Environmental heavy metal contamination arising from the Xianjin and GP NiCd battery manufacturing facilities
Huizhou, Guangdong, China, 2004

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Executive summary

The Xianjin and GP facilities manufacture nickel-cadmium (NiCd or "nicad") rechargeable batteries at separate locations in the Huizhou district of Guangdong, China. To determine the extent to which releases of heavy metals from the facilities have impacted their environs, Greenpeace visited the area on the 22nd July 2004 to collect a range of environmental samples.

Analysis of the samples demonstrated contamination in the vicinity of both factories with heavy metals. Of primary concern were the elevated levels of cadmium in some areas. This metal is highly toxic to plants, animals and humans, and is generally found in the environment at very low concentrations.

Wastewater (MI04023) carried in an open drain alongside the perimeter wall of the Xianjin factory contained very high concentration of of dissolved cadmium (169 µg/l), a metal typically found in surface waters at below 1 µg/l. Concentrations of cobalt and nickel were also above usual background levels. The sediment (MI04024) in this drain was also contaminated with heavy metals, including cadmium at a concentration of over 7 g/kg, many thousands of times higher than background levels. These data suggest the ongoing release of heavy metals *via* this drain.

A sample of dust and sand collected by the Xianjin factory wall (MI04022) contained very high cadmium concentration compared to background levels, and dust from the home of an employee at the factory (MI04016) contained cadmium at a concentration over 7 times higher than dust from a neighbouring home. These results indicate releases from the factory by routes other than direct discharge, including for example *via* airborne particles and on the clothing of workers leaving the factory.

Samples of soil collected near to the GP factory were also found to contain heavy metal concentrations above usual background levels, primarily for cadmium. The most cadmium contaminated soil was from a street adjacent to the factory (MI04025, 15mg/kg) though moderately high levels were also found in soils colleted from residential areas close to the factory. These data indicate releases of cadmium from the GP factory to the immediate area, although no firm conclusions can be drawn regarding pathways.

A river flowing to the east of the GP factory was found to be impacted by inputs of heavy metals, though the sources primarily appear to be independent of the GP factory. It is not clear if releases from the GP factory are contributing substantially to the overall contamination of the river.

Releases of heavy metals by the two factories pose potential health implications for those living and working in the areas, as well as consequences for the wider environment. The elevated levels of toxic metals in environment samples collected at both locations demonstrate a lack of adequate controls in their use within both facilities.

While more adequate control measures could greatly reduce the releases of toxic chemicals, the only sustainable solution is the substitution of toxic chemicals with non-toxic alternatives. Viable alternatives currently exist for rechargeable batteries that do not employ toxic metals such as cadmium and nickel.

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1 Introduction

The Xianjin and GP battery manufacturing facilities are located in the Huizhou district of Guangdong, China. Nickel-cadmium (NiCd or "nicad") rechargeable batteries are manufactured at these two separate facilities.

The metals and their compounds used in the manufacture of NiCd batteries are toxic to humans and animals. The release of these metals into the environment has the potential to impact significantly on humans and the wider environment. Once released, these metals cannot be broken down into safer compounds. This investigation was undertaken to determine the extent to which releases from the facilities have contaminated the environment in the vicinity of the two facilities.

2 Sampling program

Greenpeace visited the Xianjin and GP nickel-cadmium (NiCd) battery-manufacturing facilities on the 22nd July 2004 to collect a range of environmental samples.

Samples of wastewater, soil, sediment and drinking water were collected from the vicinity of the two factories. House dust was also collected from the home of an employee at the Xianjin factory. Additional samples were obtained from within both factories; these included two materials used in the manufacture of NiCd batteries at the Xianjin factory, and a sample of treated wastewater from within the GP factory.

2.1 General Sampling Procedures

All solid samples were collected in sealable plastic bags, while water samples were collected in polypropylene plastic bottles. Prior to sample collection, all containers were unused and unopened. The samples were kept cool and returned to the Greenpeace Research Laboratories for analysis. Identical unused containers were also returned to the laboratory and used to determine that the containers in no way influenced the metal concentrations determined in the samples stored in them. Detailed description of sample preparation and analytical procedures are presented in Appendix 1.

