PB287371

ENVIRONMENTAL EXPOSURE TO AIRBORNE CONTAMINANTS IN THE NICKEL INDUSTRY 1976 - 1977

Harry M. Donaldson
Melvin Cassady*
James H. Jones

Division of Surveillance, Hazard Evaluations and Field Studies

*Presently with Occupational Safety and Health Administration

Department of Health, Education, and Welfare
Public Health Service
Center for Disease Control
National Institute for Occupational Safety and Health
Division of Surveillance, Hazard Evaluations and Field Studies
Cincinnati, Ohio 45226
August 1978

BIBLIOGRAPHIC DATA SHEET	1. Report No. HEW Publication No. (NIOSH)	2.	3. Recipient's Accession No. PB287571

4. Title and Subtitle	5. Report Date
Environmental Exposure to Airborne Contaminants in the Nickel Industry 1976-1977	June, 1978
	6.
7. Author(s) Harry M. Donaldson, Melvin Cassady* and James H. Jones *Presently with Occupational Safety & Health Administration	8. Performing Organization Rept. No.
9. Performing Organization Name and Address National Institute for Occupational Safety and Health 4676 Columbia Parkway Cincinnati, Ohio 452020	10. Project/Task/Work Unit No.
	11. Contract/Grant No.
12. Sponsoring Organization Name and Address SAME	13. Type of Report & Period Covered Technical Report 1976-1977
	14.

15. Supplementary Notes

NONE

16. Abstracts

SEE ATTACHED SHEET

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages
Release Unlimited	20. Security Class (This Page) UNCLASSIFIED	22. Price PC A03/MF A01

ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) conducted an industry-wide study of three different nickel processing operations. Since arsenic and crystalline silica were found in the plants surveyed and they have been implicated as either co-carcinogens for development of lung cancer or as causative agents for fibrotic lung disease, exposures to these and other metals as well as nickel were evaluated.

The three types of facilities monitored were:

Plant A - A nickel smelter which pyro-metallurgically converts a nickel oxide ore, mined on site, to a 50% - 60% ferro-nickel alloy.

Plant B - A nickel refinery which acid treats imported sulfide ore that are partially roasted in the countries of origin to produce pure nickel and cobalt metal in the form of powder or briquettes.

Plant C - An inorganic chemical plant which manufactures nickel salts and solutions using either pure nickel metal or nickel oxide as a nickel source. The chloride, sulfate, nitrate, acetate, and carbonate of nickel are the salts normally produced, usually as solids, although some solutions of the salts are also marketed.

Almost all of the environmental concentrations of airborne nickel in these plants met the Occupational Safety and Health Administration (OSHA) standard of 1 mg Ni/m^3. Plant A was also in most cases, well below the current American Conference of Governmental Industrial Hygienists Threshold Limit Values (ACGIH-TLV) recommendations of 0.1 mg Ni/m^3. However, in none of the plants were exposures in the range of the NIOSH recommended standard of 0.015 mg/m^3.

DISCLAIMER

Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

DHEW (NIOSH) Publication No. 78-178

ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH) conducted an industry-wide study of three different nickel processes operations. Since arsenic and crystalline silica were found in the plants surveyed and they have been implicated as either co-carcinogens for development of lung cancer or as causative agents for fibrotic lung disease, exposures to these and other metals as well as nickel were evaluated.

The three types of facilities monitored were:

Plant A - A nickel smelter which pyro-metallurgically converts a nickel oxide ore, mined on site, to a 50% - 60% ferro-nickel alloy.

Plant B - A nickel refinery which acid treats imported sulfide ores that are partially roasted in the countries of origin to produce pure nickel and cobalt metal in the form of powder or briquettes.

Plant C - An inorganic chemical plant which manufactures nickel salts and solutions using either pure nickel metal or nickel oxide as a nickel source. The chloride, sulfate, nitrate, acetate, and carbonate of nickel are the salts normally produced, usually as solids, although some solutions of the salts are also marketed.

Almost all of the environmental concentrations of airborne nickel in these plants met the Occupational Safety and Health Administration (OSHA) standard of 1 mg Ni/m^3. Plant A was also in most cases, well below the current American Conference of Governmental Industrial Hygienists Threshold Limit Values (ACGIH-TLV) recommendations of 0.1 mg Ni/m^3. However, in none of the plants were exposure in the range of the NIOSH recommended standard of 0.015 mg/m^3.

Samples for free silica collected in the ferro-silicon and ore handling area indicated that airborne respirable silica was, with minor exceptions, below the current OSHA standard. They were with minor exceptions above the NIOSH recommended standard for respirable crystalline silica of 0.05 mg/m^3, with the average exposure being approximately 0.058 mg/m^3.

Plants B and C though they essentially met the OSHA standard of 1 mg Ni/m^3 for nickel, have several operations where worker exposure levels exceeded the ACGIH-TLV of 0.1 mg Ni/m^3. These plants, with some effort, could be modified to meet the lower ACGIH-TLV. However, in these plants the air level standard recommended by NIOSH (0.015 mg/m^3) might require major changes in process and plant design.

CONTENTS

Preceding page blank

ACKNOWLEDGMENTS

The authors wish to acknowledgment Frances Stephenson, Paul Johnson, Terrence Boyle, Thomas Maham, and Rick Culross of NIOSH for their assistance with the field surveys. Analytical work was performed by Karen Lyon, F.D. Pierce, and J.H. Nelson of Utah Biomedical Test Laboratory.

INTRODUCTION

In the preparation of the NIOSH criteria document for inorganic nickel, it was found that although some documentation was available on the exposure of the industrial population to the insoluble forms of airborne nickel, no data existed that documented the exposure of this population to water soluble nickel compounds. These surveys were conducted in order to provide additional exposure information.

In the United States, exposures to insoluble nickel could be expected in the production of nickel alloys and in the smelting of nickel oxide to produce ferro-nickel alloy used in the manufacture of stainless steel. Exposures to water soluble nickel would be expected in the processing of partially roasted nickel sulfide ores. These roasted ores are leached with acid and the nickel is then recovered from the leachate by hydrogenation. Other water soluble exposures occur in the production of various nickel salts and their subsequent application in the electroplating and related industries.

