *Br J Ind Med* 1989; 46: 782–786.
30. Mackay IR, Oliphant R, Laby B, *et al.* – An immunologic and genetic study of asthma in workers in an aluminium smelter. *J Occup Med* 1990; 32: 1022–1026.
31. Burge PS. – Problems in the diagnosis of occupational asthma. *Br J Dis Chest* 1987; 81: 105–115.
32. Burge PS, Perks WH, O'Brien IM, *et al.* – Occupational asthma in an electronics factory: a case control study to evaluate aetiological factors. *Thorax* 1979; 34: 300–307.
33. Field GB, Milne J. – Occupational asthma in aluminium smelters. *Aus NZ J Med* 1975; 5: 475–483.
34. Jahr J, Norseth T, Rodahl K, Wannag A. – Fluoride exposure of workers in different types of aluminium smelters. *In*: Forberg H, ed. Proceedings of 103rd AIME Annual Meeting, Dallas, Texas, 1974; 1: pp. 209–236.
35. Durand P, Martin RR, Becklake M. – Acute respiratory changes in aluminium potroom workers. *Scand J Work Environ Health* 1983; 9: 71.
36. Boushey HA, Holtzman MJ, Sheller JR, Nadel JA. – Bronchial hyperreactivity. *Am Rev Respir Dis* 1980; 126: 389–413.
37. Hopp RJ, Bewtra AK, Nair NM, Townley RG. – Specificity and sensitivity of methacholine inhalation challenge in normal and asthmatic children. *J Allergy Clin Immunol* 1984; 74: 154–158.
38. Hargreave FE, Thomson NC, O'Byrne PM, Latimer K, Juniper EF, Dolovich J. – Bronchial responsiveness to histamine and methacholine: measurement and clinical significance. *J Allergy Clin Immunol* 1981; 68: 347–355.
39. Woolcock AJ. – Epidemiologic methods for measuring prevalence of asthma. *Chest* 1987; 91: 89S–92S.
40. Bakke P, Gulsvik A, Eide G, *et al.* – Smoking habits and lifetime occupational exposure to gases or dust, including asbestos and quartz, in a Norwegian community. *Scand J Work Environ Health* 1990; 16: 195–202.
41. Burge PS. – Nonspecific bronchial hyperreactivity in workers exposed to toluene diisocyanate, diphenyl methane diisocyanate and colophony. *Eur J Respir Dis* 1982; 63 (Suppl. 123): 91–96.
42. Dodge R. – Sensitivity of methacholine testing in occupational asthma. *Chest* 1986; 89: 324–325.
43. Hargreave FE, Ramsdale EH, Pugslet SO. – Occupational asthma without bronchial hyperresponsiveness. *Am Rev Respir Dis* 1984; 130: 513–515.
44. Larsson K, Eklund A, Arns R, *et al.* – Lung function and bronchial reactivity in aluminium potroom workers. *Scand J Work Environ Health* 1989; 15: 296–301.
45. Venables KM. – Epidemiology and the prevention of occupational asthma. *Br J Ind Med* 1987; 44: 73–75.
46. Venables KM. – Low molecular weight chemicals, hypersensitivity, and direct toxicity: the acid anhydrides. *Br J Ind Med* 1989; 46: 222–232.
47. Constantopaidos F. – Aluminum respiratory disorders at Saint Nicholas Aluminum de Grèce. *In*: Coulon J-P, ed. Seminar on aluminum respiratory disorders, St Nicholas Aluminum, Greece. Paris, Aluminum Penchiney, 1980; pp. 81–90.
48. Chan-Yeung M, Lam S, Koerner S. – Clinical features and natural history of occupational asthma due to western red cedar (*Thuja plicata*). *Am J Med* 1982; 72: 411–415.
49. Adams WG. – Long term effects on the health of men engaged in the manufacture of toluene diisocyanate. *Br J Ind Med* 1975; 32: 72–78.
50. Paggiaro PL, Loi AM, Rosso O, *et al.* – Follow-up study of patients with respiratory disease due to isocyanate (TDI). *Clin Allergy* 1984; 14: 463–469.
51. Hudson P, Pineau L, Cartier A, Malo JL. – Follow-up of occupational asthma due to various agents (Abstract). *J Allergy Clin Immunol* 1984; 73: 174A.
52. Cote J, Kennedy S, Chan-Yeung M. – Outcome of patients with cedar asthma with continuous exposure. *Am Rev Respir Dis* 1990; 141: 373–376.
53. O'Donnell TV, Welford B, Coleman. – Potroom asthma: New Zealand experience and follow-up. *Am J Ind Med* 1989; 15: 43–49.
54. Saric M, Marelja J. – Bronchial hyperreactivity in potroom workers and prognosis after stopping exposure. *Br J Ind Med* 1991; 48: 653–655.
55. Venables KM, Dally MB, Nunn AJ, *et al.* – Smoking and occupational allergy in workers in a platinum refinery. *Br Med J* 1989; 299: 939–942.
56. Hjortsberg U, Nise G, Ørbæk P, Søes-Petersen U, Arborelius M. – Bronchial asthma due to exposure to potassium aluminum tetrafluoride. *Scand J Work Environ Health* 1986; 12: 223.
57. Nemery B. – Metal toxicity and the respiratory tract. *Eur Respir J* 1990; 3: 202–219.
58. Simonsson BG, Sjøberg A, Rolf C, Haeger-Aronsen B. – Acute and long-term airway hyperreactivity in aluminium-salt exposed workers with nocturnal asthma. *Eur J Respir Dis* 1985; 66: 105–118.
59. Tarlo SM, Broder I. – Irritant-induced occupational asthma. *Chest* 1989; 96: 297–300.
60. Cartier A, Bernstein L, Burge PS. – Guidelines for broncho-provocation on the investigation of occupational asthma. *J Allergy Clin Immunol* 1989; 84: 823–829.