2.2 Xianjin factory

An open drain situated by the perimeter wall of the Xianjin factory carries wastewaters that are believed to originate from the Xianjin factory. Samples of the water (MI04023) and sediment (MI04024) were collected from within this drain. A sample of dust and sand (MI04022) was also collected from the base of the factory perimeter wall close to the open drain.

Additional samples were collected to investigate the dispersal of heavy metals further from the factory. A sample of soil (MI04021) was collected from a residential area adjoining the Xianjin factory. Two samples of house dust were also collected, one from the home of an employee at the Xianjin factory (MI04016), and one from a neighbouring house in which none of the resident were employed at this factory (MI04017). The homes from

Sample no.	Sample type	Factory	Sample location
MI04016	House dust	Xianjin	Home of a worker from the Xianjin factory, located away from the facility
MI04017	House dust	Xianjin	Neighbouring home to that of the factory worker. Occupants not involved with NiCd manufacturing
MI04021	Soil	Xianjin	Residential area adjacent to the factory
MI04022	Dust / sand	Xianjin	Near an open drain immediately outside the factory
MI04023	Effluent	Xianjin	Open drain immediately outside the factory
MI04024	Sediment	Xianjin	Open drain immediately outside the factory
MI04031	Manufacturing material	Xianjin	Red coated metal sheeting used within the factory
MI04032	Manufacturing material	Xianjin	Green sheeting used within the factory
MI04018	Sediment	GP	River near the factory, downstream of the facility
MI04019	River water	GP	River near the factory, downstream of the facility
MI04020	River water	GP	River near the factory, upstream of the facility
MI04025	Soil	GP	Street, immediately outside the factory (part pp2)
MI04026	Soil	GP	Rooftop plant pots, residential building next to factory (pp2)
MI04027	Effluent	GP	Inside the factory (part pp2)
MI04028	Drinking water	GP	Well in a residential block opposite the factory (pp1)
MI04029	Drinking water	GP	Tap in a residential block opposite the factory (pp2)
MI04030	Soil	GP	Courtyard of a residential block adjacent to factory (pp2)

Table 1. Description of the samples associated with the Xianjin and GP NiCd battery manufacturing facilities, Huizhou, Guangdong, China, 2004.

which the dusts were collected are located a few kilometres from the factory and, therefore, unlikely to have been impacted directly by the plant.

In addition, two samples of materials used in the manufacture of batteries within the factory were obtained. These included a section of thin perforated metal sheeting with a red coating (MI03031) and a section of green cardboard-like sheeting (MI04032).

2.3 GP factory

The GP factory has three separate sections; pp1, pp2 and pp3. The activities the each individual sections are not known. A sample of soil (MI04025) was collected from a street immediately outside section pp2 of the GP factory. Two further soil samples were collected from residential areas adjoining the pp2 section; one sample from plant pots on a rooftop of a residential building (MI04026), and one from the courtyard of a residential block (MI04030). Two samples of drinking water were also collected from residential areas immediately next to the factory, one from a well in a block opposite section pp1 (MI04028) and one from a tap in a block opposite section pp2 that is believed by residents to draw water from a well in the residential area (MI04029).

A further three samples were collected from a river that flows to the east of the factory. A sample of river water (MI04019) and sediment (MI04018) were collected from the river downstream of the GP factory and, for comparison, a sample of river water was collected from a location upstream of the factory (MI04020).

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A sample of wastewater (MI04027) was obtained from within section pp2 of the GP factory. It is believed that this effluent had already undergone treatment and was ready for discharge, though we were unable to verify this.

3   Results and discussion

The results of the quantitative heavy metals analyses for samples associated with the Xianjin and GP factories are presented in Tables 2 and 3 respectively.

3.1   Xianjin factory

Both materials used in the manufacture of NiCd batteries within the Xianjin factory contained very high concentrations of toxic metals. The metal and coating parts of the coated perforated metal sheeting (MI03031) were analysed separately. Both parts contained very high concentrations of both cadmium and nickel. The concentration of cadmium in the red coating removed from the metal sheet (MI03031b) was 66.6% of the total material. This coating is likely to consist primarily of cadmium oxide. NiCd batteries are generally formulated using cadmium oxide, crystals of which are often red-brown in colour (ATSDR 2000). The coating material also contained nickel at a concentration of 1.11%. The metal sheeting (MI03031a) contained cadmium and nickel at 7.38% and 5.18% of the material respectively. Traces of the cadmium oxide coating remaining on the metal sheeting may have contributed to the cadmium concentration determined for the thin perforated metal sheeting.

