



Using science to create a better place

Soil Guideline Values for nickel in soil

Science Report SC050021 / Nickel SGV

This technical note is one in a series that describe Soil Guideline Values (SGVs) for individual, or groups of similar, chemicals to assist in the assessment of risks from land contamination.

SGVs are an example of generic assessment criteria (Defra and Environment Agency, 2004) and can be used in the preliminary evaluation of the risk to human health from long-term exposure to chemicals in soil. Specifically, this note provides SGVs for inorganic forms of nickel in soil. It does not include organonickel compounds, which are unlikely to be found in soil.

The SGVs and the additional advice found here should be used only in conjunction with the introductory guide to the series entitled *Using Soil Guideline Values* (Environment Agency, 2009a), the framework documents *Updated technical background to the CLEA model* (Environment Agency, 2009b) and *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c), and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Nickel* (Environment Agency, 2009d). Supplementary information on nickel is also available (Environment Agency, 2009e).

All notes in the SGV series, the introductory guide and further supplementary information can be downloaded from our website (<http://www.environment-agency.gov.uk/clea>).

Nickel and its inorganic compounds

In its elemental form, nickel (CAS No. 7440-02-0) is a hard, lustrous, silvery-white transition metal (ATSDR, 2005; McGrath, 1995). However, its powder is reactive in air and may spontaneously ignite (ATSDR, 2005). Nickel is resistant to corrosion by air and water under ambient conditions and combines readily with other metals including iron, copper, chromium and zinc to form alloys (ATSDR, 2005; Kabata-Pendias and Mukherjee, 2007).

Nickel occurs naturally in the environment although

rarely in its elemental form (DEPA, 2005a; McGrath, 1995). Nickel has a strong affinity for iron and sulphur, forming nickel-iron sulphides such as pentlandite $[(\text{Ni,Fe})_9\text{S}_8]$ within basic igneous rocks and sulphides such as millerite (NiS) and ullmanite (NiSbS) in mineralised areas (McGrath, 1995; Kabata-Pendias and Mukherjee, 2007). Nickel also substitutes for iron in other rock forming minerals such as pyrite, and occurs as oxides and silicates within laterite deposits as a result of the prolonged weathering of parent rocks in tropical climates (McGrath, 1995; Kabata-Pendias and Mukherjee, 2007).

Nickel forms compounds in various oxidation states although the most important is +2 (ATSDR, 2005; Greenwood and Earnshaw, 1997). It forms divalent salts with virtually every anion and has an extensive aqueous chemistry based on the green coloured hexahydrate cation $[\text{Ni}(\text{H}_2\text{O})_6]^{2+}$ (Greenwood and Earnshaw, 1997). Nickel chloride hexahydrate (CAS No. 7791-20-0), nickel dinitrate hexahydrate (CAS No. 13478-00-7), nickel sulphate hexahydrate (CAS No. 10101-97-0), and trinickel monocarbonate tetrahydroxide (CAS No. 12607-70-4) are all industrially important inorganic salts (DEPA, 2005b, 2005c, 2005d, and 2005e). Nickel also forms organometallic complexes including nickel carbonyl $[\text{Ni}(\text{CO})_4]$, which is a colourless volatile and highly reactive liquid (ATSDR, 1997; Greenwood and Earnshaw, 1997). In general, nickel organometallic compounds are not very stable, often only intermediate complexes in the synthesis of other organic compounds (Greenwood and Earnshaw, 1997).

Nickel is extracted from sulphide ores by roasting and smelting, and refined either by electrochemical concentration, chemical leaching with hydrochloric acid, or by reduction of the oxide by a mixture of hydrogen and carbon monoxide (ATSDR, 2005; Greenwood and Earnshaw, 1997). Nickel is produced from laterite ores by smelting with and without sulphur, or by chemical leaching with either ammonia or sulphuric acid (ATSDR, 2005). In 2000, the annual production of nickel metal in Europe was 182,000 tonnes, about twenty per cent of

the worldwide total (DEPA, 2005a). Production of inorganic salts was much lower, between 10,000 and 15,000 tonnes (DEPA, 2005b, 2005c, 2005d, and 2005e).¹

The primary uses of nickel metal are in the production of alloys including stainless steel, in nickel plating, in the manufacture of nickel containing products such as batteries and welding electrodes, and in the production of chemicals containing nickel including nickel sulphate, nickel chloride, and in catalysts (DEPA, 2005a). In 2000, European countries used around 396,000 tonnes of nickel metal, more than twice the amount they produced and about one-third of worldwide consumption (DEPA, 2005a). More than 90 per cent was used in the production of stainless steel and other alloys, four per cent in nickel plating, and five per cent for batteries, chemicals and other uses including magnetic components (DEPA, 2005a; Kabata-Pendias and Mukherjee, 2007).

Nickel salts are used mainly in the production of catalysts, in nickel plating, in batteries, and in the manufacture of pigments and other nickel containing chemicals (ATSDR, 2005; DEPA, 2005b, 2005c, 2005d, and 2005e).

