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CONCLUDING REMARKS

The main conclusion that can be reached from the examination of the ten cohorts is that it appears that more than one form of nickel gives rise to lung and nasal cancer. Although much of the respiratory cancer risk seen among the nickel refinery workers could be attributed to exposure to a mixture of oxidic and sulfidic nickel at very high concentrations, exposure to large concentrations of oxidic nickel in the absence of sulfidic nickel was also associated with increased lung and nasal cancer risks. There was also evidence that soluble nickel exposure increased the risk of these cancers and that it may enhance risks associated with exposure to less soluble forms of nickel.

There was no evidence that metallic nickel was associated with increased lung and nasal cancer risks, and no substantial evidence was obtained to suggest that

occupational exposure to nickel or any of its compounds was likely to produce cancers elsewhere than in the lung or nose. No excess of any type of cancer was observed in the cohorts that did not show an excess of cancer of the lung and nose. The few small excesses that were observed in the cohorts with excess lung and nasal cancer could be attributed to misdiagnoses (bone and pharynx) or to chance (prostate).

There were other questions that were left unanswered by this investigation. The primary one was the level of exposure at which nickel becomes a substantial hazard. Our investigation focused mainly on the identification of nickel species hazardous to human health, and it left the development of quantitative dose-specific models of risk for future work. This will be a challenging effort because of the uncertainty in esti-

mates of the types and levels of nickel in the workplaces of occupationally exposed workers.

Although the investigation did not provide dose-specific estimates of risks for individual nickel species, it is possible to comment on the cancer risks associated with the level of airborne nickel to which the general population is exposed. The evidence from this study suggests that respiratory cancer risks are primarily related to exposure to soluble nickel at concentrations in excess of 1 mg Ni/m³ and to exposure to less soluble forms at concentrations greater than 10 mg Ni/m³. With excess risks being confined to these high levels of exposure and the absence of any evidence of hazard from metallic nickel, it can be concluded that the risk to the general population from exposure to the

extremely small concentrations (less than 1 µg Ni/m³) to which it is exposed in the ambient air is minute, if indeed there is any risk at all.

Other information to help refine our understanding of human health risks associated with nickel exposure is on the horizon. For example, animal carcinogenesis studies using inhalation as the route of exposure for nickel subsulfide, high temperature nickel oxide, and nickel sulfate hexahydrate are currently underway, and it will be of great interest to see if they support our findings. In addition, future work that improves our understanding of the mechanisms of nickel carcinogenesis may help to unify and explain the results of our findings in conjunction with those provided by animal experimentation.

REFERENCES

1. Bridge JC. Annual report of the chief inspector of factories and workshops for the year 1932. London: His Majesty's Stationery Office, 1933:103—9.
2. Doll R. Cancer of the lung and nose in nickel workers. *Br J Ind Med* 1958;15:217—23.
3. Morgan JG. Some observations on the incidence of respiratory cancer in nickel workers. *Br J Ind Med* 1958;15:224—34.
4. Doll R, Morgan LG, Speizer FE. Cancers of the lung and nasal sinuses in nickel workers. *Br J Cancer* 1970;24:623—32.
5. Doll R, Mathews JD, Morgan LG. Cancers of the lung and nasal sinuses in nickel workers: a reassessment of the period of risk. *Br J Ind Med* 1977;34:102—5.
6. Cuckle H, Doll R, Morgan LG, Price D. Mortality study of workers engaged in the production of soluble nickel compounds. In: Brown SS, Sunderman FW Jr, ed. *Nickel toxicology*, London: Academic Press, 1980: 11—4.
7. Peto J, Cuckle H, Doll R, Hermon C, Morgan LG. Respiratory cancer mortality of Welsh nickel refinery workers. In: International Agency for Research on Cancer. *Nickel in the human environment: proceedings of a joint symposium: March 1983*. Lyon: International Agency for Research on Cancer, 1984:36—46. (IARC scientific publication; no 53.)
8. Kaldor J, Peto J, Easton D, Doll R, Hermon C, Morgan L. Models for respiratory cancer in nickel refinery workers. *J Natl Cancer Inst* 1986;4:841—9.
9. Mastromatteo E. Nickel: a review of its occupational health aspects. *J Occup Med* 1967;9:127—36.
10. Roberts RS, Julian JA, Muir DCF, Shannon H. Cancer mortality associated with the high-temperature oxidation of nickel sub-sulfide. In: International Agency for Research on Cancer. *Nickel in the human environment: proceedings of a joint symposium: March 1983*. Lyon: International Agency for Research on Cancer, 1984:23—9. (IARC scientific publication; no 53.)
11. Pedersen E, Høgetveit AC, Andersen A. Cancer of respiratory organs among workers at a nickel refinery in Norway. *Int J Cancer* 1973;12:32—41.
12. Magnus K, Andersen A, Høgetveit AC. Cancer of respiratory organs among workers at a nickel refinery in Norway. *Int J Cancer* 1982;30:681—5.
13. International Agency for Research on Cancer. Cadmium, nickel, some epoxides, miscellaneous chemicals, and general considerations on volatile anaesthetics. Lyon: International Agency for Research on Cancer, 1976. (IARC monographs on the evaluation of carcinogenic risks of chemicals to man; vol 2.)
14. Shannon HS, Julian JA, Muir DCF, Roberts RS, Cecutti AC. A mortality study of Falconbridge workers. In: International Agency for Research on Cancer. *Nickel in the human environment: proceedings of a joint symposium: March 1983*. Lyon: International Agency for Research on Cancer, 1984:117—24. (IARC scientific publication; no 53.)
15. Saknyn AV, Shabynina NK. Nekotorye statisticheskie materialy o kanserogennoi o pasnostiv proizvodstve nikelya na baze okislenykh rud [Some statistical data on carcinogenic hazards in the production of nickel on an ore oxide base]. *Gig Tr Prof Zabol* 1970;14:10—3.
16. Saknyn AV, Shabynina NK. Epidemiology of malignant neoplasms in nickel plants. *Gig Tr* 1973;9:25—8.
17. Cragle DL, Hollis DR, Newport TH, Shy CM. A retrospective cohort mortality study among workers occupationally exposed to metallic nickel dust at the Oak Ridge gaseous diffusion plant. In: International Agency for Research on Cancer. *Nickel in the human environment: proceedings of a joint symposium: March 1983*. Lyon: International Agency for Research on Cancer, 1984:57—63. (IARC scientific publication; no 53.)
18. Ottolenghi AD, Haseman JK, Payne WW, Falk HL, MacFarland HN. Inhalation studies of nickel sulfide in pulmonary carcinogenesis of rats. *J Natl Cancer Inst* 1974;54:1165—72.
19. Enterline PE, Marsh GM. Mortality among workers in a nickel refinery and alloy manufacturing plant in West Virginia. *J Natl Cancer Inst* 1982;68:925—33.
20. Goldberg M, Fuhrer R, Bodeur J, et al. Cancer des voies respiratoires parmi les travailleurs d'une entreprise d'extraction et de raffinage du nickel en Nouvelle Calédonie: une étude cas-témoins au sein d'une cohorte. In: Brown SS, Sunderman FW Jr, ed. *Progress in nickel toxicology*. Cambridge: University Press, 1985:215—22.
21. Goldberg M, Goldberg P, Leclerc A, et al. Epidemiology of respiratory cancers related to nickel mining and refining in New Caledonia. *Int J Cancer* 1987;40:300—4.
22. Godbold JH Jr, Tompkins EA. A long-term mortality study of workers occupationally exposed to metallic

