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REYNOLDS ALUMINUM

REYNOLDS METALS COMPANY • RICHMOND, VIRGINIA 23261

1980 December 10

Mr. Thomas B. Bonney
Aluminum Company of America
1501 Alcoa Building
Pittsburgh, Pennsylvania 15219

Dear Tom:

Please find my second draft of the section on contaminants in our write-up of the sampling and analytical procedures in the aluminum reduction industry. After the recent Washington meeting of the task group, substantial revision of my initial draft was proposed. In addition, a new section dealing with the ingot plant as well as a table listing the contaminants and possible ranges of exposure was to be included.

Please look at the section on the ingot plant and the list of contaminants especially regarding the range of exposures to be very preliminary and subject to change.

As you know, other members of the task force were going to send me the range of exposures for their particular operation. Also, Mr. Martyn was to provide a detailed description of the processes. Since neither of these items has been accomplished, I attempted to draw them together using Tom Walker's list of contaminants as indicated in the initial IPAI Health Protection Seminar in Copenhagen. Task group members should feel free to make whatever changes they deem necessary in this draft and I will try to have it reworked by the IPAI Health Committee meeting in January.

Thank you very much.

Sincerely,

Homer M. Cole

Homer M. Cole
Manager,
Environmental and Industrial
Hygiene

HMC:jct
cc: Mr. Peter Martyn
Dr. Alfred Steinegger
Mr. Eirik Nordheim
Mr. Thomas J. Walker

DRAFT - 1980, December 09

SAMPLING AND ANALYTICAL PROCEDURES IN THE ALUMINUM REDUCTION INDUSTRY

ALUMINUM PRODUCTION PROCESSES

Introduction

Aluminum is produced by using the Hall Heroult process in which alumina is electrically reduced to aluminum. The alumina is dissolved in a molten bath (approximately 950 C.) of fused salt electrolytes consisting primarily of cryolite with minor additions of other salts, mainly fluorides. The entire process is carried out in a reduction cell consisting mainly of a carbon anode, a cathode, and the electrolyte contained in a carbon-lined steel shell.

After reduction, the metal, being more dense than cryolite, is deposited at the cathode. Oxidation of carbon is primarily to carbon dioxide, but with some secondary production of carbon monoxide occurring at the anode. Consequently, the anode carbon is continuously being consumed during the reduction of alumina.

There are currently two types of processes (prebake and Soderberg) being used in aluminum reduction. Both processes contain basically the same type of cathodes, i.e. a steel shell lined with an insulating material and a carbon layer approximately 12 inches thick. The main difference is in the design of the carbon anodes.

Prebake Process

In the prebake process, anode blocks (previously baked in the carbon plant) are suspended along the entire length of the pot. Aluminum or copper electrical connector rods, used to support the anode blocks in the pot, are attached to the anodes in the rodding room. Prebake pots may be of two types depending upon the method in which the alumina is added to the pots. The first type is the "center brake pot" in which the alumina is fed into the center of the pot.

The second type is the "side brake pot" in which the alumina is added in the interval between the outside of the anode blocks and the inside walls of the pots.

In the prebake potrooms, several emissions are produced during the reduction process. Particulate and gaseous fluorides are emitted from the electrolyte; sulfur dioxide originates from the sulfur content of the coke used to make the anodes. Carbon monoxide and carbon dioxide emissions result from the oxidation of the carbon anodes. Nuisance dust (alumina and carbon dust) is released into the workplace during the normal operation and maintenance of the pots. As mentioned previously, the anodes are pure carbon and, consequently, contain no PNAs. There may, however, be other sources of PPOM such as the line cathode baking process (coal tar pitch used as a binder in the cathode mix) or pitch used as a binder to secure the anode to the electrical connector rod.

In the prebake carbon plant green mill, sized calcined petroleum coke is proportioned along with reclaimed anode material and approximately 25 percent coal tar or petroleum pitch in a batch or continuous mode. The materials are then blended and heated in a mixer to a temperature of approximately 160 C. The mixture is then transported via a conveyor to an anode press (mixture temperature about 135 C.). Here, the mix is pressed into carbon blocks by the hydraulic anode press, or vibrated. Lubricant may be sprayed onto the molds to prevent sticking of the anode paste mixture. The green blocks are then packed in layers in the carbon baking pits, with coke or anthracite coal packed between the layers of blocks and the refractory flue wall, to provide mechanical support and heat transfer, as well as to prevent oxidation during the baking of the carbon. The uppermost layer of blocks is also covered with a blanket of packing material.

The blocks are then slowly heated to a temperature of approximately 1200 C. They are held at this temperature for approximately 40 hours and then slowly cooled to a temperature of about 160 C., before they are removed from the carbon furnace. During this baking period and cooling cycle, which may be extended

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over several weeks, pitch volatiles from the baking blocks are drawn into the combustion flue through open spaces in the refractory brickwork. During the entire baking and cooling cycles, the baking pits are operated under a negative pressure, to contain the pitch volatiles and burn them for the available fuel value. As a result, very little volatile hydrocarbons are released into the workplace in the carbon bake area.

