Human Health Risk Assessment

Appendix 3

Detailed Estimates of Daily Intakes of Metals

Table of Contents
Human Health Risk Assessment - Appendix 3
Detailed Estimates of Daily Intakes of Metals

A3-1 Assessing Exposures to Metals

Each of the exposure pathways identified in Section 4.1 of the main report, that can contribute to the total daily metal exposures experienced by the residents of the Rodney Street community, is discussed below. The method of calculation is presented, identifying all of the receptors and site-specific parameters that are considered for each pathway. Exposures are assessed for all of the receptors identified in Section 4.1 of the main report, and were estimated using the receptor parameters listed in Table 4-3 of the main report and discussed in Appendix 6.

A3-1.1 Intake of Metals from Supermarket Food

Estimates of the daily dietary intakes of metals from supermarket foods are generally limited and the amount of information available varies widely between metals. The metals of concern in the Rodney Street community addressed in this exposure assessment include, antimony, beryllium, cadmium, cobalt, copper and nickel. Information regarding daily dietary intakes of these metals has been taken from Canadian and international regulatory agencies. Additional information has been taken from the available literature. For the purposes of assessing likely daily dietary metal intakes for the residents of the Rodney Street community, preference has been given to data generated from the Canadian population. It was felt that information from Canadian sources would provide the best reflection of likely dietary habits and metal intakes for residents of the Rodney Street community. The daily dietary intake of metals is discussed in detail in Appendix 4. A summary of the daily dietary intake of metals for all age groups is presented in Table A3-1.

Table A3-1: Estimated Daily Intakes of Metals from Supermarket Food

Receptor	Daily Intakes of Metals from Supermarket Food (µg/day)					
	Antimony	Beryllium	Cadmium	Cobalt	Copper	Nickel
Infant	1.3	4.8	5.08	4.18	518	109.2 (72.2-146.2)*
Toddler	2.3	8.6	10.6	7.0	822	190
Child	3.5	13.2	16.8	10.0	1230	251
Teen	4.0	15.0	17.3	12.0	1520	313
Adult	3.4	12.7	14.8	10.0	1430	307
Reference	FSA, 1997	Vaessen & Szteke, 2000	CEPA, 1994	Dabeka & McKenzie, 1995	CCME, 1997	Dabeka, 1989; Dabeka & McKenzie, 1995

*see table A4-4.

A3-1.2 Intake of Metals from Drinking Water

Daily intakes of metals from drinking water are dependent on the amount of drinking water consumed on a daily basis and the level of metals present in the drinking water. The estimated intakes of metals from drinking water for the Rodney Street community has been calculated as shown in equation A3-1. Estimates of the intake of antimony, beryllium, cadmium, cobalt, copper and nickel from the consumption of drinking water for all age groups are shown in Table A3-2.

EQ A3-1:

$$Intake_{dw} = IR_{dw} * C_{dw}$$

Where:	$Intake_{dw}$	=	Intake from drinking water	µg/day
	IR_{dw}	=	Ingestion rate of drinking water	L/day
	C_{dw}	=	Metal concentration in drinking water	µg/L

The intake estimates are based on the highest level of each metal reported by the monitoring of drinking water taken from the municipal system at Charlotte Street. Although water quality was also measured at the treatment plant, the data from within the distribution system was felt to be more representative of the water quality in the Rodney Street community. The data in Table A3-2 shows that for most metals, daily intakes from drinking water are generally less than 1 µg/day. The most notable exception to this is copper, where intakes from drinking water range between 13 µg/day for infants and 66 µg/day for adults. For infants and toddlers, intakes of nickel from drinking water are below 1 µg/day, but intakes for children, teens and adults are greater than 1 µg/day. These values will be used in conjunction with intakes from other sources to provide estimates of total daily exposure for people in all age groups.

Table A3-2: Estimated Metal Intakes from Drinking Water

Metal	Receptor	C_{dw} (µg/L)	IR_{dw} (L/day)	$Intake_{dw}$ (µg/day)
Antimony	0 - 6 months	0.97	0.3	0.29
	7 months - <5 years	0.97	0.6	0.58
	5 - <12 years	0.97	0.8	0.78
	12 - <20 years	0.97	1	0.97
	20 + years	0.97	1.5	1.5
Beryllium	0 - 6 months	0.20	0.3	0.06
	7 months - <5 years	0.20	0.6	0.12
	5 - <12 years	0.20	0.8	0.16
	12 - <20 years	0.20	1	0.20
	20 + years	0.20	1.5	0.30
Cadmium	0 - 6 months	0.083	0.3	0.025
	7 months - <5 years	0.083	0.6	0.050
	5 - <12 years	0.083	0.8	0.066
	12 - <20 years	0.083	1	0.083
	20 + years	0.083	1.5	0.12
Cobalt	0 - 6 months	0.040	0.3	0.012
	7 months - <5 years	0.040	0.6	0.024
	5 - <12 years	0.040	0.8	0.032
	12 - <20 years	0.040	1	0.040
	20 + years	0.040	1.5	0.060
Copper	0 - 6 months	44	0.3	13
	7 months - <5 years	44	0.6	26
	5 - <12 years	44	0.8	35
	12 - <20 years	44	1	44
	20 + years	44	1.5	66
Nickel	0 - 6 months	1.3	0.3	0.39
	7 months - <5 years	1.3	0.6	0.78
	5 - <12 years	1.3	0.8	1.0
	12 - <20 years	1.3	1	1.3
	20 + years	1.3	1.5	2.0

A3-1.3 Intake of Metals from Ambient Air

Unlike other environmental media, such as soil or water, air quality may fluctuate from day to day or hour to hour, and exposure levels are also influenced by changes in meteorological conditions. To protect the general population against contaminants in outdoor air, on a continuous basis, time periods such as 24 hours or annual are used. These prescribed time periods are referred to as “averaging times” and are an important aspect of controlling air quality. This also has significance from a toxicological perspective since the dose of a chemical, which is time dependent, is a major determinant of toxicological effects. One consideration in establishing averaging time is to limit exposure peaks for airborne chemicals, which could occur within a long averaging period, such as a year.

Averaging time can be used to ensure protection against the different effects of airborne chemicals by ensuring that exposure limits for specific effects, acute or chronic, are not exceeded. Short term acute effects are normally based on a one hour (or less) exposure period while longer term chronic effects are based on a 24 hour or annual averaging time. Averaging times also provide useful benchmarks to monitor ambient air quality.