In order to obtain an overview of the exposures of American workers to nickel compounds (exclusive of nickel carbonyl), it was decided that surveys of the three facilities listed below would give an indication of the exposure of the industrial population of the United States to airborne nickel. These facilities were:

Plant	Total Plant Population	Nickel Production Population
A - A nickel smelter	450	390
B - A nickel refinery	500	440
C - An inorganic chemical plant	250	40

Surveys of these plants were started in October 1976 and completed in April of 1977.

DESCRIPTION OF PROCESSES

Nickel Smelting

At Plant A, the crude nickel ore contains about 1.5% nickel with over 20% water content. This ore is transported from the mine to the smelter where it passes through drying, crushing, and calcining stages after which it is fused and reacted with molten ferro-silicon. This results in the formation of a ferro-nickel alloy with over 50% nickel content. The ferro-silicon used in this process is produced by the reduction of quartz with coke and iron turnings in an electric furnace. Figure B-1 in Appendix B shows a detailed flow sheet of the process supplied by the company.

Nickel Refining

At Plant B, partly processed imported ore (matte) containing Co, Cu and Ni is crushed and then reacted with the circuit electrolyte (a sulfuric acid solution from the copper tank house). The resultant solution is treated to remove iron and other impurities. After intricate chemical separations, copper is obtained by a hydrogenation process. Both nickel and cobalt are marketed in the form of a metal powder or briquettes. Ammonium sulfate, a by-product of this process, is marketed as a fertilizer. Figure B-2 in Appendix B shows a general process flow sheet supplied by the company.

Inorganic Chemical Manufacturing

At Plant C, nickel salts are produced. The process consists basically of reacting nickel metal or oxide with various acids (H_2SO_4, HCl, HNO_3, and HAc) followed by cooling of the salt solution and the crystallization of the salt. The salts are usually centrifuged, and either packaged at this point, or dried and sometimes classified for uniform crystal size prior to packaging. This process applies, in general, to the manufacture of all soluble nickel salts. Figure B-3 in Appendix B shows a typical flow diagram for the manufacture of these salts.

Nickel carbonate is also produced at Plant C. This is accomplished by the addition of a sodium carbonate solution to a nickel sulfate solution. The precipitated nickel carbonate is filtered and washed on a rotary filter, dried, crushed, screened, and bagged. In addition to nickel salt crystals and nickel carbonate, nickel solutions are also made up and marketed to the plating industry.

SURVEY METHODS

Personal air samples for exposure to metals were collected at all three plants on 0.8 µm pore size, 37 mm mixed cellulose ester fiber filters by drawing air through the filter at a rate of 2.0 liters per minute with a MSA Model G pump.

The pump is worn on the worker's belt and the filter is held in place by a clamp on the worker's collar. At Plant A, the personal samples collected were analyzed for nickel, cobalt, copper, lead, and chromium. These analyses were all performed on the same filter by atomic absorption spectroscopy. In addition, at Plant A, general area samples for arsenic were collected since it was suspected that the ore might contain arsenic, which is a carcinogen. These samples were collected over approximately a full shift, using the same equipment employed for the collection of personal samples.

At Plant B, the company made available its environmental data which consisted of air sampling data (both general area and personal), which give exposures levels to airborne nickel. The samples were collected using the same methodology employed by NIOSH. At Plant C, the personal air samples collected were analyzed for nickel, cobalt, manganese, and zinc utilizing the same methodology as described under Plant A.

SURVEY RESULTS

Plant A

Of the 78 personal samples collected at this plant (see Tables A-1 and A-2) analyses indicated that the highest exposure level to nickel was 0.42 mg/m^3 and that the lowest exposure was 0.004 mg/m^3. Five samples out of the 81 were above 0.100 mg/m^3 (ACGIH-TLV), and 18 samples were above 0.015 mg/m^3 (NIOSH recommended level). The average of all the nickel air samples was 0.030 mg/m^3.

Analyses for cobalt, copper, and lead fell between 0.001 mg/m^3 and 0.010 mg/m^3, all of which are below the current recommended standards. Chromium equalled or, in several areas, exceeded the NIOSH recommended standard of 0.001 mg/m^3.

The results of the 30 personal samples analyzed for respirable free silica showed only three samples to be above the current OSHA standard. These were all associated with the operation of the ferro-silicon furnace. Only three of these samples were below the recommended NIOSH standard of 0.05 mg/m^3.

The results of the general area samples collected in nine areas of the plant and analyzed for arsenic showed less than the detectable limit of 0.1 micrograms on the filter in all cases. Details of the monitoring and analytical data for metals are shown in Appendix A, Tables A-2 and A-3 and results of analyses for free silica are in Appendix A, Table 4. The table below indicates the range of airborne nickel in trace metals.

Airborne Nickel and Trace Metals, mg/m^3
78 Samples

	Nickel	Cobalt	Copper	Lead	Chromium
Range	0.004-0.420	0.002-0.007	0.001-0.014	0.004-0.013	0.001-0.008
Average	0.030	0.002	0.002	0.006	0.002

Plant B

At this plant no air samples were collected by NIOSH, but air samples collected routinely by the company for nickel dust were obtained. These consisted of personal air samples and general area samples for airborne nickel. Personal samples on the matte storage operator, skip hoist operator, and payload operator taken over the period 7/75 - 12/75 (Appendix A, Table A-5 and A-6) indicated exposures to nickel ranged from 0.1 mg/m^3 to 0.60 mg/m^3 (current OSHA standard for Ni is 1 mg/m^3 and NIOSH recommended standard is 0.015 mg/m^3). Samples taken in the powder washing, packaging, and briquetting areas ranged as follows:

Nickel Dust, mg/m^3

	Powder Washing	Packaging	Briquetting
No. of Samples	5	12	5
Range	0.15-4.54	0.05-2.51	0.1-12.9
Average	1.24	0.54	4.84

Plant C

At this facility 29 employees out of approximately 33 employees working in the soluble nickel operation were monitored. These samples were analyzed for cobalt, manganese, and zinc, in addition to nickel. As shown in the table below, they show significant exposure only to nickel.

Airborne Nickel and Trace Metals, mg/m^3
29 Samples

	Nickel	Cobalt	Manganese	Zinc
Range	0.009-2.780	<0.001-0.012	<0.001-0.096	<0.005
Average	0.244	0.002	0.005	<0.005

Complete details of monitoring and analytical data are shown in Appendix A, Tables A-7, A-8, A-9 and A-10.