The baked blocks are then cleaned to remove minor amounts of the packing material adhering to the blocks. These prebaked blocks are then transported to the rodding room, where the anode connector rod is attached. The blocks may also be spray-coated with aluminum, to prevent oxidation. The finished anode assembly is then ready for installation into a pot.

Occupational exposure in the carbon bake area would be to carbon monoxide, sulfure dioxide, fluorides, and nuisance dust. Carbon monoxide results from the incomplete combustion of organic materials (e.g. natural gas or oil used to fire furnaces, as well as the coal tar pitch binder). Sulfur dioxide is produced from the sulfur present in the coke or coal used to make the blocks. Fluorides are generated from the fluoride contained in recycled anodes. Finally, nuisance dust, primarily carbon, is produced by the handling of coke and used anode blocks.

<u>Soderberg Process</u>

In the Soderberg process, the anode, which consists of petroleum coke and coal tar pitch binder, is of the self-baking type. The anode mix is added to the top of the anode superstructure as a viscous paste or briquette. The anode is continuously lowered to amintain the desired distance from the cathode. As the paste mix gradually lowers into the pot, its temperature rises until it reaches that of the bath at which time it has been completely baked to pure carbon.

Iron rods or steel pins are inserted into the soft anode to carry electrical current to the pots. The pins may be arranged either vertically or horizontally.

In the Soderberg potrooms, a variety of emissions are produced. Particulate and gaseous fluoride are emitted from the electrolyte; sulfur dioxide originates from the sulfur found in the coke, which comprises the major portion of the anode. Carbon monoxide and carbon dioxide emissions result from the oxidation of the carbon anodes. Coal tar pitch volatiles are produced during the anode baking porcess, and nuisance dust (alumina and carbon dust) is released into the workplace during the normal operation and maintenance on the pot.

In the Soderberg paste plant, calined petroleum coke is ground in ball mills to the proper sizes. This material is mixed with 25 to 26 percent coal tar pitch (softening point is approximately 120 C.) and blended in a heated mixer. After mixing, the anode paste is dumped into the anode paste bucket at a temperature of 160 to 190 C. The material is then transported to the potroom, where it is added to the top of the pot by an overhead crane.

Exposures in the Soderberg paste plant include coal tar pitch volatiles, coal tar pitch dust, and carbon dust. The coal tar pitch volatiles found in the Soderberg paste plant are generally of a lower molecular weight than those found in the Soderberg potroom.

<u>Cathode Lining</u>

The cathode material is produced by mixing sized anthrocite coal with approximately 13% coal tar pitch or petroleum pitch binder. The mixture is blended and heated in a mixer to a temperature of approximately 135 C. The material is then transported to the pot repair area where it is used for cathode relining.

Exposures in the cathode lining operation are mainly low molecular weight hydrocarbons and nuisance dust. Minor amounts of PNA's may be released during the ramming process.

Maintenance

In this complex industry systematic and effective maintenance of plant and equipment is essential.

Pollution abatement systems such as fume collection hoods, burners, etc., must be kept in good working order to insure that process workers are given the maximum protection. Special attention should be paid to maintenance workers to minimize undue exposure to harmful vapors, gases and dust when carrying out repair or changes to process our fume control equipment. Although some occupational exposures to maintenance personnel are unique to the particular process, many are quite similar (e.g. welding fumes, coal tar pitch volatiles, dust, etc.). The following is a brief description of the major maintenance operation at an aluminum reduction plant.

Reworking and/or replacement of cathode shells requires the removal of old bath and spent cathode from the shell. Water is normally added to the pot at this stage for cooling purposes as well as loosening up spent pot lining material. Pot shells may then be dumped or dug out using a pneumatic pot digger. The shell is then cleaned by abrasive blasting so that welders may repair cracks and patch holes. Exposures during this process include ammonia generated by the addition of water to the pots as well as nuisance dust and fluorides from the old bath and cathode. Abrasive cleaning of the shell usually results in exposure to either crystalline silica or alumina. Finally, welders are exposed to a variety of dust and welding fumes associated with mild steel welding.

Electrical connections (aluminum and copper bus bars, flex, and prebake rods, etc.) are continually being replaced and repaired. Exposures during this procedure are mainly to copper dust and fume.

Cleaning and reworking of the used anode pins and channels involve abrasive cleaning and straightening. Consequently, workers may be exposed to dust of carbon alumina and fluorides.

Finally, repair of the fume control system results in a variety of exposures. Ducts must be continually cleaned to prevent accumulation of material which reduces the effectiveness of the ventilation system. In addition, continual cleaning and repair of scrubbers (Wet Electrostatic Precipitators, Dry Electrostatic Precipitators, etc.) must be performed to maintain the necessary collection efficiency for the various contaminants. Employees involved in these jobs can be exposed to nuisance dust, fluorides, carbon monoxide, and coal tar pitch volatiles.