The green cardboard like material (MI04032) consisted primarily of nickel, at 59.4% of the material. This material also contained high concentrations of cobalt (3.21%) and cadmium (2.5%). The colour and nature of this material suggests that these metals were present in the form of their inorganic salts.

Information on the toxicity and environmental fate of the toxic heavy metals employed in the manufacture of NiCd batteries within this facility (cadmium, cobalt and nickel) are discussed below in sections 4.1-4.3.

The discharged wastewater (MI04023) collected from an open drain by the factory perimeter wall contained a very high concentration of cadmium as well as moderately concentrations of cobalt and nickel. The concentration of dissolved cadmium in this sample was 169 µg/l, highly elevated compared to uncontaminated surface waters that generally contain cadmium at less than 1 µg/l (ATSDR 2000, Elinder 1992). The unfiltered effluent contained cadmium at almost 2 mg/l though it is not possible to separate out the contribution due to disturbance of the highly contaminated sediment in the drain caused by the flow of effluent along its course.

The concentrations of dissolved cobalt (78 µg/l) and nickel (46 µg/l) in this sample were also elevated above typical surface water background concentrations though to a lesser degree. Cobalt and nickel concentrations in uncontaminated surface waters are typically <3 µg/l and <10-20 µg/l respectively (ATSDR 2000, Eckel & Jacob 1988, Mance and Yates 1984).

Sample number	MI04023	MI04023	MI04022	MI04024	MI04021	MI04016	MI04017	MI04031	MI04031a	MI04032b
Description	effluent unfiltered	effluent filtered	dust / sand	sediment	soil	house dust	house dust	component metal	component coating	component thin card
Location	drain by factory	drain by factory	drain by factory	drain by factory	residential area	home of worker	home of non-worker	use in factory	use in factory	use in factory
Metals	µg/L	µg/L	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw	mg/kg dw
Arsenic (As)	<50	<50	<20	<20	<20	<20	<20	<2	<2	<20
Cadmium (Cd)	1970	169	139	7070	7	7	<1	73800	666000	25900
Chromium (Cr)	<20	<3	27	41	13	9	29	60	<3	5
Cobalt (Co)	264	78	24	200	4	2	4	51	5	32100
Copper (Cu)	<30	<30	39	110	12	8	26	79	<2	15
Lead (Pb)	256	<5	277	430	30	35	121	<5	<5	<5
Manganese (Mn)	184	68	310	456	179	122	196	1890	1	21
Mercury (Hg)	<10	<10	<2	<2	<2	<2	<2	<2	<2	<2
Nickel (Ni)	300	46	263	2230	23	20	12	51800	11100	594000
Zinc (Zn)	623	19	288	1910	95	2940	1700	17	3	553

Table 2. Heavy metals quantified in samples associated with the Xianjin NiCd manufacturing factory, Huizhou, Guangdong, China, 2004.

Sample number	MI04027	MI04028	MI04029	MI04025	MI04026	MI04030	MI04020	MI04019	MI04018a	MI04018b
Description	effluent	drinking water	drinking water	soil	soil	soil	river water	river water	sediment	blue solids
Location	inside factory	well near pp1	tap near pp2	street outside pp2	roof next to pp2	courtyard next to pp2	upstream of factory	down-stream of factory	down-stream of factory	down-stream of factory
Metals	µg/l	µg/l	µg/l	mg/kg dw	mg/kg dw	mg/kg dw	µg/l	µg/l	mg/kg dw	mg/kg dw
Arsenic (As)	<50	<50	<50	<20	<20	<20	<50	<50	<20	<20
Cadmium (Cd)	<4	<4	<4	15	4	2	<4	<4	6	6
Chromium (Cr)	<3	<3	<3	38	27	22	<3	<3	241	41
Cobalt (Co)	<10	<10	<10	8	8	5	<10	<10	20	27
Copper (Cu)	<5	<5	<5	48	32	29	<30	162	1700	338
Lead (Pb)	<5	<50	<5	92	44	24	<5	<50	337	650
Manganese (Mn)	<1	77	47	545	597	203	5	305	222	81
Mercury (Hg)	<10	<10	<10	<2	<2	<2	<10	<10	<2	<2
Nickel (Ni)	<20	<2	<2	33	32	17	28	153	153	52
Zinc (Zn)	<10	60	48	1096	265	86	13	200	9200	110000

Table 3. Heavy metals quantified in samples associated with the GP NiCd manufacturing factory, Huizhou, Guangdong, China, 2004.

