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Estimates of dietary exposure to bisphenol A (BPA) from light metal packaging using food consumption and packaging usage data: a refined deterministic approach and a fully probabilistic (FACET) approach

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The FACET tool is a probabilistic model to estimate exposure to chemicals in foodstuffs, originating from flavours, additives and food contact materials. This paper demonstrates the use of the FACET tool to estimate exposure to BPA (bisphenol A) from light metal packaging. For exposure to migrants from food packaging, FACET uses industry-supplied data on the occurrence of substances in the packaging, their concentrations and construction of the packaging, which were combined with data from a market research organisation and food consumption data supplied by national database managers. To illustrate the principles, UK packaging data were used together with consumption data from the UK National Diet and Nutrition Survey (NDNS) dietary survey for 19–64 year olds for a refined deterministic verification. The UK data were chosen mainly because the consumption surveys are detailed, data for UK packaging at a detailed level were available and, arguably, the UK population is composed of high consumers of packaged foodstuffs. Exposures were run for each food category that could give rise to BPA from light metal packaging. Consumer loyalty to a particular type of packaging, commonly referred to as packaging loyalty, was set. The BPA extraction levels used for the 15 types of coating chemistries that could release BPA were in the range of 0.00005–0.012 mg dm^{-2}. The estimates of exposure to BPA using FACET for the total diet were 0.0098 (mean) and 0.0466 (97.5th percentile) mg/person/day, corresponding to 0.00013 (mean) and 0.00059 (97.5th percentile) mg kg^{-1} body weight day^{-1} for consumers of foods packed in light metal packaging. This is well below the current EFSA (and other recognised bodies) TDI of 0.05 mg kg^{-1} body weight day^{-1}. These probabilistic estimates were compared with estimates using a refined deterministic approach drawing on the same input data. The results from FACET for the mean, 95th and 97.5th percentile exposures to BPA lay between the lowest and the highest estimates from the refined deterministic calculations. Since this should be the case, for a fully probabilistic compared with a deterministic approach, it is concluded that the FACET tool has been verified in this example. A recent EFSA draft opinion on exposure to BPA from different sources showed that canned foods were a major contributor and compared results from various models, including those from FACET. The results from FACET were overall conservative.

Keywords: bisphenol A; BPA; FACET; dietary exposure; packaging; cans; coatings; metal packaging

Introduction

Bisphenol A (BPA, 2,2-*bis*(4-hydroxyphenyl)propane) is a chemical used as a starting substance to make resins and plastics (EFSA 2013). Residues of BPA may be present in certain epoxy resins used to make protective coatings and linings for food and beverage cans and aluminium foil containers, as well as for the metal lids on glass jars (Oldring 1997). BPA is also a starting substance for some polycarbonate plastics used to make food containers such as water bottles, tableware and storage containers (EFSA 2013). BPA can migrate in small amounts into food and beverages stored in materials containing the substance (Goodson et al. 2002; EFSA 2013). Several expert bodies and regulatory authorities have issued risk assessments of consumer exposure to BPA over recent years. EFSA started work in 2012 on a new risk assessment of BPA (EFSA 2012). It completed a full risk assessment of BPA as recently as 2006 (EFSA 2006) and established a TDI of 0.05 mg kg^{-1} body weight day^{-1} for the substance, as have other recognised bodies. The TDI is an estimate of the amount of a substance, expressed on a body weight basis, that can be ingested daily over a lifetime without appreciable risk. EFSA also evaluated intakes of BPA through food and drink for adults, infants and children (EFSA 2006) and found that intakes were all well below the TDI. EFSA has updated its scientific advice on BPA several times since 2006, most recently in 2010 (EFSA 2010) when the TDI was reaffirmed. Notwithstanding this, the European Commission and member states decided to prohibit the use of BPA in polycarbonate articles

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that were considered to be one of the major contributors of exposure, particularly for babies, so the use of BPA to make plastic infant feeding bottles was banned in the European Union from 2011 (EC 2011).

