NGU Report 98.138

Assesssment of heavy metal emissions from the copper-nickel industry on the Kola Peninsula and in other parts of Russia

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REPORT

Report no.: 98.138	ISSN 0800-3416	Grading: Open

Title:

Assesssment of heavy metal emissions from the copper-nickel industry on the Kola Peninsula and in other parts of Russia

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County:	Commune:
Map-sheet name (M=1:250.000)	Map-sheet no. and -name (M=1:50.000)
Deposit name and grid-reference:	Number of pages: 18 Price (NOK): Kr. 40,- Map enclosures:

Fieldwork carried out:	Date of report: 30.11.1998	Project no.: 2590.02	Person responsible: A. Bjørlykke

Summary:

Published estimates for heavy metal emissions from the copper-nickel industry on the Kola Peninsula in Northwest Russia are re-examined in the light of: a) Official Russian emission figures for 1993 and 1994, b) Modelled emissions based on calculated dry and wet deposition estimates based on data from snow and rain sampling carried out in 1994, c) Chemical data on the composition of the ores being processed by the industry. The modelled emissions, official emission figures and chemical data are compatible, one with the other for nickel, copper and cobalt and indicate that previous estimates underestimated the emissions of the major elements, nickel and copper (though within the same order of magnitude). Consideration of the published estimates in relation to the modelled emissions and to chemical data for trace elements in the ores indicate that previously published figures overestimated the emissions of certain trace metals by up to several orders of magnitude, in some cases exceeding the calculated total input of these metals to the plants. These conclusions have implications for estimates of emissions from the copper-nickel industries in Siberia (the Noril'sk area) and from the metallurgical industry in the Urals; published estimates of these emissions have neglected the implications of information on the nature of the ores being processed (in the case of plants in the Urals) and on the chemistry of the ores (plants in both the Urals and at Noril'sk).

Keywords: Heavy metals	Nickel	Copper
Russia	Emissions	

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INTRODUCTION

Considerable attention has been devoted within the last thirty years to the detrimental effects of heavy metal emissions from a range of anthropogenic sources on the earth's environment including human, animal and plant life. The Arctic regions have been the focus of a number of major studies on regional and international scales (e.g. AMAP), because of the sensitivity of the Arctic environment, including its life forms, because of transport of pollutants to the Arctic from outside the area and because of the presence in the Arctic of a number of major, point-source emitters. The Russian nickel-copper industry, with major plants at Noril'sk in western Siberia, and at Nikel, Zapolyarniy and Monchegorsk on the Kola Peninsula (Fig. 1) constitutes perhaps the most important sources of anthropogenic heavy metal emissions to the atmosphere from within the Arctic (the industry also includes metallurgical plants at Krasnoyarsk, further south in Siberia).

The metallurgical industry in the cities on the Kola peninsula processes both local Ni-Cu sulphide ore, from deposits in the Pechenga Zone (the basis for the Ni-Cu industry in Nikel and Zapolyarniy), and ore from deposits in the Noril'sk province in Western Siberia. Several open-pit and underground mines are in operation. Annual production is estimated to be 30-35,000 tons Ni metal (Strishkov, 1989, quoted in Melezhik et al., 1994; Mining Journal 1997, 1998). Production is dominated by disseminated ore, typically containing c. 1 % Ni and 0.5 % Cu.

Part of the production from deposits in the Noril'sk province in Western Siberia (which totalled c. 150, 000 t in 1996, assuming c. 30,000 t from the Pechenga area (Mining Journal 1998) is transported by sea (the only means of surface transport to and from Noril'sk) for processing in Nikel and Monchegorsk. Deposits in this province have been mined since 1935 but transport of ore to the Kola Peninsula commenced in 1971-72. C. 22% of the Noril'sk Combine's total production (Mining Journal 1998) is processed by Severonickel, suggesting that transport of ore from Noril'sk is probably equivalent to less than 10,000 ton Ni metal. Collectively the Noril'sk deposits form a Cu-Ni resource comparable to those of the Sudbury deposits in Canada (DeYoung et al., 1985) and are one of the two largest sources of platinum metals in the world (along with the Bushveld deposits in South Africa). The Noril'sk province contains a wide range of ore types, including large volumes of massive ore, also of various types: In general the ores are characterised by having contents of Cu greater than those of Ni and by much higher contents of the platinum metals than the Pechenga ores. The Noril'sk and Pechenga ores thus have compositions as regards major metals which are quite distinct one from the other. The type of Noril'sk ore processed at Nikel and Monchegorsk is thought to contain, on average, 2.35% Ni and 2.7% Cu in ore with 70% sulphides (Elkem Technology, 1993).

