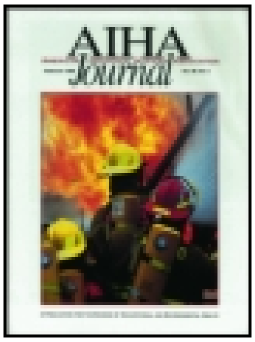

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Urinary Fluoride as an Exposure Index in Aluminum Smelting

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Urinary fluoride was evaluated as an exposure index for a prospective study of asthma in an aluminum smelter. Two studies were conducted to evaluate the relationship between airborne exposure and urinary excretion over a workweek, and to describe exposures among jobs and over time. Thirty-two subjects were evaluated on Days 1 and 3 of a 3-day workweek. On each day, spot urine samples were collected prior to the start of work and again at the end of the shift. Samples were analyzed for fluoride and expressed as milligrams fluoride per gram of creatinine. Airborne exposures to total particulate, fluoride particulate, and hydrogen fluoride (HF; using a 37-mm filter cassette containing a filter and treated back-up pad) were also evaluated on each subject. In the second study, postshift urine samples were collected from asthma study volunteers in three surveys extending over 1.5 years and analyzed for fluoride. Average airborne exposures were 15.7, 4.1, and 0.7 mg/m^3 for particulates, particulate fluorides and HF, respectively, and were substantially higher among carbon setters than other workers. However, average urine fluorides among the same workers were reasonably low, 1.3 and 3.0 mg/g creatinine in pre- and postshift urine samples, respectively. Carbon setters, who routinely wore respiratory protection during high exposure periods, had urinary fluoride levels similar to those of other potroom personnel. A significant variation in dose, as expressed by postshift urinary fluoride levels, was observed between potroom and nonpotroom jobs and over three survey periods. These results suggest that postshift urinary fluorides provide a reasonable exposure index for surveillance of exposure levels for an epidemiologic study, and that a substantial variation of exposure occurs between jobs and over time. Although urinary fluorides may be used for exposure surveillance, additional details on individual exposure agents and patterns of exposure over time are required for complete assessment.

Keywords: aluminum smelting, asthma, urinary fluoride

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During the smelting of aluminum metal, workers may be exposed to a wide variety of agents, notably fluorides (including aluminum fluoride [AlF_3] and cryolite [Na_3AlF_6]), irritant gases (SO_2 and HF), and polycyclic aromatic hydrocarbons (PAHs), in addition to the feedstock (alumina, Al_2O_3) and product (aluminum).[1,2] Several occupational diseases have been associated with work in aluminum smelters including osteofluorosis,[3,4] lung and bladder cancer,[5,6] and "potroom asthma."[7] Exposure assessment for fluorosis appropriately has focused on either airborne fluorides or urinary excretion of fluoride as an indicator of fluoride body burden, and exposure to PAHs has been used for studying cancer outcomes. However, the environmental agent responsible for potroom asthma, and therefore the appropriate exposure indicator for studying the incidence of asthma in aluminum smelting, has not been determined. Some investigators have suggested an immunologically mediated mechanism based on a specific antigen such as vanadium or an unspecified organic hapten as the etiologic agent for potroom asthma,[7,8] but no conclusive evidence for this hypothesis has been produced. Other investigators favor repeated exposures to low level irritants including HF and SO_2 as responsible for increasing airway reactivity.[7] An irritant-induced asthma mechanism appears plausible and has been described in case series of low chronic irritant exposures[9,10] and discrete high level irritant exposures (reactive airways disease syndrome, RADS).[11,12] Without a specific etiologic agent, the use of a nonspecific indicator for potroom exposures is needed, and total particulates (TP) or total fluoride (TF) exposure have been used widely in the aluminum industry.[13,14] In this study we evaluate the use of urinary fluoride as an indicator of exposure in a prospective study of reactive airways and asthma symptoms in an inception cohort.[15]

METHODS

Study Setting

The study was conducted at a large prebake smelter built in 1942, with eight potlines, each line encompassing two side-by-side potrooms separated by a courtyard. Each room is approximately 200 m long with 71 pots in each, for a total of 142 pots per line. Each pot has 24 anodes, 12 on each side, which are attended from raised catwalks the each pot. On either side of the room are large window openings, and the roof has an open cupola, allowing for strong convective natural ventilation as long as the window coverings are open. Each pot is covered by removable shields, and mechanical ventilation removes contaminants from the top of each pot to a central air cleaning system that dry-scrubs the effluents through fresh alumina.