The FACET project (Flavours, Additives and Food Contact Materials Exposure Task) was a 4-year project part funded by DG-Research of the European Commission as part of its Framework FP7 Programme. The project's aim was to develop a probabilistic model to estimate exposure to chemicals in foodstuffs originating from flavours, additives and food contact materials. The FACET tool, described elsewhere (Oldring et al. 2013), is a significant advance in assessing exposure to migrants from food packaging.

Polymeric coatings on light metal packaging, used for foods and beverages, are one of the previously identified major sources of exposure to via the diet (EFSA 2013). Migration from coatings of canned products and from lids of glass jars and bottles may occur due to the presence of BPA monomer from incompletely polymerised epoxy resin coatings and of BPA present as a residual impurity of the epoxy substance bisphenol A diglycidyl ether (BADGE). EFSA has given an overview of literature data for BPA in foodstuffs (EFSA 2013). Oldring et al. (2006) give some references for BADGE and a stochastic model approach in estimating exposure to BADGE from canned foodstuffs.

Euromonitor International (hereafter referred to as Euromonitor) is a market research company that supplied data on the different types of retail packaging used (Oldring et al. 2013). In addition to food and beverage cans (bodies and ends) along with metal lids (closures) used on glass jars and bottles, the assessment of exposure here also covers aerosol cans (as used, for example, for cream and desert toppings) and collapsible metal tubes (as used, for example, for tomato paste, mayonnaise, mustard, some fish products, etc.). These pack types were included for completeness although, as seen below, they make only a minor contribution to exposure because only a limited number of foodstuffs are packaged in them. By far the main exposure for light metal packaging is from cans and lids. It should be noted that in some, but not all, countries there are specific uses for aerosols and tubes reported in the Euromonitor data, e.g. only in Ireland has the use of aerosols for oils and fats (presumably as non-stick on a cooking utensil) been reported. Similarly, for collapsible metal tubes there are specialised uses such as spreadable processed cheese reported for some countries.

This estimation of exposure was conducted using the recently completed FACET exposure tool which is fully probabilistic (Monte Carlo statistical modelling) (Oldring et al. 2009; 2013; Hearty et al. 2011). The food consumption data and the packaging usage data contained within the FACET tool have also been summarised and used here for refined deterministic estimates too. In this way the workings of the FACET tool are described step by step to aid in the understanding of it, and the refined deterministic approach has also been compared with the output of FACET to check if the probabilistic FACET tool is working properly. In this paper the exposure estimate is restricted to food packaged in metal for the UK population of 19–64 year olds. Only results from UK data are presented, and when reference is made to other data, these data are not considered in this paper but are only given for information to show the variability of information within the European market.

Materials and methods

It was necessary to collect different data which were then combined. Food consumption data were combined with data on possible types of packaging and the composition of that packaging. This work only focused on exposure to BPA from canned and jarred foodstuffs, so any food packaged in any other form of packaging than a can, can end, metal closure, metal tube or aerosol was not considered further. The data on concentration of the BPA in the foodstuff were obtained analytically, normally using recognised simulants or solvent extraction. This is expressed as weight per unit area, hence it was necessary to know the surface area to weight ratios of the different sized packaging in order to derive a concentration of BPA in the foodstuff.

For the FACET project, food consumption data were obtained from individual food consumption diaries contained within the national food surveys (Oldring et al. 2013). The food consumption data were supplied by the database managers for the countries involved in FACET. For the refined deterministic approach at verifying the FACET results, the UK National Diet and Nutrition Survey (NDNS) survey for 19–64 year olds (Henderson et al. 2002) was used as the data were readily available from previous work (Holmes et al. 2005; Castle et al. 2006; Oldring et al. 2006; Northing et al. 2009). Data on the type of packaging for different foodstuffs were obtained from Euromonitor data for 2005 as well as information on the surface area to packed food weight of the packaging. Data on packaging materials used for different foodstuffs and whether they could contain BPA were collected by industry. The extraction/migration data were also provided by industry. This section describes how all these data were collected and combined.