The annual arithmetic mean is a relatively stable measure of air quality that reflects the total cumulative dose of airborne substances to which an individual or population is exposed. Short-term peaks have an influence on the arithmetic mean that is proportional to their frequency, magnitude and duration, and thus, their contribution to cumulative exposure and risk. As a result, the annual arithmetic mean form of an annual standard provides protection across a wide range of the air quality distribution contributing to exposure and risk, in contrast to other forms, such as the geometric mean that de-emphasize the effects of short-term peak concentrations.

The time taken for chemical exposure to cause adverse health effects varies among chemicals and even a single chemical can cause different effects at different doses. Chemicals such as sulphur dioxide, may trigger an effect within 15 minutes, or less, of exposure. Others, such as the carcinogenic chemicals, may have a longer term cumulative effect, which may not clinically manifest for several years. The times over which concentrations should be averaged to reflect the time frame during which their effects become apparent varies, and averaging times are often set to reflect this.

Air monitoring data is usually collected on air samplers over relatively short time periods, e.g., one to two days, and the results integrate the chemical concentration over the volume of air filtered and the time period the sampler was running. A single air sample would result in the air concentration over a daily time period. In the course of a year, if sufficient "daily" samples are taken, an annual average air concentration can be calculated. This way a picture of the peak levels and the overall average concentration in the air over the year can be constructed.

In Ontario, the Ministry of the Environment (MOE) has established air quality standards (air standards) including ambient air quality criteria (AAQC) and point of impingement (POI) standards. Ambient air quality criteria are established to protect human health and the environment (terrestrial vegetation and wildlife), and to prevent aesthetic impacts such as odor, soiling of property and visibility. The AAQC are used to assess the quality of the ambient environment, while POI standards are used to evaluate the impacts of airborne emissions.

AAQC are developed to protect the most sensitive sub-populations, with consideration of the most sensitive adverse effect(s) induced by the exposure to a pollutant. These criteria are derived from the most reliable and up-to-date scientific, toxicological and epidemiological information obtained from peer reviewed literature or from the studies from which other environmental protection agencies derive their respective air guidelines. In some occasions, AAQC can be derived based on the scientific rationale of occupational exposure limits. However, occupational exposure limits are developed to protect the safety of workers and their derivation may include science/policy decisions which may not be directly applicable to environmental health decision making.

Cancer risk is in general considered the likelihood of developing this disease as a result of a life-time exposure of an individual to low doses of a carcinogenic substance. Most of the cancer-based guidelines are derived from cancer slope factors which are mathematical estimates of additional or excess risk. Cancer risk-specific exposure concentrations can be derived from the slope factors. Cancer risk can also be expressed as the probability of developing this disease at a risk-specific exposure concentration, such as one case in a population of one million, one-hundred thousand or ten thousand. In line with risk levels considered for other MOE environmental programmes, the ministry has adopted the risk level of one in a million to derive an annual average AAQC for carcinogens. Corresponding air standards for other averaging times such as the 24 hour average AAQC and the half hour POI can be derived mathematically based on a power law equation and the scaling factors as follows:

24 hour average AAQC = annual AAQC x 5
half hour POI limit = annual AAQC x 15

It should be noted that the cancer-based AAQC or corresponding POI standards may be derived based on a risk level of greater than one in a million. This happens when the air standards are not immediately achievable because of implementation issues, which may include high background concentrations, technical feasibility, significant economic impacts, or allowing a reasonable time frame for compliance. The ministry is in the process of developing a risk management framework to resolve these potential implementation issues.

In the case of the risk assessment for the Rodney Street community, air monitoring data comes from several sources and locations. Local air sampling for nickel, lead, copper and total suspended particulates was obtained from the ministry’s sampling station at Davis Street and Fraser Street, which operated from 1992 to 1996, and air sampling done during the summer of 2000 near schoolyards in Port Colborne by Jacques Whitford Environmental Limited (JWEL, 2000a). The ministry’s sampling station was about 600m north of Rodney Street. Prevailing winds in the general Port Colborne area are from the west and southwest. These sectors account for about 45-50% of winds. The other sectors occur less and fairly evenly, about 5-15% each (Frank Dobroff, MOE, personal communication). While the Davis and Fraser location may be deemed slightly upwind of the Rodney Street community, inspection of the nickel concentration in soil maps in the ministry’s Phytotoxicology Soil Investigation Reports (MOE, 1999; MOE, 2000) indicate that it is located in an area where nickel levels in surface soils range up to 1,000 µg/g, and depending on wind direction would sample air particulates representative of the area just north of Rodney Street. The air monitoring performed at Port Colborne schools in the summer of 2000 (JWEL, 2000a) was only collected for the portion of the year that dust levels would normally be higher and may not be representative of long term average levels in the community. However, in all cases where air monitoring data exists for arsenic, cobalt, copper, nickel, and TSP, the maximum and average air concentrations for each metal from the JWEL (2000a) air monitoring are less than or comparable with either the MOE or Environment Canada information.

Air concentrations of other metals not sampled extensively in Port Colborne (antimony, arsenic, cadmium, cobalt, lead) were taken from Environment Canada's National Air Pollution Surveillance (NAPS) air monitoring program for Ontario for 1995-1999 (Tom Dann, Environment Canada, personal communication). Environment Canada air monitoring data comes from nine sites spread across Ontario, six of which are in Hamilton, Toronto and Windsor. In general, the Environment Canada air monitoring data for the same chemicals sampled by MOE at Davis and Fraser (the maximum and annual average air concentrations) was lower. In the absence of more suitable air quality data for chemicals not sampled extensively in Port Colborne, Environment Canada air monitoring data was used.

A summary of the metal levels in air, used in the current assessment is provided in Table A3-3. The recent 2001 MOE air monitoring data for the Rodney Street location (Table A1-3) is not annualized, however, it supports the Table A3-3 values based on Environment Canada air monitoring data.

Table A3-3: Levels of Metals in Ambient Air in Port Colborne

	Metal Concentration in Air in Port Colborne (µg/m^3)					
	Antimony	Beryllium	Cadmium	Cobalt	Copper	Nickel
Short term maximum	0.0115	n/a	0.0067	0.017	0.56	0.69
Annual average (highest)	0.0011	0.00012	0.0007	0.002	0.11	0.033

In the Rodney Street community, inhaled metals will be associated with particulate matter and will not be present as free metal. Therefore, there is a potential for the inhaled particulate matter to be cleared from the lungs, through mucocilliary transport, and swallowed. Material cleared from the lungs in this fashion will add to the total daily ingestion of metal. The amount of particulate delivered to the stomach by this process is difficult to predict with any accuracy. Therefore, to provide conservative estimates of the amount of metal ingested as a result of the clearance of inhaled particles, it has been assumed that all inhaled metal is cleared from the lung and passed to the stomach. This approach will overestimate the contribution that inhalation exposures make to the total daily intakes of metals.