Nickel metal alloys and nickel plated items have been used extensively in the transport, consumer, industrial and construction sectors including the production of motor vehicles, consumer white goods and bathroom fittings, kitchen and tableware, electronics, food processing, textiles, fasteners, wires, and cables (DEPA, 2005a). Nickel and its water soluble salts are potent skin sensitisers and their use in products that come into direct and prolonged contact with the skin (such as jewelry, watch straps, rivet buttons, and zippers) has been restricted across the European Union (Environment Agency, 2009d; TSO, 2005).

Potential harm to human health

The principles behind the selection of Health Criteria Values (HCVs), and the definition of concepts and terms used, are outlined in *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c). Specific information on the toxicity of nickel and its compounds has been reviewed in *Contaminants in soil: updated collation of toxicological data and intake values for humans. Nickel* (Environment Agency, 2009d) and only a brief summary is presented here.

Nickel is a potent skin sensitiser (that is, able to cause allergic reaction in humans) and as many as 1 – 4 per cent of men and 8 – 20 per cent of women in the general population may be nickel-sensitive (Environment Agency, 2009d). Ingestion of nickel can cause skin reactions in previously sensitised individuals. The other main concern for oral exposure to nickel is its developmental toxicity potential, which has been

observed in experimental animal studies (Environment Agency, 2009d).

Soluble nickel salts and the mixture of nickel sulphides and oxides present in refinery dust are carcinogenic to the lung and nasal tissues in humans (Environment Agency, 2009d). Other toxic effects of nickel observed following inhalation exposure include chronic bronchitis, emphysema, reduced vital capacity and asthma.

Health Criteria Values (HCVs) for nickel and its inorganic compounds are summarised in Table 1.

The oral tolerable daily intake (TDI_{oral}), which is based on the current recommendation of the World Health Organization (WHO), is protective of both the developmental effects seen in animals and the skin hypersensitivity reactions in humans (Environment Agency, 2009d).

The inhalation tolerable daily intake (TDI_{inh}), which is based on several expert group opinions, is protective of both carcinogenicity and non-cancer effects since guidelines based on both types of endpoint would be approximately the same (Environment Agency, 2009d).

The adult inhalation mean daily intake (MDI_{inh}) for nickel is estimated at $0.06 \mu\text{g day}^{-1}$. The adult oral mean daily intake (MDI_{oral}) for nickel compounds from food and water combined is approximately $130 \mu\text{g day}^{-1}$ (Environment Agency, 2009d).

Both oral and dermal exposure to nickel can cause hypersensitivity reactions of the skin and both exposures should be assessed together. Inhalation exposure may be considered separately for its effects on the respiratory system but it potentially also contributes systemically to skin effects in sensitised individuals (Environment Agency, 2009d).

Table 1

Recommended Health Criteria Values and estimated background adult intakes for inorganic compounds of nickel (Environment Agency, 2009d).

Parameter	Nickel
$TDI_{oral}, \mu\text{g kg}^{-1} \text{ bw day}^{-1}$	12
$MDI_{oral}, \mu\text{g day}^{-1}$	130
$TDI_{inh}, \mu\text{g kg}^{-1} \text{ bw day}^{-1}$	0.006
$MDI_{inh}, \mu\text{g day}^{-1}$	0.06

Notes:

bw = bodyweight

TDI = tolerable daily intake

MDI = mean daily intake

¹ Based on weight as nickel only

Exposure assessment

Occurrence in soil

Nickel occurs naturally in soils as a result of the weathering of the parent rock (McGrath, 1995). The highest concentrations are found in basic igneous rocks with much lower levels found in sedimentary rocks including shales, clays, limestones, and sandstones (Kabata-Pendias and Mukherjee, 2007; McGrath, 1995). The underlying geology and soil-forming processes strongly influence the amount of nickel in soils with higher median concentrations reported in clays, silts, and fine grained loams relative to coarser grained loams, sandy and peaty soils (Kabata-Pendias and Mukherjee, 2007; McGrath, 1995).

Anthropogenic activity has resulted in the widespread atmospheric deposition of nickel from the burning of oil and coal (McGrath, 1995). Localised nickel contamination may also occur near to a smelter or plating works or be associated with mining activity such as around Clydach in South Wales (ATSDR, 2005; McGrath, 1995). Agricultural fertilisers, especially phosphates, are also a significant source of nickel in soil but it is unlikely to build-up in soil in the long term from their use (McGrath, 1995). More important is the application of wastes to land including sewage sludge and pulverised fuel ash, for example coal can contain up to 70 mg kg⁻¹ nickel which can become highly concentrated in ash residues (ATSDR, 2005; McGrath, 1995).

The UK Soil and Herbage Survey (UK SHS) is a comprehensive survey of the concentrations of major contaminants in soils and herbage across the UK. The UK SHS found total nickel concentrations in the range 1.16 to 216 mg kg⁻¹ for rural UK soils, with a mean value of 21.1 mg kg⁻¹. Urban UK soils were found to contain nickel concentrations in the range 7.07 to 102 mg kg⁻¹, with a mean value of 28.5 mg kg⁻¹ (Environment Agency, 2007).

