

29 May 2026

BfR MEAL Study on cadmium in food

Health impairments for the majority of the population not to be expected

In brief

- **Cadmium in the food chain.** Cadmium is a rare element found in the Earth's crust. It can be released both through natural processes (volcanic eruptions, weathering of rock) and through human activities. It enters the food chain when, for example, it is taken up by plants and animals used for food production.
- **Cadmium in the human body.** Due to its long biological half-life of 10–30 years, cadmium ingested through food accumulates in the human body, particularly in the liver and kidneys. Cadmium in the human body is associated with a wide range of health impairments. The kidneys are particularly sensitive to cadmium. Furthermore, cadmium can lead to bone demineralisation.
- **BfR MEAL Study.** As part of the BfR MEAL Study (Meals for Exposure Assessment and Analysis of Food; MEAL), a large-scale investigation was carried out in Germany to determine the average concentrations of substances found in food. To this end, food was purchased, prepared according to typical household practices, and analysed for its substance levels – including cadmium. This allows for changes in content that may occur during meal preparation to be taken into account. The study covers more than 90 per cent of the consumption in Germany. This provides representative data on the average substance concentrations in a broad spectrum of foods. It thus offers a very good basis for determining average exposure.
- **Evaluation of the MEAL study results for cadmium.** In order to estimate the average dietary cadmium intake of the population in Germany for this opinion, the analysis results on cadmium levels in food from the BfR MEAL Study were combined with consumption data from various consumption studies for children (KiESEL study, EsKiMo II), adolescents and adults (NVS II).
- **Foods with the highest cadmium concentrations.** In the BfR MEAL Study, boletus/porcini mushrooms, cocoa powder, sunflower seeds, linseeds and algae were among the plant-based foods with the highest concentrations. Among animal food

products, the highest cadmium concentrations were found in liver, kidney, squid/octopus and mussels.

- ***Foods contributing most to cadmium intake in the population.*** When estimating total intake, not only the concentration but also the quantity consumed plays a role. Thus, even foods with lower cadmium concentrations but high long-term consumption can make a significant contribution to total intake. On average across all respondents, 'grains and grain-based products' make the highest contribution to cadmium intake in all age groups, accounting for 40% to 50%. These are primarily wheat products, such as white bread/rolls, pasta, wholemeal and rye-wheat bread. However, potatoes are also among the top three foods contributing most to cadmium exposure in all age groups considered. The main food group 'potatoes and potato products' accounts for the second-highest proportion of exposure, at 13% to 15%. Although wheat and potato products do not have the highest cadmium concentrations, the overall cadmium exposure results from the large amounts by which they are consumed by the general population.

Among children, those who eat spinach or creamed spinach take up the most cadmium. Spinach is among the ten foods with the highest concentrations according to the BfR MEAL Study. Creamed spinach has slightly lower concentrations due to the additional ingredients, but is consumed much more frequently.

- ***Conclusion.*** For the majority of the population, cadmium intake is below the health-based guidance value TWI (Tolerable Weekly Intake) of 2.5 µg/kg body weight (bw) per week, and there is a low probability of the occurrence of health impairments. For certain population subgroups, the exposure to cadmium determined from the MEAL data is higher. Thus, exposure in children of certain age groups exceeds the TWI, depending on the foods consumed.
- ***Recommendations for consumers.*** As cadmium is released through natural processes (volcanic eruptions, weathering of rock) as well as through human activities and enters the food chain, the presence of cadmium in food cannot be completely prevented. However, a varied, diverse and colourful selection of foods helps to keep the intake of undesirable substances, such as cadmium, as low as possible and also ensures a balanced nutrient intake.

1 Subject of the assessment

In this opinion, the German Federal Institute for Risk Assessment (BfR) has carried out an exposure assessment based on the results of the BfR MEAL Study on cadmium, including a comparison with currently valid health-based guidance values (HBGVs).

2 Results

Cadmium is a heavy metal that has a high prevalence in soil and water and can enter the environment through human activity. Cadmium passes from soil and water into plants and

animals and ultimately enters the food chain as an environmental contaminant. For the non-smoking population, food is considered the main source of cadmium exposure. Furthermore, cadmium can be taken up via tobacco, ambient air, house dust or toys. Cadmium has been linked to kidney damage, bone demineralisation and cancer development, among other things. Based on the cadmium-induced increase of a marker for tubular kidney damage in urine, the European Food Safety Authority (EFSA) derived a Tolerable Weekly Intake (TWI) for cadmium of 2.5 micrograms per kilogram ($\mu\text{g/kg}$) body weight (kg) and week, which is used for the health risk assessment of external dietary cadmium intake.

Dietary cadmium exposure was calculated for children, adolescents and adults in Germany. The current, representative dietary surveys the 'Children's Nutrition Survey to Record Food Consumption' (KiESEL study), the dietary survey as a KiGGS module (EsKiMo II) and the National Dietary Survey II (NVS II) were used as the basis for consumption. The cadmium levels are based on the National Total Diet Study (BfR MEAL Study). The BfR MEAL Study is characterised by its coverage of >90% of consumption and its consideration of preparation-related changes in substance levels.

The median cadmium exposure determined does not result in a TWI exceedance for any of the age groups considered, but for children under three years of age it approaches the TWI, with a percentage of up to 93%. The estimated high exposure (P95) to cadmium results in the TWI being exceeded by up to 1.5 times in children aged 0.5 to <10 years. When considering the general population, 'grains and grain-based products' (primarily wheat products) and 'potatoes and potato products' make the largest contribution to exposure, mainly due to their high consumption.

In selected consumption scenarios, children's (0.5 to <6 years) exposure approach the TWI (96%) through the consumption of spinach alone. Overall, high exposure in this age group across all foods exceeds the TWI by up to 2.3 times, particularly among those consuming foods containing spinach, potatoes and cereals. Among adolescents and adults who consume squid/octopus or boletus/porcini mushrooms, high exposure (P95) exceeds the TWI solely through the consumption of these foods.

Based on data on internal exposure from the German Environmental Survey GerES V (2014–2017), no exceedances of the HBM-I value (human biomonitoring; HBM) were found at the median or P95 level among children and adolescents aged between 3 and 17 years. Maximum urine levels in children of all age groups are above the HBM-I value, which corresponds to 0.6% of the participating children.

In summary, the BfR considers that for the vast majority of the population in Germany, the likelihood of health impairments resulting from dietary exposure to cadmium is low. With increasing age, the level of dietary external exposure relative to body weight decreases. At the same time, blood and urine cadmium levels in the participating children in the GerES V study increase with age. This increase may be linked, among other things, to the accumulative properties of cadmium, particularly in the kidneys, and highlights the importance of up-to-date data on internal exposure for adults. Representative data on the current level of internal exposure in the adult population of Germany from GerES VI (data collection 2023–2024) have not yet been published. As external exposure for some population groups is at or above the TWI, exposure to cadmium in the German population should continue to be reduced.

3 Rationale

3.1 Risk assessment

3.1.1 Hazard identification

Cadmium occurs as a natural element in the Earth's crust and in seawater. In the Earth's crust, it occurs primarily in combination with zinc ores, and, to a lesser extent, with lead and copper ores. It is therefore an unavoidable by-product of the metallurgy of these elements. It is used in vast quantities in batteries and is also recovered from used batteries; furthermore, it is used in pigments, coatings, stabilisers for plastics, non-ferrous alloys and photovoltaic equipment. It enters the air, soil and water through the smelting of other metals, the use of fossil fuels, waste incineration and the application of phosphate fertilisers and sewage sludge. In addition, natural processes such as volcanism and rock weathering contribute to the release of cadmium into the environment (ATSDR, 2012; EFSA, 2009; IARC, 2018).

In the atmosphere, cadmium is present as airborne particulate matter in the form of fine particles, and as vapour following release through industrial processes involving very high temperatures. The vast chemical species in the air is cadmium oxide, but some cadmium salts, such as cadmium chloride, can also enter the air. These compounds are stable and can be transported over very long distances before reaching the Earth's surface via wet and dry deposition. In surface water and groundwater, cadmium is present as a free ion or as an ionic complex. Soluble forms are mobile in water, whereas cadmium in insoluble complexes or adsorbed onto sediments is less mobile. In soil, cadmium may be present in soluble form in soil water or form insoluble complexes with organic or inorganic soil components. The mobility of cadmium in soil is much lower than in air and water and depends on soil type and various soil properties, particularly pH. As pH decreases, the mobility of cadmium in soil increases. Increased transfer from soil to plants is therefore observed, for example, in acidic soils (Smolders, 2001).