The major metallurgical plants in the Nikel-Zapolyarniy area (Fig. 1), belonging to the Pechenganickel company (a subsidiary of Noril'sk Nikel), in addition to flotation plants, are a

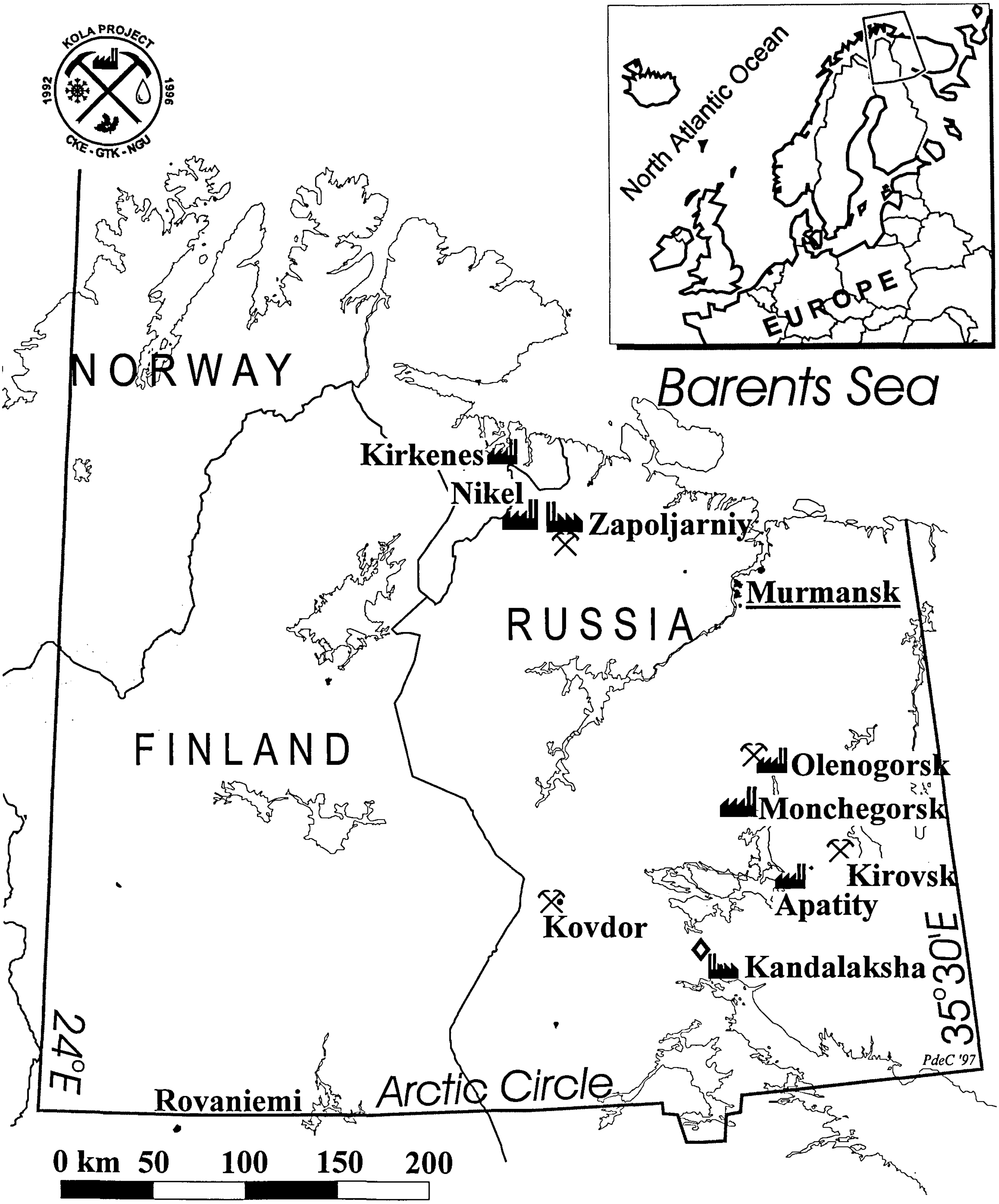

Fig. 1: Map of the Kola Ecogeochemistry project area, showing the major industrial centres on the Kola Peninsula (modified from Reimann et al. 1998).