For these estimates the highest annual average air concentration from the MOE or Environment Canada air monitoring data was used. This is a more conservative estimate for long term inhalation exposure. Inhalation R*f*C and unit risks are developed for life-time exposure not short term maximum air concentrations. Characterization of potential health risks from inhalation is discussed in Section 5.0 of the Human Health Risk Assessment main report (Part B) (Risk Characterization). The estimated inhalation intake of each metal for each receptor based on the highest annual average level (Table A3-3) is shown in Table A3-4. These values are calculated as shown in equation A3-2.

Eq A3-2:

$$Intake_{air} = Intake_{airout} + Intake_{airin}$$
$$Intake_{airout} = (Time_{outsum} * IR_{air} * Cair_{out}) + (Time_{outwin} * IR_{air} * Cair_{out})$$
$$Intake_{airin} = (Time_{insum} * IR_{air} * Cair_{in}) + (Time_{inwin} * IR_{air} * Cair_{in})$$

Where: $Intake_{air}$ = Intake from air µg/day
$Intake_{airout}$ = Intake from air while outdoors µg/day
$Intake_{airin}$ = Intake from air while indoors µg/day
IR_{air} = Inhalation rate m^3/day
$Cair_{out}$ = Outdoor air concentration (measured) µg/m^3
$Cair_{in}$ = Indoor air concentration µg/m^3
(75% of outdoor air concentration based on Roberts et al. (1974))
$Time_{insum}$ = Fraction of time spent indoors during summer; see Appendix 6 unitless
$Time_{inwin}$ = Fraction of time spent indoors during winter; see Appendix 6 unitless
$Time_{outsum}$ = Fraction of time spent outdoors during summer; see Appendix 6 unitless
$Time_{outswin}$ = Fraction of time spent outdoors during winter; see Appendix 6 unitless

Table A3-4: Estimated Metal Intakes from Air

Metal	Receptor	C_{air} (µg/m^3)	IR_{air} (m^3/day)	$Intake_{air}$ (µg/day)
Antimony	0 - 6 months	0.0011	2.1	0.0018
	7 mo - <5 years	0.0011	9.3	0.0081
	5 - <12 years	0.0011	14.5	0.013
	12 - <20 years	0.0011	15.8	0.014
	20 + years	0.0011	15.8	0.014
Beryllium	0 - 6 months	0.00012	2.1	0.0002
	7 mo - <5 years	0.00012	9.3	0.0009
	5 - <12 years	0.00012	14.5	0.0014
	12 - <20 years	0.00012	15.8	0.0015
	20 + years	0.00012	15.8	0.0015
Cadmium	0 - 6 months	0.0007	2.1	0.0011
	7 mo - <5 years	0.0007	9.3	0.0051
	5 - <12 years	0.0007	14.5	0.0080
	12 - <20 years	0.0007	15.8	0.0087
	20 + years	0.0007	15.8	0.0086
Cobalt	0 - 6 months	0.002	2.1	0.0033
	7 mo - <5 years	0.002	9.3	0.015
	5 - <12 years	0.002	14.5	0.023
	12 - <20 years	0.002	15.8	0.025
	20 + years	0.002	15.8	0.025
Copper	0 - 6 months	0.112	2.1	0.18
	7 mo - <5 years	0.112	9.3	0.82
	5 - <12 years	0.112	14.5	1.28
	12 - <20 years	0.112	15.8	1.39
	20 + years	0.112	15.8	1.38
Nickel	0 - 6 months	0.033	2.1	0.053
	7 mo - <5 years	0.033	9.3	0.24
	5 - <12 years	0.033	14.5	0.37
	12 - <20 years	0.033	15.8	0.41
	20 + years	0.033	15.8	0.40

A3-1.4 Intake of Metals from Backyard Garden Produce

Eating produce grown in backyards where metal levels are above typical levels, represents a potential exposure pathway if the metals present in the soil are taken up into the plant. The exposures received by people eating such produce depends upon the concentration of the metals in the fruits and vegetables and the amount of fruits and vegetables consumed from backyard gardens. The current assessment has assumed that backyard garden produce is consumed on a daily basis throughout the year. The amount of backyard garden fruits and vegetables consumed on an annually averaged daily basis is discussed in detail in Appendix 6.

As part of the ongoing work in Port Colborne, samples of backyard produce have been collected by the MOE and JWEL from Rodney and Mitchell Streets. The levels of individual metals in the various types of produce tested are provided in Appendix 1 of this report. For the purposes of this assessment, backyard garden produce has been divided into three general categories in order to ensure consistency with food consumption rates provided in Appendix 6:

root vegetables	includes: beet root, carrot, onion and radish
other vegetables	includes: beet tops, celery, lettuce, peppers, rhubarb, squash, leeks and tomatoes
fruits	includes: pear, apple, cantaloupe, peach, plum, watermelon, and grapes

For nickel, additional data sources such as those compiled from journal articles, MOE reports, and other relevant studies and reports have also been considered. Studies using forms of nickel with highly plant extractable or forms of nickel more soluble ($NiCl_2$ or $NiSO_4$) than in the Rodney Street soils (predominantly NiO) were not considered. Studies investigating only low soil nickel concentrations were also not considered. Port Colborne data prior to 1984 were not considered since they would have been strongly influenced by atmospheric deposition of Inco emissions such that nickel concentrations in produce would have resulted from atmospherically deposited nickel. The following table (Table A3-5) provides data sources considered for this evaluation and the rationale for the selection of relevant data sets.