In general, cadmium accumulates more in the leaves of plants than in fruits and storage organs. Cadmium also enters the food and feed chain via crops. Food-producing animals take up cadmium via forage plants and also via soil particles adhering to them. Accumulation occurs particularly in offal such as liver and kidneys. Intake from plankton and water leads to the accumulation of cadmium in mussels and crustaceans and thus to its entry into aquatic food chains (EFSA, 2009).

With regard to human exposure, food is the main source of exposure in the general population (non-smokers) (90%), with grains and vegetables contributing the most. Less than 10% of exposure comes from drinking water or inhalative exposure from ambient air (EFSA, 2009). Smokers have a considerably higher level of exposure because tobacco leaves naturally accumulate large amounts of cadmium (IARC, 2018) and cadmium compounds are relatively volatile (UBA, 1998). Children in particular are additionally exposed via toys and house dust (the BfR, 2009).

3.1.2 Hazard characterisation

3.1.2.1 Toxicokinetics

In the human body, cadmium absorption in the gastrointestinal tract via food intake is low, at around 1–10% (ATSDR, 2012).

In the blood, cadmium is found mainly in red blood cells, where it is bound to a low-molecular-weight protein known as metallothionein (EFSA, 2009).

Cadmium is distributed throughout the body via the blood, with the highest concentrations found in the liver and kidneys.

As only a small proportion of the cadmium present in the intestine is absorbed, the majority is excreted as unabsorbed cadmium in faeces. Absorbed cadmium is eliminated very slowly, with excretion via urine and faeces occurring in roughly equal proportions (ATSDR, 2012). Cadmium has a long biological half-life of 10–30 years in the human body and accumulates particularly in the liver and kidneys (EFSA, 2009).

3.1.2.2 Biomarkers

Measurements of cadmium levels in blood, urine, faeces, liver, kidneys, hair and other tissues serve as biomarkers of cadmium exposure (ATSDR, 2012; EFSA, 2009).

Blood cadmium levels primarily reflect the most recent exposure(s) to cadmium and not the total body burden (ATSDR, 2012). Blood cadmium levels are considered the most meaningful marker of current exposure to cadmium and are usually measured in whole blood (EFSA, 2009).

Urinary cadmium levels reflect total body burden, although they also vary to some extent due to current exposure. Cadmium levels in faeces can be used as a direct indicator of daily dietary cadmium intake, as cadmium from food is poorly absorbed in the intestine (ATSDR, 2012).

As liver and kidney tissues accumulate cadmium, cadmium levels in both the liver and the kidney can be measured using non-invasive techniques (e. g. *in vivo* neutron activation analysis or, in the kidney, X-ray fluorescence analysis) (ATSDR, 2012).

Hair has also been used for biomonitoring cadmium exposure, although the possibility of exogenous contamination has led to considerable controversy regarding the reliability of hair concentrations as a measure of the absorbed dose (ATSDR, 2012).

3.1.2.3 Toxicology

Exposure to cadmium has been linked to nephrotoxicity, osteoporosis, neurotoxicity, carcinogenicity and genotoxicity, teratogenicity, as well as endocrine and reproductive effects (EFSA, 2009).

The most sensitive target organs for cadmium toxicity following oral intake are the kidneys and bones. In the kidney, cadmium accumulates particularly in the cells of the proximal renal tubule. An early biomarker and a measure of damage to the cells of the proximal renal tubule is increased excretion of low-molecular-weight proteins such as beta-2-microglobulin (B2M) in the urine. Following prolonged and/or high exposure, tubular damage in the kidneys can progress and lead to a reduced glomerular filtration rate, potentially resulting in kidney failure. Furthermore, cadmium is capable of mimicking the function and behaviour of essential metals, thereby disrupting, for example, calcium, zinc or iron homeostasis. In particular, cadmium can lead to calcium loss from the bones and increased calcium

excretion via the kidneys, thereby causing bone demineralisation either through direct bone damage or indirectly as a result of renal dysfunction (ATSDR, 2012; EFSA, 2009).

The genotoxic potential of cadmium has been investigated in *in vitro* and *in vivo* studies. The results are not always consistent, but are generally interpreted to mean that cadmium has a clastogenic (chromosome-damaging) effect, which has a rationale based on the induction of DNA damage, micronuclei, sister chromatid exchange and chromosomal aberrations (ATSDR, 2012). Cadmium is regarded as a non-directly genotoxic agent whose genotoxicity is mediated via indirect mechanisms, such as the formation of reactive oxygen species (oxidative stress) or the disorder in DNA repair (EFSA, 2009).

According to the report cited by EFSA (2009) (EC, 2007), there is no evidence of a carcinogenic effect of cadmium following oral intake. On the basis of occupational studies involving inhalative exposure to cadmium, the International Agency for Research on Cancer (IARC) classified cadmium as carcinogenic to humans (Group 1) (IARC, 2018, 1993).

3.1.2.4 Derivation of a health-based guidance value (HBGV)

Based on the cadmium-induced increase in a marker of tubular kidney damage in urine, the EFSA derived a Tolerable Weekly Intake (TWI) of cadmium of 2.5 µg/kg bw per week (EFSA, 2009).

The cadmium content in urine is a measure of body burden (cumulative internal exposure). EFSA conducted a meta-analysis of 35 studies to model the concentration-effect relationship between urinary cadmium levels as a measure of body burden (cumulative internal exposure) and B2M as a marker of tubular kidney damage.

A lower confidence limit for the benchmark dose associated with a 5% increase (BMDL₅) in the prevalence of elevated B2M was derived as 4 µg cadmium/g creatinine. To account for inter-individual variability in urinary cadmium within the study populations, an adjustment factor of 3.9 was applied, resulting in a critical urinary cadmium concentration of 1 µg/g creatinine.

Dietary cadmium exposure corresponding to the critical urinary cadmium concentration of 1 µg/g creatinine after 50 years of exposure was then calculated using a kinetic model. This was based on a large dataset comprising non-smoking women aged between 58 and 70 years. To ensure that 95% of the population aged 50 remain below the critical urinary cadmium concentration, the average daily dietary cadmium intake should not exceed 0.36 µg/kg bw, which corresponds to a weekly dietary cadmium intake of 2.52 µg/kg bw. The calculation took into account human variability in absorption rates (1–10%), thereby accounting for high absorption rates, such as those observed in women of child-bearing age.

The ANSES (French Agency for Food, Environmental and Occupational Health & Safety) derived a health-based guidance value of a similar magnitude based on a different toxicological endpoint (Leconte *et al.*, 2023). Accordingly, following a review of epidemiological data on cadmium toxicity published after 2011, the effects on bone were selected as the most sensitive endpoint. A critical threshold of 0.5 µg/g creatinine was chosen for cadmium levels in human urine. A modified physiologically based pharmacokinetic (PBPK) model was used to derive a HBGV. Back-calculation using the PBPK model yielded a tolerable daily intake (TDI) of 0.35 µg/kg bw per day (equivalent to 2.45 µg/kg bw per week) (Leconte *et al.*, 2023).

The BfR uses the TWI of 2.5 µg/kg bw per week for the health risk assessment of dietary cadmium intake, but points out that this reflects the state of scientific knowledge as of 2009.

3.1.3 Exposure estimation and assessment

3.1.3.1 Data basis for consumption

The Children's Nutrition Survey to Record Food Consumption (**Kinder-Ernährungsstudie zur Erfassung des Lebensmittelverzehrs, KiESEL**) served as the data source for dietary intake among **infants, toddlers and children aged between 0.5 and <6 years**. A total of 1,104 children aged between six months and five years inclusive took part in KiESEL. The survey was conducted between 2014 and 2017. During an interview, the parents or carers completed a questionnaire on general nutrition, nutrition during the first year of life, and a Food Propensity Questionnaire on rarely consumed foods. Of these, 1,008 children also took part in the dietary assessment using a weighing/estimation record. The children's food intake was documented in a weighing record for three consecutive days plus one non-consecutive day. In addition, food consumption outside the home (e.g. in childcare facilities) was recorded using a simplified estimation record (Nowak *et al.*, 2022a; Nowak *et al.*, 2022b). For the evaluation, the results from the weighing records are used, and only non-breastfed individuals are included (N = 952).

The nutrition survey EsKiMo II (Mensink *et al.*, 2021) served as the data basis for consumption among **children aged 6 to <12 years**. As part of EsKiMo II, 2,644 children and adolescents aged 6 to <18 years were surveyed between 2015 and 2017 regarding their food consumption and dietary habits. These participants had previously taken part in the second wave of the 'German Health Interview and Examination Survey for Children and Adolescents' (KiGGS) Wave 2 conducted by the Robert Koch Institute (RKI). For the exposure assessment, four-day weighing records from 1,190 children aged between 6 and <12 years were used. Consumption from the age of 14 onwards is covered by the NVS II.