Sites in Scotland contributed higher nickel concentrations to the UK dataset; these concentrations are considered likely to reflect the local geology of igneous rocks. In England, Wales and Northern Ireland, soil nickel concentrations generally reflected lower nickel concentrations in parent materials (Environment Agency, 2007).

The UK SHS data are consistent with:

- a survey of soils in Scotland (Berrow and Reaves, 1986) that reported a geometric mean concentration of nickel in soil of 27 mg kg⁻¹; and
- a survey of soils in England and Wales by McGrath and Loveland (1992) that reported a geometric mean concentration of 20 mg kg⁻¹.

Behaviour in the soil environment

Recommended values for chemical data used in the exposure modelling of nickel and its inorganic compounds are shown in Table 4. Further information about the selection of chemical properties and the

derivation of the soil-to-plant concentration factors for inorganic compounds of nickel can be found in *Supplementary information for the derivation of SGV for nickel* (Environment Agency, 2009e).

Natural nickel mineralogy includes sulphides and silicates, with a correspondingly low environmental mobility (IPCS, 1991). Massoura *et al.* (2006) observed in a number of weathered European soils that goethite, serpentine, and talc were the most frequently found nickel-bearing minerals. Secondary mineral enrichment in nickel was found to be much lower in the soils from a temperate climate compared to those from a humid tropical area.

In sequential extractions of soil, nickel is commonly found predominantly in the residual and iron-manganese oxide fractions (Kabata-Pendias and Mukherjee, 2007; McGrath, 1995). Nickel sulphate, nickel sulphide, and nickel ferrite were found in urban air particulates characterised from a study in Florida (ATSDR, 2005).

The soil chemistry of nickel is based on the divalent cation (Ni²⁺) with nickel ferrite the most probable solid phase that can precipitate in soils (McGrath, 1995). Above pH 8, the hydroxy complex Ni(OH)⁺ is also a major species in soil solution, whilst in acid soils nickel sulphate and nickel hydrogen phosphate are important, depending on the levels of sulphate and phosphate present (McGrath, 1995). In surface and sludge amended soils, nickel may be increasingly bound to organic matter, a part of which forms easily soluble chelates (Kabata-Pendias and Mukherjee, 2007). In the presence of fulvic and humic acids, these complexes are much more mobile and may be more important than the hydrated divalent cation in soil solution chemistry (ATSDR, 2005).

Soil pH is the most important factor controlling nickel solubility, sorption and mobility with the clay, iron-manganese mineral, and soil organic matter content being of secondary importance (ATSDR, 2005; Ge *et al.*, 2000; Kabata-Pendias and Mukherjee, 2007; McGrath, 1995; Suave *et al.*, 2000). Tye *et al.* (2004) found that free metal ion activity for nickel in a wide range of UK soils with historical contamination could be reasonably well described by simple solubility equations that included soil pH, total metal concentration, organic carbon concentration, and solution ionic strength.

The solubility and mobility of nickel increases with decreasing pH (Kabata-Pendias and Mukherjee, 2007; Tye *et al.*, 2004; McGrath, 1995). Many nickel compounds are soluble at a pH less than 6.5 (IPCS, 1991). In a study of soils from disused railyards, Ge *et al.* (2000) found that above pH 8, nickel carbonate was the major species in soil solution but fulvic acid complexes were significant across the pH range. Compared with other heavy metals such as cadmium and zinc, nickel is rather weakly sorbed to clay and iron minerals, and likely to be more mobile (ATSDR, 2005; McGrath, 1995). Nickel adsorption by soils may decrease with complexation, for example in the presence of EDTA and increasing levels of soil organic matter (ATSDR, 2005).

The phytoavailability of nickel has been correlated with free nickel ion activity in soil solution and so plant uptake also depends on soil properties such as soil pH, organic matter, and iron / manganese oxide content (Ge *et al.*, 2000; Kabata-Pendias and Mukherjee, 2007; Massoura *et al.*, 2006; Rooney *et al.* 2007, Tye *et al.*, 2004). Plants are reported to uptake nickel more readily in its simple ionic form (Ni^{2+}) than as inorganic and organic complexes (Kabata-Pendias and Mukherjee, 2007). It has also been suggested that nickel from anthropogenic sources might be more readily taken up than naturally occurring nickel (an increase of more than 20 per cent compared with natural sources) (Environment Agency, 2009e).

Plant species also differ in their tolerance and ability to take up nickel from soil (Environment Agency, 2009e). Plant families that have been reported for their tolerance to, and hyperaccumulation of, nickel include Cruciferae (e.g. cabbage, cauliflower and turnip) and Leguminosae (e.g. pea and bean) (Kabata-Pendias and Mukherjee, 2007).