There are four primary job titles in the potrooms: carbon setter, potman, tapper, and crane driver. All subjects in the asthma study were assigned to carbon setter at the beginning of the study period, but some have migrated into other jobs as they gained experience and seniority. Carbon setters work in teams of three or six, breaking up the hard crust that forms on top of the molten bath, replacing "spent" anodes with new ones, removing spent anodes from the potlines, adding ore (mainly alumina) and bath (mainly cryolite) to the cells, and cleaning up. Crust breaking and anode changing requires work over open pots with the shields removed.

Potmen are responsible for maintaining the smooth functioning of all the pots on their line, and their work involves "jacking" the anode bus to compensate for metal tapping. Although some of the potmen's work takes place on the pot catwalk, it rarely involves work with the shields removed.

Tappers siphon pure aluminum from the bottom of the pots into large crucibles. Crane drivers work in overhead crane cabs, attending to each of the other crew members when they require movement of heavy objects such as spent or new anodes, jacking frames, ore buckets, or crucibles.

The standard work cycle for potroom personnel is rotating 12-hour shifts with 3 days on and 3 days off. Every 12 days, workers rotate between a day and night schedule. Jobs outside the potrooms follow a more standard 8-hour shift. Respiratory protection is required whenever working on an open pot. Standard issue respirators are half-masks fitted with a prefilter and acid gas cartridge. Some individuals choose to use powered air purifying respirators. All employees in the potroom are given quantitative fit-testing and respiratory protection training, and respirators are issued from a central supply office, which also cleans and maintains the equipment and ensures an adequate supply of fresh cartridges.

Study 1

The first part of this study involves characterizing the air exposures, urinary excretion of fluoride, and the relationship between these exposure measures. Thirty-two volunteers from among the asthma study subjects were recruited to participate during the last week of February 1996. Each subject was monitored on Days 1 and 3 of a single workweek. On each monitored shift, subjects wore personal air sampling pumps calibrated to approximately 1 L/min connected to a standard 37-mm polystyrene cassette. Pumps and filters were changed at the middle of the shift to ensure pump life and avoid overloading. The two sample results were combined to calculate a 12-hour time weighted average (TWA), assuming zero exposure during any unmonitored intervals.

Air samples were collected and analyzed following a modification of National Institute for Occupational Safety and Health (NIOSH) Method 7902 using an 0.8 μm cellulose ester membrane and a backup pad pretreated with sodium carbonate, separated by a half-inch extension ring.[16] The membrane filter was also equilibrated and weighed before and after sampling to provide a measure of particulate mass exposure. Before and after each shift the subjects were asked to provide a urine sample in a collection cup pretreated with 0.2 grams EDTA. Samples were collected and analyzed according to NIOSH Method 8308 with results expressed as milligrams fluoride per gram of creatinine (mg/g creat.).[16]

Laboratory quality was assessed for air samples by collecting 10% field blanks, 10% of samples spiked by the analytical laboratory and another 5% spiked by a third-party laboratory. The lab-reported standard analytical errors were 0.11, 0.10, and 0.10 for total particulate, particulate fluoride, and HF, respectively. Recoveries were 106, 99, and 71% for the outside lab-spiked HF, lab-spiked HF, and lab-spiked fluoride samples, respectively. Correction for low recovery was made for the particulate fluoride samples only. Urine sample analyses were evaluated by duplicate analyses of about 5% of the samples yielding a relative standard deviation of 3.4%, and by repeated analyses of two laboratory-spiked samples yielding relative standard deviations of 2.1 and 2.7%.

Study 2

The second part of the study involved repeated collection of urine samples from a larger group of asthma study participants to characterize fluoride levels from a wider set of work environments over time. All members of the cohort who were working at the time of collection were asked to provide a single postshift urine sample. Collection and analyses were conducted in the same manner as the initial study. These data were collected in March and September 1997, and they are presented here in conjunction with the postshift urine samples collected for the initial study in February 1996. The ambient outdoor temperatures during these three collection periods averaged about −5°C in February 1996, 5°C in March 1997, and 18°C in September 1997.