The National Consumption Study II (NVS II) conducted by the Max Rubner Institute (MRI) served as the data basis for consumption among **adolescents and adults aged between 14 and 80 years**. The NVS II is the current representative study on the consumption patterns of the German adult population. The study, in which around 20,000 people aged between 14 and 80 were surveyed on their dietary habits using three different data collection methods (dietary history, 24-hour recall and weighing record), took place throughout Germany between 2005 and 2006 (Krems *et al.*, 2006; MRI, 2008). The dietary evaluations are based on data from the two independent 24-hour recalls of the NVS II, which were collected in a computer-assisted interview using 'EPIC-SOFT'. Data from 13,926 individuals, for whom both interviews were available, were evaluated.

These nutrition surveys are suitable for estimating long-term consumption levels. The intake estimates are evaluated according to the age groups listed in Table 1.

Table 1 : Consumption surveys for estimating population exposure in German

Age group	Consumption study
Infants (0.5 – <1 year) ^a	KiESEL
Toddlers (1 – <3 years)	KiESEL
Children (3 – <6 years)	KiESEL
Children (6 – <10 years)	EsKiMo II
Adolescents (10 – <12 years)	EsKiMo II
Adolescents (14 – <19 years)	NVS II
Adults (19–24 years)	NVS II
Adults (25–35 years)	NVS II
Adults (35 – <51 years)	NVS II
Adults (51 – <65 years)	NVS II
Elderly and very elderly (aged 65 and over)	NVS II

^a The survey included children from the age of six months. (Partially) breastfed children were excluded

3.1.3.2 Data basis for occurrence of substances in food

Cadmium was analysed in the core module of the BfR MEAL Study across all 356 foods on the MEAL food list¹. Based on the 24-hour recalls from the NVS II for adults and the VELIS data for children (Banasiak *et al.*, 2005), the MEAL food list covers at least 90% of the average food intake for various age groups in the German population for each major food group and also takes into account rarely consumed foods known to have high concentrations of undesirable substances. The MEAL foods were purchased between December 2016 and May 2019 across four different regions in Germany, with the product selection taking into account the varying shopping habits of the German population as well as regional and seasonal characteristics. The information underlying the representative composition of the samples was collected via consumer surveys and generated from market share data. The food was prepared in the MEAL study kitchen, replicating typical consumer behaviour. The food and dishes were then pooled (grouped) and homogenised. A MEAL pool consists of 15–20 individual food items (so-called subsamples) (Sarvan *et al.*, 2017). An overview of the cadmium occurrence data from the BfR MEAL Study can be found in the appendix (Table A.1 to Table A.3). Cadmium-specific details on data collection and a discussion of the concentrations were published in Fechner *et al.* (2022).

3.1.3.3 Estimation of long-term exposure across all types of food

Methodology

For all participants in the aforementioned dietary surveys, the mean intake per MEAL food item was calculated for each protocol day relative to individual body weight and linked to the respective measured cadmium concentration. Concentrations below the limit of detection (LOD) or limit of quantification (LOQ) were treated according to the *modified Lower Bound* (mLB) and *Upper Bound* (UB) approach. In the mLB approach, results below the limit of quantification (<LOQ) were assigned the value of the limit of detection (LOD), and

¹ https://www.bfr.bund.de/cm/343/Lebensmittelliste_Deutsch_2021_Web_bf_final_1.pdf

results below the limit of detection (<LOD) were assigned the value zero. In the UB approach, results below the limit of quantification (<LOQ) were assigned the value of the respective limit of quantification (LOQ), and results below the limit of detection were assigned the value of the respective limit of detection (LOD).

The exposure assessment was calculated by default according to the categories 'organic' and 'conventional production'. This means that, where MEAL foods were sampled separately according to their production method, they were not averaged but assigned to two separate evaluations. In this context, all foods not differentiated by production type (seasonal, regional or unspecified²) were included, together with conventionally produced foods, in the scenario of consumption of predominantly conventionally produced foods; conversely, all exclusively organically produced foods were included in the scenario of consumption of predominantly organically produced foods. In total, 105 of the 356 MEAL foods examined were differentiated by production type. In both exposure scenarios, it was assumed that all individuals consumed either exclusively organically or conventionally produced products, provided that a differentiation was present in the food list. Differences in exposure are solely due to differences in occurrence data, as no differentiation was made in the consumption data.

Total exposure was determined on the basis of all respondents who took part in the dietary survey. The median (P50) and the 95th percentile (P95) of the resulting exposure distribution are shown. Exposure is expressed in µg/kg bw per week.

Long-term cadmium exposure across all types of food

Consumers who primarily choose conventional foods take up approximately 1.2 times higher amounts of cadmium than those who primarily choose organic products. This is due exclusively to differences in the occurrence data, as the same consumption data were used. It should be noted that no generally higher trend is observed across all conventional foods; rather, differences are apparent in individual food groups (Fechner *et al.*, 2022). These differences can primarily be attributed to the different composition of the organic and conventional food groups (e.g. the use of different cereal varieties for the same product).

As a more conservative scenario, therefore, only the conventional scenario is described below. Intake estimates for the organic scenario are presented in the appendix Table A.4.

Table 2 shows cadmium intake based primarily on a conventional product selection. The differences between the mLB and UB approaches are only minor, which is why the following descriptions refer only to the UB approach. Children under one year of age show the highest median (P50) exposure at 2.32 µg/kg bw per week, followed by one- to two-year-olds at 2.31 µg/kg bw per week. This age group shows the highest cadmium intake at the P95 level, at 3.70 µg/kg bw per week. Cadmium exposure decreases with increasing age.

On average across all respondents, 'grains and grain-based products' make the highest contribution to cadmium intake in all age groups, accounting for 40% to 50% to exposure. These are primarily wheat products, such as white bread/rolls, pasta, wholemeal and rye-wheat bread. However, potatoes are also among the top three foods contributing most to cadmium exposure in all age groups considered. The main group 'potatoes and potato

² Non-specific MEAL foods were not further subdivided into pooled samples by season, region or production method. Only one measurement result is available.

products' accounts for the second-highest proportion of exposure, at 13% to 15%. Although 'grains and grain-based products' and 'potatoes and potato products' are not among the main food groups with the highest cadmium concentrations, when compared across all main groups, they do tend to have higher median concentrations of 0.014 mg/kg and 0.013 mg/kg respectively (Fechner *et al.*, 2022). The additionally high long-term consumption levels of potatoes make them one of the main contributors to cadmium exposure.

Table 2 : Long-term cadmium exposure [$\mu\text{g/kg}$ bw per week] for children, adolescents and adults in the German population, assuming a diet consisting predominantly of conventionally produced foods.

Consumption survey	Age group (years)	modified Lower Bound			Upper Bound	
		N	P50	P95	P50	P95
KiESEL	0.5 – <1	57	2.09	3.30	2.32	3.49
	1 – <3	308	2.10	3.50	2.31	3.70
	3 – <6	588	1.66	3.02	1.81	3.15
EsKiMo II	6 – <10	789	1.52	2.65	1.63	2.73
	10 – <12	401	1.17	2.08	1.25	2.14
NVS II	14 – <19	937	0.72	1.69	0.81	1.81
	19 – <25	1,200	0.68	1.39	0.77	1.53
	25 – <35	1,961	0.67	1.38	0.77	1.50
	35 – <61	4,311	0.64	1.34	0.74	1.46
	51 – <65	2,860	0.60	1.32	0.70	1.44
	≥ 65	2,657	0.64	1.25	0.73	1.35

N: Number of individuals

To identify dietary patterns that pose a particular risk, the exposure for consumers of the foods contributing most to exposure was also calculated. The ten foods contributing most to exposure were identified among the individuals at the upper end of the exposure distribution. For these foods, the standard parameters of the exposure distribution were presented for all consumers. The calculation took into account the intake from all foods consumed by the selected individuals. This approach specifically identifies foods that are rarely consumed but make a significant contribution to exposure. The top 10 cadmium intakes are shown, sorted by exposure at the P50 level.