There is some evidence that nickel is essential for higher plants although its metabolic role, if any, has yet to be established (Kabata-Pendias and Mukherjee, 2007). Nickel phytotoxicity has been frequently studied with commonly reported systems including chlorosis followed by yellowing and necrosis of leaves, restricted growth, and tissue injury (Environment Agency, 2009e; Kabata-Pendias and Mukherjee, 2007; Rooney *et al.*, 2007). Phytotoxic nickel concentrations vary widely among plant species and cultivars and have been reported in the range 40 to 246 mg kg^{-1} DW plant tissue (Kabata-Pendias and Pendias, 2001).

Phytotoxicity will also depend on nickel availability in the soil solution and was found to vary by more than one order of magnitude in standard growth based toxicity tests for tomato and barley plants carried out for a range of European soils based on total added nickel (Rooney *et al.*, 2007). This variation was substantially reduced when toxicity threshold values were based on soil solution nickel concentrations or free ion activity.

Environment Agency (2009b) noted that the dermal absorption fraction (ABS_d) is chosen on a contaminant-by-contaminant basis, following review of the scientific literature. Experimentally derived values were presented for a short list of inorganic and organic compounds based on compiled information, which did not include nickel (US EPA, 2004a and 2004b).

There has been a limited number of studies on the dermal absorption of nickel through human skin and even fewer examining uptake from soil (Moody *et al.*, 2009). Moody *et al.* (2009) measured *in vitro* dermal absorption of radioactive nickel chloride through human breast skin over a 24 hour period with and without a spiked commercial soil. Mean dermal absorption (taken as the sum of nickel passing through the skin and retained within the skin after washing) was one per cent with soil and 23 per cent without soil present. Although the results are not directly comparable, Turkhall *et al.* (2008) reported similar rates of dermal absorption of nickel chloride by pig skin (two to three per cent) from

aged spiked sandy and clay soils. The soils used by Turkhall *et al.* had much lower organic matter contents than the soil used by Moody *et al.* although the experimental soil loading was much higher (47 mg cm^{-2} compared to 5 mg cm^{-2}).

Several studies have noted that most nickel applied as a soluble salt is bound within the skin and does not reach systemic circulation (Hostynek *et al.* 2001; Moody *et al.*, 2009; Turkhall *et al.* 2008). Although acknowledging that metals bound within the skin may not be bioavailable, Moody *et al.* (2009) cautioned that until this effect is well documented a worst-case exposure scenario should be assumed. The ABS_d calculated from Moody *et al.* (2009), corrected from 24 to 12 hour contact time, is $0.005 [0.01 * 12 / 24]$ and this value has been used in the derivation of the SGV.

A review of the literature found no data that could be used to provide a generalised nickel soil-to-dust transport factor. In the absence of a contaminant-specific soil-to-dust transport factor, the default value of 0.5 g g^{-1} dry weight (DW) has been used.

Soil Guideline Values

Soil Guideline Values (SGVs) for nickel are presented according to land use in Table 2. The SGVs apply only to nickel and its inorganic compounds. For residential and allotment land uses, SGVs are based on estimates representative of exposure of young children because they are generally more likely to have higher exposures to soil contaminants. Further information on the default exposure assumptions used in the derivation of SGVs can be found in *Updated technical background to the CLEA model* (Environment Agency, 2009b).

Analytical limits of detection² for total nickel concentration in soil will depend on the analytical technique used and range from 0.3 to 2.0 mg kg^{-1} DW, with limits of quantification³ ranging from 1.5 to 10 mg kg^{-1} DW. Limits of detection and quantification can vary due to the sample matrix and the range, sensitivity and set-up of the instrumentation being used. MCERTS⁴ accredited analytical methods for total nickel in soil are available.

Further risk evaluation

The SGVs for nickel are based on separate consideration of the toxic endpoints upon which the health criteria values are based.

Nickel can cause allergic skin reactions in sensitised individuals following either dermal or oral exposure. In addition inhaled nickel may also be absorbed into the systemic circulation (Environment Agency, 2009d). The oral based assessment criterion has therefore been derived by comparing the oral TDI with estimates from all exposure pathways relevant to each land use, although the contribution to total exposure from

² The amount of a substance that can be detected, but not quantitatively measured

³ Amount present of a substance that can be quantitatively measured

⁴ Environment Agency's Monitoring Certification Scheme

inhalation is very small. Inhaled nickel may result in carcinogenic and non-cancer toxicity in the lung and nasal passages. Since oral exposure does not contribute to the local effects seen in the lung following inhalation (Environment Agency, 2009d), it seems reasonable to assess inhalation toxicity separately. Therefore, the inhalation assessment criterion has been derived by comparing inhalation exposure only with the inhalation TDI.

The SGV is the lower value of the two independently derived oral and inhalation assessment criteria, which vary according to exposure pattern and land use scenario (Environment Agency, 2009b).