Analysis

The distributions of air and urine data were considered using visual impressions of probability plots. Descriptive analyses were conducted using both box plots and calculation of distribution parameters, stratifying by each potential exposure determinant variable. The lower and upper ends of the boxes displayed in the box plots represent the 25th and 75th percentiles, respectively, and the central line represents the median. Circles and asterisks represent values more than 1.5 or 3 interquartile ranges from the upper or lower quartile, respectively. Differences in means were tested using a t-test or one-way analysis of variance. Regression models were developed manually adding

TABLE I. Personal Airborne Exposure Levels

	Particulate Mass (mg/m^3)		Total Fluoride (mg/m^3)		Hydrogen Fluoride (mg/m^3)	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Overall	52	15.7 (8.9)	52	4.07 (2.15)	52	0.74 (0.34)
By day						
1	28	16.4 (7.2)	28	4.39 (1.91)	28	0.77 (0.31)
3	24	15.0 (10.7)	24	3.71 (2.38)	24	0.70 (0.35)
By job						
Carbon setter	43	18.5 (7.2)	43	4.76 (1.68)	43	0.84 (0.26)
Potman	5	2.1 (0.7)	5	0.52 (0.23)	5	0.16 (0.09)
Tapper	4	3.6 (0.9)	4	1.17 (0.24)	4	0.36 (0.08)

TABLE II. Urine Fluoride Concentrations

	Preshift		Postshift		Post-Pre	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Overall	58	1.31 (0.77)	60	3.02 (1.87)	56	1.71 (1.73)
By day						
1	28	0.93 (0.47)	31	2.77 (1.22)	27	1.80 (1.19)
3	30	1.66 (0.83)	29	3.29 (2.37)	29	1.61 (2.14)
By job						
Carbon setter	48	1.23 (0.68)	50	2.77 (1.47)	46	1.51 (1.60)
Potman	5	1.22 (0.35)	5	2.53 (0.91)	5	1.31 (0.96)
Tapper	5	2.16 (1.35)	5	6.07 (3.40)	5	3.92 (2.18)

Note: mg fluoride per gram creatinine

potential exposure determinants and evaluating their contribution to the overall model fit (model r^2) and the significance of individual variables.

RESULTS

Study 1

A total of 124 half-shift air samples were collected; however, 11 were lost because of contamination or destruction during collection, providing 52 valid 12-hour TWA samples for analysis. Surprisingly, visual inspection of probability plots revealed that airborne exposures conformed closely to a normal distribution, and they were analyzed accordingly. Table I presents TWA results for particulate mass, TF (particulate and gaseous), and HF, and Figure 1 presents the TF results by job and day. Very little difference was observed between exposure days; however, carbon setters had substantially higher exposures than potmen or tappers (no crane drivers were included in this part of the study). TP, TF, and HF all follow similar patterns of exposure. HF was 18% of TF overall, and this fraction was higher for potmen and tappers (about 30%).

Unlike the normality of the airborne exposure levels, urinary fluoride concentrations were approximately lognormally distributed with geometric standard deviations around 1.7. Nevertheless, for consistency with the air levels, these data are presented using arithmetic means and standard deviations. Table II presents creatinine-corrected urinary fluoride results for the preshift, postshift, and the change in level from pre- to postshift by day and job. Overall, the average urinary fluoride went up significantly between the preshift sample and postshift sample. The preshift fluoride levels rose over the workweek, as did the postshift levels; however, these changes are complicated by the high postshift samples seen in the tappers, who were represented on Day 3 only. Figures 2 and 3 demonstrate that preshift samples rose significantly from Day 1 to Day 3 for carbon setters and potmen, whereas the postshift samples did not differ greatly over the workweek. The few (5) samples on tappers on Day 3 contributed significantly to the apparent increase in postshift urine fluorides on Day 3 only. The similarity in postshift urinary fluorides between carbon setters and potmen is quite notable given the pronounced difference in their airborne exposure levels.