Among **children** (KiESEL and EsKiMo II), those who consume spinach or creamed spinach take up the highest levels of cadmium (Table 3, Table 4). With a cadmium concentration of up to 0.100 mg/kg, spinach is among the ten foods with the highest concentrations analysed in the BfR MEAL Study (the BfR, 2023). Creamed spinach has slightly lower concentrations of up to 0.073 mg/kg due to the other ingredients, but is consumed much more frequently. In addition to the total intake of 5.84 $\mu\text{g/kg}$ bw per week (P95), it should be noted that

consumers of spinach already take up 2.41 µg/kg bw per week (P95) through the consumption of spinach alone (Table 3). In addition, consumers of potato soup achieve an equally high weekly intake of 5.84 µg/kg bw (P95). If only the intake from potato soup alone is considered, 1.10 µg/kg bw per week are taken up. It is also notable that, in addition to consumers of spinach/creamed spinach, consumers of 'Ready-to-eat mixed meal for infants and toddlers' also take up high amounts solely through the consumption of complementary feeding (1.74 µg/kg bw per week, P95). It should be noted that 'Ready-to-eat mixed meal for infants and toddlers' has comparatively low cadmium levels (0.011 mg/kg). It can be assumed that the children consuming these products are fed almost exclusively on complementary feeding, with the aforementioned complementary feeding meal making up a large proportion of their nutrition.

For the consumers of the other foods, however, it is the total intake from all other foods that is more likely to be responsible for the high cadmium exposure. Consumers of rarely eaten foods with high cadmium concentrations, such as buckwheat (0.043 mg/kg), squid/octopus (0.205 mg/kg), poppy seed cake and pastry (0.060 mg/kg – 0.073 mg/kg)³ and linseeds (0.185 mg/kg) (also takes up high levels of cadmium solely through the consumption of these foods (Table 3, Table 4). However, the sample size of these consumers is too small to allow for statistically reliable conclusions.

Looking at the overall picture for children (KiESEL and EsKiMo II), it can therefore be concluded that nutrition rich in vegetables (particularly spinach), potatoes and grains is associated with higher cadmium exposure. However, intake from foods containing buckwheat, squid/octopus, linseeds or poppy seeds is also a significant contributor to overall exposure. A relevant contribution from other pseudo-cereals such as quinoa, amaranth or millet cannot be ruled out, as no meaningful consumption data was available for these. Quinoa, however, has the same cadmium concentration as buckwheat (0.043 mg/kg), so that if consumed in similar quantities, the probability of exceeding the TWI is also high. Millet and amaranth have lower concentrations of 0.019 mg/kg and 0.016 mg/kg (the BfR, 2023).

³ Range between four regional MEAL pools.

Table 3: Cadmium exposure [µg/kg bw per week] of children (0.5 – <6 years) for consumers of foods with a high contribution to exposure. Shown is the total exposure across all foods consumed by individuals who consumed the selected food during the survey period. In addition, the exposure resulting solely from the consumption of the respective food is given in brackets (basis: KiESEL, consumers only, conventional scenario, upper bound).

MEAL food	n (percentage)	P50 ^a	P95 ^a
Spinach	38 (4%)	2.73 (0.66)	5.84 (2.41)
Ready-to-eat mixed meal for infants and toddlers ^b	93 (10%)	2.46 (0.63)	3.87 (1.74)
Creamed spinach	100 (11%)	2.43 (0.44)	3.97 (1.68)
Potato-vegetable-based meal for infants and toddlers ^c	47 (5%)	2.24 (0.35)	3.40 (1.15)
Muesli with dried fruits	58 (6%)	2.21 (0.09)	3.26 (0.54)
Potato soup	49 (5%)	1.99 (0.28)	5.84 (1.10)
Meat and vegetable soup ^d	50 (5%)	1.96 (0.27)	3.40 (0.82)
Lasagna with vegetable-based sauce ^e	28 (3%)	1.74 (0.25)	3.53 (0.77)
Buckwheat ^f	12 (1%)	2.54 (0.40)	3.58 (0.58)
Potato-vegetable-meat-based meal for infants and toddlers ^{c,f}	9 (1 %)	2.53 (0.51)	3.41 (1.17)

n: Number (percentage) of consumers of the selected food; Total N: 952 ^a The number in brackets indicates exposure exclusively through consumption of the respective food (consumers and consumption of the selected food only) ^bMixed baby food jars containing approximately 20–30% pasta or potatoes (less frequently rice), 30–40% vegetables (mainly carrots and tomatoes with varying other vegetables), with the remaining proportion composed of varying ingredients such as meat, fish, milk/cheese (~10%) as well as oil and spices ^cContains no spinach ^dNine out of 15 subsamples contain potatoes; no subsample contains spinach ^eEight out of 20 subsamples contain spinach ^fThe sample size does not permit statistically valid conclusions. Information on exposure should be understood as indicative.

Table 4: Cadmium exposure [µg/kg bw per week] among children (aged 6–<12 years) for consumers of foods with a high contribution to exposure. Shown is the total exposure from all foods consumed by individuals who consumed the selected food during the survey period. In addition, the exposure resulting solely from the consumption of the respective food is given in brackets (basis: EsKiMo II, consumers only, conventional scenario, upper bound).

MEAL foods	n (percentage)	P50 ^a	P95 ^a
Spinach	23 (2%)	2.43 (0.49)	3.94 (0.79)
Creamed spinach	88 (7%)	2.04 (0.40)	3.34 (1.18)
Potato crisps	217 (18%)	1.67 (0.17)	2.80 (0.76)
Meat and vegetable soup ^b	86 (7%)	1.60 (0.13)	3.60 (1.10)
Peanuts	26 (2%)	1.49 (0.09)	2.22 (0.83)
Squid/octopus	1 (0.1%)	3.07 (1.19)	3.07 (1.19)
Poppy seed cake and pastry	2 (0.2%)	2.11 (0.63)	2.49 (1.00)
Linseeds ^c	13 (1%)	2.02 (0.04)	3.73 (0.54)
Lasagna with vegetable-based sauce ^{d,e}	12 (1%)	1.93 (0.24)	2.35 (0.50)
Vegetables, gratinated ^{c,e}	19 (2%)	1.69 (0.18)	3.20 (0.50)

n: Number of consumers of the selected food; total N: 952 ^a The figure in brackets indicates exposure exclusively through consumption of the respective food (consumers and consumption of the selected food only) ^b Nine out of 15 subsamples

contain potatoes; no subsample contains spinach ^cEight out of 15 subsamples contain potatoes, four subsamples contain leaf spinach, four subsamples contain sunflower seeds, four subsamples contain breadcrumbs ^dEight out of 20 subsamples contain spinach ^eThe sample size does not permit statistically valid conclusions. Exposure data should be regarded as indicative.

In the group comprising **adolescents and adults** (NVS II), those who consume squid/octopus take up the highest levels of cadmium, at 4.64 µg/kg bw per week (P95). The contribution from the consumption of squid/octopus alone amounts to 4.06 µg/kg bw per week. Similarly, consumers of boletus/porcini mushrooms take up high amounts through total consumption (P95: 3.80 µg/kg bw per week) and through the consumption of boletus/porcini mushrooms alone (P95: 2.76 µg/kg bw per week) (Table 5). Furthermore, if only the intake from the consumption of the selected foods alone is considered, kidneys (mammals), sunflower seeds, mussels and poppy seed cake and pastry make significant contributions. It should be noted that the proportion of the general population (aged 14 to 80) consuming any of the foods mentioned is low, at <1%. The high proportion of these foods in the exposure is due to their high cadmium concentration. For example, boletus/porcini mushrooms had the highest cadmium concentration among the 356 MEAL foods, at 0.320 mg/kg. Sunflower seeds and squid/octopus have the third and fourth highest cadmium levels at 0.265 mg/kg and 0.205 mg/kg (the BfR, 2023).

As a result, children have the highest cadmium exposure relative to bw. Grain and potato products make the largest contribution. Consumers of certain foods have particularly high cadmium intakes. This applied above all to consumers of dishes containing spinach and potatoes. Of particular note are those who consume spinach (children in KiESEL), who achieve high cadmium intakes solely through the consumption of spinach. High intakes are also achieved for some foods that are rarely consumed but have high cadmium concentrations (squid/octopus, buckwheat, linseeds, poppy seed cake and pastry). However, the data set on consumers is too small to allow valid conclusions to be drawn.

Among adolescents and adults, too, grain and potato products make the largest contribution to exposure. High cadmium intakes can be demonstrated for consumers of foods with particularly high cadmium levels (boletus/porcini mushrooms, kidneys (mammals), squid/octopus, sunflower seeds). However, this affects only a small proportion of the population (<1%). For this group, however, the consumption of these foods alone leads to high intakes.