smelter in Nikel and a roasting plant in Zapolyarniy. The smelter processes ore from Noril'sk, rich Pechenga ore, concentrate produced from lower-grade local ore and pellets from the roasting plant (which processes local ore alone). The metallurgical plants in Nikel and Zapolyarniy date from the period immediately after World War II. Plans exist for modernisation of the smelter in Nikel but financial problems have delayed their implementation. Ni-Cu ore has been mined in the past in the Monchegorsk area (Fig. 1) but the metallurgical plants in the town, belonging to the Severonickel company (also a subsidiary of Noril'sk Nikel), now process pellets from Zapolyarniy, matte from Nikel and matte and ore from Noril'sk. Nickel and copper metal are refined, sulphuric acid is produced and a platinum metal- and gold-bearing sludge is sent from Monchegorsk for further processing in Krasnoyarsk in western Siberia. Cobalt was refined in Monchegorsk up until 1996 when the cobalt refinery had to be closed (Mining Journal 1997).

The Geological Surveys of Finland and Norway and Central Kola Expedition in Monchegorsk are in the process of completing a study of the distribution of heavy metals in near-surface media (moss, humus, soil profiles) in an area extending from 24°E to 35°30'E and south to the Arctic Circle in Finland and to the southern border of Murmansk region in Russia (Fig. 1) (Reimann et al. 1998; World Wide Web site: http://www.ngu.no/Kola). The main aims of the project have been to study the distribution of heavy metals at regional and local scales and to distinguish anthropogenic from natural concentrations. The project area included all the major emission sources in the copper-nickel industry on the Kola Peninsula. Part of the project has included modelling of total deposition of metals based on actual observational data, and assessment of deposition in relation to emission figures (Caritat et al. 1997), not least the official figures for emissions from the industry for 1993 and 1994 (Murmansk Region Committee of Ecology and Natural Resources 1995). The assessments of total deposition and emission represent significant developments in relation to previously published estimates (NILU 1984; Pacyna et al. 1985a, b; Pacyna 1995): these improvements, which are the main topic of this paper, are based on the above-mentioned observational data but also take account of the importance of information on the nature of the ores being processed including their chemistry.

Published emission estimates and official emission figures

Estimates based on the use of emission factors: The first estimates of emissions from the copper-nickel industry in the then Soviet Union were published in 1984 (NILU) (Table 1). The estimates are based on produced tonnage of major metallic components multiplied by emission factors. Emission factors (Pacyna 1985; Nriagu & Pacyna 1988) are described as being based on the trace element chemistry of the raw material and the production and pollution-control technologies employed at the source of emissions. While the general nature of the copper-nickel ores being processed was well known by 1984 little was known of the trace metal chemistry of the ores and of the pollution-control technologies. It is thus perhaps not without cause that it is stated in the preface to the NILU report (1984): «Because of the limited information available, the users should note that the present survey may contain serious omissions and mistakes. Only experience will show to what extent these data will be of help tracing the origins of atmospheric pollutants» (The document gives specific estimates for a wide range of anthropogenic sources, not only the copper-nickel industry.)

	As	Cd	Cr	*Cu	Mn	Ni	Pb	Sb	Se	Zn
Kola	154	15	2	173	2	535	412	14	16	61
Urals	462	70	5	910	5	585	1220	41,5	47	444
Noril'sk	242	24	3	312	2,5	900	650	22	24,9	235

Table 1: Estimates of metal emissions from the copper-nickel industry in the Soviet Union (t/yr) (NILU 1984, Pacyna et al. 1985, Pacyna 1995 (except for Cu).

The figures also form part of the basis for emission estimates:

- At national levels ((Ottar et al. 1986; Pacyna 1986; Axenfeld et al. 1992)
- Per unit area within Europe (Pacyna et al. 1991; Axenfeld et al. 1992; Akeredolu et al. 1994)
- At global levels (Nriagu & Pacyna 1988; Pacyna 1997)
- Used in mathematically sophisticated studies of paths of transport for heavy metals within and into the Arctic (Akeredolu et al. 1994).