Figure 4 demonstrates the lack of relationship between airborne exposure and the postshift urinary fluoride. This poor relationship may be expected because of the effective use of respiratory protection, especially by carbon setters during high exposure periods. In this figure, there appears to be a subgroup of carbon setters for whom there was no elevation of urinary fluoride despite increasing airborne exposures, whereas another subgroup did have somewhat elevated fluoride excretion. It may be

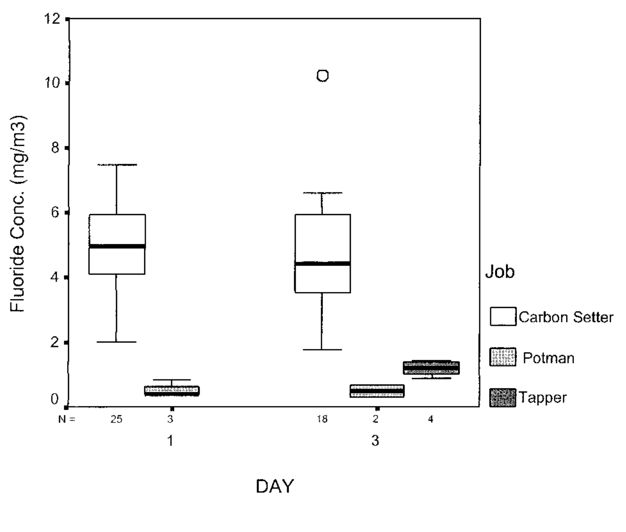

FIGURE 1. Personal airborne total fluoride concentrations by job and day

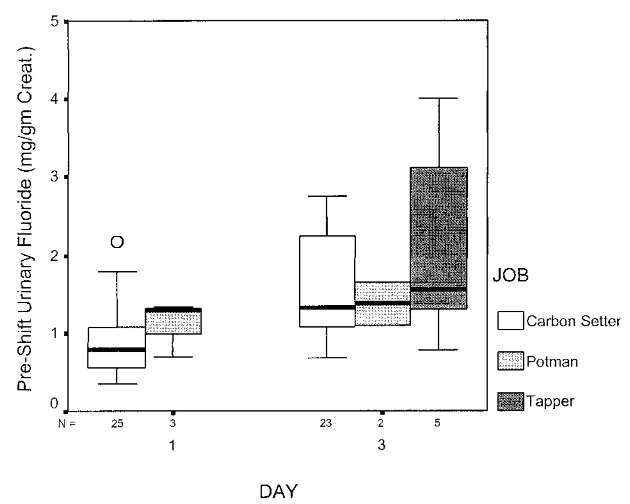

FIGURE 2. Preshift urinary fluoride by job and day

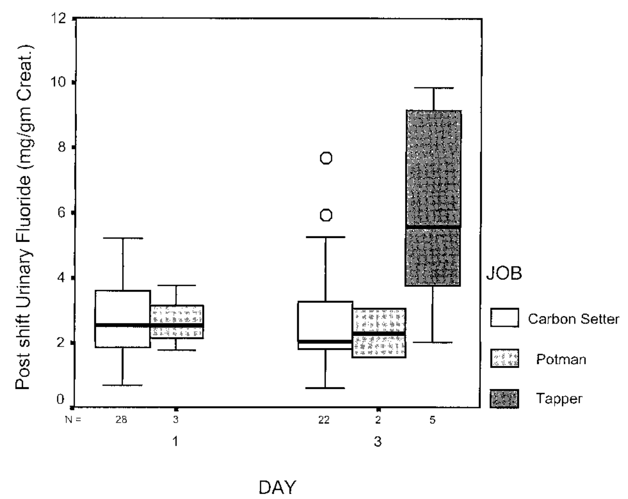

FIGURE 3. Postshift urinary fluoride by job and day

inferred that some individuals wore respiratory protection very effectively while others were somewhat less vigilant.

However, if restricted to potmen and tappers, a significant relationship between airborne exposure and the postshift urinary fluoride can be ascertained with a correlation coefficient of 0.82. This relationship is based on only nine samples, which are all at the low end of the exposure range. These data are insufficient to use for prediction; however, they do suggest that the postshift fluoride concentration may be a useful indicator of exposure, accounting for the effectiveness of respirator use.