Table 5: Cadmium exposure [$\mu\text{g}/\text{kg}$ bw per week] among adolescents and adults (14–80 years) for consumers of foods with a high contribution to exposure. Shown is the total exposure across all foods consumed by individuals who consumed the selected food during the survey period. In addition, the exposure resulting solely from the consumption of the respective food is given in brackets (basis: NVS II, consumers only, conventional scenario, upper bound).

MEAL foods	n (percentage)	P50 ^a	P95 ^a
Boletus/Porcini mushrooms	28 (0.2%)	1.74 (1.03)	3.80 (2.76)
Squid/octopus	43 (0.3%)	1.46 (0.75)	4.64 (4.06)
Poppy seed cake and pastry	207 (1%)	1.19 (0.42)	2.18 (1.00)
Spinach	595 (4%)	1.17 (0.42)	2.36 (0.92)
Sunflower seeds	66 (0.5%)	1.11 (0.18)	2.79 (1.60)
Poultry, liver	40 (0.3%)	1.05 (0.28)	1.82 (0.53)
Mussels	26 (0.2%)	1.01 (0.24)	2.36 (1.59)
Kidney (Mammals) ^b	10 (0.1%)	1.60 (1.03)	2.09 (1.34)
Creamed spinach ^b	6 (<0.1%)	1.20 (0.34)	1.67 (0.76)
Sushi ^b	19 (0.1%)	0.85 (0.26)	1.44 (0.52)

n: Number of consumers of the selected food; total N: 952 ^aThe figure in brackets indicates exposure exclusively from consumption of the respective food (consumers who consume only the selected food ^bThe sample size does not permit statistically valid conclusions. Exposure data should be regarded as indicative.

Comparison of exposure assessments from across Europe

In a European comparison using data from the last ten years, cadmium exposure among infants, toddlers and children is of the same order of magnitude as the intake levels from the French ‘infant TDS (iTDS)’, which is assessed as the most comparable study due to its recency and methodology (TDS). Children in the 0.5–3-year-old age group took up an average of between 2.04 $\mu\text{g}/\text{kg}$ bw (LB) and 2.42 $\mu\text{g}/\text{kg}$ bw (UB) per week (Jean *et al.*, 2018). This is roughly of the same order of magnitude as the intake levels determined in this opinion for children aged 0.5–<6 years in Germany. Sprong & Boon (2015) report an average weekly cadmium intake of 3.5 $\mu\text{g}/\text{kg}$ bw (Medium Bound; MB) for Dutch children aged between 2 and 6 years, which lies within the same order of magnitude as the P95 of the MEAL intake estimates (3.02 $\mu\text{g}/\text{kg}$ bw to 3.15 $\mu\text{g}/\text{kg}$ bw). Weekly cadmium intakes for 6–15-year-olds in the Valencia region of Spain were reported to range from 1.26 $\mu\text{g}/\text{kg}$ bw to 2.89 $\mu\text{g}/\text{kg}$ bw, which is slightly above the intake estimates for children aged 6–<12 years in this opinion. EFSA assessed cadmium intake in 2012, drawing on dietary studies from various countries as well as occurrence data from 2003–2011. The cadmium intake determined in that assessment was higher than the intakes calculated here. However, there are considerable variations between the intake estimates calculated by the Member States, with values for Germany tending to be at the lower end of the European range (EFSA, 2012). This suggests a significant influence of differing dietary habits between countries.

The cadmium exposure for adolescents and adults determined in this opinion is roughly in the same order of magnitude as the cadmium exposure based on the TDS in Valencia (Marín *et al.*, 2017). However, it is approximately a factor of 2 lower than the other comparative values from the Netherlands (Sprong & Boon, 2015), Germany (Schwarz *et al.*, 2014) or from

EFSA (EFSA, 2012). These higher values are primarily based on occurrence data from monitoring surveys and are generally collected at the RAC (raw agricultural commodity) level. For the comparison of children, adolescents and adults alike, it should be noted that the comparative values between TDS fall within a similar range, whilst the estimates based on other occurrence data (primarily monitoring data) are higher.

Table 6: Comparison of cadmium exposure for children, adolescents and adults based on data from the BfR MEAL Study with exposure assessments from the European region over the past ten years, as well as the latest EFSA opinion.

	Country	Cadmium intake [µg/kg bw per week]	Parameter	Age group (years)	References
Children	France	2.04 (LB) – 2.42 (UB)	MW	0.5 – 3	Jean <i>et al.</i> (2018)
	Netherlands	3.5 (MB)	Median	2 – 6	Sprong & Boon (2015)
	Spain (Valencia) ^a	1.26 – 2.89 ^a	MW	6 – 15	Marín <i>et al.</i> (2017)
	Europe/EFSA ^b	1.86 (LB) – 7.84 (UB)	MW	<1 – <3	EFSA (2012)
		2.59 (LB) – 5.87 (UB)		3 – <10	
	Germany ^c	1.66 (mLB) – 2.32 (UB)	Median	0.5 – 5	This opinion, based on KIESEL
		1.17 (mLB) – 1.63 (UB)	Median	6 – 11	This opinion, based on EsKiMo II
Adolescents and adults	Spain (Valencia) ^a	0.77 – 1.78 ^a	MW	16 – 95	Marín <i>et al.</i> (2017)
	Netherlands	1.82 (MB)	Median	7 – 69	Sprong & Boon (2015)
	Germany	1.46 (MB)	MW	14–80	Schwarz <i>et al.</i> (2014)
	Europe/EFSA ^b	1.21 (LB) – 2.53 (UB)	MW	18 – <75	EFSA (2012)
	Germany ^c	0.60 (mLB) – 0.81 (UB)	Median	14 – 80	This opinion; based on NVS II

^a‘Optimistic’ and ‘pessimistic’ scenario ^bRange between the lowest and highest cadmium intake determined in various countries ^cConventional scenario

3.1.3.4 Uncertainties

The concept of a TDS involves creating a food list (the TDS food list) comprising foods that account for at least 90% of the population’s dietary habits. This reduces uncertainties regarding occurrence data from a TDS compared to other data collection methods, such as food monitoring. From a methodological perspective, a further advantage is that in a TDS, substance levels are measured in prepared and ready-to-eat foods, thereby taking into account any changes in content that may occur during food preparation. TDSs provide representative data on the average concentrations in a wide range of foods, and thus offer a very good basis for determining long-term exposure (Kolbaum, 2022) .

It should be noted that none of the pooled samples analysed in the BfR MEAL Study exceeded the legally established maximum levels. However, it must be borne in mind that pooled samples do not allow conclusions to be drawn about the statistical distribution of the measured concentrations. Consequently, the occurrence data collected as part of a TDS are

not suitable for monitoring maximum levels, and it cannot be ruled out that individual samples within the pooled samples may have exceeded the maximum level.

To perform an exposure assessment, occurrence data must be combined with dietary intake data. The data for children (KiESEL, EsKiMo II) were collected as part of the KiGGS Wave 2 between 2014 and 2017. The dietary intake data for adults (NVS II) were collected in 2005 and 2006. It cannot be ruled out that dietary habits among the German population have changed since then. In this context, particular mention should be made of the possible change in consumption of plant-based substitutes (e.g. soya drinks) and pseudo-cereals (e.g. quinoa), which have higher cadmium levels than conventional alternatives. For example, no cadmium was detected in cow's milk in the BfR MEAL Study (<0.0003 mg/kg), whereas soya drink had a concentration of 0.005 mg/kg. For consumers of these foods, exposure may therefore be underestimated.

As the TDS covers $> 90\%$ of foods, the cadmium exposure determined here may underestimate the actual exposure across all foods consumed. However, as the most commonly consumed foods and those known to be highly contaminated were included in the estimate, the underestimation is considered to be minor.

The intake estimate was based on the average consumption over the recording days. This may lead to an overestimation of exposure at the extremes of the distribution, as intra-individual variability was not adequately accounted for. However, compared with the EFSA recommendation to use at least two recording days, KiESEL and EsKiMo II already provide better coverage of intra-individual variability.

3.1.4 Exposure estimation and assessment: internal (human biomonitoring)

Cadmium levels in whole blood and urine in children

In the German Environmental Health Study GerES V (2014–2017), one focus was on human biomonitoring of a representative sample of children and adolescents in Germany aged 3 to 17 years. Among other things, cadmium concentrations were analysed in the whole blood of 720 and in the urine of 2,250 children and adolescents. Cadmium was found in quantifiable amounts in 76% of the urine samples and 44% of the blood samples from the children and adolescents. The median concentration of cadmium (P50) in urine was 0.08 µg/l; for cadmium in blood, it was below the LOQ. The statistical summary of the results for cadmium concentrations in blood and urine from the GerES V study is presented in Table 7 (UBA, 2023).