- nickel at the Oak Ridge gaseous diffusion plant. *J Occup Med* 1979;21:799—806.
23. Cox JE, Doll R, Scott WA, Smith S. Mortality of nickel workers: experience of men working with metallic nickel. *Br J Ind Med* 1981;38:235—329.
 24. Redmond CK. Site specific cancer mortality among workers involved in the production of high nickel alloys. In: International Agency for Research on Cancer. Nickel in the human environment: proceedings of a joint symposium: March 1983. Lyon: International Agency for Research on Cancer, 1984:73—86. (IARC scientific publication; no 53.)
 25. Archibald FR. The Kristiansand nickel refinery. *J Met* 1982;14:648—52.
 26. Stensholt EO, Zachariassen H, Lund JH. The Falconbridge chlorine leach process: *Extractio Metallurgy '85*. London: The Institution of Mining and Metallurgy, 1985.
 27. Waterhouse J, Calum M, Shanmugaratnam K, Powell J. Cancer incidence in five continents. Lyon: International Agency for Cancer Research, 1982. (IARC scientific publication; M42.)
 28. United States Environmental Protection Agency. Health assessment document for nickel and nickel compounds. Research Triangle Park, NC: US Environmental Protection Agency, Office of Health and Environmental Assessment, Environmental Criteria and Assessment Office, 1986. (EPA publication; EPA/600/8—83/012FF.)
 29. Marsh GM, Preininger M. OCMAP: a user oriented occupational cohort mortality analysis program. *Am Stat* 1980;34:245—6.
 30. Breslow, NE. Cohort analysis in epidemiology. In: Atkinson AC, Fienberg SE, ed. A celebration of statistics. New York, NY: Springer Verlag, 1982:111—43.
 31. Muller J, Wheeler WC, Gentleman JM, et al. Study of the mortality of Ontario miners, 1955—1977: Part 1. Toronto: Atomic Energy Control Board of Canada, Ontario Workmen's Compensation Board, Ontario Ministry of Labour, 1983.

APPENDIX

Environmental exposure estimates

Air sampling devices

There was considerable uncertainty in the exposure estimates of the individual nickel species because of differences in the monitoring devices used to make environmental measurements. Three different devices were used, each potentially measuring a different segment of the size distribution of airborne dust particles. The personal gravimetric sampler is the monitoring device of choice today because of its purported ability to measure "total dust" in the environment in which a person actually works. In fact, the personal sampler does not measure "total dust" or any biologically relevant fraction of the total dust (1). Nevertheless, it is the sampler used most by industrial hygienists today, although particle size-selective sampling is expected eventually to replace the present personal monitoring devices.