Table 3 presents the individual assessment criteria for each land use and the estimated contribution via each exposure pathway to total human exposure at a soil concentration equal to the assessment criteria for each land use scenario. Where the SGV (the lower of the two assessment criteria for a land use scenario) is based only on inhalation exposure, the specific contributions to total inhalation exposure are also presented so that the risk driving pathways can more easily be identified. The data show that:

- the inhalation assessment criterion is lower than the oral assessment criterion for the residential and commercial land use scenarios
- the oral assessment criterion is lower than the inhalation assessment criterion for the allotment land use
- background exposure is a significant contributor to total exposure for all land use scenarios
- soil ingestion makes the greatest contribution from soil to total exposure for the residential and commercial land use scenarios
- inhalation of indoor dust makes a very small contribution to total exposure but is the most significant risk driver for the residential and commercial land use scenarios because of the lower threshold for inhalation health effects
- consumption of homegrown produce is the largest contributor from soil to total exposure for the allotment land use scenario and is the risk driver pathway for that land use

The critical effects of ingested nickel are developmental effects on the offspring of females exposed during pregnancy and dermal effects in those previously sensitised to nickel (Environment Agency, 2009d). As it has been suggested that young children are less likely than adults to have been sensitised to nickel (COT, 2004), it could be argued that, for oral exposure to nickel, the critical receptor is a woman of child-bearing age. This argument would seem to be strengthened if the recent introduction of legislative restrictions on the use nickel (TSO, 2005) reduces the prevalence of nickel hypersensitisation in the UK population – perhaps initially in children.

However, a study of sensitisation in American infants (Bruckner *et al.* 2000) indicates that sensitisation may be prevalent in children. In addition, the effect which the EU Directive on nickel will have on the prevalence of nickel hypersensitisation in the UK population is unclear. In view of the uncertainties, and the greater exposure of infants and children to soil contaminants compared to adults (on a per bodyweight basis), the available data do not provide sufficient basis for departing from the default child critical receptor in deriving screening level SGVs for the residential and allotment scenarios.

One further consideration is whether at soil concentrations equal to the SGV, there is a risk of elicitation of existing nickel induced allergic dermatitis through skin contact with soil (Environment Agency, 2009d). Horowitz and Finley (1994) proposed a screening level approach for assessing risk to health from contact allergens and this has been applied to nickel in the accompanying text box. From this simple analysis, it can be concluded that contact with soil at the SGV level for nickel would not be expected to pose a risk of eliciting dermatitis in previously sensitised individuals in the general population for the land use scenarios considered.

Table 2

The Soil Guideline Values for nickel presented in this table should only be used in conjunction with the information contained in this briefing note and with an understanding of the exposure and toxicological assumptions contained in *Updated technical background to the CLEA model* (Environment Agency, 2009b), *Human health toxicological assessment of contaminants in soil* (Environment Agency, 2009c) and *Contaminants in soil: updated collation of toxicological data and intake values for humans. Nickel* (Environment Agency, 2009d).

Land use	Soil Guideline Value (mg kg ⁻¹ DW) ^{1,2,3}
	Nickel
Residential ⁴	130
Allotment ⁵	230
Commercial ⁴	1,800

- Notes:
- ¹ Figures are rounded to one or two significant figures
 - ² Based on a sandy loam soil as defined in Environment Agency (2009b) and 6% SOM
 - ³ In applying the rules for non-soil background to the SGV, the background ADE is limited to being no larger than the contribution from the relevant soil ADE
 - ⁴ Based on comparison of inhalation exposure with inhalation TDI
 - ⁵ Based on comparison of oral, dermal, and inhalation exposure with the oral TDI

Other site specific factors

Although only a small contributor to total exposure, the most significant pathway for the residential and commercial land use scenarios is inhalation of indoor dust derived from soil. On a site-specific basis, assessors may wish to consider the plausibility and magnitude of this pathway further by measuring the level of nickel in house dust, the amount of house dust present, and the contributions from outdoor soil.

In the absence of indoor exposure the consumption of homegrown produce, and to a lesser extent direct soil ingestion, will drive the risk from nickel and are the major contributors to total exposure. The phytoavailability of nickel and its inorganic compounds to garden fruit and vegetables depends on a number of complex factors but soil pH appears from the scientific literature to be

especially important (Environment Agency, 2009e). The soil-to-plant concentration factors used in the derivation of the SGV are based on a geometric mean value calculated from a review of field and experimental studies (Environment Agency, 2009e).

In circumstances where the SGV is exceeded and the consumption of produce is a significant pathway, assessors may wish to consider nickel phytoavailability on a site-specific basis and collect data on soil pH and organic matter content. Assessors undertaking a Detailed Quantitative Risk Assessment (DQRA) (Defra and Environment Agency, 2004) could also carry out further investigation (including the sampling and chemical analysis of edible parts of fruits and vegetables) to establish site-specific plant concentration factors.

Assessing the risk of elicitation of allergic dermatitis at the SGV level in soil

Environment Agency (2009d) noted that prolonged skin exposure to soluble nickel and nickel containing substances may result in dermatitis in sensitive individuals. This effect is not explicitly considered in the derivation of the SGV.