Table A3-5: Data Sources Considered for Vegetation Uptake of Nickel

Data Source	Reason for Exclusion
MOE. 1977. Effect of Heavy Metal on the Growth of Lettuce, Celery, and Onion, Groetelaars Farm, Port Colborne.	atmospheric deposition
MOE. 1978a. Investigations of the Effects of Heavy Metals on Muck Farms East of International Nickel Company, Port Colborne, Ontario, 1976 - 1977.	atmospheric deposition
MOE. 1978b. Investigations of the Effects of Heavy Metals on Muck Farms East of International Nickel Company, Port Colborne, Ontario, 1976-1977. Ontario Ministry of the Environment, Air Resources Branch, Phytotoxicology Section.	atmospheric deposition
MOE. 1979. Phytotoxicology Complaint Investigation, J. Overholt, Port Colborne, 1979.	atmospheric deposition
OMAF. 1980. Report on Agronomic Problems Experienced by Three Growers Located Near Port Colborne.	atmospheric deposition

Table A3-5: Data Sources Considered for Vegetation Uptake of Nickel

Data Source	Reason for Exclusion
MOE. 1980a. Investigations of Agronomic Problems Associated with Metal Toxicity on Muck Farms in the Vicinity of Inco, Port Colborne, 1976-1979.	atmospheric deposition
MOE. 1980b. Phytotoxicology Complaint Investigation, J. Overholt, Port Colborne, 1980.	atmospheric deposition
MOE. 1981. Effects of Heavy Metals and Root Knot Nematode on Celery Grown on Organic Soil in the Vicinity of International Nickel Company, Port Colborne, Ontario, 1980.	atmospheric deposition
MOE. 1983. Levels of Ni, Cu, and Co in Vegetable and Soil Samples Collected from Residential Gardens in the Vicinity of Inco Limited, Port Colborne.	atmospheric deposition
MOE. 1984a. Investigation of Alleged SO_2 Injury to Celery on Overholt Farm, Port Colborne, October 3, 1983.	atmospheric deposition
MOE. 1984b. Nickel Phytotoxicity on Celery and Lettuce Grown on Soil Contaminated by a Nickel Refinery.	atmospheric deposition
MOEE. 1994. Nickel Uptake into Vegetables Growing in Experimental Plots. Ecological Standards & Toxicology Section, MOEE, unpublished data.	low soil concentrations
Cantox. 1999. Deloro Village Exposure Assessment and Health Risk Characterization for Arsenic and Other Metals, Cantox Environmental Inc., December, 1999.	low soil concentrations
JWEL. 2001. 2001 Food Basket Collection. Unpublished data supplied by JWEL on October 4, 2001. Jacques Whitford Environmental Limited.	not excluded
JWEL. 2000b. Garden Soil Data - Rodney Street Area, Sampled from the 18th-22nd of September, 2000. Jacques Whitford Environmental Limited.	not excluded
MOE. 2001. Garden soil and plant data from Rodney Street, Sampled from November 2000 to January 2001.	not excluded
Biró, B., I. Köves-Péchy, and I. Kádár. 1998. Toxicity of Some Field Applied Heavy Metal Salts to the Rhizobial and Fungal Microsymbionts of Alfalfa and Red Clover. Agrokémia és Talajtan 42:265-276.	$NiSO_4$ (soluble form of nickel)
Braillier, S., R.B. Harrison, C.L. Henry, and X. Dongsen. 1996. Liming effects on availability of Cd, Cu, Ni and Zn in a soil amended with sewage sludge 16 years previously. Water, Air and Soil Pollution. 86:195-206.	low soil concentrations
Frank, R., K.I. Stonefield, P. Suda, and J.W. Potter. 1982. Impact of nickel contamination on the production of vegetables on an organic soil, Ontario, Canada, 1980-1981. Sci. Total Environ. 26:41-65.	atmospheric deposition

Table A3-5: Data Sources Considered for Vegetation Uptake of Nickel

Data Source	Reason for Exclusion
Guo, Y., R. Schulz, and H. Marschner. 1995. Genotypic differences in uptake and distribution of cadmium and nickel in plants. Agnew. Bot. 69:42-48.	$NiSO_4$ (soluble form of nickel) & low soil concentrations
L'Huillier, L., and S. Edighoffer. 1996. Extractability of nickel and its concentration in cultivated plants in Ni rich ultramafic soils of New Caledonia. Plant and Soil. 186:255-264.	Soil with exceptionally high plant extractable nickel
Maclean, A.J. and A.J. Dekker. 1978. Availability of zinc, copper and nickel to plants grown in sewage treated soils. Can. J. Soil Sci. 58:381-389.	$NiSO_4$ (soluble form of nickel)
Sajwan, K.S., W.H. Ornes, T.V. Youngblood, and A.K. Alva. 1996. Uptake of soil applied cadmium, nickel, and selenium by bush beans. Water, Air, Soil Pollut. 91:209-217.	$NiCl_2$ (soluble form of nickel) & low soil concentrations
Sauerbeck, D. R., and A. Hein. 1991. The nickel uptake from different soils and its prediction by chemical extractions. Water, Air, Soil Pollut. 57-58: 861-871.	low soil concentrations
Traynor, M.F. and B.D. Knezek. 1973. Effects of nickel and cadmium contaminated soils on nutrient composition of corn plants. Proc. Annual Conf. on Trace Substances in the Environment. 7:82-87.	$NiCl_2$ (soluble form of nickel)
Vergnano Gambi, O., R. Gabbrielli, and L. Pancaro. 1982. Nickel, chromium and cobalt in plants from Italian serpentine areas. Acta Oecologica Oecologica Plantarum 3(17): 291-306.	low soil concentrations

Data sources were narrowed down to three relevant data sets (JWEL, 2000b, JWEL, 2001 and MOE, 2001 data) that were reflective of current conditions. An additional backyard produce nickel data set from Port Colborne was recently available from JWEL, but the subsequent tissue nickel fresh weight mean and 95th percentile concentrations in the three produce categories and in the pooled data set were not significantly different from the values already calculated for the original data. Laboratory analysis of vegetables typically report concentrations on a dry weight basis. This was the case for all of the JWEL (2000b) and MOE (2001) and some of the JWEL (2001) data discussed above. Since vegetables are not typically consumed in a dry state, these concentrations were converted to a fresh (or wet) weight (as consumed). To convert dry weight to fresh weight, dry weight tissue concentrations were multiplied by the appropriate dry weight to fresh weight conversion factor based on the typical moisture contents of vegetables. The USDA (1963), Baes et al., (1984) and US EPA (1997) have recommended dry weight to fresh weight conversion factors for several fruits and vegetables collected as part of the JWEL (2000b), MOE (2001) and JWEL (2001) surveys (Table A3-6). Where plant specific factors were not available, the conversion factor was based on a similar plant type. The majority of the JWEL (2001) data was provided on a fresh weight basis (conversion was not necessary for this data).