Prior to the widespread use of personal samplers, high-volume samplers were used as area samplers. However, in many instances, neither personal gravimetric nor high-volume samplers were available, and konimeter readings were often the only available means of assessing the level of airborne dust. The konimeter, which was originally devised to measure the concentration of free silica in mining operations, samples only a small fraction of airborne dust, however, and gives no indication of the nickel content of the dust. Although the konimeter samples air from a worker's breathing zone, it provides an instantaneous (as opposed to a time-integrated) estimate of dust concentration. Because of the inability of the konimeter to give any nickel species information, its readings must be used in conjunction with industrial process information to estimate nickel species concentrations.

Konimeters, high-volume samplers, and personal gravimetric samplers give different estimates of airborne dust levels, even when sampling the same environment. The difference is due to the fact that the devices sample different fractions of the dust. The konimeter gives a particle count, while the other devices allow measurements of dust concentration as mass per unit volume. Furthermore, the high-volume sampler collects more large dust particles than does the personal gravimetric sampler, which, in turn, collects more large particles than does the konimeter. The estimates of environmental levels of nickel species given in the report are those that would be expected from a personal gravimetric sampler operated in the "closed face" mode. Conversion of the high-volume sampler and konimeter measurements to the personal gravimetric sampler standard introduced another uncertainty into the environmental estimates. The main reason for this uncertainty is that it is impossible to derive unique conversion factors to interrelate measurements from the three devices; different particle size distributions give rise to different conversion factors. Information concerning the sizes of the particles in the airborne dusts was seldom available in the workplace under study.

INCO, Ontario — development of exposure estimates

Comparison of sintering operations. INCO Limited has operated three sinter plants in Ontario, Canada. Two of the plants, Copper Cliff and Coniston, were in the Sudbury area, while the third was at Port Colborne on Lake Erie in southern Ontario. The Port Colborne sinter plant was used between 1926 and 1958 and

the Copper Cliff sinter plant was in operation between 1948 and 1963. The Coniston sinter plant opened in 1914 and remained in use until 1972.

The Copper Cliff and Port Colborne plants removed sulfur from impure nickel subsulfide (Ni_3S_2) by oxidation with atmospheric oxygen according to the following reaction:



It was necessary to conduct the reaction at temperatures as high as 1650°C to obtain low sulfur levels in the product; eg, 0.2–0.3 % sulfur. These high temperatures also sintered the charge so that the nickel oxide (NiO) product was much coarser (6.5–13 mm) than the sulfide feed.

To initiate the reaction the air was drawn down through a layer of charge on a sintering machine with a traveling grate. The charge consisted essentially of a mixture of fresh sulfide and at least three times its weight of fine (<6.5 mm) recycled oxide sinter and analyzed no more than 6 % sulfur. It was necessary to dilute the sulfide with oxide sinter to keep the charge layer permeable to air since the sulfide melts at temperatures above about 750°C . The sulfur content of the charge was too low to provide the necessary heat; therefore about 2 % of fine coke was added as fuel. The grates were protected from the high temperatures in the burning charge by a layer of coarse (13–50 mm) recycled sinter. Thus at least 80 % of the oxide sinter that was discharged from the machine was recycled through the process.

The Copper Cliff sinter plant had five parallel rows of sintering machines and associated equipment. There were complex mechanical systems for comminuting the sinter; separating it into coarse grate dressing, product, and fines; transporting the fines; blending them with fresh sulfide, dust and coke; and feeding the mixture to the sintering machines. These systems gave rise to large amounts of airborne dust at many different locations and elevations. The major nickel species in these dusts were nickel subsulfide and nickel oxide. The strong convection currents created by the hot sintering machines and the recycled sinter helped lift and spread this dust. The calculated average vertical velocity of air in the building was about 0.1 m/s, a velocity sufficient to suspend particles with diameters of about 25 μg or less; coarser particles would tend to settle out of the slowly rising air. Particles were also captured by impingement. In this manner, dust accumulated on all horizontal surfaces at the rate of one-eighth to one-fourth an inch per day (1 inch = 2.54 cm) until the angle of repose was exceeded and it became airborne once again. All the elevated floors were made of open grating and therefore did not impede the spread of dust.

The Port Colborne sinter plant, 22 years older, differed in detail from the Copper Cliff description but did not differ in principle. For instance, it had seven

sintering machines, but they were smaller than those at Copper Cliff.

The sintering operation at Coniston began with two sintering machines in 1914, increased to four machines in 1923, and culminated in a new installation of six larger machines in 1930. Sintering was used at an earlier stage of nickel production to preheat and agglomerate fine materials to keep them from being blown out of the blast furnace and to oxidize about a third of the sulfur. The feed to the machines was a mixture of limestone, flue dusts, fine ore, and/or ore concentrates. From 1968 onward, the mixed feed was pelletized on discs, and fine ore was no longer used.