CONCLUSIONS

Results of exposures to nickel in various forms in the three plants show that at Plant A, which is a smelting operation producing ferro-nickel alloy, exposure of personnel to airborne nickel is below the current OSHA standard of 1 mg/m^3 and, for the most part, below the ACGIH-TLV of 0.1 mg/m^3. With some modification of operations, the exposure levels of personnel could meet the proposed NIOSH standard of 0.015 mg/m^3.

Plant B, which recovers nickel, cobalt, and copper from imported ore by a wet process, has airborne exposures to nickel which run considerably higher than in Plant A, and in a few instances up to ten times the current OSHA standard. Work in revamping the ventilation system for the briquetting operation has now been completed.

This work, designed to reduce high airborne nickel levels to 0.100 mg/m^3 (the ACGIH-TLV level) would require further modification to reduce exposures to the proposed NIOSH standard.

Plant C, a chemical plant where nickel inorganic salts are produced, essentially met the current OSHA standard of 1 mg/m^3, and with some effort could be modified to meet the ACGIH-TLV of 0.100 mg/m^3. Considerable effort will be necessary to reduce exposures to the proposed NIOSH standard.

Other potential exposures in the plants consist of noise and free silica in Plant A; and noise, sulfuric acid mist, and radiation from beta gauge sources in Plant B. All of these are either under control or are being worked on. Plant C has problems with the nickel carbonate bagging operation which was not in operation at the time of the survey, but which was apparently a dusty operation judging from condition of the equipment, walls, and floors of the area where the bagging was done.

Though in general all three plants surveyed currently meet the OSHA standard of 1 mg Ni/m^3, the amount of effort that would be required to meet the proposed NIOSH nickel standard of 0.015 mg/m^3 will vary with each plant. Plant A, which handles only insoluble nickel material had concentrations about two times the proposed NIOSH standard, but should be able to meet it. Plant B, which handles nickel solutions, as well as nickel powder, will require a greater effort to contain process materials so they will not become airborne. Plant C, an old plant founded in 1900, may require considerable effort in upgrading its facility, and some process equipment may need to be modified or replaced if they are to meet the proposed NIOSH standard.

Appendix A. Sampling Results

Table A-1. Summary of nickel exposures by operation at Plant A, December, 1976.

Operation	No. of Samples	Range (Lo-Hi) (mg/m^3)	Mean (mg/m^3)	Standard Error (mg/m^3)	Geometric Mean (mg/m^3)	Geometric Standard Deviation	L1 (mg/m^3)	L2 (mg/m^3)
Ore Handling	3	0.005-0.145	0.052	0.046	0.017	6.39	0.002	1.72
Drying	4	0.011-0.026	0.016	0.003	0.016	1.44	0.009	0.028
Calcining	4	0.037-0.146	0.090	0.025	0.079	1.85	0.030	0.210
Skull Drilling	8	0.004-0.043	0.016	0.005	0.011	2.32	0.006	0.023
Ferro-Silicon Mfg.	15	0.004-0.214	0.032	0.014	0.018	2.67	0.010	0.031
Mixing	17	0.004-0.022	0.006	0.001	0.005	1.55	0.004	0.006
Refining	10	0.004-0.034	0.011	0.003	0.008	2.00	0.005	0.014
Handling of Finished Product	5	0.004-0.009	0.005	0.001	0.005	1.42	0.003	0.008
Maintenance	9	0.007-0.168	0.039	0.017	0.022	2.81	0.010	0.050
Miscellaneous	3	0.008-0.420	0.193	0.121	0.080	7.81	0.005	13.1

L1 and L2 are the lower and upper 95% confidence limits, respectively, based on geometric mean and geometric standard deviation of the individual estimates of daily time weighted average exposure.

Table A-2. Analyses for nickel and other exposures at Plant A, December, 1976

Operation	Shift	Air Vol. (m3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Copper (mg/m^3)	Lead (mg/m^3)	Chromium (mg/m^3)
ORE HANDLING							
Loader Operator	2	0.766	0.005	0.002	0.001	0.006	0.001
" "	1	0.690	0.007	0.003	0.001	0.007	0.001
Crusher Operator	1	0.830	0.145	0.002	0.001	0.006	0.004
DRYING							
Dryer Operator	1	0.924	0.015	0.002	0.001	0.005	0.001
" "	2	0.782	0.014	0.003	0.001	0.006	0.003
Dryer Helper	2	0.780	0.011	0.003	0.001	0.006	0.001
" "	1	0.810	0.026	0.002	0.001	0.006	0.005
CALCINING							
Calciner Operator	2	0.822	0.146	0.002	0.001	0.006	0.004
" "	1	0.840	0.114	0.002	0.001	0.006	0.004
Calciner Helper	2	0.832	0.063	0.002	0.001	0.006	0.002
" "	1	0.840	0.037	0.002	0.001	0.006	0.001
SKULL DRILLING							
Skull Driller	2	0.928	0.007	0.002	0.001	0.005	0.001
" "	2	0.896	0.010	0.002	0.001	0.006	0.001
" "	2	0.898	0.025	0.002	0.001	0.006	0.002
" "	2	0.902	0.006	0.002	0.001	0.006	0.002
" "	2	0.726	0.004	0.003	0.001	0.007	0.001
" "	2	0.708	0.007	0.002	0.001	0.007	0.001
" "	2	0.720	0.024	0.002	0.001	0.007	0.001
Skull Driller (Helper)	2	0.898	0.043	0.002	0.001	0.006	0.002

Table A-2. (cont'd)