Table A3-6: Dry Weight to Fresh Weight Conversion Factors

Vegetables	Conversion Factor	Fruits	Conversion Factor
Basil	0.045	Apples	0.15
Beans	0.099	Cantaloupes & Melons	0.10
Beets	0.13	Grapes	0.19
Beet tops	0.091	Peaches	0.11
Broccoli	0.093	Pears	0.17
Cabbage	0.0468	Plums	0.21
Carrots	0.12	Watermelons	0.10
Celery	0.059		
Leeks	0.124		
Lettuce	0.045		
Onions	0.11		
Parsnips	0.21		
Peppers	0.066		
Radish/Horse Radish	0.0516		
Rhubarb	0.052		
Squash	0.057		
Tomatoes	0.065		
Zucchini	0.054		

A review of the available produce data indicated that the concentrations of metals in produce is not strongly affected by the levels of metals present in the soil and as such it was not possible to derive appropriate uptake factors for the Rodney Street community. As a result, upper bound produce concentrations measured in the area were assumed for all gardens in the assessment. With the exception of nickel, maximum values were selected due to limited data sets (see Appendix 1). For nickel, over 180 relevant plant samples were available and as a result it was considered more appropriate to select an upper bound plant concentration to represent all gardens in the assessment (Appendix 1 presents the data available at the time of this assessment). The 95th percentile concentration was selected based on the following rationale: (i) others have considered the 95th percentile of a non-normal distribution to be representative of an upper bound value (the data set appears to be log-normally distributed); (ii) the data set is highly skewed and maximum values would not be reflective of reasonable upper bound exposures; (iii) a typical diet would consist of a composite of the available produce types, while the maximum level is only reflective of a single plant type and garden location. No distinction was made for different produce types, rather the selected upper bound concentration was assumed to represent all plant types. These selected levels are reported in Table A3-7.

Table A3-7: Metal Levels in Backyard Produce in Port Colborne

Vegetable	Metal Concentrations in Vegetables (µg/g) (Fresh Weight)					
	Antimony	Beryllium	Cadmium	Cobalt	Copper	Nickel
Root Vegetables	0.021	0.007	0.063	0.048	1.92	2.44
Other Vegetables	0.021	0.007	0.063	0.048	1.92	2.44
Fruits	0.021	0.007	0.063	0.048	1.92	2.44

Daily intakes of metal from backyard produce are calculated as shown in equation A3-3. Estimates of daily metals intakes from backyard garden produce for all age groups are shown in Table A3-8.

Eq A3-3:

$$Intake_{veg} = \left(IR_{root} * C_{root}\right) + \left(IR_{other} * C_{other}\right)$$

Where:	$Intake_{veg}$	=	Intake from backyard garden produce	µg/day
	IR_x	=	Yearly averaged daily intake of backyard root or other vegetables (see Appendix 6)	g/day
	C_x	=	Metal concentration in root/other vegetables on a fresh weight basis	µg/g

Table A3-8: Estimated Metal Intakes from Backyard Vegetables

Metal	Receptor	Root Vegetables			Other Vegetables			Fruits			Total (µg/day)
		C_{root} (µg/g)	IR_{root} (g/day)	$Intake_{veg}$ (µg/day)	C_{root} (µg/g)	IR_{other} (g/day)	$Intake_{veg}$ (µg/day)	C_{root} (µg/g)	IR_{fruit} (g/day)	$Intake_{veg}$ (µg/day)	
Antimony	0 - 6 months	0.021	6.05	0.127	0.021	5.25	0.11	0.021	3.96	0.08	0.32
	7 mo - <5 years	0.021	7.65	0.161	0.021	4.88	0.10	0.021	6.81	0.14	0.41
	5 - <12 years	0.021	11.7	0.25	0.021	7.14	0.15	0.021	7.80	0.16	0.56
	12 - <20 years	0.021	16.5	0.35	0.021	8.75	0.18	0.021	7.51	0.16	0.69
	20 + years	0.021	13.7	0.29	0.021	9.99	0.21	0.021	7.13	0.15	0.65
Beryllium	0 - 6 months	0.007	6.05	0.04	0.0070	5.25	0.037	0.0070	3.96	0.028	0.11
	7 mo - <5 years	0.007	7.65	0.05	0.0070	4.88	0.034	0.0070	6.81	0.048	0.14
	5 - <12 years	0.007	11.7	0.08	0.0070	7.14	0.050	0.0070	7.80	0.055	0.19
	12 - <20 years	0.007	16.5	0.12	0.0070	8.75	0.061	0.0070	7.51	0.053	0.23
	20 + years	0.007	13.7	0.10	0.0070	9.99	0.070	0.0070	7.13	0.050	0.22
Cadmium	0 - 6 months	0.063	6.05	0.38	0.063	5.25	0.33	0.063	3.96	0.25	0.96
	7 mo - <5 years	0.063	7.65	0.48	0.063	4.88	0.31	0.063	6.81	0.43	1.22
	5 - <12 years	0.063	11.7	0.74	0.063	7.14	0.45	0.063	7.80	0.49	1.7
	12 - <20 years	0.063	16.5	1.0	0.063	8.75	0.55	0.063	7.51	0.47	2.1
	20 + years	0.063	13.7	0.86	0.063	9.99	0.63	0.063	7.13	0.45	1.9
Cobalt	0 - 6 months	0.048	6.05	0.29	0.048	5.25	0.25	0.048	3.96	0.19	0.73
	7 mo - <5 years	0.048	7.65	0.37	0.048	4.88	0.23	0.048	6.81	0.33	0.9
	5 - <12 years	0.048	11.7	0.56	0.048	7.14	0.34	0.048	7.80	0.37	1.3
	12 - <20 years	0.048	16.5	0.8	0.048	8.75	0.42	0.048	7.51	0.36	1.6
	20 + years	0.048	13.7	0.66	0.048	9.99	0.5	0.048	7.13	0.3	1.5
Copper	0 - 6 months	1.92	6.05	12	1.92	5.25	10.1	1.92	3.96	7.6	29
	7 mo - <5 years	1.92	7.65	15	1.92	4.88	9.4	1.92	6.81	13.1	37
	5 - <12 years	1.92	11.7	22	1.92	7.14	14	1.92	7.80	15	51
	12 - <20 years	1.92	16.5	32	1.92	8.75	17	1.92	7.51	14	63
	20 + years	1.92	13.7	26	1.92	9.99	19	1.92	7.13	14	59
Nickel	0 - 6 months*										
	7 mo - <5 years	2.44	7.65	19	2.44	4.88	12	2.44	6.81	17	47
	5 - <12 years	2.44	11.7	29	2.44	7.14	17	2.44	7.80	19	65
	12 - <20 years	2.44	16.5	40	2.44	8.75	21	2.44	7.51	18	80
	20 + years	2.44	13.7	33	2.44	9.99	24	2.44	7.13	17	75

*While it is possible that the infant would consume some produce in the first six months of life, home garden produce was not considered since total diet estimates included produce and inclusion of home garden produce would over-estimate infant exposures. See section 5.6.1, Table A4-4 and footnotes for details of nickel intake in the infant diet.