Environmental conditions in the Copper Cliff sinter plant. A single high-volume sample of dust was taken at the operating level of the Copper Cliff sintering plant on 28 November 1960 for presentation to the District Engineer of Mines of the Ontario Government. A gas volume of 82.1 m^3 was sampled over a period of 40 h. The concentration of total dust was found to be 46.4 mg/m^3 . A sample taken by a high-volume sampler on the operating floor 3 August 1960 analyzed 58 % as nickel. A simultaneous konimeter reading yielded a dust count of 255 particles/ cm^3 . These two measurements combined suggest that the concentration of total nickel at this location was 27 $\text{mg Ni}/\text{m}^3$. This datum is shown as the star shaped symbol in figure A-1. The konimeter measurements made from various locations along the centerline of the plant in the period 1959–1962 ranged from 108 to 2100 particles/ cm^3 . The average of 24 konimeter readings (truncated at 1000 particles/ cm^3) was 683 particles/ cm^3 . If this information is used in conjunction with the government's konimeter and high-volume measurements, an average high-volume concentration of total nickel of 72 $\text{mg Ni}/\text{m}^3$ is estimated.

Although these measurements are the only ones available for the actual work area, estimates of dust concentrations can be obtained from metallurgical accounting data because surveys of the dust lost through the four roof monitors were usually conducted twice a year. Since plant air could leave the building only through the monitors or the windows just below (when the weather permitted opening them), it is reasonable to assume that the dusty air passing through these vents was a high-volume sample of the work environment in the building. As figure A-1 shows, the concentrations inferred from the roof monitors are compatible both with the high-volume sample collected on the operating floor and with the extrapolated (with konimeter data) value of that sample. Since air often came in through the windows and diluted the dusty air escaping from the monitors, the concentration of dust at the monitors was probably a conservative estimate of the dust at the work level. The average (or median and range) nickel concentrations of the dust samples collected from four different roof monitors are shown in figure A-1. These data suggest that the dust

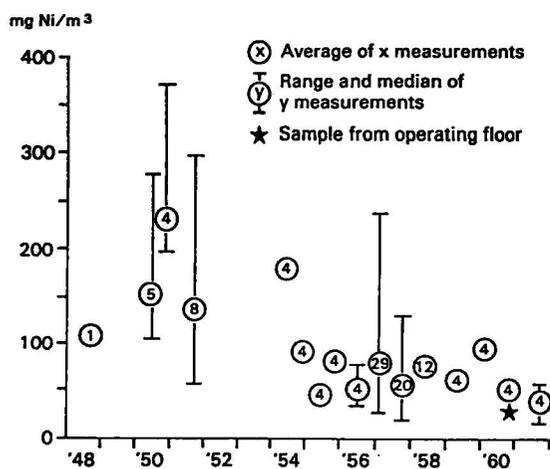


Figure A-1. Concentrations of nickel in dusty air leaving the roof monitors of the Copper Cliff sinter plant (2).

levels at Copper Cliff decreased dramatically over time. In its early years of operation, airborne levels of nickel were typically in excess of 100 mg Ni/m³ with some nickel concentrations as high as 350 mg Ni/m³. After 1955, it appears that the levels of dust and nickel were reduced dramatically, the total nickel concentrations fluctuating between 20 and 100 mg Ni/m³. Process knowledge and analytical data for seven airborne dust samples suggested that approximately 60 % of the nickel in the dust was present as nickel oxide, 35 % as nickel subsulfide, and that 5 % could have been present as nickel sulfate. The samples of the roof monitor were taken isokinetically, and hence all particle sizes should have been sampled with equal efficiency. The government reported that the dust ranged in size mainly from 5 to 50 μm, few particles being smaller than 5 μm. These facts, together with knowledge of the collection efficiency of the personal gravimetric samplers, suggested that the data derived from the roof monitors should be multiplied by 0.4 to correct it to the equivalent of personal gravimetric samples.

The improvement in the plant environment was achieved partly by constant attention to dust control, but accumulated operating experience was probably an even more important factor. If a sintering machine was not operating properly, it would discharge hot, dry, unoxidized, and unsintered charge. This fine material increased the generation of dust all around the plant as it had to be reverted and reprocessed. This reprocessing was reflected in a lower production rate; ie, fewer pounds of nickel per machine-hour. Evidence that the ineffective operation of the sinter machines was the principal factor responsible for the high level of airborne dust is seen in a generally inverse relationship between the amount of dust escaping from the roof monitors and sintering efficiency during the period 1948—1961. This observation also suggests that the proportion of nickel present as nickel subsulfide

should have been greater in the early years of operation.

Environmental conditions in the Port Colborne sinter plant. Representatives of the Ontario Department of Health, Division of Industrial Hygiene, made five determinations of the concentration of dust in the Port Colborne sinter plant by high-volume sampling in April 1953. The samples that they obtained had dust concentrations of 317, 125, 1075, 61, and 120 (average 340, SE 169) mg/m³. Without the highest sample value, the average was 156 (SE 55) mg/m³. In the period 1954—1960, the dust concentrations at Copper Cliff averaged 125 mg/m³, with no measurement above 365 mg/m³. Even in the years prior to 1954, none of the rooftop monitoring samples taken at Copper Cliff had a dust concentration greater than 405 mg/m³. Thus, in April 1953, the dust levels at the Port Colborne plant appear to have been generally comparable in magnitude to those at the Copper Cliff plant during the 1954—1963 period, with an indication that one area within the Port Colborne plant was at least as dusty as the Copper Cliff plant at any time in its operating life. During the 1954—1963 time period, the airborne nickel concentrations of total nickel at Copper Cliff were between 20 and 100 mg Ni/m³. Because of the similarity of the processes in the two plants, it is reasonable to conclude that similar levels of nickel were in the air at the Port Colborne sinter plant.

