Nickel: estimate of long-term intake via food based on the BfR MEAL Study

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Nickel is a metal that is widespread in the environment, as a component of the Earth's crust. Alongside this natural source, nickel can also end up in drinking water and food as a result of industrial applications. When it comes to assessing the effects of nickel on the human body following long-term oral intake, adverse effects on foetal development in animal studies have been identified as the critical effect. In 2020, the European Food Safety Authority (EFSA) re-evaluated the health risks related to the presence of nickel in food, deriving a Tolerable Daily Intake (TDI) of 13 micrograms per kilogram (µg/kg) of body weight and day.

With its MEAL Study, the German Federal Institute for Risk Assessment (BfR) has analysed 90% of the foods most commonly consumed in Germany with the aim of detecting various substances such as nickel. The result: The main food groups 'Legumes, nuts, oil seeds and spices' and 'Coffee, cocoa and tea' exhibit the highest average nickel concentrations, with approximately 1.6 milligrams per kilogram (mg/kg) and 1.5 mg/kg, respectively. Of these, cocoa powder is the food with the highest concentration measured, at approx. 11.1 mg/kg, followed by cashew nuts, at approx. 5.4 mg/kg. As a result of the relatively high intake amount, foods in the main group 'Grains and grain-based products' account for the highest nickel intake, at 24% for adults and adolescents, and 28% for children.

In the case of adults and adolescents, nickel intake via food as calculated according to the MEAL data amounts to 11% of the health-based guidance value (TDI) on average. In children, intake as a proportion of the TDI amounts to 42% on average. In the case of some (<5%) highly exposed children (0.5–5 years), nickel intake exceeds the TDI. By way of comparison, the EFSA estimate states that the intake of highly exposed children typically exceeds the TDI. In the opinion of EFSA, the intake of nickel via food may therefore raise a health concern in the young age groups. In the case of individuals with an existing contact allergy, oral intake of nickel may also trigger allergic skin reactions or make such reactions worse. For methodological reasons, however, nickel exposure via food cannot be assessed with regard to this acute effect with the present data.

In recent years, the BfR has published opinions on a number of products containing nickel (including toys, tattoos, scented candles, etc.). More information can be found here: https://www.bfr.bund.de/en/a-z_index/nickel-130376.html

1 Background

The BfR MEAL Study represents the first German Total Diet Study (TDS). MEAL is an acronym for '**M**ahlzeiten für die **E**xpositionsschätzung und **A**nalytik von **L**ebensmitteln' ('Meals for exposure assessment and analysis of foods'). Conducted on behalf of the German Federal Ministry of Food and Agriculture (BMEL), the study covers more than 90% of the foods consumed by the average of the German population. This has produced a representative dataset on the concentrations of substances in foods according to the consumption habits of the general population. In addition, rarely consumed foods with known high concentrations of undesirable substances are also taken into account. Before analysis, the foods are prepared for consumption as is standard practice in German households. Through the BfR MEAL Study, uncertainties in existing exposure assessments can be minimised and datasets obtained for substances that have not been adequately investigated to date (Sarvan et al. 2017).

2 Hazard characterisation

Nickel (Ni) is a metal that is found everywhere in the environment, as a component of the Earth's crust. The element occurs in several oxidation states. In food and in drinking water, nickel is typically present in the divalent form, which represents its most stable oxidation state. In the case of chemical analyses of nickel in food, the total concentration of all nickel compounds is typically specified as 'total nickel' – only a few studies are available on individual nickel compounds found in food. In food, nickel is found as part of various organic complexes and therefore exhibits physical and chemical properties that differ from inorganic nickel, and may also exhibit different biological properties (EFSA 2020). As one example, nickel in cocoa beans is generally found in organic form as a Ni-gluconate complex (Ni-citrate complex in traces), while cocoa powder primarily contains the water insoluble divalent (Ni^{2+}) form (Peeters et al. 2017). The highest bioavailability is described for the water-soluble divalent (Ni^{2+}) form (Peeters et al. 2017, Schaumlöffel 2005).

While a proportion of the nickel found in food is naturally occurring, the nickel found in food and drinking water can also result from a number of industrial and technological applications. In 2020, the European Food Safety Authority (EFSA) updated its scientific opinion on the risks to human health related to the presence of nickel in foods and in drinking water, which it had published in 2015 (EFSA 2020). As part of the toxicological assessment of nickel, a new health-based guidance value was derived for the Tolerable Daily Intake (TDI[1]) of 13 micrograms per kilogram of body weight and day (µg/kg BW and day, EFSA 2020). This value is higher than the previously derived value of 2.8 µg/kg BW and day). This can be ascribed to the application of the updated guidelines for the benchmark dose (BMD[2], EFSA 2017).

Human exposure to nickel is mainly via food (EFSA 2015). EFSA's CONTAM panel (Panel on Contaminants in the Food Chain) describes the following toxicological/toxicokinetic properties (EFSA 2020). The absorption of nickel from the gastrointestinal tract depends on the type of nickel compound and its solubility. For the health assessment of chronic intake, an absorption rate of around 10% is assumed. Absorbed nickel is distributed in the organism by the blood. Nickel can cross the placental barrier and may also pass into breast milk during lactation. Nickel is primarily excreted via the urine. Studies in rodents and dogs have shown that short-term repeated oral intake primarily affects body weight and organ weight (liver and kidneys). Adverse effects on bones and the intestinal microbiota have also been observed. Beyond this, a number of studies also indicate disruptions to neurological function in mice and rats. In mice, soluble nickel compounds impair fertility. Developmental toxicity has been identified in mice and rats, with rats being more sensitive than mice in experimental studies. EFSA considered the increased incidence of post-implantation loss in rats following repeated oral exposure to soluble nickel compounds as the most critical effect in the context of a health risk assessment. Using the BMD analysis based on this effect from one- and two-generation studies in rats, a $BMDL_{10}$ (benchmark dose lower confidence limit) of 1.3 mg nickel/kg BW and day was determined as a reference point for deriving a TDI. With the application of a

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[1] The TDI specifies the quantity of a substance that can be consumed orally on a daily basis over an entire lifetime without a detectable risk to health. The TDI is derived for substances introduced into the food chain, including drinking water, and applied to the assessment of the health risk that is associated with chronic exposure to such substances. The TDI is typically specified in mg/kg body weight per day.