The database managers recoded their national surveys into the FACET food-coding system (Hearty et al. 2011). These data were then linked to the different types of packaging used for the different food groups consumed. FACET has an agreed list of substance codes, material codes, pack type codes and food codes. The challenge for the packaging industry was to make the link between the food groups (as recorded in the food diaries) to the materials (e.g. glass, metal, plastics, paper, etc.) used to package those foods, and finally to the substances used to make

Table 1. Information sources and the linking needed for estimating exposure.

Substances	<–>	Material types	<–>	Pack types	<–>	Food types
FACET substance code	<–>	FACET material code	<–>	FACET pack code	<–>	FACET food code
BPA	<–>	BPA-containing coatings	<–>	Cans, lids, tubes, aerosols	<–>	All those in metal packaging

those materials. Once this link is made, it is possible to use migration levels or extraction levels from each material to derive concentrations in the food and thereby estimate exposure at the level of the individual consumer. Table 1 gives an overview of how the data were linked.

The FACET Industry Group (FIG) supplied information on substances, materials and packaging construction. Market share data for each type of food packaging were obtained for most of the European Union member states from Euromonitor. An accompanying paper (Oldring et al. 2013) gives a more detailed description of the FIG and of how data were collected and combined. Whilst the packaging usage factors were from 2005, the food consumption survey for 19–64 year olds was from 2000 (Oldring et al. 2013).

Establishing packaging usage factors for each food type

It is necessary to link the food description to its packaging. The national food consumption diaries contained food descriptions and it was necessary to allocate every one of these descriptions to one or more types of food packaging. Information on the types of food packaging was obtained from Euromonitor, but they used their own food item descriptions. Thus, it was necessary to recode all food items into 'food group codes' (P.*x.y.z*). These were split into three tiers, with Tier 1 being common to flavours and additives as well as packaging (Oldring et al. 2013) with 18 food groups. Tier 1 is subdivided into 59 food groups (Tier 2), whilst Tier 3 contains 174. Consider as an example vegetables, starchy roots, legumes and seaweeds, which are coded P.04 at Tier 1. Tier 2 has four subcategories, P.04.1 Fresh vegetables, P.04.2 Processed vegetables, P.04.3 Frozen vegetables and P.0.4 Dried vegetables. P.04.2 is further subdivided into P.04.2.1 Preserved vegetables, no sauces; P.04.2.2 Canned/preserved tomatoes; P.04.2.3 Canned beans and pulses; P.04.2.4 Tomato paste/purees; P.04.2.5 Pasta sauces (tomato based); and P.04.2.6 Pickled vegetables.

In order to allocate material codes to the food groups, a spreadsheet was prepared with the food group in the left-hand column. This was done at either FACET Tier 2 or Tier 3. From these data, packaging usage factors were derived. To illustrate how data are used in FACET, the food packaging data from Euromonitor for the UK for 2005 have been linked to FACET food group codes. Euromonitor updates its surveys annually. Although the 2005 data set may seem to be 'old' data, none of the food consumption surveys used in FACET was more recent than 2005. The UK 19–64-year-old NDNS survey for food consumption data were from 2000.

Table 2 gives the individual food groups and the number of packs (millions of units sold per annum) for each type of metal packaging derived from Euromonitor data. Note that for ease of reading the number of beverage or food can ends is not given individually, as it equals the number of cans for that foodstuff group. Also, in Table 2 as with the others subsequently, some of the figures have been rounded for clarity. The precise (unrounded) numbers have been used in all calculations, however. Table 2 does not contain 15 food groups at Tier 3, because the relevant data were not available in Euromonitor, because, for example, they were not retail, being vended drinks and takeaway foods. The impact for light metal packaging is negligible. For vended carbonates in beverage cans the packaging is the same as for retail cans. The missing food groups are P.01.1.4, P.04.4.2, P.06.4.2, P.06.5.5, P.07.4.2, P.11.1.2, P.12.2.7, P.14.1.1, P.14.3.4, P.14.3.5, P.18.2.1, P.18.3.3, P.18.4.4, P.18.5.10 and P.18.5.11. For a complete list including a description of these missing food groups, see Oldring et al. (2013).