There was no quantitative information available to permit extrapolating this conclusion to later years. However, it is relevant that the Port Colborne plant in 1953 had already been operating for over a quarter of a century and so was not likely to achieve lower dust concentrations by accumulating more operating experience. Since it was due to be phased out of operation, it was also unlikely that efforts to improve the plant further were undertaken. In addition, in 1953 the Port Colborne plant was sintering the same finely ground (20 % finer than 10 μm) nickel subsulfide feed produced at Copper Cliff, and it continued to do so until it closed in 1958. Furthermore, the plant was operated only a few shifts per week during this period. These frequent start-ups aggravated dust conditions within the plant. It was therefore likely that the dust (and nickel) concentrations measured in April 1953 were encountered until the plant closed in 1958.

Extrapolation to years earlier than 1949 was more difficult since the Port Colborne feed was different during these early years. Port Colborne had treated coarsely ground (less than 25 % passing 150 mesh) nickel subsulfide produced by the Orford process from the beginning of the sintering operation in 1926—1927 until July 1949. During the period from 1946 to July 1949, a mixture of sulfidic nickel from these two sources was sintered. The change to a finer feed in 1946 reduced the production rate of the Port Colborne sin-

tering machines by about 23 %. Employees stated that the change also resulted in noticeably dustier conditions in the plant. It was therefore believed that during the 1946—1949 transition the conditions were not appreciably different than in later years. No information was available on the chemical composition of the dusts, but the feed was very similar in composition to that treated at Copper Cliff. It was reasonable to assume that the species distribution at Port Colborne was similar to that at Copper Cliff. In the absence of information on particle size, it was necessary to assume that the correction factor from high-volume samples to the equivalent of personal gravimetric samples was the same as at the Copper Cliff plant; ie, 0.4. All of the foregoing information places the estimated concentrations of the individual species for the period 1946 to 1958 in the same ranges as reported earlier for Copper Cliff.

Prior to the change of feed in 1946, it was estimated that the dust levels in the Port Colborne plant were not less than 60 % of those estimated for 1946 and later. Furthermore, qualitative information suggested that the Port Colborne sinter plant underwent a period early in its operating life like that shown for the Copper Cliff plant in figure A-1. Sintering had to be reduced to a practical art, and many changes were made in the equipment with the express purpose of reducing airborne dust. Thus the dust concentrations were likely to have been high for many years after the plant commenced operation in 1926—1927 before conditions like those experienced just before 1946 became consistent. Given the coarser feed handled at Port Colborne, it seems reasonable to assume that the concentrations of individual species could have been, say, 80 % of those estimated for the early years in the Copper Cliff plant and could have persisted until the mid 1930s. On the basis of these assumptions, the range of concentrations of nickel present as oxidized nickel was estimated to have declined from about 20—40 mg Ni/m³ in the early years to about 3—15 mg Ni/m³ by

the mid 1930s before rising to 5—25 mg Ni/m³ in 1946 and later. The range of concentrations of nickel as the subsulfide in these later periods was probably about 10—20, 2—10, and 3—15 mg Ni/m³, respectively. If nickel sulfate was present in the dusts, it probably never exceeded about 3 mg Ni/m³.

Environmental conditions in the Coniston sinter plant.

The Coniston sinter plant was dusty but less so than the Port Colborne or Copper Cliff sinter plants. The greatest concentration of dust was generated at the discharge end of the sintering machines. A wall separated this area from the rest of the plant, and the few men working there always wore dust masks. Another particularly dusty spot was outside the plant where flue dusts from the smelter were dumped into a large receiving bin. Both of these problem areas and the plant in general were greatly improved in 1968—1969 when better dust collection equipment was installed. Table A-1 presents some of the dust concentrations measured by high-volume sampling. These data indicate that conditions at Coniston were generally less dusty than at the other two sinter plants. Because the plant was treating ore and concentrates rather than nickel subsulfide, the nickel levels were generally much lower than at the other two sinter plants. However, the sinter loading platform was a dustier area with higher nickel concentrations. One of the samples from the sinter loading platform had an extraordinarily high dust concentration (1390 mg/m³) with a nickel content (56 mg Ni/m³) similar in magnitude to rooftop monitoring samples from Copper Cliff between 1956 and 1963. No information on the size of the dust particles was found. However, studies at the similar Falconbridge sinter plant suggested that concentrations of nickel determined by high-volume sampling should be divided by seven to convert them to the equivalent of personal gravimetric samples. If this factor applied to the Coniston plant as well, the concentrations of

Table A1. Dust concentrations in high-volume samples taken between 1960 and 1972 in the Coniston sinter plant of INCO in Ontario.