Horowitz and Finley (1994) proposed a screening methodology for dermal contact allergens. It uses data from chemical skin patch tests, soil to skin adherence factors, and knowledge of dermal absorption from soil to derive a screening level soil concentration for health-based risk assessment. The equation below is based on their proposals:

$$GAC_{contact} = \frac{P}{AF} \times \frac{1}{ABS_d} \times 1000000 \text{ mg.kg}^{-1}$$

Where

$GAC_{contact}$	Soil screening level for dermal contact with skin allergen, mg kg^{-1} DW
P	Patch test threshold for no effect level following exposure to allergen, $\text{mg - allergen cm}^{-2}$ - skin
AF	Soil-to-skin adherence factor, mg - soil cm^{-2} - skin
ABS_d	Dermal absorbed fraction including amount reaching systemic circulation and retained by skin, dimensionless

Environment Agency (2009d) cited a study by Uter *et al.* where 92 nickel-allergic patients were patch tested with serial dilutions of nickel sulphate. Minimal reactions were elicited in none of the patients exposed to $0.026 \mu\text{g cm}^{-2}$ of skin, and this value has been assumed for the patch test threshold (P). AF values of 1 mg cm^{-2} and 0.14 mg cm^{-2} have been assumed for the residential and commercial land uses respectively and are taken from the land use scenario defaults described in Environment Agency (2009b). An ABS_d value of 0.01 has been assumed from the study by Moody *et al.* (2009) described earlier in this report. The calculated $GAC_{contact}$ values for the residential and commercial land use scenarios are 2,600 and 18,500 mg kg^{-1} DW respectively. Therefore, the SGV are also considered to be protective of elicitation of contact dermatitis from nickel in soil.

Table 3

Individual oral and inhalation based assessment criteria for each land use scenario are presented in the table below. Percentage pathway contributions to total exposure from soil and background sources are provided for all land use scenarios to illustrate exposure pattern. Pathway contributions for inhalation exposure only are also provided for the residential and commercial land use scenarios, where the inhalation assessment criterion is also the SGV. All data calculated using the CLEA software.

	Individual assessment criteria (mg kg ⁻¹ DW)				
	Residential		Allotment	Commercial	
Comparison of oral, dermal, and inhalation exposure with oral TDI	530		230	22,000	
Comparison of inhalation exposure with inhalation TDI	130		3,700	1,800	
Exposure pathways	Contribution to exposure from soil and background sources according to land use (%) ¹				
	All pathways	Inhalation only	All pathways	All pathways	Inhalation only
Ingestion of soil and indoor dust ²	32.8		3.8	49.1	
Consumption of homegrown produce and attached soil	16.2		46.1	NA	
Dermal contact (indoor)	<0.1		NA	0.2	
Dermal contact (outdoor)	0.8		0.1	0.2	
Inhalation of dust (indoor)	0.1	50.0	NA	0.3	85.1
Inhalation of dust (outdoor)	<0.1	<0.1	<0.1	<0.1	0.6
Inhalation of vapour (indoor)	NC		NC	NC	
Inhalation of vapour (outdoor)	NC		NC	NC	
Oral background	49.9		50.0	49.8	
Inhalation background	0.1	50.0	0.0	0.1	14.3

Notes: ¹ Rounded to one decimal place

² Treated as one pathway (see Environment Agency, 2009b)

NA = not applicable (This exposure pathway is not included in the scenario for the generic land use.)

NC = not calculated (This exposure pathway is not included for chemical-specific reasons.)

Table 4

Recommended chemical data for inorganic compounds of nickel (at 10°C unless stated)

Chemical property	Inorganic nickel	
Air-water partition coefficient, dimensionless	NA	
Dermal absorption fraction, dimensionless	0.005	Moody <i>et al.</i> (2009)
Diffusion coefficient in air, m ² s ⁻¹	NA	
Diffusion coefficient in water, m ² s ⁻¹	NA	
Octanol–water partition coefficient (log), dimensionless	NA	
Organic carbon–water partition coefficient (log), cm ³ g ⁻¹	NA	
Relative molecular mass, g mol ⁻¹	NA	
Soil–water partition coefficient, cm ³ g ⁻¹	500	Environment Agency (2009e)
Vapour pressure, Pa	NA	
Water solubility, mg L ⁻¹	2.5 × 10 ⁶ (20°C)	Environment Agency (2009e)
Soil-to-dust transport factor, g g ⁻¹	0.5	Environment Agency (2009b)
<i>Soil-to-plant concentration factor, mg kg⁻¹ FW per mg kg⁻¹ DW</i>		
Green vegetable produce	3.8 × 10 ⁻³	Environment Agency (2009e)
Root vegetable produce	4.3 × 10 ⁻³	Environment Agency (2009e)
Tuber vegetable produce	1.9 × 10 ⁻³	Environment Agency (2009e)
Herbaceous fruit produce	2.5 × 10 ⁻³	Environment Agency (2009e)
Shrub fruit produce	2.5 × 10 ⁻³	Environment Agency (2009e)
Tree fruit produce	3.4 × 10 ⁻³	Environment Agency (2009e)

Notes:

FW = fresh weight

DW = dry weight

NA = not applicable (The CLEA model does not require these values in the derivation of assessment criteria for inorganic chemicals.)