Study 2

An examination of probability plots of the postshift urinary fluoride concentrations over three seasons demonstrated that they too were approximately lognormally distributed; analyses of these data were conducted on the log scale. The arithmetic and geometric means and standard deviations of the postshift urine fluorides are given in Table III. Small differences between jobs were observed,

TABLE III. Postshift Urine Fluoride Concentration over Three Seasons

	n	Geometric Mean (GSD)	Arithmetic Mean (SD)
Overall	216	1.92 (2.10)	2.46 (1.84)
By department			
Potroom	197	2.14 (1.94)	2.63 (1.84)
Other	19	0.63 (1.78)	0.75 (0.53)
Job within potroom			
Carbon setter	155	1.90 (1.61)	2.49 (1.81)
Potman	11	2.49 (1.59)	2.72 (1.13)
Tapper	18	3.33 (1.79)	3.92 (2.43)
Crane operator	9	1.59 (1.61)	2.08 (0.89)
By session			
February 1996	60	2.59 (1.75)	3.02 (1.87)
March 1997	91	1.90 (2.06)	2.41 (1.76)
September 1997	65	1.48 (2.27)	2.02 (1.81)

Note: mg fluoride per gram creatinine

though it is useful to note that the carbon setters again did not have levels higher than subjects working other jobs. A trend is observed toward higher levels during colder periods. These data, stratified by both job and survey, are displayed in Figure 5. Here the mild effect of season is observed for carbon setters and, primarily because of the high values observed during the winter survey, also for tappers.

These data were modeled using a linear model with the log of urinary fluoride as the dependent variable. Independent variables considered for inclusion in the model were job (coded for the four potroom jobs and nonpotroom work), season (coded for the three surveys), day (Day 1 versus later in the workweek). Interactions between the primary variables were tested, as was using the untransformed urinary fluoride level as the dependent variable. Day of the workweek had no effect on the model, while job and season remained statistically significant. Interactions between job and season made no significant difference in the observed model. Use of the untransformed dependent variable reduced the model r^2 and resulted in poorly distributed residuals. The final model selected for describing these data is presented in Table IV, and urinary fluoride levels predicted by the model for workers in each job and

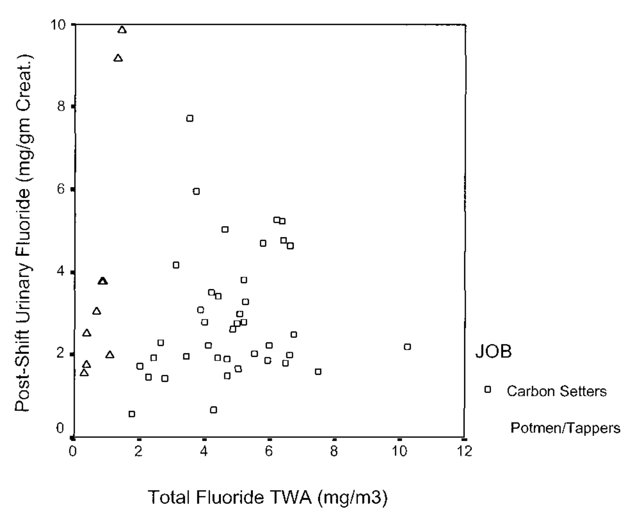

FIGURE 4. Postshift urinary fluoride versus airborne fluoride by job

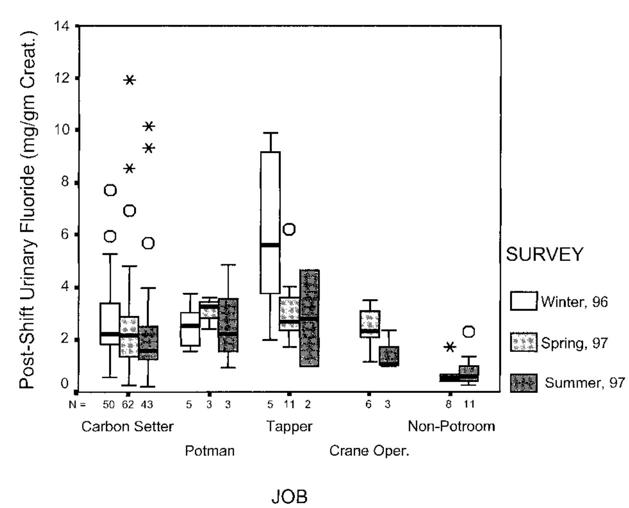

FIGURE 5. Postshift urinary fluoride by job and survey

TABLE IV. Model Parameter Estimates for Log of Urine Fluoride Concentration (ln[mg/g creat.])