Location	Approximate date	Total dust ^a (mg/m ³)	Nickel in dust ^b (mg Ni/m ³)
Receiving bins (concentrate)	March 1972	10	0.4
Belt below receiving bins	November 1970	8	0.2 ^c
Feed bins at tripper	November 1970	11	0.3 ^c
Feed bins at tripper	March 1972	2	0.1
Between sintering machines	November 1970	7	0.2 ^c
Sinter loading platform			
Unknown location	December 1960	60	1.7 ^c
At number 5 machine chute	1966	397	8
At number 6 machine chute	November 1970	19	0.5 ^c
At number 7 machine chute	November 1970	35	1.0 ^c

^a Total dust concentrations were translated to the equivalent of a personal gravimetric sample by dividing by 3.5.

^b Total nickel concentrations were translated to the equivalent of a personal gravimetric sample by dividing by 7.

^c Calculated from total dust concentrations and mean nickel and copper analyses of settled dusts collected after the plant closed.

Table A2. Chemical analysis of typical products of the Falconbridge Sudbury operations in 1933—1978.

Product	Nickel (% weight)	Copper (% weight)	Iron (% weight)	Sulfur (% weight)	Gangue (% weight)	-200 M (% weight)
Ore	1.2	0.9	21.0	11.3	65.0	..
Concentrates	6.5	5.0	40.5	31.5	16.0	75.0
Sinter	6.8	5.3	42.6	13.0	17.0	.
Blast furnace matte	10.1	7.9	50.0	25.3	—	..
Shipping matte	41.0	32.0	1.5	22.0	—	..

total nickel measured in almost all locations would be less than 1 mg Ni/m³. With respect to the species in the dust, the proportions given for the Falconbridge sinter plant in table A-2 should apply to the Coniston plant as well. It is worth repeating that the oxidized nickel in the dust, unlike that in the Copper Cliff and Port Colborne sinter plant dusts, was greatly diluted by iron oxide.

Environmental conditions in the nonsintering areas of the Port Colborne nickel refinery. Some measurements of the airborne dust concentrations were first taken at the Port Colborne nickel refinery in the early 1950s; the data previously presented for the sinter plant were part of that sampling effort. Between December 1959 and February 1977 INCO took 1870 konimeter readings of plant air for 45 different operations or areas. From February through September 1962 a major survey of ventilation and workplace air was made at this refinery by the industrial hygiene branch of the Ontario Department of Health and by the Inspection Department of the Ontario Department of Mines. Sixty-eight high-volume samples were collected, but the nickel concentrations were not determined. In April 1970 the Ontario Department of Health and INCO took 61 high-volume samples of air in six different buildings, and these samples were chemically analyzed for nickel. From 1970 through 1977, INCO also collected high-volume samples that were chemically analyzed for nickel content. From 1976 through 1979, personal gravimetric sampling pumps were used to collect personal and workroom samples. These were analyzed chemically, and a distinction was usually made between the water-soluble and insoluble forms of nickel. Detailed summaries of these measurements are to be published.

Personal gravimetric and high-volume samples taken of the air in the period 1970—1979 in the workplaces of the nickel, anode, and foundry additives department generally indicated low-level nickel exposure. Average nickel concentrations in most of the workplaces were close to or below 1 mg Ni/m³. The highest air concentration of nickel (high-volume) for this department was 4.9 mg Ni/m³, which was found in the area where sulfide anodes were produced. The soluble nickel concentrations were very low, with a maximum value of

0.05 mg Ni/m³. The konimeter readings indicated that the levels of dust and nickel decreased over time. However, even a doubling of the dust concentrations would result in most workplaces having total nickel concentrations of less than 5 mg Ni/m³ and soluble nickel concentrations of less than 0.1 mg Ni/m³.

As might be expected, the air samples from the electrolysis department had much higher levels of soluble nickel than the nickel, anode, and foundry additives department. However, apart from two workplaces, the soluble nickel concentrations measured in the 1970s were generally low, the average being less than 0.15 mg Ni/m³. With the exception of three workplaces, the average total nickel concentrations were less than 0.5 mg Ni/m³. The two activities with higher levels of soluble nickel exposure were the pumping of anode slimes and the washing of anode scrap, with average concentrations of 1.0—1.5 mg Ni/m³ for soluble nickel and approximately 2 mg Ni/m³ for total nickel. The workplace with the highest level of nickel (less than 2 mg Ni/m³) was the area in which reduced nickel oxide was handled. Extrapolating these concentrations to 1960—1964 with the use of high-volume total dust and konimeter samples suggested that the situation during this period was not appreciably different from that of the 1970s. The situation prior to 1960 was uncertain as no measurements were available. Nonetheless, apart from pumping slimes and washing anode scrap, there was little reason to believe that the men engaged in electrolysis work were exposed to average concentrations of soluble nickel of more than 0.5 mg Ni/m³.