References

- ATSDR, 2005. *Toxicological profile for nickel*. Atlanta, GA: Agency for Toxic Substances and Disease Registry.
- BERROW, M.L., and REAVES, G.A., 1986. Total chromium and nickel contents of Scottish soils. *Geoderma* 37, 15-27.
- BRUCKNER, A.L., WESTON, W.L., MORELLI, J.G., 2000. Does sensitization to contact allergens begin in infancy? *Pediatrics*, 105 (1), p. e3.
- COT, 2004. *Statement on twelve metals and other elements in the 2000 Total Diet Study*. London: Committee on Toxicity of Chemicals in Food, Consumer Products, and the Environment. Available at: <http://cot.food.gov.uk/pdfs/cotstatements2004metals.pdf> [Accessed April 2009]
- DEFRA and ENVIRONMENT AGENCY, 2004. *Model procedures for the management of land contamination*. Contaminated Land Report 11. Bristol: Environment Agency.
- DEPA, 2005a. *Draft risk assessment. Nickel* (CAS No: 7440-02-0), EINECS No: 231-111-4. Copenhagen: Danish Environmental Protection Agency.
- DEPA, 2005b. *Draft risk assessment. Nickel carbonate* (CAS No. 3333-67-3), EINECS No. 222-068-2. Copenhagen: Danish Environmental Protection Agency.
- DEPA, 2005c. *Draft risk assessment. Nickel chloride* (CAS No. 7718-54-9), EINECS No. 231-743-0. Copenhagen: Danish Environmental Protection Agency.
- DEPA, 2005d. *Draft risk assessment. Nickel dinitrate* (CAS No. 13138-45-9), EINECS No. 236-068-5. Copenhagen: Danish Environmental Protection Agency.
- DEPA, 2005e. *Draft risk assessment. Nickel sulphate* (CAS No. 7786-81-4), EINECS No. 232-104-9. Copenhagen: Danish Environmental Protection Agency.
- ENVIRONMENT AGENCY, 2007. *UK Soil and Herbage Pollutant Survey. Report No. 7: Environmental concentrations of heavy metals in UK soil and herbage*. Bristol: Environment Agency.
- ENVIRONMENT AGENCY, 2009a. *Using Soil Guideline Values*. Bristol: Environment Agency.
- ENVIRONMENT AGENCY, 2009b. *Updated technical background to the CLEA model*. Science Report SC050021/SR3. Bristol: Environment Agency.
- ENVIRONMENT AGENCY, 2009c. *Human health toxicological assessment of contaminants in soil*. Science Report SC050021/SR2. Bristol: Environment Agency.
- ENVIRONMENT AGENCY, 2009d. *Contaminants in soil: updated collation of toxicological data and intake values for humans. Nickel*. Science Report SC050021/SR TOX8. Bristol: Environment Agency.
- ENVIRONMENT AGENCY, 2009e. *Supplementary information for the derivation of SGV for nickel*. Bristol: Environment Agency.
- GE, Y., MURRAY, P., HENDERSHOT, W.H., 2000. Trace metal speciation and bioavailability in urban soils. *Environmental Pollution*, 107, 137 – 144.
- GREENWOOD, N.N., EARNSHAW, A., 1997. *Chemistry of the Elements*, Second Edition. Oxford: Butterworth-Heinemann.
- HOROWITZ, S.B., FINLEY, B.L., 1994. Setting health-protective soil concentrations for dermal contact allergens: a proposed methodology. *Regulatory Toxicology and Pharmacology*, 19, 31 – 47.
- HOSTYNEK, J.J., DREHER, F., NAKADA, T., SCHWINDT, D., ANIGBOGU, A., MAILBACH, H.I., 2001. Human stratum corneum adsorption of nickel salts. Investigation of depth profiles by tape stripping in vivo. *Acta Dermato-Venereologica*, Supplement 212, 11 – 18.
- IPCS, 1991. *Environmental Health Criteria 108: nickel*. Geneva: WHO, International Programme on Chemical Safety. Available at: <http://www.inchem.org/documents/ehc/ehc/ehc108.htm> [Accessed April 2009].
- KABATA-PENDIAS, A., MUKHERJEE, A.B., 2007. *Trace Elements from Soil to Human*. Berlin: Springer-Verlag.
- KABATA-PENDIAS, A., PENDIAS, H., 2001. *Trace Elements in Soils and Plants*, Third Edition. Boca Raton: CRC Press LLC.
- MASSOURA, S.T., ECHEVARRIA, G., BECQUER, T., GHANBAJA, J., LECLERC-CESSAC, E., MOREL, J-L., 2006. Control of nickel availability by nickel bearing mineral in natural and anthropogenic soils. *Geoderma*, 136, 28 – 37.
- McGRATH, S. P. and LOVELAND, P.J., 1992. *The Soil Geochemical Atlas of England and Wales*. Blackie: London.
- McGRATH, S. P., 1995. Nickel. In *Heavy Metals in Soils* (2nd edn.) (ed. B.J. Alloway). London: Blackie Academic & Professional.
- MOODY, R.P., JONCAS, J., RICHARDSON, M., PETROVIC, S., CHU, I., 2009. Contaminated Soils (II): In vitro dermal absorption of nickel (Ni-63) and mercury (Hg-203) in human skin. *Journal of Toxicology and Environmental Health, Part A*, 72, 551 – 559.
- ROONEY, C.P., ZHAO, F.-J., McGRATH, S.P., 2007. Phytotoxicity of nickel in a range of European soils:

Influence of soil properties, Ni solubility and speciation. *Environmental Pollution*, 145, 596 – 605.