More detailed information on metal packaging for foodstuffs is available from Oldring and Nehring (2007). The non-opening end (bottom) of three-piece cans has been considered as part of the body. Information for glass jars/bottles is given because many, but not all, have metal closures (e.g. metal lids for jars). Aluminium 'roll on' (the pilfer proof tops on spirit bottles, for example) and 'crown closures' (metal bottle tops, normally removed by a bottle opener) are not included in Table 2 because there is either no (a roll on closure has a plastic wad on top of the coated metal) or only minimal (crowns have a plastic liner on top of the coated metal) contact between the beverage and the metal closure.

Only those food groups for which an epoxy-coated metal would be assumed as packaging and for which no migration could be expected are listed in Table 3. Other food groups not carried forward from Table 2 to Table 3 are those for which the packaging may be metal, but it will be uncoated metal (hence no BPA) or for which no migration is expected because the foods are dry or because there is, for example, an insert preventing direct contact. These were food groups: P.01.1.7 Powdered milk, P.05.1.1 Sugar confectionery, P.07.3.1 Sweet biscuits, P.07.4.3 Cakes,

Table 2. Number of light metal food packaging units sold per annum (2005) in the UK for each packed food type (extracted from Euromonitor data).

	Number of pack units for each pack type/food type combination (millions per annum)							
	FACET pack type							
FACET food groups at Tier 3	Aerosol can	Beverage can	Food can	Glass jar/ bottle	Lid for jar/ bottle	Metal tube	Metal other	Total for all packs
P.01.1.1 Liquid milk								4012.4
P.01.1.2 Flavoured milk drinks								211.5
P.01.1.3 Drinking yoghurt								719.0
P.01.1.5 Soy beverages								87.9
P.01.1.6 Condensed/evaporated milk			67.8					67.8
P.01.1.7 Powdered milk				2.9	2.9			1498.8
P.01.1.8 Cream	11.8			0.9	0.9			336.1
P.01.2.1 Processed cheese						32.1		4150.3
P.01.2.2 Unprocessed cheese								1340.1
P.02.1.1 Butter								413.3
P.02.1.2 Cooking margarine								70.2
P.02.1.3 Spreadable oils and fats								578.4
P.02.1.4 Cooking fats								113.7
P.02.2.1 Olive oil								43.6
P.02.2.2 Vegetable and seed oil								105.7
P.03.1.1 Fresh fruit whole								5288.2
P.03.1.2 Fresh fruit cut or peeled								182.4
P.03.2.1 Fruit snacks								599.3
P.03.2.2 Fruit, nut, trail mixes								99.7
P.03.2.3 Jams and fruit preserves				161.4	161.4			161.4
P.03.2.4 Canned/preserved fruit			262.6	1.3	1.3			316.8
P.03.2.5 Frozen fruits or frozen fruit pastes								27.7
P.03.3 Nuts and seeds								299.8
P.03.4.1 Nut-based spreads				31.7	Plastic lid			43.8
P.04.1.1 Fresh vegetables								8873.1
P.04.1.2 Fresh salads								384.2
P.04.1.3 Potatoes								3614.5
P.04.2.1 Preserved vegetables without sauces			498.0	31.5	31.5			529.5
P.04.2.2 Canned/preserved tomatoes			357.8					359.5
P.04.2.3 Canned beans and pulses			989.4					989.4
P.04.2.4 Tomato paste/purees			7.6	28.7	28.7	39.5		76.4
P.04.2.5 Pasta sauces (tomato based)				89.2	89.2			137.4
P.04.2.6 Pickled vegetables			2.3	143.8	143.8			159.4
P.04.3.1 Frozen vegetables and potatoes								905.3
P.04.4.1 Dried potato powder								888.6
P.05.1.1 Sugar confectionery							7.0	15291.9
P.05.1.2 Gum								1859.2
P.05.2.1 Countlines								4022.8
P.05.2.2 Chocolate tablets								1394.2
P.05.2.3 Bagged chocolates								1374.1
P.05.2.4 Boxed chocolates								5210.1
P.05.2.5 Seasonal chocolate								779.2
P.05.2.6 Chocolate with toys								127.5
P.05.3.1 Chocolate syrups								40.8
P.05.3.2 Chocolate spreads				19.1	Plastic lid			19.3
P.06.1.1 Breakfast cereals								901.9
P.06.2.1 Snack bars								1130.2
P.06.3.1 Flour and starches								207.9
P.06.4.1 Dry and ready-to-eat rice								237.8
P.06.4.3 Other cereal grains								237.8
P.06.5.1 Dry pasta								157.9