[2] Benchmark dose (BMD): A dose calculated using mathematical dose-effect modelling that, in the investigations underlying this modelling, is associated with a certain effect size.

default uncertainty factor of 100 to account for potential variability between species and between individuals (of the same species), a TDI has been derived of 13 µg/kg BW and day.

In sensitised individuals (individuals with an existing contact allergy to nickel), oral exposure may also trigger allergic skin reactions or make such reactions worse. For this acute effect, a LOAEL (lowest observed adverse effect level) of 4.3 µg/kg BW was derived and used as the reference point for the application of the MoE[3] approach (EFSA 2020). Methodologically, however, the BfR MEAL Study is oriented solely towards determining long-term exposure: for this reason, nickel exposure via food cannot be assessed with regard to potential acute effects with the data available.

3 Exposure

Nickel was investigated in the BfR MEAL Study in all 356 foods of the MEAL food list. The foods were purchased nationwide in Germany in four separate regions between December 2016 and May 2019, with the choice of products accounting for the various purchasing patterns within the population and, for some of the foods concerned, potential regional and seasonal specialities. To ensure a representative compilation of samples was obtained, data was generated from consumer studies as well as from market data. The foods were prepared in the MEAL Study kitchen while simulating typical consumer approaches to preparation. The foods and meals were pooled (grouped together) before then being homogenised (Sarvan et al. 2017). For further information, please visit the BfR MEAL Study website (www.bfr-meal-studie.de).

For the investigation of nickel, a total of 840 pools were formed, consisting of 15–20 individual foods, respectively. The pools represent combinations of various purchasing regions (national, east, south, west and north), purchasing times (non-seasonal, season 1 and season 2[4]) and production types (non-specific, organic and conventional[5]). Of the 356 foods, 105 foods were sampled after stratification by production type and 70 stratified by region. The 356 foodstuffs were assigned to 19 main food groups (see table 1). The samples differentiated by production type (organic or conventional production) exhibited only minor differences in nickel concentration. In general, no tendency towards higher concentrations for samples of a particular production type can be identified. Accordingly, the tabular presentation of occurrence data and the exposure assessment hereinafter is made on the basis of the pools from conventional and non-specified production.

3.1 Occurrence data

Following the standard procedure, the individual results obtained for each of the 840 pools are calculated according to the modified Lower Bound (mLB) approach[6] and Upper Bound

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[3] Margin of Exposure (MoE): The ratio of a suitable reference value from the dose-effect relationship to the estimated exposure to the substance in humans.

[4] Season 1: Season featuring expectedly mostly imported goods. Season 2: Season featuring goods expectedly mostly produced in Germany.

[5] In the case of foods investigated without stratification by production type, the production type is categorised as 'non-specific'. In this case, samples from both conventional and organic production may be included.

[6] Modified lower bound (mLB) approach: if result <limit of detection (LOD), then value = 0, if result >LOD and <limit of quantification (LOQ), then value = LOD; LOQ (limit of quantification): the lowest concentration of an analyte in a sample that can be quantified within determined limits of certainty by using a specified analytical method; LOD (limit of detection): the lowest concentration of an analyte in a sample that can be distinguished from a blank sample using a specified analytical method.

(UB) approach[7], and then averaged at pool level (mean value of analytical multiple determination of a pool).

A total of 23% (193 of 840) of the pools exhibit non-quantifiable nickel concentrations. The highest proportion of non-detects was exhibited by the main food groups ‘Animal and vegetable fats and oils’ (100%) and ‘Eggs and egg products’ (90%).

Table 1 presents the main food groups, the sample structure within the main food groups and the statistical key figures for nickel concentrations. These key figures were calculated from the mean values of pools for each food, with the pools of the production type ‘organic’ not being accounted for here.

The main food groups ‘Legumes, nuts, oil seeds and spices’ and ‘Coffee, cocoa and tea’ exhibit the highest nickel concentrations, with 1,583 µg/kg and 1,488 µg/kg, respectively. The lowest nickel concentrations were determined for ‘Alcoholic drinks’ (19 µg/kg), ‘Water and water-based beverages’ (18 µg/kg) and ‘Eggs and egg products’ (17 µg/kg). The nickel concentrations of all other food groups lie between 21 µg/kg and 601 µg/kg (mean, UB in each case).

[7] Upper Bound (UB) approach: if result <LOD, then value = LOD, if result >LOD and <LOQ, then value = LOQ.

Table 1: Nickel concentrations in the BfR MEAL Study by main food groups in µg/kg, and for non-specific and conventional production (samples purchased between December 2016 and May 2019)

Main food group	Number of Foods[1]	Number of Pools[2]	Nickel concentration (µg/kg)								Food with highest concentration (maximum)
			mLB				UB				
			Mean	P50	Min.	Max.	Mean	P50	Min.	Max.	
01 Grains and grain-based products	40	82	349	163	8	1,975	359	163	20	1,975	Chia seeds
02 Vegetables and vegetable produce	34	132	83	53	6	340	84	53	17	340	Vegetable crisps
03 Starchy roots or tubers and products thereof	8	18	45	48	23	66	50	48	23	100	Fried potatoes (mLB) and potato chips (UB)
04 Legumes, nuts, oilseeds and spices	20	20	1,583	1,075	60	5,350	1,583	1,075	60	5,350	Cashew nuts
05 Fruit and fruit products	22	52	108	59	5	1,080	112	59	16	1,080	Dried fruits
06 Meat and meat products	35	85	22	22	6	60	27	24	16	60	Liver sausage (poultry)
07 Fish and seafood	30	39	23	15	6	165	30	20	16	165	Shellfish
08 Milk and dairy products	23	23	42	16	0	295	48	20	6	295	Ice cream (made from milk)
09 Eggs and egg products	2	8	5	5	5	5	17	17	17	18	Fried (chicken) eggs
10 Sugar, confectionery and water-based sweet desserts	15	15	585	350	0	2,800	601	350	30	2,800	Semisweet chocolate/dark chocolate
11 Animal and vegetable fats and oils	8	8	15	15	0	30	65	65	30	100	Corn oil and sunflower oil[3]
12 Fruit and vegetable juices and nectars	10	10	13	6	6	27	21	20	20	27	Multi-vitamin fruit juice
13 Water and water-based beverages	6	12	12	6	1	44	18	18	3	44	Energy drinks
14 Coffee, cocoa,tea and infusions	9	9	1,482	15	3	11,050	1,488	22	13	11,050	Cocoa powder