Table 7: Statistical summary of data on cadmium levels in whole blood and urine among children and adolescents participating in GerES V (UBA, 2023)

Age group (years)	Number Participants	P50	P95	Maximum
Blood cadmium levels [µg/l]				
3 – 5	138	< BG ^a	0.17	0.43
6 – 10	231	< BG	0.24	0.33
11 – 13	143	< BG	0.22	0.38
14 – 17	208	0.13	0.30	2.74
Cadmium content in urine [µg/l]				
3 – 5	399	0.05	0.16	1.85
6–10	734	0.07	0.23	1.24
11–13	457	0.09	0.27	0.57
14 – 17	660	0.10	0.29	0.72

^aLOQ: Limit of Quantification (0.12 µg/l in whole blood and 0.05 µg/l in urine)

Comparison of children's internal exposure with the reference point for renal toxicity

For cadmium, human biomonitoring values were developed by the HBM Commission of the German Environment Agency (UBA). The HBM values are based on 35 studies that investigated correlations between cadmium in urine (as an indicator of cumulative cadmium exposure) and B2M as an indicator of early nephrotoxic effects (UBA, 2011). Accordingly, the HBM values for cadmium are based on the same starting point (BMDL₅: 4 µg cadmium/g creatinine), which was also used to derive the TWI (see Chapter 3.1.2.4). The derived HBM values for cadmium are therefore based on the nephrotoxicity of cadmium following long-term chronic exposure (oral and inhalative) as the most sensitive toxicological endpoint.

The HBM-I value (test or control value) represents the concentration of a substance in human biological material below which, according to the current state of knowledge, no risk for adverse health effects is to be expected. If, on the other hand, the HBM-II value (intervention or action value) is exceeded, there is an increased risk for adverse health effects and immediate measures to reduce exposure are indicated (UBA, 2021).

For internal exposure, cadmium intake via other exposure routes, e.g. inhalative exposure, is relevant in addition to oral cadmium intake via food. It is not possible to make a reliable statement regarding the proportion of cadmium exposure via food intake relative to the internal exposure determined in GerES V. The absorption of cadmium taken in via inhalation can be significantly higher at 7–50% than the absorption of cadmium taken in orally (EFSA, 2009). For the toxicity of inhalative cadmium, the increase in urinary B2M excretion as a marker of renal toxicity may not be a suitable measure. Based on studies involving inhalative exposure, cadmium is classified as a human carcinogen (IARC, 2018). The BfR points out that the carcinogenicity endpoint is not taken into account in the derivation of the HBGV for oral exposure to cadmium, which also forms the basis for the derivation of the HBM values for the assessment of internal exposure.

3.2 Risk characterisation

3.2.1 Risk characterisation based on the external exposure assessment

For the risk characterisation, the estimated long-term external cadmium exposure for children, adolescents and adults in the German population is compared with the HBGV for cadmium (TWI: 2.5 µg/kg bw per week).

The percentage of the estimated cadmium intake relative to the TWI for all age groups, with the assumption that the consumption is primarily of conventionally produced food, is shown in Table 8 .

The estimated median exposure to cadmium (P50, mLB and UB) does not result in the TWI being exceeded for any of the age groups considered, but for children under three years of age it approaches the TWI, with a percentage of up to 84% (mLB) and 93% (UB).

The estimated high exposure (P95, mLB and UB) to cadmium results in the TWI being exceeded among children aged 0.5–<10 years, but not among older children, adolescents and adults.

Children under one year of age show the highest median exposure at 2.32 µg/kg bw per week (P50, UB), which corresponds to 93% of the TWI, followed by one- to two-year-olds with a weekly intake of 2.31 µg/kg bw (P50, UB). One- to two-year-olds show the highest exposure at the P95 level, at 3.70 µg/kg bw per week (P95, UB). The TWI is thus exceeded by a factor of 1.5. Overall, 37% of children aged 0.5–<1 year and 39% of those aged 1–<3 years exceed the TWI.

Table 8: Percentage of dietary cadmium intake relative to the TWI (2.5 µg/kg bw per week) and the proportion (%) of individuals exceeding the TWI for children, adolescents and adults in the German population, assuming a diet consisting predominantly of conventionally produced foods.

		% TWI				Proportion of individuals > TWI	
		mLB		UB		mLB	UB
Consumption survey	Age group (years)	N	P50	P95	P50	P95	
KiESEL	0.5 – <1	57	83%	132%	93%	139%	26% 37%
	1 – <3	308	84%	140%	92%	148%	29% 39%
	3 – <6	588	67%	121%	72%	126%	12% 15%
EsKiMo II	6 – <10	789	61%	106%	65%	109%	6% 9%
	10 – <12	401	47%	83%	50%	86%	2% 2%
NVS II	14 – <19	937	29%	68%	32%	72%	1% 1%
	19 – <25	1,200	27%	56%	31%	61%	1% 1%
	25 – <35	1,961	27%	55%	31%	60	0.2% 0.5%
	35 – <61	4,311	25%	54%	30%	59%	0.3% 0.4%
	51 – <65	2,860	24%	53%	28%	57%	0.1% 0.2%
	≥ 65	2,657	26%	50%	29%	54%	0.1% 0.1%

mLB: modified Lower Bound UB: Upper Bound TWI: Tolerable Weekly Intake

The estimated total dietary exposure to cadmium for consumers of foods that contribute significantly to exposure are presented in Table 9 and Table 10 for children aged 0.5–<12 years, and in Table 11 for adolescents and adults.

The median estimated exposure across all foods consumed approaches the TWI for **children** (0.5–<12 years) who consume foods that contribute significantly to their exposure, and in some cases exceeds the TWI (children aged 0.5–<6 years who consume spinach). The highest exposures correspond to a maximum of 109% and 123% of the TWI for children (0.5–<12 years) who consume spinach and squid/octopus respectively (P50, UB) (Table 9, Table 10).

The high exposure (P95) for almost all consumers of the foods shown in Table 9 and Table 10 exceeds the TWI and corresponds to a maximum of 234% of the TWI for children who consume spinach or potato soup (0.5–<6 years, P95, UB). It is particularly noteworthy that those consuming spinach already achieve a weekly cadmium intake of 2.41 µg/kg bw in the P95 from spinach consumption alone (Table 3) and that exposure is therefore already approaching the TWI by spinach consumption (96%).

Table 9: Percentage of dietary cadmium intake relative to the TWI (2.5 µg/kg bw per week) for children (0.5–<6 years), for consumers of foods with a high contribution to exposure (basis: KiESEL, consumers only, conventional scenario, upper bound).

MEAL foods	% TWI		
	n (proportion %)	P50	P95
Spinach	38 (4%)	109%	234%
Ready-to-eat mixed meal for infants and toddlers ^a	93 (10%)	98%	155%
Creamed spinach	100 (11%)	97%	159%
Potato-vegetable-based meal for infants and toddlers ^b	47 (5%)	90%	136%
Muesli with dried fruits	58 (6%)	88%	130%
Potato soup	49 (5%)	79%	234%
Meat and vegetable soup ^c	50 (5%)	78%	136%
Lasagna with vegetable-based sauce ^d	28 (3%)	70%	141%
Buckwheat ^e	12 (1%)	101%	143%
Potato-vegetable-meat-based meal for infants and toddlers ^{b,e}	9 (1%)	101%	136%

n: Number (percentage %) of consumers of the selected food; Total N: 952 TWI: Tolerable Weekly Intake ^aMixed baby food jars containing approximately 20–30% pasta or potatoes (less frequently rice), 30–40% vegetables (mainly carrots and tomatoes with varying other vegetables), with the remainder consisting of varying ingredients such as meat, fish, milk/cheese (~10%) as well as oil and spices ^bContains no spinach ^cNine out of 15 subsamples contain potatoes; no subsample contains spinach ^dEight out of 20 subsamples contain spinach ^eThe sample size does not permit statistically valid conclusions. Information on the percentage of exposure relative to the TWI should be understood as indicative.

Table 10: Percentage of dietary cadmium intake relative to the TWI (2.5 µg/kg bw per week) for children (6–<12 years) who consume foods with a high contribution to exposure (basis: EsKiMo II, consumers only, conventional scenario, upper bound).