Model r^2: 0.29	β	SE (β)	p
Intercept	−0.517	0.153	0.001
Job			
Carbon setter	1.04	0.16	<0.001
Potman	1.22	0.25	<0.001
Tapper	1.53	0.22	<0.001
Crane operator	1.07	0.26	<0.001
Nonpotroom job	0[A]		
Session			
Winter 1996	0.37	0.12	0.002
Spring 1997	0.14	0.11	0.205
Summer 1997	0[A]		

[A] Baseline level

season are given in Table V. The levels are predicted as both geometric and arithmetic means and demonstrate a substantial range (arithmetic means from 0.8 to 5.5 mg F/g creat.) of predicted exposures over these two factors.

DISCUSSION

Selection of an appropriate exposure metric and exposure monitoring strategy for epidemiologic studies are particularly challenging when the specific etiologic agent has not been identified, short-term peak exposures may be important parameters for the endpoint under study, and when respiratory protection use significantly limits the interpretation of traditionally measured airborne exposures. Nevertheless, conducting a prospective study with an inception cohort provides the opportunity to monitor exposures among the study cohort over the relevant etiologic period. The use of a simple and inexpensive monitoring technique is useful in this context if it can provide at least a reasonably accurate rank ordering of the cohort members with respect to the actual etiologically relevant exposure. In this study, we have evaluated the feasibility of urinary fluoride as a marker of exposure in a cohort of aluminum smelter workers.

A number of important observations have been made as a result of the exposure assessments described here. Whereas airborne exposures to TP, TF, and HF were substantially elevated, urine fluorides were modest, suggesting that the use of respiratory protection by carbon setters during the high exposure tasks (i.e., while working over open pots) was quite effective. In fact, urine fluoride levels suggest that the absorbed dose received by carbon setters is very comparable and even slightly lower than other potroom personnel (Tables IV and V). The model results suggest that tappers have the highest overall absorbed doses, although this result should be viewed with caution as it is heavily influenced by the five data points that were obtained on Day 3 of the first survey. These values could be explained by contamination of the urine sample during collection, or could represent chance occurrence of elevated exposures. However, tappers do have the potential for significant fluoride exposures during portions of their work cycle, and do not regularly use respiratory protection. Furthermore, for the few air samples available tappers' fluoride exposures were on average over twice those of the potmen (Table I).

TABLE V. Geometric (GM) and Arithmetic (AM) Mean Exposure Levels Predicted by Model

	Season					
	Summer		Spring		Winter	
Job	GM	AM	GM	AM	GM	AM
Carbon setter	1.69	2.32	1.94	2.67	2.44	3.36
Potman	2.02	2.78	2.32	3.19	2.92	4.02
Tapper	2.75	3.79	3.17	4.35	3.99	5.48
Crane operator	1.74	2.39	2.00	2.75	2.52	3.46
Nonpotroom job	0.60	0.82	0.69	0.94	0.86	1.19

Note: mg fluoride per gram creatinine in urine

The evidence presented suggesting that respiratory protection was effectively used in this environment was also corroborated by work observations during the study. In 95% of the observations made during crust breaking or anode changing activities, which occur over open pots, respirators were in use. In another more comprehensive observational study of respiratory protection use, respirators were used over 90% of the time during these activities and over 99% of the time while working on an uncovered pot.[17]

The American Conference of Governmental Industrial Hygienists currently recommends that exposure be controlled so that urinary fluoride levels are below 3.0 and 10.0 mg/g creatinine in pre- and postshift samples, respectively.[18] Very few of our samples exceeded these levels. However, the fact that carbon setters were well protected during high exposure periods and that the urinary fluoride levels were almost always less than the biological exposure index (BEI) does not imply that these workers are not at increased risk of respiratory effects. The BEI, as well as the threshold limit value on which the current occupational exposure standards were based, was recommended to protect workers from chronic accumulation of fluoride and the development of osteofluorosis.[19] Short-term exposure to fluorides, especially HF, are recommended to be less than 2.5 mg/m^3 over 15 min to prevent respiratory tract irritation,[19] but the relationship between these levels and the risk of development or exacerbation of asthma has yet to be firmly established.