Operation	Shift	Air Vol. (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Copper (mg/m^3)	Lead (mg/m^3)	Chromium (mg/m^3)
FERRO SILICON MFG.							
Stacker Operator	2	0.986	0.017	0.002	0.001	0.005	0.001
Crusher Operator	2	0.744	0.024	0.003	0.001	0.007	0.003
" "	2	0.754	0.065	0.003	0.001	0.007	0.003
Loader Operator	2	0.744	0.017	0.003	0.001	0.007	0.003
Furnace Charger	2	0.738	0.007	0.003	0.001	0.007	0.001
" "	2	0.748	0.027	0.003	0.001	0.007	0.003
" "	2	0.882	0.029	0.002	0.002	0.006	0.001
Furnace Feeder	1	0.820	0.009	0.002	0.001	0.006	0.001
" "	2	0.796	0.214	0.002	0.001	0.006	0.001
Furnace Tapper	2	0.746	0.004	0.003	0.001	0.007	0.001
" "	2	0.868	0.020	0.002	0.001	0.006	0.002
Furnace Tapper (Helper)	2	0.866	0.016	0.002	0.001	0.006	0.001
Furnace Operator	2	0.750	0.007	0.003	0.001	0.007	0.001
" "	1	0.878	0.019	0.002	0.001	0.006	0.001
" "	2	0.626	0.008	0.003	0.002	0.008	0.002
MIXING							
Melter Smelter Helper	2	0.704	0.004	0.003	0.001	0.007	0.001
" " "	1	0.700	0.004	0.003	0.001	0.007	0.001
" " "	2	0.902	0.005	0.002	0.001	0.006	0.001
Smelter Helper (Belt)	2	0.660	0.005	0.003	0.001	0.007	0.001
" " "	2	0.136	0.022	0.002	0.007	0.004	0.007
Crane Operator	1	0.790	0.005	0.002	0.001	0.006	0.002
Crane Chaser	1	0.710	0.004	0.003	0.001	0.007	0.001
" "	2	0.900	0.007	0.002	0.001	0.005	0.001

Table A-2. (cont'd)

Operation	Shift	Air Vol. (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Copper (mg/m^3)	Lead (mg/m^3)	Chromium (mg/m^3)
Slag Handler	1	0.680	0.006	0.003	0.001	0.007	0.003
" "	2	0.902	0.008	0.002	0.001	0.005	0.003
Mixer Operator	1	0.806	0.004	0.002	0.001	0.006	0.001
" "	1	0.820	0.004	0.002	0.001	0.006	0.001
" "	2	0.818	0.004	0.002	0.001	0.006	0.001
" "	1	0.818	0.004	0.002	0.001	0.006	0.001
" "	2	0.796	0.004	0.002	0.001	0.006	0.001
" "	1	0.820	0.004	0.002	0.001	0.006	0.001
Ladle Mixer Operator	2	0.790	0.004	0.002	0.001	0.006	0.001
REFINING							
Refinery Furnace Operator	1	0.700	0.009	0.003	0.001	0.007	0.001
" " "	1	0.820	0.006	0.002	0.001	0.006	0.001
" " "	1	0.670	0.034	0.003	0.001	0.007	0.001
" " "	2	0.926	0.018	0.002	0.001	0.005	0.001
Refinery Furnace Helper	2	0.703	0.009	0.003	0.001	0.007	0.003
" " "	2	0.703	0.004	0.003	0.001	0.007	0.003
" " "	2	0.820	0.004	0.002	0.001	0.006	0.001
" " "	2	0.930	0.004	0.002	0.001	0.005	0.001
" " "	2	0.928	0.010	0.002	0.001	0.005	0.001
Tapper Helper	2	0.748	0.008	0.003	0.001	0.007	0.001
HANDLING OF FINISHED PRODUCT							
Pig Deck Leadman	1	0.800	0.004	0.002	0.001	0.006	0.001
Pig Deck Stacker	1	0.766	0.005	0.003	0.001	0.007	0.001
Fork Lift Opr. Pig Deck	1	0.790	0.009	0.003	0.001	0.006	0.001

Table A-2. (cont'd)

Operation	Shift	Air Vol. (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Copper (mg/m^3)	Lead (mg/m^3)	Chromium (mg/m^3)
Fork Lift Opr. Pig Deck	1	0.804	0.004	0.002	0.001	0.013	0.001
Pig Deck Laborer	1	0.700	0.004	0.003	0.001	0.007	0.001
MAINTENANCE							
Welder	1	0.710	0.018	0.003	0.010	0.007	0.008
Can Welder	1	0.664	0.059	0.003	0.001	0.007	0.003
" "	1	0.648	0.041	0.003	0.001	0.007	0.003
" "	1	0.660	0.168	0.003	0.003	0.007	0.005
Millwright Welder	1	0.700	0.019	0.003	0.014	0.007	0.007
Millwright Oiler	1	0.836	0.007	0.002	0.001	0.006	0.002
" "	1	0.830	0.007	0.002	0.001	0.006	0.002
Millwright	1	0.700	0.013	0.003	0.003	0.007	0.006
Machinist	1	0.700	0.016	0.003	0.003	0.007	0.006
MISCELLANEOUS							
Utility Man	1	0.790	0.008	0.002	0.001	0.006	0.001
Plant Clean-up	1	0.690	0.420	0.007	0.006	0.007	0.001
Sweeper Operator	1	0.800	0.150	0.002	0.001	0.006	0.001
OSHA Standard			1.0	0.1	1.0	0.2	1.0
ACGIH-TLV			0.1	0.1	1.0	0.15	0.5
NIOSH Recommended Standard			0.015	---	---	0.15	0.001

Table A-3. General area samples for arsenic collected at a flow rate of 2 liters/minute at Plant A.

Operation	Shift Number	Air Volume (m^3)	Arsenic ($\mu g/m^3$)
Crusher Plant - Bottom Floor	1	0.370	<0.3
Calciner - First Floor	1	0.382	<0.3
Ferro-Silicon Furnace Area	2	0.682	<0.1
Ferro-Silicon Under Furnace	1	0.390	<0.3
Between Furnaces - In Pit	2	0.688	<0.1
In Loft Above Smelter	2	0.660	<0.2
Metal Smelter Area			
Crane Bay Shack	2	0.774	<0.1
Refining Furnace Area	1	0.410	<0.2
Refining Furnace Area	2	0.685	<0.1

Limit of Detection	0.1 micrograms
OSHA Standard	0.5 mg/m^3
OSHA Proposed Standard	0.004 mg/m^3
NIOSH Recommended Standard	0.002 mg/m^3

Table A-4. Analysis for respirable free silica exposure at Plant A, December, 1976.