MEAL foods	% TWI		
	n (proportion %)	P50	P95
Spinach	23 (2 %)	97%	158%
Creamed spinach	88 (7%)	82%	134%
Potato crisps	217 (18%)	67%	112%
Meat and vegetable soup ^a	86 (7%)	64%	144%
Peanuts	26 (2%)	60%	89%
Squid/octopus	1 (0.1%)	123%	123%
Poppy seed cake and pastry ^d	2 (0.2%)	85%	100%
Linseeds ^d	13 (1%)	81%	149%
Lasagna with vegetable-based sauce ^{b,d}	12 (1%)	77%	94%
Vegetables, gratinated ^{c,d}	19 (2%)	68%	128%

n: Number of consumers of the selected food; Total N: 952 TWI: Tolerable Weekly Intake

^a Nine out of 15 subsamples contain potatoes; no subsample contains spinach ^bEight out of 20 subsamples contain spinach

^cEight out of 15 subsamples contain potatoes, four subsamples contain spinach leaves, four subsamples contain sunflower

seeds, four subsamples contain breadcrumbs ^dThe sample size does not allow for statistically valid conclusions. Figures on the percentage of exposure relative to the TWI should be regarded as indicative.

When considering consumers of foods with a high contribution to exposure, the percentage of total dietary exposure relative to the TWI for **adolescents and adults** who consume squid/octopus, boletus/porcini mushrooms and sunflower seeds is 186%, 152% and 112% respectively (P95, UB). The median total exposure to cadmium via the consumption of foods with a high contribution to exposure is below the TWI (34%–69%, P50, UB). Overall, it is notable that only consumers of rarely eaten foods exceed the TWI. Their consumption alone accounts for a relatively large proportion of exposure (Table 5). The high cadmium intakes (P95) among consumers of boletus/porcini mushrooms (2.76 µg/kg bw per week) and squid/octopus (4.06 µg/kg bw) already exceed the TWI solely through the consumption of these foods.

Table 11: Percentage of dietary cadmium intake relative to the TWI (2.5 µg/kg bw per week) for adolescents and adults (14–80 years) who consume foods with a high contribution to exposure (basis: NVS II, consumers only, conventional scenario, upper bound).

MEAL foods	n (percentage %)	% TWI	
		P50	P95
Boletus/Porcini mushrooms	28 (0.2%)	69%	152%
Squid/octopus	43 (0.3%)	58%	186%
Poppy seed cake and pastry	207 (1%)	48%	87%
Spinach	595 (4%)	47%	94%
Sunflower seeds	66 (0.5%)	44%	112%
Poultry, liver	40 (0.3%)	42%	73%
Mussels	26 (0.2%)	40%	94%
Kidney (Mammals) ^a	10 (0.1%)	64%	84%
Creamed spinach ^a	6 (<0.1%)	48%	67%
Sushi ^a	19 (0.1%)	34%	58%

n: Number of consumers of the selected food; Total N: 952 TWI: Tolerable Weekly Intake ^a The sample size does not permit statistically valid conclusions. Information on the percentage of the TWI should be regarded as indicative.

3.2.2 Risk characterisation based on the internal exposure assessment

For cadmium, an HBM-I value of 0.5 µg/l and an HBM-II value of 2 µg/l in urine were derived for children and adolescents. Consequently, the median and 95th percentile cadmium concentrations in the urine of participants were below the HBM-I value. Maximum urine levels in children of all age groups were above the HBM-I value. According to the UBA (2023), this corresponds to 0.6% of the participating children.

3.2.3 Conclusion of the risk characterisation based on estimates of internal and external exposure

Dietary exposure to cadmium approaches the TWI or exceeds it for some age groups in the German population. In particular, for children under 3 years of age, the estimated cadmium intake from all foods exceeds the TWI by up to 1.5 times (high exposure, P95, UB) and, when considering the consumption of foods that highly contribute to exposure (e.g. spinach), by

up to 2.3 times (high exposure, P95, UB). For adolescents and adults, the TWI is not exceeded when considering the high cadmium exposure (maximum contribution of exposure to the TWI of 72%, P95, UB). However, when considering the consumption of foods that highly contribute to exposure (e.g. squid/octopus), exposure exceeds the TWI by up to 1.7 times (P95, UB).

The TWI was derived on the basis of the critical cadmium concentration in urine following 50 years of exposure (see chapter 3.1.2.4). With weekly oral cadmium intake up to the level of the TWI, it is not expected that critical urinary cadmium concentrations, in terms of renal toxicity, will be reached in adulthood as a result of this exposure. It has not been conclusively established scientifically whether, in the case of temporary intake above the TWI, e.g. during childhood, cadmium concentrations in urine are reached that can be considered critical in terms of adverse health effects. This depends, among other things, on the extent and duration of the TWI exceedance and on pre-existing internal exposure to cadmium. The estimates made in this opinion yielded values for dietary cadmium intake (external exposure) in children that exceed the TWI.

In the GerES V study, cadmium levels in the urine of children aged 3–17 years (internal exposure P50 and P95) were found to be below the HBM-I value. Maximum urine levels in children of all age groups are above the HBM-I value, which corresponds to 0.6% of the participating children. In the GerES V study, the level of dietary external exposure relative to bw decreases with increasing age. At the same time, the blood and urine cadmium levels of the participating children increase with increasing age. This increase may be linked, among other things, to the bioaccumulative properties of cadmium, particularly in the kidneys, and highlights the importance of up-to-date data on internal exposure for adults. Representative data on the current level of internal exposure in the adult population of Germany from GerES VI (data collection 2023–2024) have not yet been published.

The differing results of the risk characterisation based on external and internal exposure can be explained primarily by the underlying methodology and the associated uncertainties. Internal exposure reflects the amount actually absorbed by the body, which results from all exposure pathways and takes into account individual differences in metabolism and excretion. External exposure is calculated using a model based on concentration and consumption data in order to describe the contribution of individual foods to total exposure and to investigate the impact of potential individual risk management measures. The observed discrepancy is therefore methodologically justifiable.

In summary, the BfR considers that for the vast majority of the population in Germany, the likelihood of health impairments resulting from dietary exposure to cadmium is low. However, for children aged 0.5 – < 12 years, exposure exceeds the TWI, depending on the foods consumed (see Tables 8 – 11, particularly in scenarios taking into account foods with a high contribution to exposure). For younger children (0.5–<6 years), this affects a higher percentage of the age groups.

With increasing age, the level of dietary external exposure relative to bw decreases. At the same time, blood and urine cadmium levels in children increase with age in the GerES V study. This increase may be linked, among other things, to the accumulative properties of cadmium, particularly in the kidneys, and highlights the importance of up-to-date data on internal exposure for adults. Representative data on the current level of internal exposure in

the adult population of Germany from GerES VI (data collection 2023–2024) are not yet publicly available.

As the results of the external exposure assessment in this opinion show that the exposure of some population groups, e.g. children, is at or above the TWI, it is desirable from a toxicological perspective to continue reducing cadmium exposure in the German population. A particular starting point here could be the foods that, in the present calculations, were found to contribute highly to total intake.

4 References

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5 Appendix

Table A.1 : Cadmium levels from the BfR MEAL Study by main food groups for unspecified production in µg/kg.

Food group	N	mLB				UB			
		MW	P50	Min	Max	MW	P50	Min	Max
01 Grains and grain products	25	17.0	13.0	0	65.5	17.1	13.0	2.0	65.5
02 Vegetables, vegetable products and mushrooms	21	29.5	4.5	0.6	320.0	29.6	4.5	1.1	320.0
03 Starchy roots or tubers and products derived therefrom	4	30.5	21.5	7.0	72.0	30.5	21.5	7.0	72.0
04 Pulses, nuts, oilseeds and spices	16	35.2	8.5	0	265.0	35.8	8.5	1.0	265.0
05 Fruit and fruit products	15	2.4	0.7	0	10.5	2.8	2.0	0.3	10.5
06 Meat and meat products	23	9.6	1.2	0	113.3	9.9	1.5	0.3	113.3
07 Fish, crustaceans, molluscs and products derived therefrom	30	16.9	3.5	0	205.0	17.0	3.5	0.3	205.0
08 Milk and dairy products	16	0.8	0.3	0	5.5	1.1	1.0	0.3	5.5
09 Eggs and egg products	0	-	-	-	-	-	-	-	-
10 Sugar, confectionery and sweet water-based desserts	12	17.8	9.5	0	110.0	18.6	9.5	2.0	110.0
11 Animal and vegetable fats and oils ^a	4	0	0	0	0	2.0	2.0	2.0	2.0
12 Vegetable juices, fruit juices and nectars	8	0.4	0	0	2.0	0.7	0.3	0.3	2.0
13 Water and water-based drinks ^b	6	< 0.1	0	0	< 0.1	0.3	0.3	0.1	0.3
14 Coffee, cocoa, tea and infusions	6	52.2	0.3	0	281.7	52.6	1.0	0.3	281.7
15 Alcoholic beverages ^c	5	0	0	0	0	0.6	0.3	0.3	2.0
16 Foods for infants and young children	7	8.3	8.0	0	20.5	8.3	8.0	0.3	20.5
17 products for special dietary requirements and food substitutes	6	11.6	10.5	1.0	25.8	11.6	10.5	1.0	25.8
18 Food and dishes	31	9.5	7.5	1.2	26.5	9.5	7.5	1.5	26.5
19 Condiments and sauces	16	6.5	3.8	0	32.5	6.7	3.8	0.3	32.5

N: Number of food items mLB: modified Lower Bound UB: Upper Bound MW: Mean P50: Median Min: Minimum Max: Maximum

^a all measurements < LOD (2 µg/kg); ^b all measurements < LOD (0.3 or 0.07 µg/kg) or < LOQ (1 or 0.2 µg/kg); ^c all measurements < LOD (2 or 0.3 µg/kg)

Table A.2 : Cadmium levels from the BfR MEAL Study by main food group for conventionally produced foods, in µg/kg.