Environmental data for the maintenance and yard personnel suggested that these men were exposed to low levels of nickel compounds. Personal gravimetric sampler measurements from the 1977—1979 period showed none of the work areas to have average concentrations of total nickel in excess of 0.4 mg Ni/m³. The exposure levels for soluble nickel were almost exclusively less than 0.05 mg Ni/m³. The konimeter readings suggested that the dust levels may have been higher in earlier years. However, even if the levels were four times as high, most of the workplaces would have had total nickel concentrations of less than 2.0 mg Ni/m³ and soluble nickel concentrations of less than 0.20 mg Ni/m³.

Environmental exposure estimates for the miners. Estimates of the historic nickel exposures of INCO's miners in Ontario indicated that they were exposed to <0.5 mg Ni/m³. The principal form of nickel to which the miners were exposed was pentlandite [(Fe,Ni)₉S₈]. The miners were also exposed to nickeliferous pyrrhotite (Fe₇S₈), but its nickel content is only about 1 %. Nickel sulfate may also be present in the mining environment, but at only a few locations and at low concentrations.

Falconbridge, Ontario — development of exposure estimates

Mines and mills. Falconbridge Limited operates several mines from which ore is recovered and fed to two mills where it is ground and subjected to concentration by froth flotation. An analysis of the ore, concentrate, and other products is given in table A-3. Since the drilling of the ore is done wet, the dust levels in the mines are low, but some dust is created in the blasting and handling of broken ore. As indicated in table A-3, the airborne nickel levels are estimated to have averaged no higher than 0.02 mg Ni/m³ and are due to the minerals pentlandite (34 % nickel) and nickeliferous pyrrhotite (about 1 % nickel). The remaining constituents of the dust are chalcopyrite (CuFeS₂), silicate

gangue minerals, and, after 1970, carbonaceous matter from diesel fumes.

Mined ore is conveyed to the ore dressing plant for two or three stages of crushing and screening. Dusting is more severe in this area than in the mines due to the absence of water, but the composition of the dust is the same. Crushed ore is wet ground in rod and ball mills and is treated as a slurry thenceforth. Flotation yields concentrates running 6—8 % nickel and 4—5 % copper and a mineral-laden tailing which is discarded. In spite of the upgrading effected, dusting is relatively low due to the wet nature of the materials.

Feed preparation. Until 1955 substantially all of the feed to the smelter was obtained on site and consisted of partially dried concentrate filter cake blended with recycled furnace dust to form green pellets. Between 1955 and 1975 the local feed was augmented by partially dried concentrates originating in mills remote from the smelter. This material was subject to self-heating in the rail cars so that its unloading in the concentrate-receiving station occasioned considerable dusting. Similar dust levels occurred in the pellet plant, as shown in table A-3. In 1975 the concentrate-handling system was converted to one in which shipments arrived in wet form, either as filter cake or slurry, and were subjected to a single blending and drying oper-

Table A3. Estimates of average air concentrations of specific nickel forms in the Falconbridge Sudbury operations in 1933—1978.

Department	Nickel form (mg Ni/m ³) ^a						Total nickel	Total dust
	Nickel subsulfide	Nickel-iron sulfide	Nickel sulfate	Pentlandite	Nickel-iron oxide	Pyrrhotite		
Mining	—	—	—	0.01	—	0.01	0.02	2.0
Milling								
Ore dressing	—	—	—	0.03	—	0.01	0.04	3.8
Concentrator	—	—	—	0.02	—	0.01	0.03	3.2
Feed preparation								
Concentrate receiving	—	—	0.01	0.15	—	0.01	0.17	4.9
Pellet plant	—	—	0.01	0.13	—	0.01	0.15	4.3
Briquetting	—	—	0.01	0.13	—	0.01	0.15	4.3
SFD plant	—	—	—	0.03	—	—	0.03	0.9
Smelter								
Sinter plant	—	0.07	—	0.12	0.02	0.01	0.22	6.3
Blast furnace	—	0.04	—	0.07	0.01	—	0.13	3.7
Settlers	—	0.03	—	0.05	0.01	—	0.09	3.0
Converters	—	0.03	—	0.01	0.01	—	0.05	1.0
Matte room	0.09	—	—	—	—	—	0.10 ^b	1.2
Pyrrhotite treatment								
Po plant	—	—	0.01	—	—	—	0.02	0.9
NIR	—	—	—	—	0.01	—	0.01	0.5
Maintenance								
Miscellaneous	—	0.04	—	0.05	—	—	0.09	2.5
Repair crew	—	0.08	—	0.08	0.01	0.01	0.18	5.0
Welders	—	—	—	—	0.05	—	0.05	3.7
Shops	—	—	—	—	0.03	—	0.03	2.2
Surface								
Unexposed	—	—	—	—	—	—	<0.001	—

^a Nickel content: nickel subsulfide 73 %, nickel-iron sulfide 55 %, nickel sulfate 38 %, pentlandite 34 %, nickel-iron oxide 3 %, pyrrhotite 1 %.

^b Includes 0.01 mg Ni/m³ as nickel-copper alloy.

ation in the slurry, filtering, and drying plant to produce a uniform feed for the smelter. The dust levels were greatly reduced.