There appears to be a significant accumulation of circulating fluoride over the 3-day workweek, as shown by the increase in mean preshift urinary fluorides from Day 1 to Day 3 (Figure 2). This finding suggests that the circulating fluoride has not completely cleared during the time between the end of one shift and the beginning of the next—in this plant, 12 hours. Estimates of the biological half-life of fluoride in blood or urine range from about 4 to 7 hours.[19] On a traditional 8-hour work schedule with 16 hours between work periods, little excretion due to the previous day's exposure would be expected in a preshift sample. However, with the 12-hour shift schedule used in this facility, it appears plausible that a small increase would be seen in the preshift sample from day to day.

A similar increase over the workweek would be expected in the postshift urinary concentration, whereas this was not seen (Figure 3). Dinman et al. have shown an increase in postshift urinary concentrations for at least 3 days of a workweek.[20] The majority of high exposure tasks in the current plant were conducted during the first half of the 12-hour shift. Thus, there is a substantial period of time (one to two half-lives) during which fluoride washout may occur. As a result, a sample taken at the end of a 12-hour shift reflects a relatively small percentage of the TF excretion compared with one taken at the end of an 8-hour shift. On the other hand, the postshift sample may be quite affected by the level of activity, and therefore exposure, occurring toward the end of the shift.

Some authors[21] recommend using the change in urinary biomonitoring results from pre- to postshift to correct for baseline body burden. Given the pattern of results seen here, this would not appear advisable; the change in urinary concentrations over the workday was dependent on the day of the workweek because of the increase in preshift sample concentrations. Thus, the cross-shift change in concentration would be useful only on the first day back to work after a weekend. Use of the postshift sample alone also has the great advantage of minimizing the effort required by the study participants.

Urine samples collected in and out of the potrooms over three surveys demonstrated a significant spread in fluoride exposures between jobs. Variability in exposure levels is a requirement for observation of a dose-response relationship in an epidemiological analysis. A significant variation also was observed with time of the survey, adding to the overall spread of group mean exposures over time. Although this change in mean concentration with time could indicate a general reduction of exposures over time, no significant changes have been made to the work process or control systems during the monitored period. It would appear more likely that these differences reflect a seasonal variation dependent on the outdoor temperatures. During cold periods workers are more likely to close the window shutters and to spend more time in close proximity to the smelting cells, thus increasing potential exposures. During warm periods, windows are maximally opened and workers spend as little time as possible near the pots. A final determination of the source of this variability will require ongoing surveillance of the fluoride levels over time.

Use of postshift urinary fluoride concentration would appear to present a useful, though not perfect, indicator of exposure for aluminum potroom workers. The measure effectively accounts for the use of respiratory protection, which gives it a major advantage over the use of traditional industrial hygiene measures of airborne exposure.

However, the use of urinary fluoride as an indicator of exposure to asthma-causing agents may be limited. First, it is specific to fluoride exposure, which is only one possible etiologic agent for asthma. The degree of correlation between fluoride and the other particulates and gases present in the potroom requires further investigation. Second, urinary fluoride excretion is affected by the temporal variation of exposure over the workday and workweek. Collection of 24-hour urines would provide a significant improvement in the assessment of total absorbed dose, but does not appear feasible for this study. Finally, urinary fluoride excretion is a highly integrated exposure marker and cannot account for peak exposures, which may be important in the etiology of potroom asthma.

As a result of these considerations, a postshift urinary fluoride has been adopted as a general measurement technique for tracking individual and group exposure levels over time for this prospective study. However, to account for the characteristics of exposure not adequately assessed by urinary fluoride, these data are being supplemented with chemical-specific, real-time, and task-based assessments to consider these potentially important characteristics of potroom exposures.[17]