SUAVÉ, S., HENDERSHOT, W., ALLEN, H.E., 2000. Solid-solution partitioning of metals in contaminated soils: Dependence on pH, total metal burden, and organic matter. *Environmental Science and Technology*, 34 (7), 1125 – 1131.

TSO, 2005. The Dangerous Substances and Preparations (Nickel) (Safety) Regulations 2005. Statutory Instrument No. 2001. London: The Stationery Office. Available at: <http://www.opsi.gov.uk/si/si2005/20052001.htm> [Accessed April 2009]

TURKHALL, R.M., SKOWRONSKI, G.A., ABDEL-RAHMAN, M.S., 2008. Effects of soil and aging on the dermal bioavailability of hydrocarbons and metals in soil. *International Journal of Soil, Sediment and Water*, 1 (1), 1 – 13.

TYE, AM., YOUNG, S., CROUT, N.M.J., ZHANG, H., PRESTON, S., ZHAO, F.J., McGRATH, S.P., 2004. Speciation and solubility of Cu, Ni and Pb in contaminated soils. *European Journal of Soil Science*, 55, 579 – 590.

USEPA, 2004a. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), Final Report EPA/540/R/99/005. Washington: United States Environmental Protection Agency.

USEPA, 2004b. Additional and current dermal absorption fraction values for soil (ABS_d) (Supplementing Exhibit 3-4 of Part E) [online]. Washington: United States Environmental Protection Agency. Available from www.epa.gov/oswer/riskassessment/ragse/index.htm [Accessed 15 January 2007].

WHO, 2006. *Environmental Health Criteria 234. Elemental speciation in human health risk assessment*. Geneva: World Health Organization. Available at: <http://www.who.int/ipcs/publications/ehc/ehc234.pdf> [Accessed April 2009].

YIN, Y., IMPELLITTERI, C., YOU, S., ALLEN, H., 2002. The importance of organic matter distribution and extract soil:solution ratio on the desorption of heavy metals from soils. *The Science of the Total Environment*, 287, 107 – 119.

Publication Information

This technical note presents information from Science Project SC050021.

Project manager: Jo Jeffries, Science, Head Office

This work was funded by the Environment Agency's Science Department, which provides scientific

knowledge, tools and techniques to enable us to protect and manage the environment as effectively as possible.

Published by: Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD.

© Environment Agency March 2009

Author(s): Ian Martin, Hannah Morgan¹, Caroline Jones¹, Elizabeth Waterfall¹ and Jo Jeffries

Research Contractor:

¹ Atkins Ltd, The Axis, 10 Holliday Street, Birmingham, B1 1TF, 0121 483 5870

Dissemination Status:

Released to all regions
Publicly available

Legal Status and Disclaimer

The CLEA Guidance incorporates the following

- 1) *Science Report SC050021/SR2: Human health toxicological assessment of contaminants in soil.*
- 2) *Science Report SC050021/SR3: Updated technical background to the CLEA model.*
- 3) *Science Report SC050021/SR4: CLEA Software (Version 1.04) Handbook.*
- 4) *CLEA Software version 1.04 (2009)*
- 5) *Toxicological reports and SGV technical notes*

The CLEA Guidance can help suitably qualified assessors to estimate the risk that a child or adult may be exposed to a soil concentration on a given site over a long period of exposure that may be a cause for concern to human health. The CLEA Guidance does not cover other types of risk to humans, such as fire, suffocation or explosion, or short-term and acute exposures. Nor does it cover risks to the environment or the pollution of water.

The CLEA Guidance is non-statutory. It does not purport to interpret the policies or procedures of the Environment Agency and shall not operate as a statutory licence, waiver, consent or approval from the Environment Agency. Nothing in the CLEA Guidance shall prejudice, conflict with or affect the exercise by the Environment Agency of its statutory functions, powers, rights, duties, responsibilities, obligations or discretions arising or imposed under the Environment Act 1995 or any other legislative provision enactment, bye-law or regulation.

The CLEA guidance describes the soil concentrations above which, in the opinion of the Environment Agency, there may be concern that warrants further investigation and risk evaluation for both threshold and non-threshold substances. These levels are a guide to help assessors estimate risk. It does not provide a definitive test for telling when risks are significant.

Regulators are under no obligation to use the CLEA Guidance.