Ingot

After the molten metal has been removed from the pot (tapped with a tapping crucible) it is taken to the casthouse where the metal is prepared for distribution to the customer. The raw pot metal may be sent directly to the customer in the molten state. The molten metal may also be pigged directly into 1,000 and 2,000 lbs. molds. The final possibility is for the metal to be added to a holding furnace where it is alloyed and fluxed to remove impurities and degas the metal. The fluxing process, which uses C/2 or a mixture of chlorine and other gases, causes the impurities to float to the top of the molten metal. This dross is removed prior to casting and stored in a dross house until it is cool. After the skimming has been completed the metal is cast into ingots, billets, or small pigs.

Exposures in the casthouse would be to fluorides, chlorine, chlorides, ammonia, phosphine, nuisance dust, oil mist, asbestos and possibly alloying agents. Fluorides are produced from the cooling dross material due to the presence of pot bath material. Chlorine exposure results from the use of chlorine as a component in the fluxing gas. Consequently, chlorides, reaction by-products of the chlorine, are also emitted from the cooling dross. Ammonia is produced from hot dross when it comes in contact with moisture. *Nuisance dust is also produced from the dross as well as scrap handling. Oil mist is emitted from

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the billet saws which utilize the oil as a cutting lubricant. *Metal exposures may occur from the various alloying agents being used, e.g., magnesium, chromium, etc.

*Phosphine may also be produced from the hot wet dross if there is some arsenic present.

*Asbestos exposure can occur due to the use of marinite in the molten metal transfer troughs. The marinite must be machined and sized for each particular casting operation. Asbestos exposure may also occur in the siphon cleaning and repair shop where siphons are cleaned with a pneumatic router, and asbestos gaskets removed and installed on the crucible lid and siphon.

AIRBORNE CONTAMINANT	PRINCIPAL USE OR SOURCE OF EMISSION	TYPICAL EXPOSURE RANGE
ALUMINUM		
ALUMINUM OXIDE		<1-30 mg/m^3
AMMONIA	By-product from dross & H_2O	<1.0-40 ppm
ASBESTOS	Insulation; coverings; lagging materials; marinite; molten metal control; brake linings	<0.1-50.0 fibers/cc
BERYLLIUM		
CADMIUM DUST/FUME	Silver soldering; brazing	<0.01 mg/m^3
CARBON DIOXIDE	Potrooms; anode baking pits; combustion sources	
CARBON MONOXIDE	By-product of incomplete combustion in: potrooms, furnaces, internal combustion engines; inert gas furnaces; enclosed spaces, tanks and silos	<5-1200 ppm*
CHLORINE & CHLORIDES	Fluxing in casting operations; water treatment	<0.05-18 ppm
COAL TAR PITCH VOLATILES	Binder for electrodes	<0.01-2.0 mg/m^3
COPPER DUST/FUME	Anode rods and flex; electrical connectors; metal alloying; brazing	<0.01-20.0 mg/m^3
FLUORIDES (Gaseous, liquid & particulate)	Cryolite plant; potrooms; pot repair, solid fluxes, metal treatment; welding flux; dross recovery	<0.01-50 mg/m^3
HYDROGEN CHLORIDE	Casting; (formed from chlorine in presence of water); demineralizers	<0.01-20.0 mg/m^3
HYDROGEN FLUORIDE		<0.01-5.0 ppm
HEXACHLOROETHANE		
LEAD	Alloying agent	<0.01-200 $\mu g/m^3$
MANGANESE	Metal alloying	<0.01-5.0 mg/m^3
MERCURY	Rectifiers; laboratories	<0.01-0.30 mg/m^3
NITROGEN DIOXIDE		<0.01-5.0 ppm
MAGNESIUM OXIDE FUME	Alloying agent	<0.01-15 mg/m^3
NUISANCE DUST (Coke, fibrous glass, mineral wool fiber)		<1.0-50.0 mg/m^3
OZONE	By-product in electrical discharge and welding	<0.01-5 ppm
PHOSGENE	Combustion product of halides; Note: No welding in confined space in presence of chlorinated solvent or other halide	<0.01 ppm
PHOSPHINE	Gaseous by-product of dross and water	<0.01-1.0 ppm
SILICA (Amorphous)		<1-20 mg/m^3
SILICA (Crystalline)	Sandblasting	<1.0-200 $\mu g/m^3$
SULFUR DIOXIDE	By-product of combustion of coke, coal, anodes, oil and gas; waste water treatment	<0.1-5 ppm
WELDING FUME	By-product of welding; principally ozone, oxides of nitrogen and metal(s) welded	<0.01-30 mg/m^3

IPAI
International Primary Aluminium Institute

New Zealand House (9th Floor)
Haymarket
London SW1Y 4TE
United Kingdom

Telephone 01-930 0528
Telex 917837 IPAI London

2nd October 1987

To all Members of the IPAI Health Committee

Copy to the Chairman, IPAI Environmental Committee

Report: "Mortality of Aluminium Reduction Plant Workers in France"

Please find enclosed a copy of the above report mentioned by Dr J-P Coulon at the recent Sixteenth IPAI Health Committee Meeting.