(*continued*)

Table 2. Continued.

FACET food groups at Tier 3	Number of pack units for each pack type/food type combination (millions per annum)							
	FACET pack type							
	Aerosol can	Beverage can	Food can	Glass jar/ bottle	Lid for jar/ bottle	Metal tube	Metal other	Total for all packs
P.06.5.2 Fresh pasta								65.5
P.06.5.3 Dried noodles								38.9
P.06.5.4 Chilled noodles								3.5
P.07.1.1 Dough								0.0
P.07.2.1 Bread								2072.0
P.07.2.2 Chilled bakery products								7.9
P.07.2.3 Bread substitutes								107.8
P.07.2.4 Frozen bakery products								78.6
P.07.3.1 Sweet biscuits							21.8	2883.3
P.07.4.1 Pastries								856.0
P.07.4.3 Cakes							1.7	1768.1
P.07.4.4 Pancakes								80.4
P.07.4.5 Frozen sweet bakery wares								183.0
P.07.4.6 Chilled snacks								0.0
P.08.1.1 Fresh meat								4595.1
P.08.2.1 Processed meat and meat products								1771.0
P.08.2.2 Coated/battered meat and products								203.8
P.08.2.3 Preserved meat and meat products			118.3					118.3
P.08.3.1 Unprocessed frozen meat and products								266.1
P.08.3.2 Frozen meat substitutes								60.5
P.09.1.1 Chilled fish/seafood								298.9
P.09.2.1 Chilled processed fish								181.5
P.09.2.2 Chilled coated fish								43.6
P.09.2.3 Chilled smoked fish								182.1
P.09.2.4 Preserved fish/seafood without sauce			347.2					350.9
P.09.2.5 Pickled fish and seafood				24.0	24.0			24.0
P.09.3.1 Unprocessed frozen fish or seafood								266.1
P.09.3.2 Frozen coated fish/seafood								185.6
P.10.1.1 Eggs								1713.5
P.11.1.1 Sugar								728.2
P.11.2.1 Honey				26.6	26.6			41.8
P.11.2.2 Ice cream toppings and dessert sauces	8.4		22.3	12.0	12.0			94.9
P.12.1.01 Mayonnaise				46.6	46.6			71.0
P.12.1.02 Vinaigrettes				11.1	11.0			12.1
P.12.1.03 Salad dressings				50.9	50.9			67.0
P.12.1.04 Ketchup				72.1	72.1			166.1
P.12.1.05 Mustard				18.8	18.8	0.2	1.8	22.6
P.12.1.06 Vinegar								121.6
P.12.1.07 Soy-based sauces				11.7	3.5			11.7
P.12.1.08 Table sauces				136.0	136.0			160.8
P.12.1.09 Pasta sauces				89.2	89.2			137.4
P.12.1.10 Wet sauces			27.9	219.2	219.2			271.7
P.12.1.11 Dips				12.9	12.9			111.6
P.12.1.12 Liquid stocks and fonds				2.9	2.9			5.9
P.12.1.13 Gravy granules/sauce powders				45.5	45.5			249.6

(*continued*)

Table 2. Continued.