The sediment collected from this open drain (MI04024) contained 7070 mg/kg of cadmium, over 7 g/kg. This is many thousands of times higher than background levels of cadmium in uncontaminated soils and sediments, which typically contain less than 2 mg/kg cadmium (Alloway 1990, Salomons & Forstner 1984). The sediment also contained other metals at concentrations above background levels; namely cobalt (200 mg/kg), copper (110 mg/kg), lead (430 mg/kg), and particularly nickel (2230 mg/kg) and zinc (1910 mg/kg). These metals are typically present in uncontaminated sediments at the following concentrations; cobalt 6-22 mg/kg, copper 40-50 mg/kg, lead 20-30 mg/kg, nickel 45-65 mg/kg and zinc <100 mg/kg (Alloway 1990, ATSDR 2000, Hamilton 1994, Salomons & Forstner 1984).

Following the discharge of wastewaters containing elevated concentrations of heavy metals, a significant proportion of the metal content in the water will bind to suspended sediment particles and settle to bottom sediments (Salomons & Forstner 1984). Ongoing discharge of waters containing these metals will, over time, result in their accumulation in bottom sediments.

The high concentrations of cobalt, nickel, and particularly cadmium in the sediment collected from the drain demonstrate that wastewaters containing these metals at high concentrations flow through the drain on an ongoing basis. Considering the demonstrated use of these metals within the Xianjin battery manufacturing factory and the location of the drain, the data strongly suggest that this factory is the source of the contaminated wastewater, and therefore responsible for the release of these toxic metals into the wider environment.

It is not clear if the factory is a source of copper, lead and zinc to the sediment at this location. In urban environments, many general diffuse sources of these metals can exist, including emissions and releases from vehicles. Such sources may be contributing to the elevated concentrations of these metals in the sediment (ATSDR 2000)

The sample of dust and sand (MI04022) collected below the factory wall close to the open drain was also found to be highly contaminated with cadmium, present at a concentration of 139 mg/kg. It would seem unlikely that effluent carried in the drain would cause an accumulation of cadmium at this location. The high cadmium concentration is presumably a result of releases from the factory by other routes, such as fine particles (*i.e.* dusts) transported through the air and subsequently deposited outside the factory.

The sample of soil collected in a residential areas adjacent to the factory (MI04021) was not contaminated with any of the metals quantified in this study.

The sample of house dust from the home of an employee of the Xianjin factory (MI04016) contained cadmium at 7 mg/kg. The cadmium concentration in an equivalent dust sample collected from a neighbouring house where the residents are not involved in any activities at the factory was below 1 mg/kg. The two homes are located a few kilometres from the factory and so direct contamination from the factory through routes such as airborne particles is highly unlikely. The significantly higher cadmium concentration in dust from the employees home suggests that cadmium is being transported to this home by the worker, probably as particles trapped on clothing. Transport of cadmium from the factory to the home of an employee may result in increased exposures for members of the workers family to this highly toxic metal.

Both dust samples also contained reasonably high levels of zinc. The source of zinc in these samples is not clear but may be a consequence of the use of galvanised materials in the construction of the properties, which has been shown to increase the level of zinc in household dusts (Kim & Fergusson 1993).

3.2 GP factory

The industrial wastewater (MI04027) collected inside the GP factory was highly alkaline. This may have been a result of treatment to precipitate any dissolved metals from the waters. This sample did not contain any of the metals quantified at significant concentrations. The treatment of wastewaters containing heavy metals such as cadmium and nickel, however, may result in the formation of additional wastestreams (*e.g.* sludges) containing these metals. The fate of any additional wastestreams created in this way within the GP factory is not clear.