Operation	Shift	Wt. of Dust (mg)	Free Silica %	Free Silica µg	Vol. of Air (m^3)	Resp. Dust (mg/m^3)	OSHA Std. = 10 / $\%SiO_2+2$	µg SiO_2 / m^3	% OSHA Std.
Stacker Operator	1	0.022	-	40	0.822	0.027	-	-	-
Dryer Operator	1	0.254	<16	<40	0.788	0.322	>0.55	<51	<58
Dryer Helper	1	0.265	<15	<40	0.810	0.326	>0.59	<49	<55
Calciner Opr.	1	0.487	8	40	0.800	0.610	>1.00	<50	<61
Calciner Helper	1	0.733	6	50	0.733	1.000	1.25	65	80
Skull Plant Opr.	1	0.279	22	60	0.876	0.318	0.42	68	76
Skull Plant Helper	1	0.914	22	40	0.906	0.214	0.42	44	51
No 1 Skull Driller	1	0.252	16	40	0.760	0.322	0.55	53	60
No 2 Skull Driller	1	0.376	<11	<40	0.770	0.490	>0.77	<52	<64
Fe-Si Furnace Opr	1	0.679	< 6	<40	0.742	0.915	>1.25	<54	<73
Fe-Si Charger	1	1.402	4	60	0.730	1.92	1.67	82	110
Fe-Si Furnace Feeder	2	0.117	<34	<40	0.792	0.148	>0.28	<51	<53
Fe-Si Furnace Feeder	2	0.172	23	40	0.780	0.221	0.40	51	55
Fe-Si Tapper	1	0.482	8	40	0.900	0.535	1.00	45	54
Fe-Si Tapper Helper	1	0.911	8	70	0.744	1.230	1.00	94	120
Fe-Si Crusher	1	0.572	12	70	0.750	0.760	0.71	93	110
Crane Operator	1	0.269	<15	<40	0.790	0.340	>0.59	<51	<58
Crane Operator	2	0.374	<11	<40	0.808	0.463	>0.77	<50	<60
Crane Chaser	1	0.165	<24	<40	0.744	0.222	>0.38	<54	<58
Melting Operator	2	0.096	<42	<40	0.796	0.113	>0.23	<50	<49
Melter Helper	2	0.151	<26	<40	0.724	0.208	>0.36	<55	<58
Mixer Operator	2	0.179	<22	<40	0.780	0.229	>0.42	<51	<55
Mixer Operator	2	0.129	<31	<40	0.782	0.165	>0.30	<51	<55

Table A-4. (cont'd)

Operation	Shift	Wt. of Dust (mg)	Free Silica %	Free Silica µg	Vol. of Air (m^3)	Resp. Dust (mg/m^3)	OSHA Std. $= \frac{10}{\% SiO_2 + 2}$	µg SiO_2/m^3	% OSHA Std.
Mixer Operator	2	0.286	14	40	0.786	0.364	0.62	51	59
Mixer Operator	2	0.244	16	40	0.798	0.305	0.56	50	54
Slag Handler	2	0.245	<16	<40	0.746	0.329	>0.56	<54	<59
Refining Furnace Operator	2	0.219	18	40	0.754	0.286	0.50	53	57
Refining Furnace 1st Helper	1	0.245	22	50	0.844	0.290	0.42	59	69
Refining Furnace 2nd Helper	1	0.378	13	50	0.734	0.513	0.67	68	77
Pig Machine Operator	1	0.231	26	60	0.738	0.314	0.36	82	87

OSHA Standard $\frac{10}{\% \text{ Respirable Silica} + 2}$ mg/m^3 of respirable dust

NIOSH Recommended Standard - 0.050 mg/m^3

Limit of Detection for free silica - 0.040 mg/sample

Table A-5. Analysis for nickel exposure ($mg\ Ni/m^3$). General area samples at Plant B.

Operation	9/8/75	9/9/75	9/10/75	9/28/75	9/29/75	9/30/75
Powder Washer	4.54	0.99	0.15	---	0.27	0.27
Packaging Nickel Powder	0.13 0.12	0.65 0.59	1.60 2.51	0.13 0.07	0.05 0.05	0.44 0.14
Briquetting Nickel Powder	2.0	6.1	0.1	---	12.9	3.1

NOTE: Samples collected and analysed by company personnel.

OSHA Standard $1.0\ mg/m^3$
ACGIH - TLV $0.1\ gm/m^3$
NIOSH Recommended Std. $0.015\ mg/m^3$

Table A-6. Analysis for nickel exposure (mg Ni/m^3). Personal samples at Plant B.

Operation	7/21/75	7/28/75	7/29/75	7/30/75	11/30/75	12/8/75
Matte Storage Area	0.41 0.20 0.37	0.29 0.17 1.09	0.14 0.37	0.20		
Skip Hoist Operator			0.60		0.19	
Pay Loader Operator					0.19	0.09

NOTE: Samples collected and analysed by company personnel

OSHA Standard 1.0 mg/m^3
ACGIH - TLV 0.1 mg/m^3
NIOSH Recommended Std. 0.015 mg/m^3

Table A-7. Summary of nickel exposure by operation at Plant C, October, 1976.

Operation	No. of Samples	Range (Lo-Hi) (mg/m^3)	Mean (mg/m^3)	Standard Error (mg/m^3)	Geometric Mean (mg/m^3)	Geometric Std. Dev.	L1 (mg/m^3)	L2 (mg/m^3)
Nickel Sulfate	12	0.009-0.590	0.017	0.047	0.057	3.66	0.025	0.130
Nickel Chloride	11	0.020-2.78	0.431	0.241	0.162	4.03	0.063	0.413
Nickel Acetate and Nitrate	6	0.038-0.525	0.155	0.076	0.099	2.60	0.036	0.270

L1 and L2 are the lower and upper 95% confidence limits, respectively, based on geometric mean and geometric standard deviation of the individual estimates of daily time weighted average exposure.

Table A-8. Analysis for nickel and other exposures at Plant C, nickel sulfate operation, October, 1976.