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REFERENCES

1. **Burgess, W.:** Metals production: Aluminum, iron, and steel. In *Recognition of Health Hazards in Industry: A Review of Materials and Processes,* W. Burgess (ed.) New York: John Wiley & Sons, 1995. pp. 13–32.
2. **Benke, G., M. Abramson, and M. Sim:** Exposures in the alumina and primary aluminium industry: An historical review. *Ann. Occup. Hyg. 42*:173–189 (1998).
3. **Steinegger, A.F., and C. Schlatter:** Evaluation of fluoride exposure in aluminium smelters: State of the art. *Med. Lav. 83*:489–498 (1992).
4. **Dinman, B.D., M.J. Elder, T.B. Bonney, P.G. Bovard, and M.O. Colwell:** Prevention of bony fluorosis in aluminum smelter workers. A 15-year retrospective study of fluoride excretion and bony radiopacity among aluminum smelter workers—Pt. 4. *J. Occup. Med. 18*: 21–23 (1976).
5. **Armstrong, B., C. Tremblay, D. Baris, and G. Theriault:** Lung cancer mortality and polynuclear aromatic hydrocarbons: A case-cohort study of aluminum production workers in Arvida, Quebec, Canada. *Am. J. Epidemiol. 139*:250–262 (1994).
6. **Ronneberg, A., and A. Andersen:** Mortality and cancer morbidity in workers from an aluminium smelter with prebaked carbon anodes—Part II: Cancer morbidity. *Occup. Environ. Med. 52*:250–254 (1995).
7. **Abramson, M.J., J.H. Wlodarczyk, N.A. Saunders, and M.J. Hensley:** Does aluminum smelting cause lung disease? *Am. Rev. Respir. Dis. 139*:1042–1057 (1989).
8. **Desjardins, A., J.P.Bergeron, H. Ghezzo, A. Cartier, and J.L. Malo:** Aluminum potroom asthma confirmed by monitoring of forced expiratory volume in one second. *Am. J. Respir. Crit. Care Med. 150*: 1714–1717 (1994).
9. **Kipen, H.M., R. Blume, and D. Hutt:** Asthma experience in an occupational and environmental medicine clinic. Low-dose reactive airways dysfunction syndrome. *J. Occup. Med. 36*:1133–1137 (1994).
10. **Lemiere, C., J.L. Malo, and D. Gautrin:** Nonsensitizing causes of occupational asthma. *Med. Clin. North Am. 80*:749–774 (1996).
11. **Brooks, S.M., M.A. Weiss, and I.L. Bernstein:** Reactive airways dysfunction syndrome (RADS). Persistent asthma syndrome after high level irritant exposures. *Chest 88*:376–384 (1985).
12. **Kennedy, S.M., D.A. Enarson, R.G. Janssen, and M. Chan-Yeung:** Lung health consequences of reported accidental chlorine gas exposures among pulpmill workers. *Am. Rev. Respir. Dis. 143*:74–79 (1991).
13. **Kongerud, J., and S.O. Samuelsen:** A longitudinal study of respiratory symptoms in aluminum potroom workers. *Am. Rev. Respir. Dis. 144*:10–16 (1991).
14. **Soyseth, V., J. Boe, and J. Kongerud:** Relation between decline in FEV1 and exposure to dust and tobacco smoke in aluminum potroom workers. *Occup. Environ. Med. 54*:27–31 (1997).
15. **Kaufman, J., F. Daroowalla, N. Nelson, S. Sama, N. Seixas, and M. Cohen:** A prospective study of respiratory health in aluminum smelter work. In *Managing Health Issues in the Aluminum Industry,* N. Priest (ed.). Montreal, Canada: International Primary Aluminium Institute, 1997.
16. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Manual of Analytical Methods.* Cincinnati, OH: U.S. Department of Health and Human Services, 1994.
17. **Moore, P.:** An assessment of occupational exposure to respirable particulates and sulfur dioxide during aluminum smelter potroom operations. Seattle: University of Washington, 1998. p. 100.
18. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.* Cincinnati, OH: ACGIH, 1997.
19. **American Conference of Governmental Industrial Hygienists (ACGIH):** *Documentation of Threshold Limit Values and Biological Exposure Indices.* Cincinnati: ACGIH, 1991.
20. **Dinman, B.D., W.J. Bovard, T.B. Bonney, J.M. Cohen, and M.O. Colwell:** Prevention of bony fluorosis in aluminum smelter workers. Excretion of fluorides during a seven-day workweek—Pt. 2. *J. Occup. Med. 18*:14–16 (1976).
21. **Lauwerys, R., and P. Hoet:** *Industrial Chemical Exposure: Guidelines for Biological Monitoring.* Boca Raton, FL: Lewis Publishers, 1993.