The samples of soil collected from a street outside section pp2 of the factory (MI04025) contained cadmium at 15 mg/kg, significantly elevated compared to uncontaminated soils which typically contain less than 2 mg/kg cadmium (Alloway 1990). Emissions from the GP factory in the form of airborne particles is a likely source of the elevated cadmium at this location, though a contribution from diffuse urban sources cannot be ruled out. This sample also contained a reasonably high zinc concentration. There is no evidence of the use of zinc or zinc compounds within the GP factory, and the levels found are likely to be due to other urban sources (ATSDR 2000, Sadiq *et al.* 1989).

The two samples of soil collected from residential areas adjacent to section pp2 of the GP factory contained higher concentrations of cadmium than would normally be expected in soil. The soil collected from the courtyard of a residential block (MI04030) contained 2 mg/kg cadmium, the upper end of concentrations typically found in uncontaminated soils (Alloway 1990, ATSDR 2000). The soil collected from plant pots on the roof of a residential building (MI04026) contained cadmium at 4 mg/kg, twice this highest background soil concentration. The moderately elevated cadmium concentrations in these soil samples suggest the release of cadmium compounds from the factory to the neighbouring area, most likely through air transport of fine particles (*i.e.* dusts).

While lower than the cadmium concentrations found in street side soil, the presence of elevated cadmium in the soils from residential areas highlights the increased potential for exposure to cadmium containing dusts in these areas. Furthermore, certain plants including food crops are to accumulate cadmium from the soil in which they are grown (Jackson & Alloway 1992). The use of the cadmium contaminated soils for growing food crops can have implications for human exposure.

Additional information on the toxicity and environmental fate of cadmium is presented in section 4.1.

Neither sample of drinking water collected from residential areas adjoining sections pp1 (MI04028) and pp2 (MI04029) contained elevated concentrations of any of the metals quantified.

Three samples were collected from a river that flows to the east of the factory. The

samples of river water contained high levels of suspended solids and were analysed as both filtered and unfiltered samples to distinguish the dissolved metal content. The sample of river water collected upstream of the factory (MI04020) did not contain any of the metals at elevated dissolved concentrations. The river water sample collected downstream of the factory (MI04019) contained dissolved copper, nickel and zinc at concentrations approximately five times higher than typical uncontaminated river waters (ATSDR 2000, Mance *et al.* 1984, Salomons & Forstner 1984). The concentration of copper in the unfiltered sample was 20 times higher than the dissolved concentration, indicating a high concentration of copper in the suspended solid. The concentrations of all other metals in both unfiltered samples were not significantly higher than their respective dissolved concentrations as presented in Table 3.

The river sediment collected downstream of the GP factory contained bright blue solid material, the source of which is not clear. The river sediment (MI04018a) and the blue solid material (MI04018b) were analysed separately. The blue solid material contained 11% zinc, as well as moderately high concentrations of copper and lead. There is no evidence that materials containing these metals are used within the GP factory. The material did contain cadmium at 6 mg/kg; however this is likely to be the result of the very high zinc concentration, as zinc can contain cadmium as a trace impurity at this level (Kroschwitz & Howe-Grant 1995). The content of the blue solid material would suggest its presence in the river sediment is not related to activities at the GP factory.

The river sediment (MI04018a) contained concentrations of cadmium, copper, lead, nickel and zinc that were elevated compared to typical background sediment levels, particularly for copper and zinc at approximately 30 and 90 times background levels respectively. The cadmium concentration in the sediment was approximately six times typical background sediment concentrations (ATSDR 2000, Salomons & Forstner 1984). Releases from the GP factory may be contributing to the elevated cadmium concentration in the river sediment, though other sources would appear to dominate heavy metal inputs to the river.

4   Key pollutants

4.1   Cadmium

Cadmium (Cd) is a relatively rare metal that naturally occurs in the environment in very low concentrations, principally as ionic compounds (Alloway 1990, WHO 1992). Where anthropogenic emissions dominate over natural sources, elevations above natural background levels will be found.

Cadmium is a highly toxic metal with effects on plants, animals and humans (Alloway 1990, ATSDR 2000, WHO 1992). It is an accumulative metal, and the kidney is the main target organ of cadmium toxicity in both humans and animals following extended exposure. Other effects in humans include skeletal disorders such as osteoporosis, or osteomalacia (softening of the bones) aw well as the development of hypertension (high blood pressure) and heart disease (Alloway 1996, ATSDR 2000, Goyer 1996, Elinder & Jarup 1996, WHO 1992).