Job Classification	Shift	Air Volume (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Manganese (mg/m^3)	Zinc (mg/m^3)
Process Helper	1	0.866	0.029	<0.001	<0.001	<0.005
Process Operator	1	0.852	0.018	0.006	<0.001	<0.005
Chief Operator	1	0.858	0.040	<0.001	<0.001	<0.005
Process Helper	1	0.836	0.113	<0.001	<0.001	<0.005
Leadman	1	0.858	0.029	<0.001	<0.001	<0.005
Chief Operator	2	0.870	0.009	<0.001	<0.001	<0.005
Process Operator	2	0.886	0.009	0.002	<0.001	<0.005
Process Operator (cleaning tanks)	1	0.866	0.091	0.002	<0.001	<0.005
Process Operator (cleaning tanks)	1	0.842	0.134	<0.001	<0.001	<0.005
Bagger	2	0.864	0.590	0.000	<0.001	<0.005
Process Helper (scraping screens)	2	0.858	0.145	<0.001	<0.001	<0.005
Operator (Mixes Ni and H_2SO_4)	2	0.852	0.198	<0.001	<0.001	<0.005
Limit of Detection - mg/sample			0.003	0.001	0.001	0.005
OSHA Standard - mg/m^3			1.0	0.1	5.0	5.0
ACGIH-TLV (1976) - mg/m^3			0.1	0.1	5.0	5.0
NIOSH Recommended Std. mg/m^3			0.015	---	---	5.0

Table A-9. Analysis for nickel and other exposures at Plant C, nickel chloride operation, October, 1976

Job Classification	Shift	Air Volume Meters (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Manganese (mg/m^3)	Zinc (mg/m^3)
Process Helper	1	0.848	0.080	<0.001	<0.001	<0.005
Process Helper	1	0.844	0.079	<0.001	<0.001	<0.005
Process Operator	1	0.840	0.020	<0.001	<0.001	<0.005
Process Operator	1	0.840	0.143	<0.001	<0.001	<0.005
Process Operator	2	0.862	2.780	0.012	<0.001	<0.005
Process Operator (busts out opens)	2	0.856	0.470	0.005	<0.001	<0.005
Process Operator (makes batches)	2	0.854	0.054	<0.001	<0.001	<0.005
Process Helper	1	0.840	0.049	<0.001	<0.001	<0.005
Process Operator	1	0.846	0.485	<0.001	<0.001	<0.005
Process Helper	2	0.862	0.430	0.005	<0.001	<0.005
Process Helper	2	0.856	0.153	0.002	<0.001	<0.005
Limit of Detection – mg/sample			0.003	0.001	0.001	0.005
OSHA Standard – mg/m^3			1.0	0.1	5.0	5.0
ACGIH – TLV – mg/m^3			0.1	0.1	5.0	5.0
NIOSH Recommended Std. mg/m^3			0.015	---	---	5.0

Table A-10. Analysis for nickel and other exposures at Plant C, nickel acetate and nitrate operation, October, 1976

Job Classification	Shift	Air Volume Meters (m^3)	Nickel (mg/m^3)	Cobalt (mg/m^3)	Manganese (mg/m^3)	Zinc (mg/m^3)
Process Operator	1	0.840	0.525	<.001	0.004	<0.005
Process Operator	1	0.820	0.073	<.001	0.001	<0.005
Process Operator	2	0.848	0.061	<.001	0.003	<0.005
Process Trainee	1	0.834	0.061	<.001	0.002	<0.005
Operator-Centrifuge	2	0.852	0.173	<.001	0.096	<0.005
Process Operator	1	0.818	0.038	<.001	0.003	<0.005
Blank	-	--	--	<.001	<0.001	<0.005
Limit of Detection - mg/sample			0.003	0.001	0.001	0.005
OSHA Standard - mg/m^3			1.0	0.1	5.0	5.0
ACGIH - TLV mg/m^3			0.1	0.1	5.0	5.0
NIOSH Recommended Std. mg/m^3			0.015	---	---	5.0