15 Alcoholic beverages	8	8	6	6	0	21	19	20	6	48	Red wine (mLB) and spirits (UB)[4]
16 Food products for infants and toddlers	11	11	176	37	6	1040	185	50	20	1,040	Porridge (millet) (powder)
17 Vegan/vegetarian products	7	7	386	180	48	1000	386	180	48	1,000	Soy protein extrudate
18 Composite dishes	52	136	52	42	6	220	53	42	20	220	Lentil, pea, bean soup
19 Sauces and condiments	16	19	105	43	6	565	111	51	10	565	Soy sauce

Mean: Mean value
P50: 50th percentile (median)
Min.: Minimum
Max.: Maximum

[1] Number of separate foods in the main food group. For example, the main group ‘01 Grains and grain-based products’ contains foods such as ‘White bread/rolls’, ‘Rusk’, ‘Pasta, with egg’, ‘Oatmeal’ and ‘Cake, with fruit’.

[2] Number of pools that belong to the respective main food group in total, depending on whether the foods in this main group have been stratified.

[3] All samples <LOQ (100 µg/kg)

[4] All samples for ‘Spirits’ <LOD (30 µg/kg) or <LOQ (100 µg/kg), LOD (6–30 µg/kg) and LOQ (20–100 µg/kg) differ between the foods.

In the main food group ‘Legumes, nuts, oil seeds and spices’, the maximum nickel concentration was detected at 5,350 µg/kg in the pool sample cashew nuts, while in ‘Coffee, cocoa and tea’, cocoa powder exhibited the maximum concentration at 11,050 µg/kg. Apart from these results, the ten MEAL foods with the highest concentrations include sunflower seeds, walnuts, dark chocolate, beverage powder (total), hazelnuts and hazelnut spread, Chia seeds and pumpkin seeds (Table 2; since these foods exhibit no concentrations below the limit of detection/quantification, the results in the mLB correspond to those in the UB and are not listed).

Table 2: Food pools with the highest nickel concentration (µg/kg) from the BfR MEAL Study (samples purchased between December 2016 and May 2019, UB scenario).

No.	Food pool	Pool stratification	Nickel concentration (µg/kg)
1	Cocoa powder	not stratified[1]	11,050
2	Cashew nuts	not stratified	5,350
3	Sunflower seeds	not stratified	4,750
4	Walnuts	not stratified	4,300
5	Semisweet chocolate/ dark chocolate	not stratified	2,800
6	Beverage powder (total)	not stratified	2,150
7	Hazelnuts	not stratified	2,000
8	Hazelnut spread	not stratified	2,000
9	Chia seeds	not stratified	1,975
10	Pumpkin seeds	not stratified	1,850

[1] No sampling differentiated by region, season or production type.

3.2 Consumption data

The data set for consumption by adolescents and adults was taken from the German National Nutrition Survey (NVS II) conducted by the Max Rubner Institute (MRI). NVS II is the current representative study for food consumption in the German population. The study, which surveyed about 20,000 individuals aged between 14 and 80 on their eating habits using three separate survey methods (dietary history, 24-hour recall and weighing protocol), was conducted between 2005 and 2006 throughout Germany (Krems et al. 2006, MRI 2008). The analyses of consumption are based on the data from the two independent 24-hour recalls from NVS II, which were surveyed in a computer-aided interview using ‘EPIC-SOFT’. Data were evaluated from 13,926 people for whom both interviews were available.

Consumption data from the VELS study (consumption survey to determine the food intake of infants and toddlers for the assessment of an acute toxicity risk from pesticide residues) were used as the basis for data on consumption for children under 5 years of age (Heseker et al. 2003; Banasiak et al. 2005). This nationwide study was carried out from 2001 to 2002 in Germany, covering 816 infants and toddlers aged from 6 months to under 5 years old. The parents logged the food consumed by each child in two nutritional records kept over three consecutive days. For the exposure assessment, children no longer being breastfed (N = 732) were selected.

3.3 Exposure estimate and assessment

3.3.1 Total exposure

The estimate of total exposure to nickel in the adult population and in children in Germany was made while considering all respondents and all foods. Exposure is calculated for various subgroups of the population in Germany. These subgroups are based on gender as well as various age groups. For adults and adolescents, these age groups are as follows: 14–18, 19–24, 25–34, 35–50, 51–64 and 65–80 years of age. Children are placed in the age groups of 6 months–<1, 1–<2 and 2–<5 years of age. Due to only minor differences between the mLB and UB scenario, only the results in the UB are described. Any significant differences between mLB and UB are indicated.

Adults and adolescents

Table 3 presents the nickel exposure for adolescents and adults, stratified by gender. The average exposure to nickel (P50) for adolescents and adults is 1.4 µg/kg BW and day in the UB. For high consumers (P95), nickel intake amounts to 3.2 µg/kg BW and day. Nickel intake for women roughly corresponds to that for men. In all scenarios, there are also only minor differences between age groups in terms of body weight-related nickel intake (data not shown).

Table 3: Nickel intake in µg per kg body weight/day (µg/kg BW and day) for adolescents and adults in the population in Germany, assuming consumption of primarily conventionally produced food* (basis: NVSII; all respondents).