In the industrial context, the inhalation of high levels of cadmium oxide fumes or dust can be intensely irritating to respiratory tissue, with symptoms including pulmonary oedema

able to develop within hours of exposure. Severe exposure can be fatal (ATSDR 2000, Goyer 1996, WHO 1992). There is also a relationship between exposure to cadmium oxide fumes and the development of lung cancer (DHSS 2002). The US Department of Health and Human Services lists cadmium and cadmium compounds as 'known to be human carcinogens' (DHSS 2002). Similarly, cadmium and cadmium compounds are listed by the International Agency for Research on Cancer (IARC) as carcinogenic (IARC 1994).

Upon release to the environment cadmium is often more mobile than most other metals in aquatic environments, though once adsorbed to sediments it is relatively immobile. When present in bioavailable forms, bioaccumulation of cadmium can occur in both aquatic and terrestrial organisms. Cadmium is also readily accumulated in plants, including food crops such as grain, rice and vegetables. There is a clear relationship between the cadmium concentration in soil and the plants grown on that soil, which has important implications for human exposure (Elinder & Jarup 1996, Jackson & Alloway 1992).

4.2   Cobalt

Cobalt (Co) is a naturally occurring metal that is found in the environment in relative low concentrations, primarily in the form of ionic compounds. Compounds of cobalt generally contain the +2 Co(II) or +3 Co(III) oxidation states (ATSDR 2000).

Cobalt is an essential element for humans and animals in small quantities. However, exposure to high concentrations either through inhalation or ingestions can result in harmful effects in humans and animals. Inhalation of cobalt or cobalt compounds in high concentrations by humans or animals primarily affects the lungs, with symptoms including asthma and pneumonia (Nordberg 1994). Cardiovascular effects and skin dermatitis have also been seen for workers exposed to high levels of cobalt dusts (ATSDR 2000, Lauwerys & Lison 1994). The ingestion of high levels of cobalt can cause result in gastrointestinal and cardiovascular effects in animals and humans. High levels of exposure have also been shown to cause liver and kidney effects in animals, and similar effects may also occur in humans (ATSDR 2000).

Upon release to the environment, some cobalt compounds will be soluble in water though the majority of cobalt in aquatic environments is adsorbed on to suspended and bottom sediments. Cobalt is a relatively mobile metal in soils compared to most metals, though this is dependant on the nature of the soil, particularly the pH (Hamilton 1994). Cobalt does not significantly bioaccumulate in aquatic organisms. Some bioaccumulation can occur in plants though generally only in highly acidic soils (ATSDR 2000, Evans *et al.* 1988, Mejstrik & Svacha 1988).

4.3   Nickel

Nickel (Ni) is a naturally occurring element that is present at low concentrations in the environment, primarily in ionic forms. It has an average concentration in the Earths crust of 75 mg/kg (Alloway 1990). As a pure metal, nickel Ni(0) is a hard silver-white solid. In ionic forms nickel primarily exists in the +2 oxidation state Ni(II) (ATSDR 2000). Simple ionic nickel compounds or 'salts' are generally quite soluble in water, especially under

acidic conditions (ATSDR 2000).

Very small amounts of nickel are essential for normal growth and reproduction in some species of animals, plants and micro-organisms, and it is probable that small amounts are also be essential to humans (ATSDR 2000, Alloway 1990). However, toxic and carcinogenic effects can result from exposure to higher concentrations for a wide range of life forms (ATSDR 2000).

For non-occupational exposures, toxic effects following ingestion generally only occur after high level exposures (ATSDR 2000). However, a significant proportion of the population (2-5%) is nickel sensitive, primarily through allergic contact dermatitis. Once a person is sensitised to nickel any further contact will produce a reaction, and adverse health effects can occur at far lower concentrations compared to non sensitised individuals (ATSDR 2000). There is also evidence for the carcinogenicity of nickel and certain nickel compounds where individuals are frequently exposed to high atmospheric levels in industrial contexts (ATSDR 2000, Goyer 1996). The US Department of Health and Human Services lists nickel compounds as a known human carcinogen, and metallic nickel as reasonably anticipated to be a human carcinogen (DHHS 2002). Similarly the International Agency for Research on Cancer lists certain nickel compounds as human carcinogens (IARC 1990).