Appendix B. Flow Diagrams

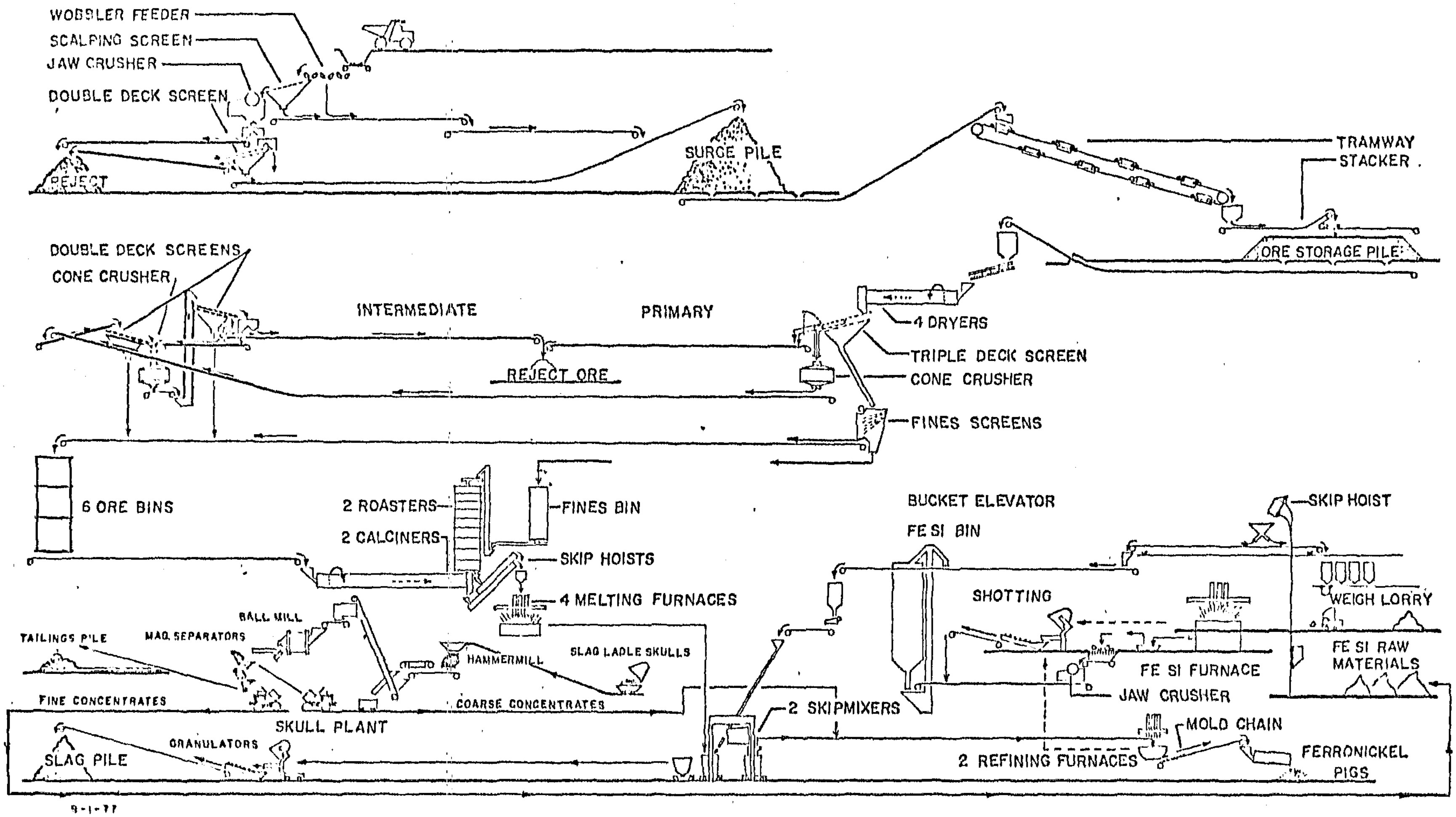
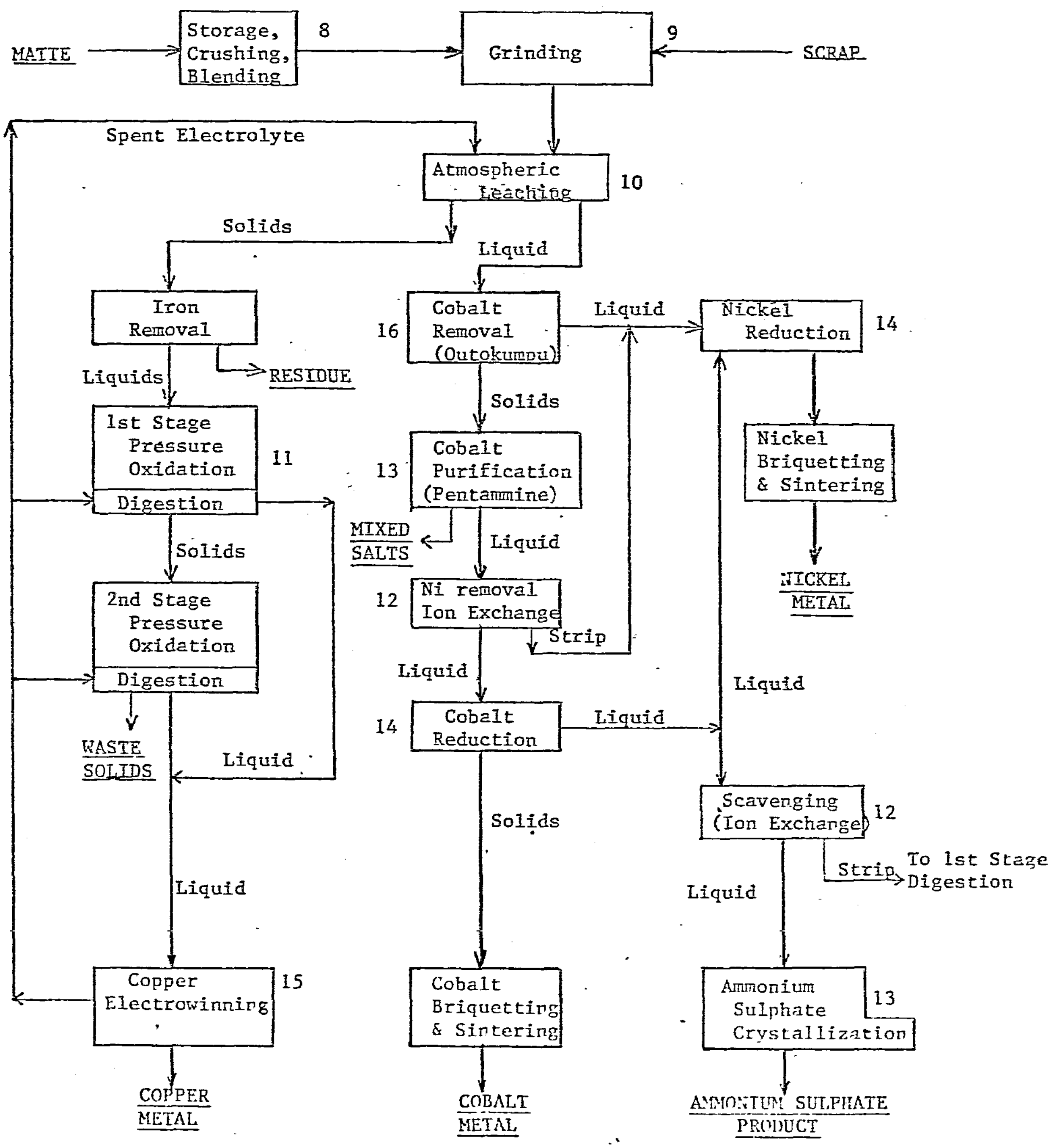


Figure B-1. Nickel Smelter at Plant A, flow diagram



(Numbers refer to plant areas)

Figure B-2. Nickel Refinery, Plant B.