Peter Martyn
Secretary General

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Mortality of Aluminium Reduction Plant Workers in France

J M MUR*, J J MOULIN*, C MEYER-BISCH*, N MASSIN*, J P COULON† AND J LOULERGUE†

Mur J M (Institut National de Recherche et de Sécurité, Avenue de Bourgogne—54500—Vandoeuvre les Nancy, France), Moulin J J, Meyer-Bisch C, Massin N, Coulon J P and Loulergue J. Mortality of aluminium reduction plant workers in France. *International Journal of Epidemiology* 1987, 16: 257–264.
The mortality between 1950 and 1976 of 6455 French aluminium plant workers was analysed in order to assess occupational risks (especially lung cancer) associated with electrolysis, particularly with the Söderberg process. Mortality from all causes (SMR = 0.85), was lower in this cohort than in the French male population ('healthy worker effect'), and cancer mortality (SMR = 1.09) was only slightly higher. There was an excess of mortality from accidents (mainly non-occupational) in electrolysis workers (SMR = 1.38) and from cirrhosis of the liver in maintenance workers (SMR = 1.63). Among electrolysis workers, only those who had worked less than 10 years had a relative excess mortality from lung cancer (SMR = 1.94), but this did not seem to be associated with a particular electrolysis process. However a substantial underlying risk of lung cancer in Söderberg workers could not be excluded, although such a risk appeared unlikely for prebake workers.

Several epidemiological surveys, analysed by Doll[1], Enterline[2] and Simonato[3], have been carried out in order to evaluate occupational risks in the aluminium industry. In particular the risk of lung cancer was suspected because certain production techniques, such as the Söderberg electrolysis process, generate in the working environment polycyclic aromatic hydrocarbons,[4–7] some of which (benzo(a)pyrene) are known to be experimental carcinogens.[8] The results of several of these surveys seemed to confirm this hypothesis, although the risk of lung cancer could not be firmly ascertained. Furthermore, some of these surveys suggested that there might be other risks for the workers in this industry: other cancer sites (brain, pancreas, liver, lymphohaematopoietic cancers) and other non-neoplastic diseases (emphysema, cirrhosis of the liver).

In order to provide additional data about all these suspected risks, a mortality survey was initiated, for the first time, among workers at all aluminium reduction plants in France.

MATERIAL AND METHODS

Aluminium Processing

Aluminium is produced by electrolytic reduction of alumina.[9] A tank, whose internal carbon-coated wall is the cathode, contains the electrolysis bath, made of alumina and of a fluxing agent (cryolite). Differences between the electrolysis processes essentially depend on the type of anode used. These anodes, made from a mixture of coke and of coal tar pitch (sometimes of petroleum pitch) can be:

—either baked (in ovens) before being used: in this case, they are solid blocks immersed in the electrolytic bath ('prebake anodes');

—or raw (Söderberg process): a paste is continuously supplied and carried to the electrolytic bath: in contact with the bath, which is at a high temperature (950°C), the lower part of the Söderberg electrode is baked ('self-baking anodes').

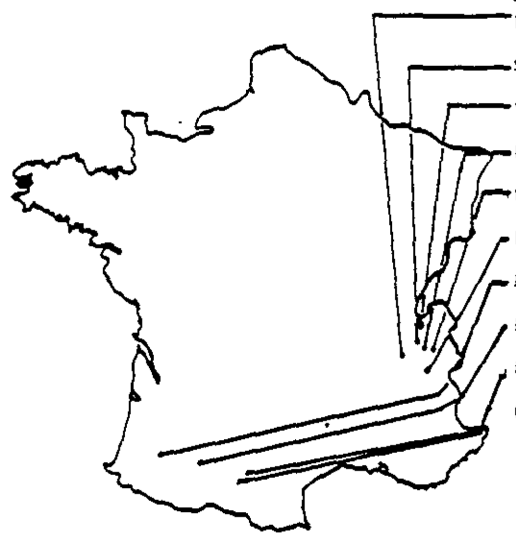
Survey Plants

The survey was conducted in all 11 French aluminium plants (Figure 1). For historical reasons (hydroelectric power generation), these are located in two mountainous regions of France, the Alps and the Pyrenees. The plants notably differ from one another in age, manpower, technology, and industrial hygiene. Moreover, certain features have evolved with time, especially electrolysis techniques and industrial hygiene. The Söderberg process which was used originally, has partially or totally been replaced by the prebake process. Pollution was gradually reduced by means of gas collection hoods on potrooms and work in tight booths.

Population

We conducted an 'historical prospective study' with the cohort including all men who had worked for at least one year in one of these plants between 1950 and 1976:

* Institut National de Recherche et de Sécurité (INRS), Avenue de Bourgogne—54500—Vandoeuvre les Nancy—France.
† Aluminium Pechiney, 23 rue Balzac—75008 Paris—France.