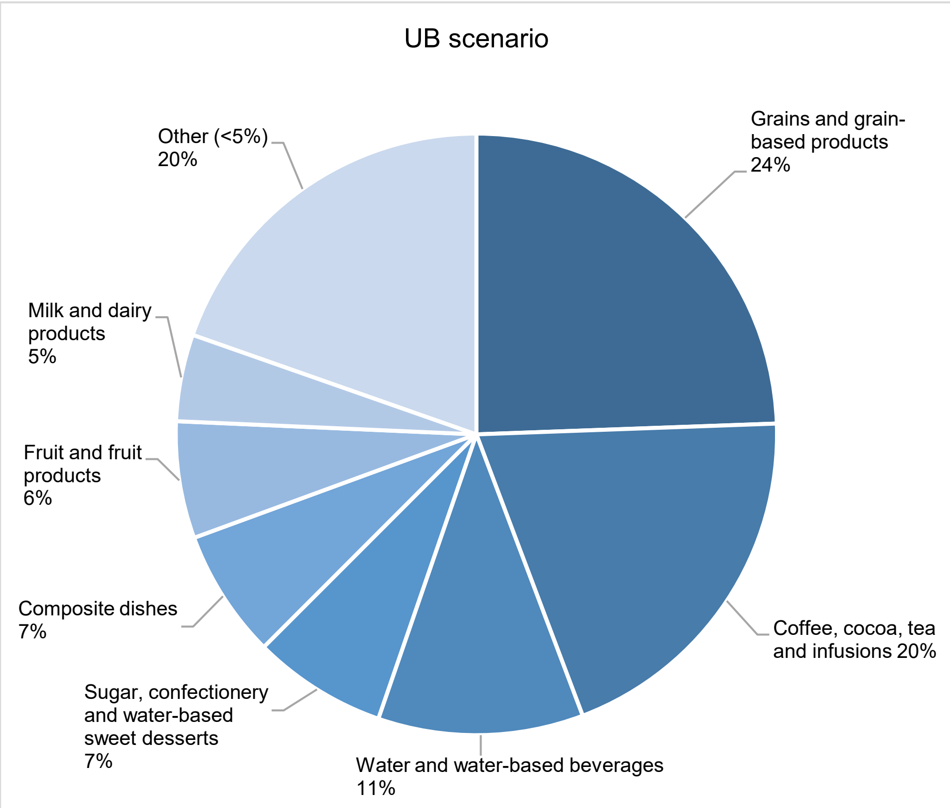
	Number of respondents (N)	Nickel intake (µg/kg BW and day)					
		mLB			UB		
		Mean	P50	P95	Mean	P50	P95
Total	13,926	1.3	1.1	2.9	1.6	1.4	3.2
Male	6,897	1.3	1.1	2.8	1.6	1.4	3.1
Female	7,029	1.4	1.2	2.9	1.7	1.5	3.2

* Concentration data from pools featuring conventional and non-specific production were used here.

The largest share of total exposure to nickel in adolescents and adults in the UB is taken by foods in the main group ‘Grains and grain-based products’ (24%) (Figure 1). This is followed by ‘Coffee, cocoa and tea’ and ‘Water and water-based beverages’, with a share of 20% and

11%, respectively. The main food group 'Composite dishes' accounts for 7% of nickel intake, while it should be noted that this group is very heterogeneous with regard to the food ingredients used. The group includes meals whose ingredients are also represented in other main food groups, and especially in 'Vegetables and vegetable products', 'Starchy roots or tubers and their products', 'Grains and grain-based products' and 'Meat and meat produce'. 'Milk and dairy produce', 'Fruit and fruit products' and 'Sugar, confectionery, and water-based sweet desserts' contribute to overall exposure with a share of 5% to 7%. All other main food groups follow with a share of <5% of nickel exposure.

Figure 1: Percentage share of main food groups in average nickel intake for adolescents and adults in the population in Germany, assuming consumption of primarily conventionally produced food (basis: NVSII; all respondents; average consumption (mean); UB scenario).



In terms of the shares of main food groups in average nickel intake, a number of differences arise between the mLB and the UB scenario. In the mLB scenario, the main food group 'Water and water-based beverages' accounts for less than 5% of nickel intake but accounts for 11% in the UB scenario. This difference can be attributed to the high proportion of concentrations below the limit of detection/quantification in the group 'Water and water-based beverages'[8]. Accordingly, the mLB scenario then results in a higher share for the remaining main food groups.

[8] Limit of detection/quantification for drinking water: LOD = 0.3 µg/kg; LOQ = 1 µg/kg; for other foods in this main group: LOD = 6 µg/kg; LOQ = 20 µg/kg.

Children

Average nickel exposure for children, both girls and boys, is 5.5 µg nickel/kg BW and day (P50) (Table 4). For high consumer (P95) boys and girls, nickel intake is calculated as 10.8 and 10.4 µg/kg BW and day, respectively. In the youngest age group (6 months–<1 year), nickel exposure is 4.4 µg/kg BW and day (P50, UB) and therefore lower than in the age groups 1–<2 years and 2–<5 years. Children in the age group 1–<2 years exhibit the highest level of nickel exposure, at 5.8 µg/kg BW and day. Nickel exposure of high consumers in this age group is 11.0 µg/kg BW and day.

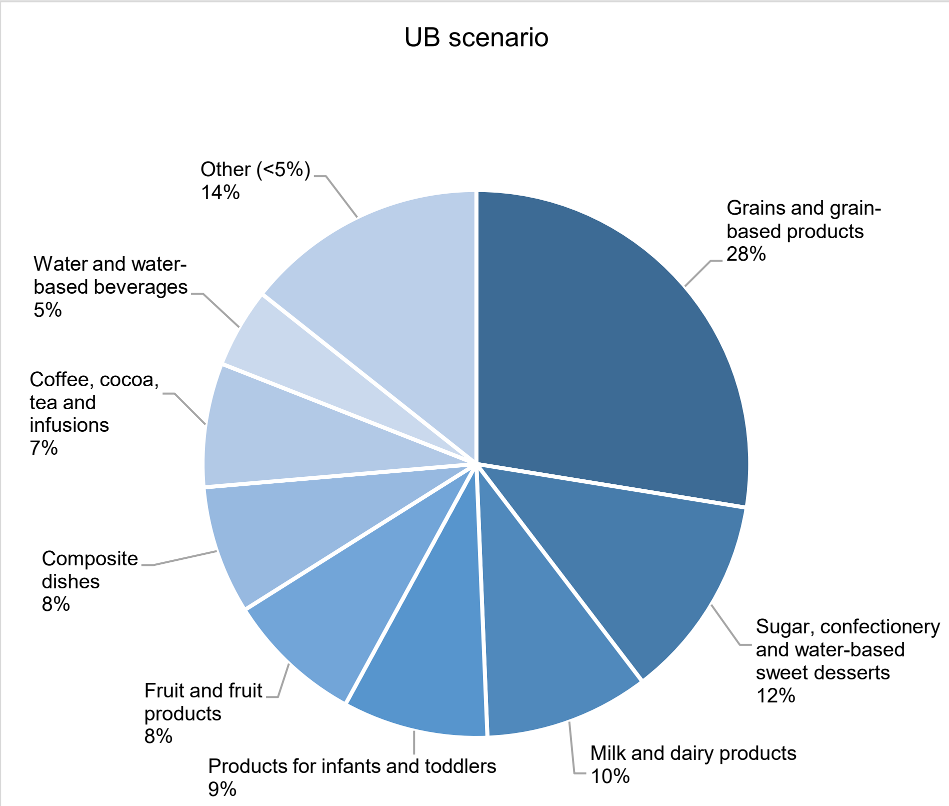
Table 4: Nickel exposure in µg per kg body weight and day (µg/kg BW and day) for children in the population in Germany, assuming consumption of primarily conventionally produced food* (basis: VELS study; all respondents).