Recently global estimates of metal emissions to the atmosphere in 1983, i.e. presumably in part based on the above data, have appeared in AMAP (1997). The same publication also states that: «Preliminary estimates of emissions from Severonickel are approximately 3,000 tonnes of copper and 2,700 tonnes of nickel annually, but this information needs verification.» (Note that Severonickel is the name of the company running the smelter complex in Monchegorsk, Pechenganickel is the company running the activities in Nikel and Zapolyarniy: both are part of Noril'sk Nickel.) These estimates, which do not appear to include emissions from Pechenganickel in Nikel and Zapolyarniy, represent roughly 20- and 5-fold increases for copper and nickel respectively, in relation to those given in Table 1 (which do). The full AMAP scientific report (AMAP 1998) repeats the statement quoted above: in addition it states, in relation to the Pechenganickel plants: «The emissions of Cu and Ni in the Pechenganickel smelter complex are estimated to be approximately 310 and 510 tonnes, respectively. However, very recent information (e.g., Pozniakov 1993, Lyangusova 1990) suggests that actual emissions could be about one order of magnitude higher. By contrast, the official Russian data place the 1994 emissions from Nickel and Zapolyarniy at about 163 tonnes of Cu and 297 tonnes of Ni (CENR 1995).» The data from NILU (1984) form the basis for a figure in AMAP (1998) showing emissions of As, Cd, Ni and Zn from various sources in the former Soviet Union though with an apparent upward adjustment of the emissions from e.g. Noril'sk in relation to the estimates quoted in Fig. 1. A further figure in AMAP (1998) indicates emissions of Pb of the order of 800 tonnes annually from the Noril'sk smelters, based on estimates in Pacyna (1993) (also a significant increase relative to the estimate in NILU (1984).

Official emission figures: Official figures for the release of base metals to the atmosphere from the copper-nickel industries on the Kola peninsula and at Noril'sk are shown in Table 2. These figures broadly reflect the compositions of the ores being processed in the different plants. The Zapolyarniy emissions have a Ni:Cu ratio similar to that found in Pechenga ore. The Nikel and Monchegorsk emissions reflect the blend of ores from both Pechenga and Noril'sk being processed, in that both have show lower Ni:Cu ratios than Zapolyarniy. The emissions from Noril'sk have the lowest Ni:Cu ratio, reflecting the higher grade of Cu than Ni, even in the ore types poorer in Cu (see Table 5): the sulphur dioxide emissions at Noril'sk are due to the predominance of massive ores as opposed to the lower-grade disseminated ores which dominate production from the Pechenga ore bodies, leading to relatively low sulphur dioxide emissions from Zapolyarniy..

	Ni	Cu	Co	SO2
Nikel	136	82	5,2	129000
Zapolyarniy	161	81	5,4	69000
Monchegorsk	1619	934	81,5	98000
Total for Kola Ni-Cu industry	**1916**	**1097**	**92,1**	**296000**
Noril'sk	**1280**	**2380**	**67,5**	**1860000**

Table 2: Official figures for metal emissions in 1994 from the Ni-Cu industry on the Kola peninsula (Murmansk Region Committee of Ecology and Natural Resources 1995) and for Ni, Cu and SO_2 from the Noril'sk plants (Surnin et al. 1997). The figure for Co emission from Noril'sk is for 1992 (MGO Review 1993), a year in which the nickel emissions were at a level similar to that in 1994.

No information has been found on emissions from Ni production in the Urals but the evidence (see below) suggests that these would have a much lower level and a different chemistry from the emissions from the Kola Peninsula and Noril'sk.

Further published evidence documenting the close correlation between the chemistry of emissions and that of the ore feed is provided by data on the platinum metal chemistry of soils around Monchegorsk, which matches that of ores from the Talnakh deposits at Noril'sk with a «low» content of Cu rather closely (Boyd et al. 1997).

The emission figures are, of course, also heavily influenced by the efficiency of the different plants from which they emanate, including in the cases of Monchegorsk and Noril'sk several individual point sources. Given the difference in the tonnages produced (see below) it appears that the Noril'sk plants have a much more efficient metal recovery than that at Monchegorsk.