Note: Due to rounding of values, total intakes may not add up to exactly the sum of the intakes for each row, in particular the final decimal place.

A3-1.5 Intake of Metals from Soil/Dust

The metals of concern in the Rodney Street community area of Port Colborne are generally tightly bound to soil particles and are present in forms that either have limited solubility in water or are largely insoluble. However, the solubility of these metals increases under acidic conditions. When ingested, metals that are insoluble in water at neutral pH (6.0 - 8.0) can be solubilized and removed from soil particles in the acidic environment of the stomach. The metals released from the soil in the stomach become accessible for uptake by the gut. Ingested metals that remain bound to soil particles in the gut are not available for absorption and are excreted in the feces. The daily intake of metal from ingested soil is a function of the amount of soil ingested, the level of metal contained in the soil and the amount of metal released from the soil particles under the acidic conditions of the stomach. Similarly, metals are bound to indoor dusts in much the same way as soil, since the source of some of the indoor dust is actually soil from outdoors. While the physical characteristics of dusts may be significantly different than those of soil (e.g., particle size and composition), current data does not allow for an adequate distinction between the exposures from these two media. As a result, the current assessment considers these as a combined media group. The estimated daily intake of metal from the ingestion of soil is calculated as shown in equation A3-4.

Eq A3-4:

$$Intake_{soil} = Intake_{soilout} + Intake_{soilin}$$

$$Intake_{soilout} = \left[\left(Csoil_{out} * Fract_{winter} * Fract_{out} * WF\right) + \left(Csoil_{out} * \left(1 - Fract_{winter}\right) * Fract_{out}\right)\right] * IR_{soil} * Bio_{soil}$$

$$Intake_{soilin} = \left[\left(Cdust_{in} * Fract_{winter} * \left(1 - Fract_{out}\right)\right) + \left(Cdust_{in} * \left(1 - Fract_{winter}\right) * \left(1 - Fract_{out}\right)\right)\right] * IR_{soil} * Bio_{soil}$$

Where:	$Intake_{soil}$	=	Intake from soil/dust	µg/day
	$Intake_{soilout}$	=	Intake from soil while outdoors	µg/day
	$Intake_{soilin}$	=	Intake from dust while indoors	µg/day
	IR_{soil}	=	Soil/dust ingestion rate	g/day
	Bio_{soil}	=	Soil bioaccessibility factor	unitless
	$Csoil_{out}$	=	Outdoor soil concentration (measured)	µg/g
	WF	=	10% winter covering factor assumed*	
	$Cdust_{in}$	=	Indoor dust concentration (0.39 indoor dust to outdoor soil concentration ratio; see Appendix 6)	µg/g
	$Fract_{out}$	=	Fraction of daily soil ingestion rate allocated to outdoor exposure; see Appendix 6	unitless
	$Fract_{winter}$	=	Fraction of year that is considered winter; see Appendix 6	unitless

A winter covering factor has been assumed for the Rodney Street community. The basis of this factor is the following: (i) between December and March 1963 to 1993, daily minimum temperatures average less than 0°C for Port Colborne (Environment Canada; Seasonal Forecasts, http://weatheroffice.ec.gc.ca/saisons/index_e.html) indicating that the ground is likely to remain frozen throughout these months reducing the accessibility of the soil for direct contact and movement of dust into homes; (ii) between December and March, daily maximum temperatures average less than 5°C for Port Colborne (Environment Canada; Climate Normals); due to these colder temperatures, it is likely that children will not be 'playing' in the dirt with exposed skin; most children will wear mittens or gloves throughout these winter months (iii) between December and March, most precipitation is in the form of snow, as a result, the ground will tend to be covered and unaccessible throughout this time period. On the basis of these factors, it has been assumed that contact with the soil will be approximately 1/10 for the four winter months as compared with other months of the year.

The soil ingestion rates and activity patterns for each of the receptor age groups are listed in Table 4-3 of the main report. The highest reported level of each metal in the soil from the Rodney Street community was used to estimate the daily ingestion of metal from soil. The Bio_{soil} parameter is a measure of the amount of metal that is released from the soil under the acidic and neutral pH conditions of the stomach and small intestine. This represents the amount of metal that is considered to be bio-accessible, or available to the gut for uptake, from the soil. The amount of each metal released from the soil in the stomach has been estimated using a simulated stomach acid leach test and a bioaccessibility test. The test methodologies are discussed in detail in Appendix 5. The results of the stomach acid leach test and bioaccessibility test for each metal are also provided in Appendix 5. For each metal, the highest average reported result for the sieved only soil samples tested by Exponent (Table A5-17) was used as a relative bioavailability adjustment factor to estimate the amount of metal that would be comparable to the form of the metal used in the toxicity data used to derive the oral R*f*D. This was used to estimate the effective daily intake for each metal from soil. The estimated daily intake of each metal from the soil is shown in Table A3-9.

Table A3-9: Estimated Metal Intakes from Soil

Metal	Receptor	C_{soil} (µg/g)	IR_{soil} (g/day)	Bio_{soil}	Total (µg/day)
Antimony	0 - 6 months	91.1	0.035	0.32	0.54
	7 mo - <5 years	91.1	0.100	0.32	1.54
	5 - <12 years	91.1	0.100	0.32	1.54
	12 - <20 years	91.1	0.020	0.32	0.309
	20 + years	91.1	0.020	0.32	0.309
Beryllium	0 - 6 months	4.56	0.035	0.59	0.050
	7 mo - <5 years	4.56	0.100	0.59	0.144
	5 - <12 years	4.56	0.100	0.59	0.144
	12 - <20 years	4.56	0.020	0.59	0.0287
	20 + years	4.56	0.020	0.59	0.0287
Cadmium	0 - 6 months	35.3	0.035	0.76	0.498
	7 mo - <5 years	35.3	0.100	0.76	1.42
	5 - <12 years	35.3	0.100	0.76	1.42
	12 - <20 years	35.3	0.020	0.76	0.284
	20 + years	35.3	0.020	0.76	0.284
Cobalt	0 - 6 months	262	0.035	0.29	1.41
	7 mo - <5 years	262	0.100	0.29	4.02
	5 - <12 years	262	0.100	0.29	4.02
	12 - <20 years	262	0.020	0.29	0.805
	20 + years	262	0.020	0.29	0.805
Copper	0 - 6 months	2720	0.035	0.43	21.7
	7 mo - <5 years	2720	0.100	0.43	61.9
	5 - <12 years	2720	0.100	0.43	61.9
	12 - <20 years	2720	0.020	0.43	12.4
	20 + years	2720	0.020	0.43	12.4
Nickel	0 - 6 months	17000	0.035	0.19	59.9
	7 mo - <5 years	17000	0.100	0.19	171
	5 - <12 years	17000	0.100	0.19	171
	12 - <20 years	17000	0.020	0.19	34.2
	20 + years	17000	0.020	0.19	34.2