Food group	N	mLB				UB			
		MW	P50	Min	Max	MW	P50	Min	Max
01 Grains and grain products	15	18.1	18.5	0	38.0	18.3	18.5	2.0	38.0
02 Vegetables, vegetable products and mushrooms	13	13.0	3.0	0	97.0	13.1	3.1	0.3	97.0
03 Starchy roots or tubers and products derived therefrom	4	15.4	14.5	10.8	22.0	15.4	14.5	10.8	22.0
04 Pulses, nuts, oilseeds and spices	4	20.7	20.3	0.3	42.0	20.9	20.3	1.0	42.0
05 Fruit and fruit products	7	0.3	0.2	0	1.2	0.8	0.7	0.3	1.5
06 Meat and meat products	12	10.2	0.8	0.3	41.9	10.5	1.0	0.9	41.9
07 Fish, crustaceans, molluscs and products derived therefrom	0	-	-	-	-	-	-	-	-
08 Milk and dairy produce	7	0.2	0	0	1.0	0.5	0.3	0.3	1.0
09 Eggs and egg products ^a	2	0	0	0	0	0.3	0.3	0.3	0.3
10 Sugar, confectionery and sweet water-based desserts	3	5.5	0	0	16.5	6.8	2.0	2.0	16.5
11 Animal and vegetable fats and oils ^b	4	0	0	0	0	2.0	2.0	2.0	2.0
12 Vegetable juices, fruit juices and nectars ^a	2	0	0	0	0	0.3	0.3	0.3	0.3
13 Water and water-based drinks	0	-	-	-	-	-	-	-	-
14 Coffee, cocoa, tea and infusions ^c	3	0.1	0	0	0.3	0.5	0.3	0.3	1.0
15 Alcoholic beverages ^a	3	0	0	0	0	0.3	0.3	0.3	0.3
16 Foods for infants and young children	4	6.8	6.5	0.3	14.0	7.4	7.3	1.0	14.0
17 Products for special dietary requirements and food substitutes	1	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
18 Dishes and meals	21	10.9	9.0	0.3	68.8	10.9	9.0	1.0	68.8
19 Condiments and sauces	0	-	-	-	-	-	-	-	-

N: Number of food items mLB: modified Lower Bound UB: Upper Bound MW: Mean P50: Median Min: Minimum Max: Maximum

^a all measurements < LOD (0.3 µg/kg); ^b all measurements < LOD (2 µg/kg); ^c all measurements < LOD (0.3 µg/kg) or < LOQ (1 µg/kg)

Table A.3 : Cadmium levels in the BfR MEAL Study by main food groups for organically produced food in µg/kg.

Food group	N	mLB				UB			
		MW	P50	Min	Max	MW	P50	Min	Max
01 Grains and grain products	15	17.6	15.0	5.0	48.0	17.6	15.0	5.0	48.0
02 Vegetables, vegetable products and mushrooms	13	10.7	4.0	0.3	71.0	10.8	4.0	1.0	71.0
03 Starchy roots or tubers and products derived therefrom	4	10.1	9.6	9.0	12.3	10.1	9.6	9.0	12.3
04 Pulses, nuts, oilseeds and spices	4	21.8	18.7	0.3	49.5	22.1	19.0	1.0	49.5
05 Fruit and fruit products	7	0.5	0.2	0	3.0	1.0	0.8	0.3	3.0
06 Meat and meat products	12	9.1	2.1	0.3	56.0	9.4	2.1	1.0	56.0
07 Fish, crustaceans, molluscs and products derived therefrom	0	-	-	-	-	-	-	-	-
08 Milk and dairy products	7	1.4	0	0	9.6	1.8	0.3	0.3	9.6
09 Eggs and egg products ^a	2	< 0.1	< 0.1	0	0.1	0.4	0.4	0.3	0.5
10 Sugar, confectionery and sweet water-based desserts	3	18.7	0	0	56.0	20.0	2.0	2.0	56.0
11 Animal and vegetable fats and oils ^b	4	0	0	0	0	2.0	2.0	2.0	2.0
12 Vegetable juices, fruit juices and nectars ^c	2	0.2	0.2	0	0.3	0.7	0.7	0.3	1.0
13 Water and water-based drinks	0	-	-	-	-	-	-	-	-
14 Coffee, cocoa, tea and infusions ^a	3	0.1	0.1	0	0.2	0.5	0.5	0.3	0.7
15 Alcoholic beverages ^d	3	0	0	0	0	0.3	0.3	0.3	0.3
16 Foods for infants and young children	4	6.1	3.8	0.3	16.5	6.9	5.1	1.0	16.5
17 Products for special dietary requirements and food substitutes	1	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
18 Dishes and meals	21	8.4	6.8	0.3	31.3	8.5	6.8	1.0	31.3
19 Condiments and sauces	0	-	-	-	-	-	-	-	-

N: Number of food items mLB: modified Lower Bound UB: Upper Bound MW: Mean P50: Median Min: Minimum Max: Maximum

^a all measurements < LOD (0.3 µg/kg) or < LOQ (1 µg/kg); ^b all measurements < LOD (2 µg/kg); ^c all measurements < LOD (0.3 µg/kg) or < LOQ (1 µg/kg); ^d all measurements < LOD (0.3 µg/kg)

Cadmium exposure:

Table A.4 : Long-term cadmium exposure [$\mu\text{g/kg}$ bw per week] for children, adolescents and adults in the German population, with the assumption that consumption is primarily of organically produced food, as well as the percentage of exposure relative to the TWI (2.5 $\mu\text{g/kg}$ bw per week) and the proportion (%) of individuals exceeding the TWI.

		Exposure					% TWI				Proportion of individuals > TWI	
		mLB		UB		mLB		UB		mLB	UB	
Consumption study	Age group (years)	N	P50	P95	P50	P95	P50	P95	P50	P95		
KiESEL	0.5 – <1	57	1.54	2.39	1.78	2.64	62%	96%	71%	106%	3%	8%
	1 – <3	308	1.70	2.94	1.87	3.10	68%	118%	75%	124%	11%	15%
	3 – <6	588	1.44	2.44	1.60	2.63	58%	98%	64%	105%	5%	7%
EsKiMo II	6 – <10	789	1.34	2.47	1.46	2.59	54%	99%	58%	104%	4%	6%
	10 – <12	401	1.06	1.72	1.12	1.87	42%	69%	45%	75%	1%	1%
NVS II	14 – <19	937	0.66	1.49	0.74	1.59	27%	60%	30%	64%	0.2%	0.2%
	19 – <25	1,961	0.61	1.29	0.70	1.41	24%	52%	28%	56%	1%	1%
	25 – <35	4,311	0.60	1.21	0.70	1.33	24%	49%	28%	53%	0.3%	0.3%
	35 – <61	2,860	0.55	1.16	0.65	1.29	22%	47%	26%	52%	0.2%	0.2%
	51 – <65	2,657	0.49	1.07	0.60	1.19	20%	43%	24%	48%	<0.1%	0.1%
	≥ 65	1,961	0.49	1.01	0.58	1.10	20%	40%	23%	44%	<0.1%	<0.1%

N: Total number of individuals mLB: Modified Lower Bound UB: Upper Bound TWI: Tolerable Weekly Intake

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Supervisory Authority: Federal Ministry of Agriculture, Food and Regional Identity

VAT ID No. DE 165 893 448

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