Evidence from models of deposition De Caritat et al (1997) have modelled total loadings of Ni, Cu and Co within circles of varying radius around Monchegorsk, on the basis of data on the chemistry of annual precipitation (water soluble and particulate) within catchments close to the city. The calculated loadings are compatible with (within 10% of) the official emission figures for Ni and Co, assuming a «shadow» zone around the source of 200-300 m. The calculated loading for Cu is c. 65% of the official figure, for the same order of «shadow» zone.

Chekushin et al (1998) have calculated deposition/km^2 for eight catchments on the Kola Peninsula, at varying distances from the sources of industrial pollution. Data for calculated deposition/km^2 for catchment 2 (5 km S of the smelters in Monchegorsk) and catchment 1 (10 km NE of the roasting plant at Zapolyarniy are given in Table 3. These data show that the calculated

	As	Cd	Cr	Cu	Ni	Pb	Sb	Co	V
Catchment 1	2,7	0,2	12	183	434	1,5	0,6	16,3	4,2
Catchment 2	2,8	0,4	5,2	494	845	5,8	0,7	60,3	19,3

Table 3: Calculated annual deposition/km^2 in kg in catchments 1 and 2 for selected elements (Chekushin et al. in press).

depositions of Cu, Ni and Co are in the general proportions found in the official emission figures. Calculated depositions of As, Cr and Pb are two orders of magnitude lower than those of Cu and Ni and those of Cd and Sb three orders of magnitude lower. V emissions are 1-2 orders of magnitude lower than those of Ni and Cu. These data thus form a basis for estimating emissions of the trace metals (see below).

The ore deposits and their chemistry

Pechenga: As noted above the deposits mined in both the Kola Peninsula and the Noril'sk area are copper-nickel sulphide deposits. General descriptions of the ore bodies have been published in a number of English-language publications (e.g. Smirnov 1977, Gorbunov et al. 1985) but little chemical data has been released, especially as regards trace constituents. Smirnov (1977) included information on the proportions of nickel:copper:cobalt in the different ore types. Naldrett (1981) published values for the content of Ni, Cu, Pt, Pd and Au in Pechenga ore, recalculated to total sulphide, based on data from Gorbunov (1968): the figures presented suggest a Ni/Cu ratio of just under 2 and a total platinum metal content in average ore of less than 1 ppm.. Melezhik et al. (1994) give general chemical information on the different ore types and their host rocks. Representative data for the major- and trace-element constituents of important ore types in the Pechenga area are shown in Table 4.

	n	Ni	Cu	S	As	Cr	Pb	Sb	Se	Zn	Co
WD	11	8300	4000	38600	7,9	2038	1,05	1,07	5	230	257
RD	8	37200	10900	135400	10	1196	3,3	1,12	32,3	257	704
BM	10	33000	5700	178700	41,1	966	3,44	0,6	32,3	230	794
M	11	71100	11600	287500	32,7	154	3,21	0,7	57,3	204	1516
Ni			0,8462	0,969328	0,538	-0,98	0,701	-0,5	0,989	-0,53	0,99
Cu				0,711238	0,086	-0,75	0,658	-0	0,825	-0,06	0,76
S					0,729	-1	0,751	-0,7	0,983	-0,59	0,99
As						-0,7	0,629	-1	0,618	-0,56	0,63
Cr							-0,78	0,67	-0,99	0,541	-0,99
Pb								-0,5	0,795	0,039	0,67
Sb									-0,58	0,659	-0,62
Se										-0,47	0,98
Zn											-0,63

Table 4: Chemical data in ppm for forty samples of Pechenga ore (S.-J. Barnes and Melezhik, unpublished data) grouped into weak dissemination (WD), rich dissemination (RD), brecciated massive ore (BM) and massive ore (M). n is the number of samples in each grouping. Correlation coefficients are shown below.

Urals: No copper-nickel sulphide deposits in the Urals have been in production in recent decades. A minor tonnage of nickel (Mining Journal 1997) is produced from nickel-cobalt laterite deposits, formed by deep weathering of silicate minerals. These have a bulk chemistry and mineralogy which is completely different from that found in the sulphide ores in the Pechenga and Noril'sk areas. The ores are dominated by secondary iron, magnesium and aluminium silicates in which the metals of economic interest are Ni and Co, of the order of 1 - 1.5% Ni and less than 0.1% Co. No information has been found on the contents of other trace metals in these ores but the literature on other deposits of this type, e.g. Golightly (1981) suggests that oxides of Cr and Mn are probable trace components in amounts under 0.5%.