	Number of respondents (N)	Nickel intake (µg/kg BW and day)					
		mLB			UB		
		Mean	P50	P95	Mean	P50	P95
Total	732	5.4	4.8	10.0	6.1	5.5	10.6
Boys	368	5.5	4.8	10.1	6.2	5.5	10.8
Girls	364	5.3	4.8	9.8	6.0	5.5	10.4
6 months–<1 year	95	4.0	3.4	8.0	4.9	4.4	9.0
1–<2 years	162	5.5	4.8	10.3	6.3	5.8	11.0
2–<5 years	475	5.6	5.1	9.9	6.3	5.7	10.5

* Concentration data from pools featuring conventional and non-specific production were used here.

For children too, the largest share of total exposure in the UB scenario is taken by foods in the main group ‘Grains and grain-based products’ (28%) (Figure 2). This is followed by the main food groups ‘Sugar, confectionery, and water-based sweet desserts’ (12%), ‘Milk and dairy produce’ (10%) and ‘Food products for infants and toddlers’ (9%). The food groups ‘Water and water-based beverages’, ‘Fruit and fruit products’, ‘Coffee, cocoa and tea’ and ‘Composite dishes’ each account for between 5% and 8% of total nickel intake. All other main food groups follow with a share of <5% of nickel exposure.

Figure 2: Percentage share of main food groups in average nickel intake for children in the population of Germany, assuming consumption of primarily conventionally produced food (basis: VELS; all respondents; average consumption (mean); UB scenario).



3.3.2 Exposure in consumers from the main food groups

The following section considers nickel intake in adolescents and adults (Table 5) and children (Table 6) by main food groups for the respective groups of consumers. This section considers only intake via the respective main food group and only considers those individuals from the consumption studies who have consumed at least one food from this main group.

Adults and adolescents

In all age groups, consumers of the main food group ‘Grains and grain-based products’ in the average consumption percentile (P50) have the highest level of nickel exposure, followed by ‘Coffee, cocoa and tea’ and ‘Vegan/vegetarian products’. When considering high consumption, the highest nickel intake is calculated for the main groups ‘Legumes, nuts, oil seeds and spices’ and ‘Vegan/vegetarian products’.

Table 5: Nickel exposure from main food groups in µg per kg body weight and day (µg/kg BW and day) for adolescents and adults in the population of Germany, assuming consumption of primarily conventionally produced food (basis: NVSII; consumers only).

Main food group		Number of consumers*	Nickel intake (µg/kg BW and day)					
			mLB			UB		
			Mean	P50	P95	Mean	P50	P95
01	Grains and grain-based products	13,865	0.39	0.29	1.06	0.40	0.29	1.07
02	Vegetables and vegetable products	11,196	0.07	0.04	0.19	0.07	0.05	0.20
03	Starchy roots or tubers and their products	7,966	0.05	0.04	0.12	0.05	0.04	0.12
04	Legumes, nuts, oil seeds and spices	5,013	0.24	0.01	1.24	0.24	0.01	1.24
05	Fruit and fruit products	11,805	0.11	0.06	0.31	0.12	0.08	0.33
06	Meat and meat produce	12,268	0.03	0.02	0.07	0.03	0.03	0.09
07	Fish and seafood	2,892	0.02	0.02	0.06	0.03	0.02	0.07
08	Milk and dairy produce	13,078	0.07	0.01	0.32	0.08	0.03	0.33
09	Eggs and egg products	2,961	<0.005	<0.005	0.01	0.01	0.01	0.02
10	Sugar, confectionery, and water-based sweet desserts	8,788	0.22	0.07	0.93	0.23	0.08	0.94
11	Animal and vegetable fats and oils	12,281	<0.005	<0.005	0.01	0.02	0.01	0.05
12	Fruit and vegetable juices and nectars	4,768	0.03	0.02	0.10	0.07	0.05	0.22
13	Water and water-based beverages	13,385	0.04	0.02	0.12	0.16	0.12	0.42
14	Coffee, cocoa and tea	12,630	0.28	0.21	0.76	0.34	0.27	0.85
15	Alcoholic drinks	6,400	0.03	0.02	0.09	0.09	0.06	0.23
16	Products for infants and toddlers	0	–	–	–	–	–	–
17	Vegan/vegetarian products	294	0.67	0.25	2.35	0.67	0.25	2.35
18	Composite dishes	9,385	0.16	0.10	0.50	0.16	0.10	0.50
19	Sauces and condiments	8,193	0.04	0.02	0.12	0.04	0.02	0.12

* Base population: N = 13,926

Children

In children, the highest nickel intakes (P50, UB) are found in consumers of the ‘Grains and grain-based products’ main food group, followed by ‘Sugar, confectionery, and water-based sweet desserts’ and ‘Products for infants and toddlers’. When considering the high-consumer (P95) children, a high nickel intake is also found for the main food groups ‘Vegan/vegetarian products’, ‘Legumes, nuts, oil seeds and spices’ and ‘Coffee, cocoa and tea’, solely from these types of foods.