A3-1.6 Intake of Metals Through Dermal Contact with Soil/Dust

Daily contact with metals through soil present on the skin represents a potential route of exposure. However, the insoluble nature of most metals in soil limits their bio-accessability for uptake into and through the skin. Where data is available, it shows that dermal uptake of metals is low (Paustenbach, 2000). The rate at which a metal is taken up into the outer layers of the skin is referred to as the *dermal uptake coefficient* (DUC). For the purposes of the current exposure assessment, the dermal uptake coefficients have been used to represent the amount of metal delivered to the skin surface from the soil that would be accessible for uptake. This is considered to be the *delivered dose* and has been considered to be equivalent to the dermal intake. A detailed discussion of the derivation of the DUC values for each of the metals is provided in Appendix 7. The delivered dose, is calculated as shown in Eq A3-5. These values have been used in conjunction with the estimates of intake from other sources to provide an estimate of the total daily dose for each age group for each metal (Table A3-10).

Eq A3-5:

$$Intake_{dermal} = Intake_{dermout} + Intake_{der\min}$$

$$Intake_{dermout} = \left[\left(Csoil_{out} * Time_{outwin} * SA_{win} * WF\right) + \left(Csoil_{out} * Time_{outsum} * SA_{sum}\right)\right] * A_{soil} * EF * DUC_{soil}$$

$$Intake_{der\min} = \left[\left(Cdust_{in} * Time_{inwin} * SA_{win} * WF\right) + \left(Cdust_{in} * Time_{insum} * SA_{sum}\right)\right] * A_{soil} * EF * DUC_{soil}$$

Where: $Intake_{dermal}$ = Dermal intake from soil/dust µg/day
$Intake_{dermout}$ = Dermal intake from soil/dust while outdoors µg/day
$Intake_{dermin}$ = Dermal intake from dust while indoors µg/day
A_{soil} = Soil adhesion to skin mg/cm^2/event
EF = Exposure Frequency (1 event/day) event/day
DUC_{soil} = Dermal uptake coefficient unitless
$Csoil_{out}$ = Outdoor summer soil concentration (measured) µg/g
WF = 10% winter covering factor assumed (see above)
$Cdust_{in}$ = Indoor summer dust concentration (0.39 indoor dust to outdoor soil concentration ratio; see Appendix 6) µg/g
SA_{win} = Exposed surface area during winter months; see Appendix 6 m^2
SA_{sum} = Exposed surface area during summer months; see Appendix 6 m^2
$Time_{insum}$ = Fraction of time spent indoors during summer; see Appendix 6 unitless
$Time_{inwin}$ = Fraction of time spent indoors during winter; see Appendix 6 unitless
$Time_{outsum}$ = Fraction of time spent outdoors during summer; see Appendix 6 unitless
$Time_{outwin}$ = Fraction of time spent outdoors during winter; see Appendix 6 unitless

Table A3-10: Estimated Metal Intakes from Dermal Contact with Soil

Metal	Receptor	C_{soil} (µg/g)	A_{soil} (mg/cm^2/event)	DUC_{soil}	$Intake_{dermal}$ (µg/day)
Antimony	0 - 6 months	91.1	0.2	0.010	0.098
	7 mo - <5 years	91.1	0.2	0.010	0.167
	5 - <12 years	91.1	0.2	0.010	0.276
	12 - <20 years	91.1	0.07	0.010	0.146
	20 + years	91.1	0.07	0.010	0.156
Beryllium	0 - 6 months	4.56	0.2	0.010	0.00495
	7 mo - <5 years	4.56	0.2	0.010	0.00845
	5 - <12 years	4.56	0.2	0.010	0.0139
	12 - <20 years	4.56	0.07	0.010	0.00739
	20 + years	4.56	0.07	0.010	0.00789
Cadmium	0 - 6 months	35.3	0.2	0.010	0.038
	7 mo - <5 years	35.3	0.2	0.010	0.0649
	5 - <12 years	35.3	0.2	0.010	0.107
	12 - <20 years	35.3	0.07	0.010	0.0568
	20 + years	35.3	0.07	0.010	0.0606
Cobalt	0 - 6 months	262	0.2	0.004	0.0113
	7 mo - <5 years	262	0.2	0.004	0.0192
	5 - <12 years	262	0.2	0.004	0.0317
	12 - <20 years	262	0.07	0.004	0.0168
	20 + years	262	0.07	0.004	0.018
Copper	0 - 6 months	2720	0.2	0.010	2.93
	7 mo - <5 years	2720	0.2	0.010	4.99
	5 - <12 years	2720	0.2	0.010	8.23
	12 - <20 years	2720	0.07	0.010	4.37
	20 + years	2720	0.07	0.010	4.66
Nickel	0 - 6 months	17000	0.2	0.00038	0.695
	7 mo - <5 years	17000	0.2	0.00038	1.19
	5 - <12 years	17000	0.2	0.00038	1.96
	12 - <20 years	17000	0.07	0.00038	1.04
	20 + years	17000	0.07	0.00038	1.11

A3-2 Summary

For each receptor age group, daily metal intakes have been estimated for each of the pathways of concern. For each metal, intakes from all exposure pathways must be combined for each receptor in order to estimate the total daily dose received by each receptor age group. This summation of exposures is presented in Section 4.4 of the Human Health Risk Assessment main report (Part B).

A3-3 References

Baes, C.F., R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. Review and Analysis of Parameters and Assessing Transport of Environmentally Released Radionuclides Through Agriculture, Oak Ridge National Laboratory, Oak Ridge, TN.

Biró, B., I. Köves-Péchy, and I. Kádár. 1998. Toxicity of Some Field Applied Heavy Metal Salts to the Rhizobial and Fungal Microsymbionts of Alfalfa and Red Clover. Agrokémia és Talajtan 42:265-276.

Braillier, S., R.B. Harrison, C.L. Henry, and X. Dongsen. 1996. Liming effects on availability of Cd, Cu, Ni and Zn in a soil amended with sewage sludge 16 years previously. Water, Air and Soil Pollution. 86:195-206.