FACET food groups at Tier 3	Number of pack units for each pack type/food type combination (millions per annum)							
	FACET pack type							
	Aerosol can	Beverage can	Food can	Glass jar/ bottle	Lid for jar/ bottle	Metal tube	Metal other	Total for all packs
P.12.1.14 Bouillon/stock cubes and powders							0.2	629.5
P.12.1.15 Other sauces, dressings, etc.				12.1	12.1			136.0
P.12.2.1 Frozen soup								0.0
P.12.2.2 Fresh soup								65.7
P.12.2.3 UHT soup								9.7
P.12.2.4 Canned/preserved soup			758.3	0.1	0.1			759.4
P.12.2.5 Dehydrated soup								19.7
P.12.2.6 Instant soup								304.5
P.12.3.1 Herbs and spices								125.7
P.12.3.2 Salt								150.7
P.12.4.1 Yeast			0.4					136.2
P.13.1.1 Infant milk formula							23.4	45.2
P.13.1.2 Dried baby food								25.2
P.13.2.1 Prepared baby food			52.9	130.3	130.3			200.9
P.13.2.2 Other baby food				11.0	11.0			24.4
P.13.3.1 Other nutritional foodstuffs		2.5					3.2	20.5
P.14.1.2 Packaged water								1959.5
P.14.2.1 Carbonates		2398.6						4894.4
P.14.2.2 Juices		10.2			2.1			2932.3
P.14.2.3 Functional drinks		230.0						860.9
P.14.2.4 Liquid concentrates								416.5
P.14.2.5 Powder concentrates (cold)								4.4
P.14.2.6 Ready-to-drink pre-packed coffee		3.1						3.1
P.14.2.7 Ready-to-drink pre-packed tea								14.7
P.14.3.1 Dry coffee				247.5	Plastic lid		2.9	943.4
P.14.3.2 Dry tea				12.7	Plastic lid			2712.1
P.14.3.3 Other hot drinks powders				22.3	Plastic lid		2.7	207.9
P.15.1.1 Beer		3530.9						4791.7
P.15.1.2 Cider		201.4						332.9
P.15.1.3 Flavoured alcoholic beverages		1.8						312.5
P.15.2.1 Wine								1407.3
P.15.3.1 Spirits								382.2
P.16.1.1 Savoury biscuits and crackers							0.5	1391.6
P.16.1.2 Pretzels								17.7
P.16.2.1 Popcorn								77.5
P.16.2.2 Chips/crisps								3268.5
P.16.2.3 Extruded snacks								1836.5
P.16.2.4 Tortilla/corn chips								146.2
P.17.1.1 Spoonable yoghurt								2541.9
P.17.1.2 Chilled and shelf stable desserts								1556.1
P.17.1.3 Fromage frais and quark								1664.4
P.17.2.1 Impulse ice cream								1495.1
P.17.2.2 Take home ice cream								257.6
P.17.2.3 Frozen yoghurt								6.8
P.17.3.1 Dessert mixes								371.0
P.18.1.1 Dressed salads								301.6
P.18.3.1 Frozen pizza								237.5

(*continued*)

Table 2. Continued.

FACET food groups at Tier 3	Number of pack units for each pack type/food type combination (millions per annum)							
	FACET pack type							
	Aerosol can	Beverage can	Food can	Glass jar/ bottle	Lid for jar/ bottle	Metal tube	Metal other	Total for all packs
P.18.3.2 Chilled pizza								147.8
P.18.4.1 Instant noodles								235.0
P.18.4.2 Canned/preserved pasta			634.6					636.5
P.18.4.3 Dried ready meals								24.0
P.18.5.01 Frozen ready meals								670.4
P.18.5.02 Frozen processed red meat and poultry								203.8
P.18.5.03 Frozen processed fish/ seafood								185.6
P.18.5.04 Other processed frozen food								152.4
P.18.5.05 Dinner mixes								48.9
P.18.5.06 Canned/preserved ready meals			466.0					472.2
P.18.5.07 Preserved fish/seafood with sauce			347.2					350.9
P.18.5.08 Chilled ready meals								1069.3
P.18.5.09 Chilled lunch kit								4.6
Grand total	20.2	6378.6	4960.2	1455.0	1338.2	71.8	65.3	135,690.0