Upon release to the environment nickel compounds can exist as soluble species or bound to particulates. The partitioning between these forms is influenced by many factors. In natural waters nickel is a fairly mobile metal though concentrations are generally low compared with the amount of nickel associated with suspended and bottom sediments (ATSDR 2000, Mance & Yates 1984). Certain aquatic organisms are able to significantly bioaccumulate Nickel (ATSDR 2000). In soils nickel compounds are very persistent, though there is a potential for leaching through the soil and subsequently enter groundwater (ATSDR 2000, Alloway 1990).

5 Conclusions

The Xianjin and GP battery manufacturing facilities utilise materials containing heavy metals, including cadmium. High concentrations of cadmium, cobalt and nickel were identified in materials employed within the Xianjin factory.

This study has demonstrated contamination of environmental samples in the vicinity of both factories with heavy metals. Of primarily concern are the elevated levels of cadmium in some areas, a highly toxic metal to plants, animals and humans. The data indicate that, as a result of the use of heavy metals within the factories, releases are occurring at both locations.

There is evidence that heavy metal releases from the Xianjin factory are occurring by a number of different routes. Wastewater, and sediment in the drain in which it is carried, were found to be highly contaminated with heavy metals, particularly cadmium. The level in the sediment indicates ongoing discharge of contaminated wastewaters by this drain. There is also indication of heavy metal releases to the local area *via* airborne particles resulting in contamination of the immediate area.

Elevated cadmium levels in the home of an employee of the Xianjin factory indicates that metals used in the factory are also inadvertently being carried on the clothing of employees leaving the factory.

Levels of heavy metals, including cadmium, were also found in the vicinity of the GP factory. Though the levels of contamination were lower than those found close to the Xianjin factory, these data still indicate the release of toxic metals used within the factory. Soils within residential areas close to the GP factory contain elevated levels of cadmium. While the levels are moderately elevated compared to those found in environmental samples collected near to the Xianjin factory, the potential for increased exposure to this accumulating and toxic metal for residents in the area is of concern.

Ground waters close to the GP factory used for drinking water do not appear to have been contaminated with the heavy metals used at the factories.

There are clearly sources of heavy metals to a river flowing to the east of the GP factory. The sources of the metal inputs to the river remain unclear, though significant inputs of these metals would appear to be independent of the GP factory as the overall heavy metal burden on the river is comprised primarily of metals other than those believed to be used within the GP factory.

The elevated levels of toxic heavy metals in the immediate vicinity of both factories has potential health implications for those living and working in the areas, as well as consequences for the wider environment. The degree of contamination and the different routes of release highlighted by these data demonstrate a lack of adequate controls in the use of hazardous and toxic chemicals within both the Xianjin and GP factories

While the use of more adequate control measures within the factories could greatly reduce the releases of toxic chemicals to the wider environment, the only sustainable solution is the substitution of toxic chemicals with less hazardous alternatives. The capability to substitute heavy metals such as cadmium and nickel in rechargeable batteries currently exists. For example, lithium-ion cells are widely employed in such batteries for a wide range of applications (Noreus 2000).

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Appendix 1; Analytical methodology

A1.1   Preparation of samples for analysis

All chemicals were of High Purity Aristar Grade. All glassware was cleaned in detergent, rinsed with tap water and deionised water, soaked in 10% nitric acid overnight, rinsed with deionised water and dried in an oven at 105°C.

A1.1.1   Solid Samples

Samples were dried at 30°C until weighing readings became constant. They were then crushed using a pestle and mortar until homogenous and sieved through a 2-mm mesh. Approximately 0.25 g of sample was accurately weighed into a glass 100 ml boiling tube and to this 5 ml of deionised water was added, followed by 3.75 ml of concentrated hydrochloric acid and 1.25 ml of concentrated nitric acid. The samples were digested at room temperature overnight prior to being placed onto a Gerhardt Kjeldatherm digestion block (40 space) connected to a Gerhardt Turbosog scrubber unit (filled with 10% w/v sodium hydroxide). The samples were then refluxed at 130°C for four hours. To prepare samples for arsenic and mercury analysis, this procedure was repeated in an identical manner other than using a digest temperature of 90°C.