Plants	Year of beginning	Process PB : Prebake S : Söderberg	Size of the cohort
Riouperoux	1926	PB + S	452
St Jean de Maurienne	1907	PB + S	1532
Venthon	1926	PB + S	511
La Saussaz	1950	PB	187
La Praz	1925	PB + S	205
L'Argentière	1925	PB	572
Nogueres	1959	S	779
Lannemezan	1939	S	747
Mercus-Auzat-Sabart	1954	PB	1163
(Several plants)			(301)
		Persons	6455
		Person-years	113 671

FIGURE 1 *Aluminium reduction plants where the study was conducted.*

ie 6455 men. The cut-off date was 31 December 1976. The cohort was formed in the following way: all the workers who had left these plants, whatever the reason (illness, death, retirement, change of occupation), between 1 January 1950 and 31 December 1976, were added to the manpower still working in the 11 plants at the beginning of 1977. These subjects were identified from the files of the company. The total man-years of the survey was 113 671.

Survey Method

—The occupational history of each employee was reconstructed from the administrative records of the plant, listing as accurately as possible the various workplaces, the length of time during which the subject worked there and the type of electrolysis process used. In a few cases, workers had been employed in industrial sectors other than aluminium electrolysis but reliable information about these occupations could not be obtained.

—Tobacco consumption was investigated by directly questioning the workers still working on 31 December 1976. For the workers who had left the plant, information was obtained by consulting the plants' medical records, or by questioning acquaintances (family, colleagues, close relations). This information could be obtained in only 49.1% of the subjects.

—The vital status of the employees included in the cohort who were not working in the plants on 31 December 1976 could be obtained, for 99% of Frenchmen, by systematically consulting the registry offices of their birthplaces. For foreigners (9.7% Italians, 7.6% North Africans, and 9.6% other nationalities), enquiries were made at the relevant consulates and embassies. Results were not as good: vital status was known only in about 95% of cases. In total, 996 deaths were ascertained in this way.

—In France, death certificates are completed without personal identification and thus cannot be used for mortality surveys. In this survey, causes of death were obtained in the following way. Firstly, local sources of medical information were sought, ie identification of the attending physician at the death, or evidence of hospitalization was obtained (hospital or cancer treatment centre . . .); then, the causes of deaths were traced at these sources, ie by questioning the attending physician and/or consulting hospital records. Such investigations are long and complex, but currently, they are the only way in France to identify individual causes of death. Using this method, causes of 71.3% of deaths could be determined. They were coded according to the International Classification of Diseases (ICD: 8th revision)[10] by a physician who knew nothing of the workers' occupational history.

TABLE 1 *Mortality in the whole cohort*

	Actual number observed	SMR	95% confidence interval
All causes of death	996	0.85	0.80–0.91
Malignant tumours, all sites (ICD: 140–209)	199	1.09	0.97–1.22
Diseases of the circulatory system (ICD: 390–458)	190	0.81	0.72–0.91
Cirrhosis of the liver (ICD: 571)	52	1.13	0.88–1.38
Accidents, poisonings, traumas (ICD: E800–E999)	129	1.27	1.09–1.46

Data Processing

Because the cause of death was not always known, the number of deaths for each cause was estimated by multiplying the number observed for this cause by a correcting factor (number of deaths/number of known causes).

The estimated number of deaths from each cause was compared to the expected number calculated according to the French male population[11,12] after adjustment for age and year of death, in order to obtain the SMR (Standardized Mortality Ratio).

The confidence intervals of the SMRs were calculated assuming a Poisson distribution of the estimated number of deaths for each cause (actual observed number multiplied by the aforementioned correcting factor); because these numbers are fractional, their confidence intervals according to the Poisson distribution were estimated from the nearest integer values.

This analysis was done for total mortality (all causes) and for the most frequent causes of death in France, ie cancers, and particularly, lung cancers (ICD = 162), upper respiratory and alimentary tract cancers (ICD = 140–149, 161), cardiovascular diseases (ICD = 390–458), cirrhosis of the liver (ICD = 571), 'violent' deaths (accidents, poisonings, traumas—ICD = E800–E999).

The mortality ratios were calculated in the whole cohort and in some subgroups defined according to workplace namely electrolysis, smelting and maintenance. For electrolysis workers, mortality ratios were calculated according to:

- —duration of service and time since first exposure, ie less than 10 years, between 10 and 19 years, 20 years or more. These categories are exclusive, ie each worker is in a single category.
- —electrolysis process, ie prebake or Söderberg process. The 'Söderberg group' was formed of all workers who had ever used the Söderberg process (including those who had also used the prebake process at some time); the 'prebake group' was formed of all workers who had only used the prebake process.

RESULTS

About two thirds of the workers had been hired before 1960 (more than 16 years before). One third had been working less than 10 years, one third from 10 to 19 years, and the remainder for 20 years or more.