Cantox. 1999. Deloro Village Exposure Assessment and Health Risk Characterization for Arsenic and Other Metals, Cantox Environmental Inc., December, 1999.

CCME (Canadian Council of Ministers of the Environment). 1997. Canadian Soil Quality Guidelines for Copper. CCME Subcommittee on Environmental Quality Criteria for Contaminated Sites. ISBN 0-662-25520-8.

CEPA (Canadian Environmental Protection Act). 1994. Cadmium and its compounds. Priority substances list assessment report. Government of Canada: Environment Canada, Health Canada. ISBN 0-662-22046-3.

Dabeka, R.W. 1989. Survey of lead, cadmium, cobalt and nickel in infant formulas and evaporated milks and estimation of dietary intakes of the elements by infants 0-12 months old. Sci. Total Environ. 89:279-89.

Dabeka, R.W and A.D. McKenzie. 1995. Survey of lead, cadmium, fluoride, nickel and cobalt in food composites and estimation of dietary intakes of these elements by Canadians in 1986-1988. J.A.O.A.C. 78: 897-909.

Frank, R., K.I. Stonefield, P. Suda, and J.W. Potter. 1982. Impact of nickel contamination on the production of vegetables on an organic soil, Ontario, Canada, 1980-1981. Sci. Total Environ. 26:41-65.

FSA (Food Standards Agency). 1997. Food Safety Information Bulletin, Bulletin Number 90, November, 1997, Department of Health; United Kingdom.

Guo, Y., R. Schulz, and H. Marschner. 1995. Genotypic differences in uptake and distribution of cadmium and nickel in plants. Agnew. Bot. 69:42-48.

JWEL. 2001. 2001 Food Basket Collection. Unpublished data supplied by Jacques Whitford Environmental Limited on October 4, 2001.

JWEL. 2000a. Document in Preparation. Jacques Whitford Environmental Limited.

JWEL. 2000b. Garden Soil Data - Rodney Street Area, Sampled from the 18th-22nd of September, 2000. Jacques Whitford Environmental Limited.

L'Huillier, L., and S. Edighoffer. 1996. Extractability of nickel and its concentration in cultivated plants in Ni rich ultramafic soils of New Caledonia. Plant and Soil. 186:255-264.

Maclean, A.J. and A.J. Dekker. 1978. Availability of zinc, copper and nickel to plants grown in sewage-treated soils. Can. J. Soil Sci. 58:381-389.

MOE. 1977. Effect of Heavy Metal on the Growth of Lettuce, Celery, and Onion, Groetelaars Farm, Port Colborne.

MOE. 1978a. Investigations of the Effects of Heavy Metals on Muck Farms East of International Nickel Company, Port Colborne, Ontario, 1976 - 1977.

MOE. 1978b. Investigations of the Effects of Heavy Metals on Muck Farms East of International Nickel Company, Port Colborne, Ontario, 1976-1977. Ontario Ministry of the Environment, Air Resources Branch, Phytotoxicology Section.

MOE. 1979. Phytotoxicology Complaint Investigation, J. Overholt, Port Colborne, 1979.

MOE. 1980a. Investigations of Agronomic Problems Associated with Metal Toxicity on Muck Farms in the Vicinity of Inco, Port Colborne, 1976-1979.

MOE. 1980b. Phytotoxicology Complaint Investigation, J. Overholt, Port Colborne, 1980.

MOE. 1981. Effects of Heavy Metals and Root Knot Nematode on Celery Grown on Organic Soil in the Vicinity of International Nickel Company, Port Colborne, Ontario, 1980.

MOE. 1983. Levels of Ni, Cu, and Co in Vegetable and Soil Samples Collected from Residential Gardens in the Vicinity of Inco Limited, Port Colborne.

MOE. 1984a. Investigation of Alleged SO_2 Injury to Celery on Overholt Farm, Port Colborne, October 3, 1983.

MOE. 1984b. Nickel Phytotoxicity on Celery and Lettuce Grown on Soil Contaminated by a Nickel Refinery.

MOEE. 1994. Nickel Uptake into Vegetables Growing in Experimental Plots. Ecological Standards & Toxicology Section, MOEE, unpublished data.

MOE. 1999. Phytotoxicology Soil Investigation: Inco - Port Colborne (1998). Ontario Ministry of the Environment. Report No. SDB-031-3511-1999. ISBN 0-7778-9260-X.

MOE. 2000. Phytotoxicology Soil Investigation: Inco - Port Colborne (1999). Phytotoxicology and Soil Standards Section, Standards Development Branch, Ontario Ministry of the Environment. Report No. SDB-031-3511-2000.

MOE. 2001. Garden soil and plant data from Rodney Street, Sampled from November 2000 to January 2001.

OMAF. 1980. Report on Agronomic Problems Experienced by Three Growers Located Near Port Colborne.

Paustenbach, D.J. 2000. The Practice of Exposure Assessment: A State-of-the-Art Review. J. Toxicol. Environ. Health, Part B. 3:179-291.

Roberts, T.M., T.C. Hutchinson, J. Paciga, A. Chattopadhyay, R.E. Jervis, J. VanLoon, and D.K. Parkinson. 1974. Lead contamination around secondary smelters: estimation of dispersal and accumulation in humans. Science 186:1120.

Sajwan, K.S., W.H. Ornes, T.V. Youngblood, and A.K. Alva. 1996. Uptake of soil applied cadmium, nickel, and selenium by bush beans. Water, Air, Soil Pollut. 91:209-217.

Sauerbeck, D.R., and A. Hein. 1991. The nickel uptake from different soils and its prediction by chemical extractions. Water, Air, Soil Pollut. 57-58: 861-871.

Traynor, M.F. and B.D. Knezek. 1973. Effects of nickel and cadmium contaminated soils on nutrient composition of corn plants. Proc. Annual Conf. on Trace Substances in the Environment 7:82-87.

USDA. 1963. Agricultural Handbook No. 8., published by the United States Department of Agriculture (revised 1963).

US EPA. 1997. Exposure Factors Handbook. US Environmental Protection Agency. EPA/600/P-95/002Fa.

Vaessen, H.A.M.G., and B. Szteke. 2000. Beryllium in food and drinking water - a summary of available knowledge. Food Additives and Contaminants. 17(2): 149-159.

Vergnano Gambi, O., R. Gabbrielli, and L. Pancaro. 1982. Nickel, chromium and cobalt in plants from Italian serpentine areas. Acta Oecologica Oecologica Plantarum. 3(17): 291-306.