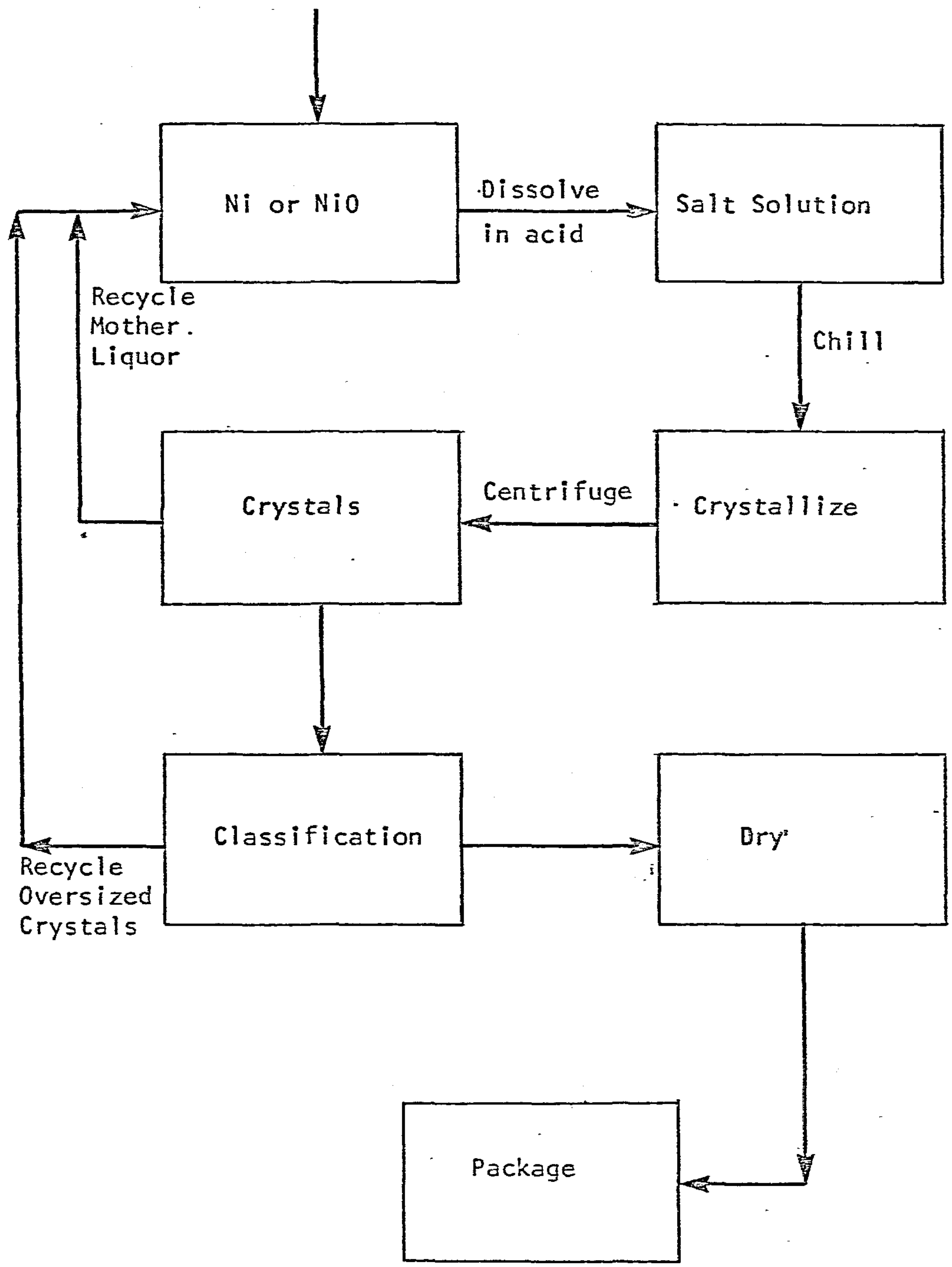


Figure B-3.

Plant C,

Inorganic Nickel Salts Manufacturing Process ($NiSO_4$, $NiCl_2$, $Ni(NO_3)_2$, $Ni(Ac)_2$).

Appendix C. Job Dictionary

Table C-1
Plant A. Job Dictionary

Job Title	Work Description
Stacker Operator	Operates ore stacker
Loader Operator	Loads ore onto trucks
Crusher Operator	Operates crushing and sampling systems to screen, reject, sample, crush, and store ore
Dryer Operator	Operates rotary dryers
Dryer Helper	Assists in the operation of rotary dryers
Calciner Operator	Operates calcining kilns
Calciner Helper	Assists the calcining operator
Skull Driller	Operates skull drill to clean ladles
Stacker Operator Fe-Si	Feeds ferro-silicon furnace
Crusher Operator Fe-Si	Breaks up ferro-silicon
Furnace Charger Fe-Si	Charges electric furnace with materials to produce ferro-silicon
Furnace Feeder Fe-Si	Keeps changing bins full of ferro silicon materials
Furnace Tapper Fe-Si	To tap electric furnace in production of ferro-silicon
Tapper Helper	Assists tappers in his duties in the production of ferro-silicon
Furnace Operator Fe-Si	Operates ferro-silicon furnace

Melter Smelter Helper	Tends, inspects and helps to maintain slag belts
Smelter Helper (belt)	Tends, inspects and helps to maintain slag belts
Crane Operator	Operates overhead crane
Crane Chaser	Hooks for overhead crane and directs operator to prepare destination
Slag Handler	Operates slag granulator
Mixer Operator (ladle mixer operator)	Pours melting furnace and operates the ladle mixer
Refinery Furnace Operator	Operates two refining furnaces in the refining and casting of ferro nickel
Refinery Furnace Helper	Assists the operator.
Pig Dock Leadman	Directs lift truck operator and pig deck-laborers in the handling, shipping or storing of ferro-nickel pigs
Fork Lift Operator Pig Deck	Operates fork lift truck
Pig Dock Stacker-Laborer	Stacks ferro-nickel pigs and related duties
Welder	Does welding
Can Welder	Welds cans
Millwright Welder	Does maintenance welding
Millwright Oiler	Oils machinery
Millwright	Repairs machinery
Machinist	Lays out work and operates machine tools
Utility Man	Does miscellaneous jobs as directed
Plant Clean-up Man	Sweeps and cleans floors in the plant
Sweeper Operator	Operates mechanical sweeper

Table C-2.

Plant B, Job titles of operators

Jobs fall into four general categories with sub-classification as indicated:

(1) Production Operation Personnel - Operates chemical process equipment

(a) Supervisor

(b) Operator

(2) Maintenance Personnel - Repairs chemical processing equipment

(a) Supervisor

(b) Operator

(3) Warehouse Personnel - Stores and issues raw material and finished products

(a) Supervisor

(b) Material Handler - Laborer

(c) Clerks and Expeditors

(4) Laboratory Personnel - Performs analytical control on intermediate and finished products

(a) Supervisor

(b) Chemist

(c) Technician

Table C-3. Plant C, job titles of operators*

Process Helper
Process Operator
Chief Operator-Leadman

*The jobs are essentially all the same and titles are in three categories, arrived at by seniority rather than by differences in duties.