Analysis of Mortality in the Whole Cohort (Tables 1 and 2)

Mortality from all causes is significantly lower (SMR = 0.85) than in the French male population taken as a reference. This deficit is particularly obvious for deaths from cardiovascular diseases (SMR = 0.81). On the contrary 'violent' deaths (accidents, poisonings, trau-

TABLE 2 *Deaths from malignant tumours in the whole cohort*

ICD	Deaths from cancers: site	Actual number observed	SMR	95% confidence interval
140–149+161	Upper respiratory and alimentary tract	27	1.04	0.75–1.43
150	Oesophagus	14	0.92	0.58–1.44
151	Stomach	20	1.01	0.67–1.44
152+154	Intestine + rectum	16	0.87	0.46–1.47
155+156	Liver, gall-bladder and hepatic bile ducts	5	2.45	0.93–4.80
157	Pancreas	9	1.49	0.78–2.49
162	Trachea, bronchus, lung	37	1.14	0.85–1.48
170–174	Bone, connective tissue, skin, breast	5	2.04	0.78–4.00
185	Prostate	9	0.87	0.31–1.45
188	Bladder	7	2.09	0.96–3.68
191	Brain	6	2.13	0.98–4.07
200+202+203	Lymphosarcoma and reticulum-cell sarcoma + other tumours of lymphoid tissues + multiple myeloma	6	1.18	0.55–2.28
204–207	Leukaemia	9	1.56	0.81–2.61

TABLE 3 *Mortality according to workplace*

	Electrolysis No. = 3245 D = 492 (69.9%)	Maintenance No. = 1963 D = 274 (74.8%)	Smelting No. = 929 D = 107 (71.0%)
All causes of death	0.87 [0.80–0.95] (492)	0.81 [0.71–0.91] (274)	0.84 [0.68–1.01] (107)
Malignant tumours All sites (ICD: 140–209)	1.09 [0.92–1.29] (99)	1.03 [0.81–1.27] (60)	0.80 [0.50–1.17] (17)
Malignant tumours of trachea, bronchus and lung (ICD: 162)	1.16 [0.78–1.65] (19)	1.05 [0.57–1.71] (11)	1.29 [0.51–2.62] (5)
Malignant tumours of upper respiratory and alimentary tracts (ICD: 140–149+161)	1.00 [0.58–1.53] (13)	1.44 [0.82–2.27] (12)	0.31 [0.01–1.24] (1)
Diseases of the circulatory system (ICD: 390–458)	0.89 [0.74–1.04] (101)	0.83 [0.66–1.02] (62)	0.90 [0.61–1.22] (23)
Cirrhosis of the liver (ICD: 571)	1.11 [0.79–1.52] (26)	1.63 [1.10–2.20] (24)	1.76 [0.96–2.24] (10)
Accidents, poisonings, traumas (ICD: E800–E999)	1.38 [1.12–1.66] (71)	0.95 [0.68–1.27] (31)	1.01 [0.61–1.56] (13)

No. = Size of subcohort
D = Number of deaths (% of known causes)
In each cell: SMR [95% confidence interval] (Actual no. of deaths observed)

mas) are more frequent (SMR = 1.27) than in the national population. Mortality from cancer does not significantly differ from the reference population, for all site cancers together (SMR = 1.09) and for the lung (SMR = 1.14) and upper respiratory and alimentary tract localizations (SMR = 1.04) which were the most frequently reported ones. SMRs for cancers of other sites are also not significantly different from 1 although close to the limit of significance for bladder (SMR = 2.09) and brain (SMR = 2.13) cancers; however there were few cases of these types.

Analysis According to Workplace (Table 3)

The Standardized Mortality Ratio for all causes is significantly lower than 1 among electrolysis (SMR = 0.87) and maintenance workers (SMR = 0.81). The difference is not significant for smelting workers (SMR = 0.84) who are less numerous.

In spite of this low overall mortality, there is a significant excess of deaths from cirrhosis of the liver among maintenance workers (SMR = 1.63) and from 'violent' deaths among electrolysis workers (SMR = 1.38).

Detailed Analysis of Mortality among Electrolysis Workers (Tables 4 and 5)

Analysis of mortality among those who had worked for some time in electrolysis, according to length of service as potroom workers, indicates a relative excess mortality from cancers (SMR = 1.36), particularly lung cancers (SMR = 1.94) among workers who had worked less than 10 years. For those who had worked longer, cancer mortality does not significantly differ from the national reference. When taking into account time since first employment (Table 5), no trend is observed in cancer mortality (all or lung cancers) according to latency. The increase in cancer mortality (all and lung cancers) observed among potroom workers who have worked less than 10 years particularly concerns those who were exposed 10 to 20 years ago.

Deaths from 'violent' causes are significantly increased in electrolysis workers whatever the length of service as potroom worker may be, but especially for those who were employed more than 20 years ago.