After cooling to ambient temperature, the digests were filtered into volumetric flasks, diluted with deionised water, made up to a volume of 25 ml and mixed. One sample (MI04022) was analysed in duplicate to assess the reproducibility of the method. The reproducibility data is presented in Table A1.1.

Metal	MI04022/1	MI04022/2	Difference	MI04019/1	MI04019/2	Difference
	mg/kg dw	mg/kg dw	(%)	μg/l	μg/l	(%)
Arsenic (As)	<20	<20	0	<50	<50	0
Cadmium (Cd)	142	136	4	<4	<4	0
Chromium (Cr)	29	25	17	<3	<3	0
Cobalt (Co)	25	24	4	<10	<10	0
Copper (Cu)	42	37	14	165	158	4
Lead (Pb)	284	270	5	<50	<50	0
Manganese (Mn)	317	303	5	310	300	3
Mercury (Hg)	<2	<2	0	<10	<10	0
Nickel (Ni)	266	259	3	156	150	4
Zinc (Zn)	297	278	7	197	203	-3

Table A1.1. Reproducibility data from duplicate analysis of solid sample MI04022 and aqueous sample MI04019

Furthermore, a blank sample and three certified reference materials (CRMs) were separately prepared in an identical manner with the batch of samples. The CRMs analysed were; 7004 (Loam with elevated analyte levels, certified by the Czech Metrological Institute, LGC6187 (Leachable metals in river sediment, certified by LGC) and CRM2583 (Trace elements in indoor dust, certified by the US National Institute of Standards and Technology). The recovery data for the CRMs are presented in Table A1.2

CRM	7004 (Loam)	LGC6187 (River sediment)	CRM2583 (Indoor dust)
	(% recovery)	(% recovery)	(% recovery)
Arsenic (As)	50	79	---
Cadmium (Cd)	104	112	84
Chromium (Cr)	54	77	63
Cobalt (Co)	101	---	---
Copper (Cu)	88	87	---
Lead (Pb)	86	90	63
Manganese (Mn)	83	85	---
Nickel (Ni)	97	89	---
Zinc (Zn)	86	89	---

Table A1.2. Percentage recovery data for the standard reference materials analysed

A1.1.2 Aqueous sample

All samples were filtered through ashless filter papers (Whatman No. 42) prior to acid digestion. For each sample, 22.5ml was transferred to a 100ml boiling tube and acidified with nitric acid (2.5ml). The tubes were placed onto the Gerhardt Kjeldatherm digestion block, and refluxed at 130°C for three hours. After cooling to ambient temperature, the digest was filtered into a volumetric flask, diluted with deionised water, made up to a volume of 25 ml and mixed. With the batch of samples, a mixed metal quality control solution of 8 mg/l and a blank sample were separately prepared in an identical manner. To prepare the sample for mercury and arsenic analysis, this procedure was repeated in an identical manner other than using a digest temperature of 90°C. One sample (MI04019) was analysed in duplicate to assess the reproducibility of the method. The reproducibility data is presented in Table A1.1.

A1.1.3 Control containers

For the containers used to store aqueous samples, 25ml of 0.1M hydrochloric acid was added to each of two control containers, which were then sealed and agitated for three days on a bottle roller to maximise contact between extractant and the bottle surface. For the containers used to store solid samples, 25ml of 0.1M hydrochloric acid and 0.1M nitric acid was added to each of two control containers, which were then sealed for three days with occasional agitation. For all control extractions, the aqueous portions were filtered and analysed directly as described for other aqueous samples. In all cases, the concentration of all determined metals in the control extractions were below the method detection limits.

A1.2 Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES)

Following preparation, samples were analysed by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES), using a Varian MPX Simultaneous Spectrometer. The following metals were quantified directly: arsenic (As), cadmium (Cd), cobalt (Co), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn). Two multi-element instrument calibration standard was prepared at concentrations of 1mg/l and 10 mg/l, matrix matched to the samples (*i.e.* in 15% v/v

hydrochloric acid and 5% v/v nitric acid for solid samples and 10% v/v nitric acid for aqueous samples). The calibration was validated using a quality control standard (8 mg/l), prepared internally from different reagent stocks. Any sample exceeding the calibration range was diluted accordingly, in duplicate, and re-analysed.