Noril'sk: The Noril'sk ore province contains two main groups of deposits, Noril'sk s.s. at which many of the deposits are worked out, and Talnakh, the latter being the focus of production at present. Scanty information on the chemistry of the economically interesting components in the ores was published in the west in the 1970s (Naldrett & Cabri 1976; Smirnov 1977; Hoffman et al. 1979), indicating that the ores were rich, containing several per cent each of Ni and Cu, with Cu>Ni, and with unusually high contents of platinum metals, especially palladium. Detailed geological and chemical information has become available in the last six years (among others Czamanske et al. 1992; a series of papers in Lightfoot & Naldrett 1994, especially Zientek et al. 1994, and Foose et al. 1995). Most of the papers focus on the chemistry of the ores (with emphasis on Ni, Cu and the platinum group elements) or their host rocks, but Czamanske et al. (1992), Zientek et al. (1994) and Foose et al. (1995) include data on the contents of other trace metals in the ores.

	Ni	Cu	S	As	Pb	Sb	Se	Zn	Co
Cu-rich ore	2,5	27	32,5	1,5	200	1	100 - 300	600	800
Cu-poor ore	3,3	4,2	31,2	0,3	20	0,15	c. 50	150	1500

Table 5: Chemistry of the main ore types in one of the largest mines in the Talnakh group of deposits at Noril'sk. The figures are based on a graphical presentation in Zientek et al. (1994). The figures for Ni, Cu and S are in weight percent and those for the trace metals in ppm. The figures for Se are from Czamanske et al. (1992) and show levels found in ores with a Cu content corresponding to the ore types defined by Zientek et al. (1994).

Various lines of evidence, including the official emission figures, calculated deposition figures and others (Elkem Technology 1993) suggest that the ore transported from Noril'sk to Nikel and Monchegorsk for processing is of the Cu-poor type.

Annual production in the industry

Pechenga: Little is known of the exact proportions of the different ore types being produced and none on their historical production. It is, however, known that the currently accessible reserves in the Pechenga area are approaching exhaustion (with a production horizon of 5-10 years, depending on a range of economic factors) and that plans exist for moving all production underground within this time period (Mining Journal 1997). This implies that the bulk of current production is from lower-grade disseminated ore being mined in the large open-pit facilities near Zapolyarniy.

The data in Table 4 suggest that a figure for production of Ni metal can be used as a basis for estimation of the tonnages of Cu, As, S, Pb, Se and Co being processed, independent of the proportions of the different ore types processed. Cr has a strong negative correlation with these elements and Sb and Zn more moderate negative correlations with Ni and substantially no correlation with Cu. Cr, Sb and Zn have moderate correlations, one with the other, indicating their presence largely in silicates or oxides. Tonnages of Cr, Sb and Zn being processed can thus only be estimated on the basis of quite detailed knowledge of the chemistry of a given tonnage of ore.

Annual production, as noted above is estimated to be 30-35,000 tons Ni metal (Strishkov, 1989, quoted in Melezhik et al., 1994). Assuming the lower value this implies, using the proportions of the metals in the low-grade dissemination, a production of the order of 15,000 tons Cu metal and 950 tons Co metal from local ore. The input of the trace metals would then, assuming the compositions in Table 4, be approximately as shown in Table 6.

Urals: Little is known of the tonnage of nickel produced from the laterites in the Urals except that it is small compared to that from Noril'sk and Pechenga.

Noril'sk: Russia's total mine output of nickel was c.180,000 tons in 1996 (Mining Journal 1998). Given the level of production indicated above from the Pechenga area this implies that production from Noril'sk was just over 150,000 tons, implying a copper production of c. 260,000 tons and c. 3,000 tons of cobalt (using ratios given in Mining Journal (1977). The production figures for nickel and copper can result from mixes of a wide range of different ore types but if the two sets of data shown in Table 5 are taken as end-members then the metal produced could be modelled as resulting from production of c. 400,000 tons of Cu-rich ore and just over 4 million tons of Cu-poor ore. Whatever the true figures, Cu-poor ore must dominate production completely. (It should be noted that the figure for SO_2 emissions from Noril'sk given in Table 2 would indicate a higher total production, minimum c. 5,5 million t, suggesting that the metal contents used in Table 5 may be too high). Given the above, hypothetical mix of Cu-rich and Cu-poor ores, the input of selected trace metals would be approximately as shown in Table 6.