Because of the difficulty of determining exactly what electrolytic processes were used in the past by the potroom workers, the analysis of mortality according to electrolysis process concerns only some (31%) of the

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TABLE 4 *Mortality among electrolysis workers according to length of employment and process*

	Length			Process	
	<10 years No. 1529 D = 151 (66.9%)	10–20 years No. = 904 D = 142 (78.2%)	>20 years No. = 592 D = 164 (70.1%)	Prebake No. = 225 D = 19 (84.2%)	Söderberg No. = 766 D = 78 (75.6%)
All causes of death	0.98 [0.82–1.15] (151)	1.13 [0.94–1.33] (140)	0.95 [0.80–1.10] (164)	1.16 [0.69–1.81] (19)	1.14 [0.90–1.43] (78)
Malignant tumours All sites (ICD: 140–209)	1.36 [1.00–1.82] (31)	1.28 [0.90–1.70] (30)	1.12 [0.82–1.46] (34)	1.26 [0.43–3.07] (4)	0.76 [0.39–1.33] (12)
Malignant tumours of trachea, bronchus and lung (ICD: 162)	1.94 [1.00–3.33] (8)	0.70 [0.20–1.90] (3)	1.08 [0.52–2.23] (6)	0.00 [0–5.27] (0)	1.36 [0.39–3.46] (4)
Malignant tumours of upper respiratory and alimentary tracts (ICD: 140–149+161)	1.13 [0.42–2.46] (4)	1.49 [0.51–3.04] (5)	0.72 [0.18–1.71] (3)	2.00 [0–7.80] (1)	0.79 [0.09–2.88] (2)
Diseases of the circulatory system (ICD: 390–458)	0.90 [0.63–1.23] (24)	1.30 [0.95–1.67] (39)	0.81 [0.58–1.07] (32)	0.30 [0–1.17] (1)	0.99 [0.58–1.58] (17)
Cirrhosis of the liver (ICD: 571)	1.09 [0.57–2.05] (7)	1.23 [0.56–2.45] (7)	1.43 [0.77–2.35] (10)	1.09 [0–4.26] (1)	1.30 [0.48–2.84] (6)
Accidents, poisonings, traumas (ICD: E800–E999)	1.54 [1.12–2.12] (27)	1.87 [1.15–2.69] (19)	1.77 [1.07–2.50] (17)	3.06 [2.47–7.58] (8)	1.20 [0.66–2.02] (14)

No. = Size of subcohort
D = Number of deaths (% of known causes)
In each cell: { SMR
[95% confidence interval]
(No. of deaths observed)

potroom workers; it indicates a significant increase only in 'violent' deaths among workers who have used the prebake anode process (SMR = 3.06). Although not significant the SMR for lung cancer mortality is higher among 'Söderberg workers' (1.36) than among 'prebake workers' (0.00).

DISCUSSION

In France, the determination of individual causes of deaths is hindered by a major obstacle, ie the law protecting personal privacy in general, and medical privacy in particular. Hence the National Mortality Register is anonymous and the release of information about a deceased patient by the attending physician is illegal. Of course, these measures protect the confidentiality of information concerning private life, but they are a considerable hindrance to epidemiological surveys and especially to mortality surveys. It is only thanks to the goodwill of the medical profession and of most of the health authorities, that we were able, with great difficulty, to determine 71% of the causes of deaths.

The lack of information on 29% of the deaths may introduce a bias when mortality by cause in this cohort is compared with that of the French population. For instance, if some causes of death in the cohort are better known than others (which is likely), the incidence of the former causes will be overrated and that of the latter underrated. However, we have established that the rate of known causes of death did not differ statistically significantly according to the main occupational factors analysed: workplace, electrolysis process, length of employment. Thus, internal comparisons between subgroups may be more informative than the comparison with national rates. This is why more attention should be given in this study to the relative values than to the absolute values of mortality ratios. Thus, as an example, the comparison of the mortality ratios among smokers (defined as ever smokers) and non-smokers (never smokers) of the cohort actually shows the well-known pathological

TABLE 5 *Mortality of potroom workers according to length of employment and latency since first exposure*

Causes of death	Latency (years)	Length of employment at electrolysis <10 years	10–20 years	>20 years
All causes	<10	0.64 [0.18–1.62]		
	10–20	0.93 [0.60–1.37]	0.70 [0.32–1.33]	
	>20	0.94 [0.79–1.12]	1.10 [0.93–1.29]	0.95 [0.81–1.02]
Malignant tumours	<10	0.00 [0.00–3.36]		
All localizations	10–20	2.18 [1.00–4.16]	1.33 [0.37–3.40]	
(ICD: 140–209)	>20	1.25 [0.82–1.83]	1.11 [0.73–1.62]	1.15 [0.80–1.60]
Malignant tumours of trachea, bronchus and lung	<10	0.00 [0.00–18.5]		
(ICD: 162)	10–20	3.00 [0.25–10.75]	0.00 [0.00–6.17]	
	>20	1.57 [0.57–3.40]	0.72 [0.14–2.11]	1.10 [0.40–2.40]
Malignant tumours of upper respiratory and alimentary tracts	<10	0.00 [0.00–18.50]		
(ICD: 140–149+161)	10–20	1.33 [0.00–7.44]	2.86 [0.29–10.29]	
	>20	1.29 (0.35–3.31]	0.95 [0.19–2.79]	0.73 [0.15–2.15]
Diseases of the circulatory system	<10	1.11 [0.00–6.22]		
(ICD: 390–458)	10–20	1.30 [0.41–3.02]	0.42 [0.00–2.33]	
	>20	0.78 [0.48–1.21]	1.29 [0.92–1.75]	0.83 [0.57–1.17]
Cirrhosis of the liver	<10	0.00 [0.00–9.25]		
(ICD: 571)	10–20	0.00 [0.00–2.44]	0.91 [0.00–5.09]	
	>20	1.28 [0.52–2.65]	1.32 [0.52–2.70]	1.46 [0.70–2.69]
Accidents, poisonings, traumas	<10	0.40 [0.00–2.24]		
(ICD: E800–E999)	10–20	0.81 [0.30–1.77]	0.91 [0.18–2.67]	
	>20	1.80 [1.10–2.79]	2.10 [1.22–3.35]	1.82 [1.06–2.91]