Table 6: Nickel intake from main food groups in µg per kg body weight and day (µg/kg BW and day) for children in the population of Germany, assuming consumption of primarily conventionally produced food (basis: VELS; consumers only)

Main food group		Number of consumers*	Nickel intake (µg/kg BW and day)					
			mLB			UB		
			Mean	P50	P95	Mean	P50	P95
01	Grains and grain-based products	720	1.72	1.31	4.52	1.76	1.34	4.59
02	Vegetables and vegetable products	610	0.17	0.11	0.48	0.18	0.13	0.52
03	Starchy roots or tubers and their products	609	0.13	0.11	0.31	0.13	0.11	0.32
04	Legumes, nuts, oil seeds and spices	152	0.76	0.26	3.12	0.76	0.26	3.12
05	Fruit and fruit products	705	0.44	0.35	1.13	0.48	0.40	1.16
06	Meat and meat produce	627	0.07	0.06	0.19	0.08	0.07	0.20
07	Fish and seafood	222	0.06	0.05	0.12	0.06	0.05	0.12
08	Milk and dairy produce	688	0.52	0.35	1.48	0.61	0.46	1.57
09	Eggs and egg products	278	0.01	0.01	0.02	0.02	0.02	0.06
10	Sugar, confectionery, and water-based sweet desserts	621	0.83	0.66	2.16	0.86	0.69	2.21
11	Animal and vegetable fats and oils	638	0.01	0.01	0.02	0.03	0.03	0.08
12	Fruit and vegetable juices and nectars	540	0.12	0.08	0.40	0.25	0.19	0.70
13	Water and water-based beverages	718	0.11	0.08	0.27	0.26	0.16	0.78
14	Coffee, cocoa and tea	494	0.79	0.18	2.59	0.93	0.35	2.86
15	Alcoholic drinks**	17	0	0	0	0.03	0.03	0.05
16	Products for infants and toddlers	276	0.69	0.39	2.26	1.00	0.65	2.89
17	Vegan/vegetarian products	48	1.00	0.27	4.45	1.00	0.27	4.45
18	Composite dishes	644	0.51	0.35	1.45	0.51	0.35	1.45
19	Sauces and condiments	532	0.11	0.08	0.34	0.11	0.08	0.35

* Base population: N = 732
** Malt beer

3.3.3 Exposure for consumers with high levels of exposure

Adults and adolescents

At the level of individual MEAL foods, steps were taken to identify the ten foods that contribute most to nickel intake in the case of individuals with the highest total exposure. Assuming average consumption (P50), these foods in adolescents and adults are ‘cashew nuts’ and ‘cocoa powder’, followed by ‘soy protein extrudate’ and ‘trail mix’. Another food accounting for a high share of exposure in highly exposed individuals is ‘soy milk’, with high consumers of this food exhibiting the highest nickel exposure overall (table 7). In the case of the ten foods listed, all of these are foods that are rarely consumed (proportion of consumers <10%), which means that a relatively small proportion of the population exhibits total exposure at the specified high level.

Table 7: Total exposure to nickel for consumers of the ten foods that account for the highest share of average intake (mean) for the top 5% of most highly exposed adolescents and adults in population of Germany, expressed in µg per kg of body weight and day (µg/kg BW and day). In calculating these figures, the consumption of primarily conventionally produced foods has been assumed (basis: NVS II; consumers only; UB)

No.	MEAL food	Number of consumers* (%)	Exposure (UB; µg/kg BW and day)		
			Mean	P50	P95
1	Cashew nuts	80 (0.6)	4.00	3.52	7.97
2	Cocoa powder	77 (0.6)	3.65	3.10	7.93
3	Soy protein extrudate	20 (0.1)	3.05	3.08	6.62
4	Trail mix	66 (0.5)	3.25	3.06	5.11
5	Soy milk	103 (0.7)	3.57	3.05	8.46
6	Walnuts	403 (2.9)	2.98	2.67	5.97
7	Dried fruits	193 (1.4)	2.92	2.61	5.39
8	Lentils	46 (0.3)	2.18	1.97	4.47
9	Hazelnut spread	148 (1.1)	1.94	1.84	3.46
n.d.	Porridge	19 (0.1)	2.75	2.80	4.39

* Base population: N = 13,926
n.d.: Position in the table cannot be determined (N consumers <20)

Children

When considering the individual foods that primarily contribute to total exposure for highly exposed children and which exhibit a sufficient number of consumers to perform a statistical analysis (N >20), consumers (P50, UB) of 'cocoa powder' have the highest exposure to nickel in children, followed by consumers of the foods 'oatmeal' and 'walnuts' (Table 8). Moreover, in the mLB scenario, the food 'chocolate chip muesli' (6.18 µg/kg BW and day) is among the ten foods with the highest share of nickel exposure in children with the highest levels of exposure. As with adults, the highest share of nickel exposure (UB, P95) was identified for consumers of 'soy milk', although this food had only seven consumers in children and the estimate is therefore associated with uncertainties. With the exception of oatmeal, the other foods listed are also foods that are rarely consumed (number of consumers <10%).

Table 8: Nickel exposure for the consumers of the ten foods that account for the highest share of average intake (mean) for the top 10% of most highly exposed children in the population of Germany, expressed in µg per kg of body weight and day (µg/kg BW and day). In calculating these figures, the consumption of primarily conventionally produced foods has been assumed (basis: VELS study; consumers only; UB)

No.	MEAL food	Number of consumers* (%)	Exposure (UB; µg/kg BW and day)		
			Mean	P50	P95
1	Cocoa powder	38 (5.2)	11.20	8.76	19.37
2	Oatmeal	80 (11)	8.67	7.40	15.31
3	Walnuts	24 (3.3)	7.61	7.14	10.90
n.d.	Soy milk	7 (1)	13.43	11.95	24.65
n.d.	Porridge	18 (2.5)	8.21	9.02	12.09
n.d.	Trail mix	4 (0.5)	8.86	8.44	10.66
n.d.	Millet	14 (1.9)	8.03	7.68	11.97
n.d.	Spelt bread	11 (1.5)	7.04	6.93	10.78
.n.d.	Sunflower seeds	10 (1.4)	7.72	6.71	13.61
n.d.	Cashew nuts	6 (0.8)	8.03	6.59	13.51

* Base population: N = 732
n.d.: Position in the table cannot be determined (N consumers <20)

3.4 Uncertainties

At the time of the evaluation[9], data from the VELS study and NVS II were the current representative data on consumption in the population of Germany. Due to the presence of consumption data for individual days, the 24-hour recall and 3-day nutrition record methods are suitable for use in exposure assessments considering both acute and chronic health risks. These data were collected some time ago, however, in 2001/2002 (VELS) and 2005/2006 (NVSII). Possible changes in consumption have not been accounted for in the present analysis.