	As	Cr	Pb	Sb	Se	Zn
Pechenga	29	7400	3,9	3,9	18	780
Noril'sk	1,8	n.a.	160	1	280	840

Table 6: «Production» of certain trace metals (in tons) from the Pechenga and Noril'sk ores, based on the known production of nickel in 1996 and the ore compositions shown in Tables 4 and 5.

Assessment of the emission estimates in relation to ore type, chemistry and processed tonnage

Pechenga: Comparison between the official emission figures (Murmansk CERN 1995) and the data on the chemistry of the Pechenga ores shown in Table 4 shows that there is an exact correspondance between the proportions of Ni:Cu:Co in the emissions from Zapolyarniy and the proportions of the same metals in weak disseminated ore. This is what would be expected, given that this is the ore type thought to be dominant in current production in the area and given the only ores processed in Zapolyarniy are of local origin. The emissions from Nikel have higher proportions of Cu:Ni and S:Ni which is, again, as would be expected given that ores from Noril'sk with higher proportions of Cu:Ni and S:Ni are smelted at Nikel as well as local ores.

As already noted modelled loadings of Ni and Co within circles of varying radius around Monchegorsk, on the basis of data on the chemistry of annual precipitation (water soluble and particulate) are compatible with (within 10% of) the official emission figures. Many factors influence the nature of deposition of emissions from the Ni-Cu plants - water solubility v. particulate character, particle size and density, etc. Given these provisos the depositions calculated/unit area (Table 3) are compatible with the ore chemistry shown in Table 4, for elements available in both sets of data. The main «anomaly» is the low calculated deposition of Cr, which is easily explained, as Cr is not sulphide-bound and would thus not be emitted to the same extent as the sulphide-bound elements.

The above lines of evidence suggest an overall compatibility between ore chemistry, official emission figures and calculated loadings and deposition rates based on comprehensive observational data. Collectively, these data have the following implications for the emission estimates based on the use of emission factors (NILU 1984, Pacyna et al. 1985, Pacyna 1995):

- Emissions of Cu and Ni were underestimated by factors of 4-6. This may well also apply to Cr, despite the fact that most of the Cr in the ore would not be emitted along with sulphide-bound metals..
- The postulated emissions of As, Pb and Sb exceed the <u>total input</u> of these metals to the plants by a factor of at least 5 for As, 25 for Pb (taking account of the fact that a limited amount of relatively Pb-rich ore from Noril'sk is processed in Nikel and Monchegorsk) and 3 for Sb.
- The estimated emission of Se is close to the calculated input and is probably also too high.

<u>Urals:</u> The estimates of emissions from «copper-nickel production» in the Urals based on the use of emission factors (NILU 1984, Pacyna et al. 1985, Pacyna 1995) cannot be related to copper-nickel deposits as such, as no deposits of this type have been in production in the Urals for many decades. As noted above the nickel deposits in the Urals which are in production are of a completely different type and have a much lower level of production. Copper, lead and zinc are produced in the Urals but from deposits of completely different types from those being considered here. The estimated emission of Ni is almost certainly much too large, while the figures for the other metals should be reassessed in relation to the chemistry of the ore types in production and other relevant factors.

<u>Noril'sk:</u> Published emission figures and chemical data presented above allow the following assessment of the emission estimates based on the use of emission factors (NILU 1984, Pacyna et al. 1985, Pacyna 1995):

- Emissions of Cu and Ni were underestimated by factors of 8 and 1,5 respectively.

- The postulated emissions of As, Pb and Sb exceed the total input of these metals to the plants by factors of c. 100, 4 and 22 respectively.