Smelter — sinter plant. The sinter plant was equipped with Dwight-Lloyd machines which were fed with minor amounts of fine ore and flux along with the partially dried concentrates. Here the sulfides were partially combusted to raise the temperature of the charge to about 900°C and to effect sufficient fusion to render it amenable to blast furnace smelting. Since such fusion was irregular, it was necessary to screen the hot product to remove undersize and dust before the blast furnace charge cars were loaded. The amount of dust shown in table A-3 was mostly due to the screening operation and the subsequent handling of the hot fines for recycling to the feed hoppers of the sinter machine. Recycle fines amounted to about 15 % of the total charge.

As shown in table A-3, about a third of the sulfur in the concentrate was burned off in the sintering operation, and a corresponding proportion of sulfide was converted to oxide. The bulk of this was nickeliferous pyrrhotite oxidized to sulfur dioxide and iron oxides, although minor amounts of the nickel mineral pentlandite and the copper mineral chalcopyrite were also oxidized. These minerals exhibit a strong tendency for the preferential oxidation of their iron content, accompanied by the formation of enriched sulfide kernels depleted in iron. The estimated nickel analyses of the principal phases of concern in dusting in the operations are listed at the top of table A-3 in decreasing order of nickel concentration; they show pentlandite at 34 % nickel becoming enriched to an estimated average of 55 % nickel, with loss of iron to an oxide carrying 3 % nickel. Because oxidation of a particle must occur from the outside, it is possible that at least some of the enriched sulfide particles occurring in the dust were coated with iron oxide.

Smelter — blast furnaces and settlers. The blast furnaces extended from the top, or feed floor of the smelter, down to the bottom, or tapping floor, where the settlers were located. The furnaces were fed with coke, sinter, and minor amounts of lump ore and revert material at the top and with compressed air at the bottom. A mixture of molten sulfides and iron silicates flowed from the furnace to the settlers, in which the two phases separated as a layer of barren slag underlain by a layer of matte containing the nickel and copper. The nickel phases in the dust around the blast furnaces and settlers were essentially the same as those described for the sinter plant.

Smelter — converters. Matte was periodically tapped from the settlers and transferred to the converters, which were horizontal, cylindrical furnaces in which

compressed air and silica flux were fed to oxidize iron and sulfur and form iron-rich slag which could be decanted from the underlying layer of substantially iron-free copper-nickel matte. The matte was then transferred by ladle to the matte room for casting.

Smelter — matte room. Until 1952 solidified matte was manually broken and transported to a crusher whence it was packed in barrels for shipment to the Kristiansand refinery. Thereafter breaking and conveying were mechanized in a system incorporating two stages of crushing, conveying to bins, and barreling. In 1968 a loadout system was installed, and all subsequent shipments were made in bulk by rail.

Notes on the environmental exposure estimates. The earliest available readings at Falconbridge, Sudbury, were konimeter results given as particles of free silica per cubic centimeter, taken in the early 1960s. High-volume gravimetric sampling was done on a regular basis from the early 1970s on. Parallel tests with high-volume and konimeter samples permitted development of a regression model from which the early konimeter readings could be converted to high-volume equivalents. Personal gravimetric samplers were first used in the late 1970s, at which time parallel testing with high-volume samplers was performed. This testing permitted the establishment of factors relating personal gravimetric readings to high-volume readings for all locations. Speciation of dust samples obtained by both personal gravimetric and high-volume sampling methods showed the same phases for a given location, but the high-volume samples contained larger particles and were richer in nickel than the personal gravimetric samples were. Although there had been a trend towards decreasing dust concentrations with time in the mines since 1960, the concentrations in the plants appeared merely to fluctuate due to changes in process and/or treatment rates, and they showed no detectable chronological pattern. Subjective comparisons of the dust conditions in the plants before 1960 with that after 1960 confirmed a lack of chronological pattern until 1978 when the new smelter was commissioned. An identification of nickel species was made by an examination and analysis of dust samples, not of the products handled.

References

1. American Conference of Governmental Industrial Hygienists. Particle size selective sampling in the workplace: report of the American Conference of Governmental Industrial Hygienists. Cincinnati, OH: American Conference of Governmental Industrial Hygienists, 1985.
2. Warner JS. Estimating past exposure to airborne nickel compounds in the Copper Cliff Sinter Plant. In: Brown SS, Sunderman FW Jr, ed. Progress in nickel toxicology. Cambridge: University Press, 1985:203—6.

ANNOUNCEMENTS

International workshop on retrospective exposure assessment for occupational epidemiologic studies
28—30 March 1990, Leesburg, VA (USA)

The National Cancer Institute and the National Institute for Occupational Safety and Health are sponsoring the International Workshop on Retrospective Exposure Assessment for Occupational Epidemiology Studies, to be held on 28—30 March 1990 in Leesburg, Virginia, in the United States. The objectives of this workshop are to present unpublished research and new ideas on approaches and validity and reliability issues, to seek a consensus on approaches taken in the

past as being reasonable in light of the available data, to identify areas of research which should be considered in future studies, and to allow a free exchange in information among investigators doing this type of work. Poster presentations are welcomed.

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