In the case of foods that are eaten only rarely, the survey period of twice a single day for the repeated 24-hour recalls of NVSII and, to a lesser extent, also in the case of the VELS study,

[9] The KiESEL study now provides us with updated consumption data (survey period from 2014 to 2017) for children between 6 months and 5 years of age. In the future, these data can be used for exposure assessments within this age group, although the data were not available at the point in time of this evaluation.

is unable to accurately reflect intra-individual variability in dietary habits. As a result, consumption for adults may be underestimated and this is also true to an extent in the case of children.

The food list used for the BfR MEAL Study covers more than 90% of consumption, but less than 100%. A corresponding underestimate of exposure may therefore result from this gap.

The drinking water used for preparing the meals and beverages in the BfR MEAL Study has a comparatively high concentration of nickel, at 3 µg/kg (mean, UB). The drinking water also regionally sampled as part of the BfR MEAL Study (n = 29) has a lower nickel concentration of 1 µg/kg (mean, UB). The effect of the higher nickel concentration in the MEAL drinking water is especially pronounced for drinking water-based foods such as tea, coffee or infant formula. In principle, the regional variability in drinking water concentrations ought to be considered on a very small-scale level, but this can only partially be accomplished in a TDS approach. However, in regions with lower concentrations in drinking water, one may assume a lower intake of nickel from food that is prepared with drinking water.

Of the 356 foods in the BfR MEAL Study, 105 foods were stratified according to organic and conventional production. The exposure scenarios as calculated account for the occurrence data in the 105 stratified foods as well as the foods that have not been stratified by type of production (N = 251). Individuals with a pronounced organically or conventionally oriented dietary habit may therefore exhibit deviating exposure patterns. However, this uncertainty is considered low on account of the minor differences in concentrations of nickel found between organically and conventionally produced foods.

4 Risk characterisation

Adults and adolescents

On average, the TDI – specified as 13 µg/kg BW and day (EFSA 2020) – is exhausted by 11% (UB, P50) in adults and adolescents. For frequent consumers (P95), the TDI is exhausted by 24% through the exposure to nickel (UB). Gender- and also age-specific (data not shown) differences in the exhaustion of the TDI are very low. Differences between the mLB and the UB scenario are also low overall (Table 9). The impact of the method of production on exposure to nickel and therefore on the exhaustion of the TDI (data not shown) is exceptionally low.

Table 9: Percentage exhaustion of the TDI (13 µg/kg BW and day) in adolescents and adults in the population of Germany, assuming consumption of primarily conventionally produced food (basis: NVSII; all respondents).

	N	Exhaustion of the TDI (%)					
		mLB			UB		
		Mean	P50	P95	Mean	P50	P95
Total	13,926	10	9	22	12	11	24
Male	6,897	10	8	21	12	10	24
Female	7,029	11	9	22	13	11	25

In both the mLB and the UB scenario, exposure exceeded the TDI only in the case of one female consumer placed in the '51–64 years' age group (data not shown). Apart from this individual, nickel intake in adolescents and adults does not exceed the health-based guidance value for nickel as a result of the long-term consumption of foods in any of the exposure scenarios considered.

A consideration of acute risks is not possible with the present data since, in methodological terms, the BfR MEAL Study (as a TDS) is oriented solely towards determining long-term exposure.

Children

Compared with adults, exposure in children results in a significantly higher exhaustion of the TDI. The exhaustion is almost identical in boys and girls, at 42% and 43% on average (UB, P50), respectively. Children in the youngest age group considered (6 months–<1 year) had the lowest level of exposure and exhaustion of TDI (34%, UB, P50). In the other age groups, the TDI exhaustion ranged between 44% and 45% (UB, P50). For high consumers, the highest exhaustion of the TDI was found in the age group 1–<2 years (84%) (Table 10).

Table 10: Percentage exhaustion of the TDI (13 µg/kg BW and day) in children in the population of Germany, assuming consumption of primarily conventionally produced food (basis: VELS; all respondents).

		Exhaustion of the TDI (%)					
	N	mLB			UB		
		Mean	P50	P95	Mean	P50	P95
Total	732	41	37	77	47	42	82
Boys	368	42	37	78	47	42	83
Girls	364	41	37	75	46	43	80
6 months–<1 year	95	31	26	61	38	34	69
1–<2 years	162	42	37	80	48	45	84
2–<5 years	475	43	39	76	48	44	80

In both the mLB and the UB scenario, exposure exceeded the TDI (data not shown) for 2% of children between 6 months and 5 years of age (N = 15). The influence of the production type of the foods consumed is marginal here. Exposure levels exceed the TDI most commonly in the case of children in the 1–<2 years age group (3%). The lowest proportion of children exhibiting a nickel intake above the TDI was determined for the 6 months–<1 year age group (1%). On the basis of the exposure assessment as presented here, based on concentration data on nickel in ready-to-eat foods from the BfR MEAL Study, exposure does exceed the TDI in the case of some highly exposed children (6 months–<5 years). At the same time, even among high-consumer children, exposure exceeds the health-based guidance value only for a total of fewer than 5% of children. By way of comparison, figures from the EFSA (2020) estimate show high exposure (P95) in infants (1–<3 years) and other children (3–<10 years) as typically being above the TDI – and also in infants (<1 year) in a number of surveys. In the opinion of EFSA, there could therefore be concerns about health risks in relation to the intake of nickel via food for these young age groups.