(in each cell: SMR [95% confidence interval])

effects of tobacco consumption, in particular on the incidence of cancers of the respiratory tract, although the SMR for smokers (1.53) versus non-smokers (0.79) is smaller than usually observed.

Mortality from All Causes

The low overall mortality (all causes) cannot be attributed to a non-exhaustive deaths count because for the French workers in the cohort, whose vital status is well-known (>99%), mortality is even slightly lower (SMR = 0.83) than that among the whole cohort (SMR = 0.85). This 'healthy worker effect',[13] is generally explained by the selection of workers hired in industrial production units.

Deaths from Cardiovascular Diseases

These were less frequent than would be expected from national statistics, but this may be due to differences in the method of determination of causes of deaths compared with the national deaths register. Only the survey carried out by EEH[14] indicates a slight excess mortality from other hypertensive diseases (ICD 1955: 444–457) among aluminium electrolysis workers.

Cirrhosis of the Liver

This disease is frequent in France and is generally attributed to overconsumption of alcohol. In this survey, cirrhosis of the liver was more frequently a cause of death among maintenance workers than among electrolysis workers. We have no information about alcohol consumption among these workers. In contrast to our results, Giovanazzi[15] noticed a relatively higher mortality from this cause among potmen compared with other aluminium electrolysis plants workers.

'Violent' deaths

Most of these (88) were caused by road accidents; 22 deaths were due to occupational causes; the annual incidence rate of fatal occupational accidents was higher among smelting workers (28.4 per 100 000) and maintenance staff (26.8 per 100 000) than among electrolysis workers (10.7 per 100 000).

Cancers

Although not statistically significant in our study, there might be, as found by other authors, a slight increase in cancers of the liver,[16,17] of the brain,[17] of the pancreas,[17,18,20] of the skin,[19] of the bladder,[21,23] and in lymphomas.[18] However, in our study cancers of these sites were not sufficiently numerous for a thorough analysis.

Mortality from lung cancer was not increased when compared with the national reference although it was a little higher among electrolysis and smelting workers

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than in maintenance staff. According to available data about tobacco consumption, these differences in lung cancer mortality could not be explained by differences in tobacco consumption between groups (Table 6). Several authors[6,7,14–19,21,24,25] have reported an excess of lung cancers in aluminium industry workers; but in most of these surveys the risk was found for particular age groups, length of employment or involvement in the electrolysis process.

As regards potmen, mortality by lung cancer is higher among those with the shortest length of employment (<10 years) and an intermediate latency (10–20 years). So, lung cancer incidence does not increase with the length of exposure, nor with the time since first exposure as some authors have observed;[24,25] instead it shows a minimum incidence for an intermediate length of work (10 to 19 years), as observed by others.[21] In our study, differences in lung cancer mortality according to length of employment as potmen may be due partly to differences in tobacco consumption according to length of service (Table 6). However, because of the number of statistical tests performed and the small size of subgroups, such variations may be accounted for by chance.

In most of the surveys which have shown an excess of lung cancer in aluminium workers, the risk could be attributed mainly to use of Söderberg electrolysis process.[6,7,14,19,24,25] In our survey, such a risk could not be significantly confirmed. However, it must be pointed out that no case of lung cancer was found among the 19 deceased electrolysis workers who had worked only with the prebake anode process. Because of the relatively small number of potmen for whom the particular electrolysis process could be established, a substantial risk of lung cancer in Söderberg workers cannot be excluded, although such a risk appears unlikely for prebake workers.

CONCLUSION

This analysis of mortality between 1950 and 1976 of aluminium reduction plant workers in France, does not reveal a major fatality risk. Indeed, a basic overall 'undermortality' is observed, although there are excess deaths from 'violent' causes and cirrhosis of the liver. Among potmen, the suspected risk of lung cancer only appears in workers with the shortest length of employment and does not seem to be associated with a particular electrolysis process. However the number of men in this study with sufficiently long exposure for a noticeable risk to be likely is too small to strongly contradict the hypothesis of such a risk. Therefore the monitoring of the incidence of cancers among workers employed in this industry will be continued.

TABLE 6 *Tobacco consumption according to occupation*

	% of smokers
All causes of death	65.1
Electrolysis	67.3
Maintenance	67.4
Smelting	61.8
Electrolysis: <10 years	64.1
Electrolysis: 10–20 years	54.8
Electrolysis: ≥20 years	75.4
Electrolysis: Prebake anodes	62.2
Electrolysis: 'Soderberg' process	78.9

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