Revised emission assessment

The consistent picture given by ore chemistry, official emission figures and calculated loadings and deposition rates for the plants on the Kola Peninsula indicates that the emissions of trace metals can be estimated using their ratios relative to nickel in the calculated deposition figures (Table 3) and applying these to the emissions of Ni or Cu. Ideally one would consider the three sources on the Kola peninsula separately but given the dominance of emissions from Monchegorsk in relation to the total emissions from the three sources and the uncertainties intrinsic in the estimates, the figures given below are based on the ratios of the trace metals to nickel in the depositions calculated for Catchment 2 (Table 3), close to Monchegorsk, applied to the total emission of Ni from the three centres (1,916 t, Table 2). This method suggests emissions of the order of 6,3 t As, 0,9 t Cd, 11,8 t Cr, 13 t Pb, 1,6 t Sb and 43,7 t V from the Ni:Cu industry on the Kola peninsula as a whole (Table 7). Interestingly the official emission figure for V_2O_5 from the industry is 94 t (Murmansk CENR 1995), corresponding to 52 t V. The figure for Pb is of the same order as the total input of Pb to the Kola plants, assuming the figures in Table 6 and that 6-7% of the Pb-rich production from Noril'sk is processed on the Kola peninsula: it may also be assumed that a part of the Pb deposition calculated for catchment 2 is due to other sources (vehicle traffic), suggesting that this might also be the case for the estimate of 13 t. Use of the annual deposition calculated for Zn (Chekushin et al. 1995) in Catchment 2 in the manner used for the elements considered above leads to an estimated Zn emission of 27 t.

No direct observational data of the type shown in Table 3 are available for the Noril'sk area. As already indicated the published emission figures (Surnin et al. 1997), viewed in relation to the production of Ni and Cu, suggest that the Noril'sk plants have a more efficient recovery of metals than those on the Kola Peninsula. Applying the ratios modelled emission:modelled input found for the metals emitted from the plants on the Kola Peninsula to the input of the same metals at Noril'sk, should give a conservative estimate of the emissions of these metals at Noril'sk. For the metals for which the relevant data are available this leads to estimates of < 1 t As, 150 t Pb, < 1 t Sb and 29 t Zn (Table 7). Without relevant observational data these figures must be viewed as speculative.

	Ni	Cu	Co	SO2	As	Cd	Cr	Pb	Sb	V	Zn
Kola	1916	1097	92,1	296000	6,3	0,9	11,8	13	1,6	43,7	27
Noril'sk	1280	2380	67,5	1860000	<1	n.a.	n.a.	150	<1	n.a.	29

Table 7: Published emission figures for the major metals and SO_2 (from Table 2) and estimates of emissions based on sources and methods described above. Note that the estimates of trace metal emissions from the Kola area have a much higher reliability than those for Noril'sk.

Conclusions

Previously published estimates of metal emissions from the Ni-Cu industry in Russia suffered from significant deficiencies, emissions having been seriously underestimated for some elements and even more seriously overestimated for others. Some of the weaknesses can be understood and were undoubtedly the reason for the note of caution sounded in the original reference (NILU 1984), a caution which has been sporadic in subsequent use of the data. Application of knowledge of the nature and chemistry of the ores being processed would have strengthened the estimates, in particular removing misconceptions about emissions from the metallurgical industry in the Urals immediately and adjusting the figures for the Ni-Cu industry on the Kola Peninsula and at Noril'sk as more ore-chemical data, official emission figures and relevant observational data have become available.

This paper has focused on emissions from the Ni-Cu industry in Russia. Several of the sources of emission estimates based on emission factors quoted above, e.g. NILU (1984), Nriagu & Pacyna (1988), Pacyna (1995) present estimates of emissions from other metallurgical and mineral-based industries in the former Soviet Union, in other regions or for the whole globe in the case of Nriagu & Pacyna (1988). There is a strong case for a re-assessment of the emission estimates given for other metallurgical and mineral-based industries: such a re-assessment should involve:

- The use of basic geological knowledge about the nature of the raw materials used in the industries.
- The use of modern data on the chemistry of the raw materials.
- The application of relevant observational data where available.

Ore geologists bear a responsibility for ensuring that society recognizes the importance of their data in all fields in which it is important, not only in the search for new deposits and in their efficient exploitation.

Acknowledgements

This report resulted from work on the Kola Ecogeochemistry Project which was funded by the Ministry of Environment of Norway and by the Geological Surveys of Finland and Norway.

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