5 Exposure to nickel in a European comparison

Adults

The nickel intake for adults in Germany determined on the basis of the MEAL concentration data is of the same magnitude as intake values that have been published on the basis of TDS data for comparable age groups from populations in Italy (Cubadda et al., 2020), Spain (Canary Islands; Gonzales-Weller et al., 2012) and the United Kingdom (Rose et al., 2010) (Table 11). In contrast, intake values based on TDS data from France (Arnich et al., 2012) are higher, as is the nickel intake determined by EFSA for the German population (EFSA, 2020).

Table 11: Comparison of nickel exposure for adults based on the data from the BfR MEAL Study with exposure assessments from countries within Europe

Country	Nickel intake (mean) (µg/kg BW and day)	Age group (years)	Reference
Spain (Canary Islands)*	1.4	18–75	Gonzalez-Weller et al. (2012)**
Italy	1.55 1.47	18–<65 ≥65	Cubadda et al. (2020)**
France	2.33	18–79	Arnich et al. (2012) **
United Kingdom	1.49 (LB)–1.63 (UB)	16–64	Rose et al. (2010)**
Europe/EFSA***	2.90 (LB)–3.41 (UB) 2.51 (LB)–2.99 (UB)	18–<65 65–<75	EFSA (2020)
Germany (EFSA)****	3.34 (LB)–3.93 (UB) 3.16 (LB)–3.73 (UB)	18–<65 65–<75	EFSA (2020)
Germany (MEAL)	1.3 (mLB)–1.6 (UB)	15–80	BfR MEAL Study**

* Standardised body weight assumed for women (60 kg) and men (75 kg)
** Exposure assessment based on TDS concentration data
*** Nickel intake (mean), specification of median value for European countries considered
**** Occurrence data from Europe, consumption data from Germany

Children

The average nickel intake for children determined on the basis of the MEAL concentration data is slightly higher when compared with data on exposure based on TDS from France, Italy and the United Kingdom (Table 12). Compared with the data calculated by EFSA (2020), the values are lower, however, and this applies in particular to the 1–3 year age group, both at European level and when considering only consumption data from Germany.

Table 12: Comparison of nickel exposure for children based on the data from the BfR MEAL Study with exposure assessments from countries within Europe

Country	Nickel intake (mean) (µg/kg BW and day)	Age group (years)	Reference
Italy	4.0	<3	Cubadda et al. (2020)*
France	0.395–2.68 (LB) 4.39–4.85 (UB)**	<3	Sirot et al. (2018)*
France	3.83	3–17	Arnich et al. (2012)*
United Kingdom	4.17 (LB)–4.87 (UB)	1.5–4.5	Rose et al. (2010)*
Europe/EFSA***	4.40 (LB)–6.14 (UB) 8.53 (LB)–10.1 (UB) 7.05 (LB)–8.16 (UB)	< 1 1–<3 3–<10	EFSA (2020)
Germany (EFSA)****	8.24 (LB)–9.91 (UB)	1–<3	EFSA (2020)
Germany (MEAL)	5.4 (mLB)–6.1 (UB)	0.5–<5	BfR MEAL Study*

* Exposure assessment based on TDS concentration data
** Value ranges refer to four age groups of children aged from 1–4 to 13–36 months
*** Nickel intake (mean); specification of median value for European countries considered
**** Occurrence data from Europe, consumption data from Germany

When considering the comparison of results for adults (Table 11) as well as for children (Table 12), one should remember that the calculation made by EFSA for Germany has been made on the basis of consumption data identical to those used for the present exposure assessment. Differences between the EFSA Opinion and the exposure assessment based on the MEAL data may be attributable to the following aspects:

- The dataset in terms of the collection of occurrence data made by EFSA originates from a number of European member states and is not necessarily representative for Germany. A TDS, on the other hand, aims to sample foods in accordance with their market relevance.
- Differences in the occurrence data for some foods that make a more significant contribution to exposure (e.g. coffee[10], various types of tea, milk, teas and hot beverages for children, brown bread and cornflakes).
- In the case of EFSA, foods are mostly combined with consumption data at a higher aggregation level (FoodEx level 2). As a result, foods with high concentrations may contribute more significantly to the mean value than is actually reflected by the proportionate consumption of the food in the respective food group.
- In the case of the BfR MEAL Study, 90% of foods consumed in Germany are considered. EFSA, however, utilises data from various European countries, which leads to rarely consumed foods with high concentrations of nickel being considered (e.g. pine kernels, chestnuts).

[10] The nickel concentration utilised by EFSA for coffee is based on both occurrence data for the dry product and for the beverage. In a TDS, however, only the ready-to-drink product is sampled. As a result of considering coffee powder, EFSA arrives at significantly higher concentrationsfor the ready-to-drink beverage, despite applying dilution factors. This may lead to a higher exposure estimate.

6 Summary and conclusion

Dietary exposure to nickel in the general population in Germany has been determined on the basis of the BfR MEAL Study, as the first German TDS. Children exhibit a significantly higher level of exposure than adolescents and adults. When compared with exposure assessments from TDS completed in other European countries, the present intake values are of the same magnitude. In the case of adolescents and adults, chronic dietary exposure is significantly lower than the TDI of 13 µg/kg BW and day. In contrast, nickel intake exceeds the TDI in the case of some highly exposed children (0.5–5 years). At the same time, even among high-consumer children, exposure exceeds the health-based guidance value only for a total of fewer than 5% of children. By way of comparison, figures from the EFSA estimate (2020) show high exposure (P95) in toddlers (1–<3 years) and other children (3–<10 years) as typically being above the TDI – and also in infants (<1 year) in a number of surveys. In the opinion of EFSA, there could be concerns about health risks in relation to the intake of nickel via food for young age groups. A consideration of acute risks (a triggering or worsening of allergic skin reactions) is not possible with the present data since, in methodological terms, the BfR MEAL Study (as a TDS) is oriented solely towards determining long-term exposure. Other potential sources of exposure, such as tobacco smoke or dust/soil particles, have not been considered as part of this exposure assessment.

For further information on this topic, please visit the BfR website:

A–Z index for nickel: https://www.bfr.bund.de/en/a-z_index/nickel-130376.html

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