P.12.1.05 Mustard, P.12.1.13 Gravy granules/sauce powders, P.12.1.14 Bouillon/stock cubes and powders, P.12.4.1 Yeast, P.13.1.1 Infant milk formula, P.13.3.1 Other nutritional foodstuffs, P.14.3.1 Dry coffee, P.14.3.3 Other hot drinks powders, and P.16.1.1 Savoury biscuits and crackers. Also not carried from Table 2 to Table 3 is the category of 'metal other', which would cover uncoated cans (tins), e.g. for oils and fats or dried herbs, because it is clear from the foodstuffs packaged in them that they are not coated.

The metal packaging types considered further are aerosol cans, beverage cans, food cans, metal lids for glass jars/bottles, metal collapsible tubes, and ends for beverage and food cans. From the numbers of packs for each material code (i.e. from the Euromonitor data), the number of metal versus other forms of packaging for those food groups can be derived and these were used as the basis for allocating the market shares (by number of packs) of each metal packaging component per food group. Table 3 gives the market shares for each of the above metal types. It should be noted that only 42 of the 174 food groups at FACET Tier 3 codes could be packaged in light metal packaging and/or metallic tubes. From the summary of Table 3 (grand totals) it is clear that less than 10% of foodstuffs are packaged in coated metal from which exposure to BPA could arise, this 9.41% being 12 769 million packs from a total of 135 690 million units of packaged food sold per annum in the UK. As a quick sense-check, the UK population in 2005 was 60.2 million (Office for National Statistics 2013) so this gives 6.2 pack units of all types sold per person per day. Of the 42 food groups, eight were solely in food cans, six were in either food cans or jars/bottles (with lids), 16 were solely in jars/bottles (with lids), seven were in beverage cans, one was either in a beverage can or a bottle (with a lid), one was either in an aerosol or a jar (with a lid), one was solely in a tube, one was in either an aerosol, food can or jar (with a lid), and finally one was either in a jar (with a lid) or a tube.

Pack sizes and surface area: pack weight ratios

Euromonitor data contain the pack weight for each pack size. The surface area to pack weight ratio is important in deriving concentration levels in foods. A high contact area ratio gives higher concentrations in food. Table 4 gives the ratio (in $cm^2\ g^{-1}$) of the surface area to food weight of the can (food and beverage), can end (food and beverage), metal lid on a glass jar/bottle, metal tube or aerosol for each foodstuff. The data were derived from Euromonitor statistics and reflect the size(s) with the most units sold. When two or more of the most popular sizes were significantly different, the highest surface area to weight ratio was used to be conservative. For example, there are 161 million metal closures (jar and bottle tops) per annum for jars of processed fruit P3.2.3 (jams and preserves) varying in size from 0.11 to 0.18 $cm^2\ g^{-1}$ and in number from 3

Table 3. Food items (millions of units per annum) considered as being packaged in coated metal which could contribute towards exposure to BPA and their market shares.

FACET food groups	Aerosol can	Beverage can	Food can	Lid	Tube	Total metal	Total all packs	Percentage metal (maximum)	Aerosol can (%)	Beverage can (%)	Food can (%)	Lid (%)	Tube (%)
P.01.1.6 Condensed/evaporated milk			67.8			67.8	67.8	100			100		
P.01.1.8 Cream	11.8			0.9		12.7	336.1	3.8	3.5			0.3	
P.01.2.1 Processed cheese					32.1	32.1	4150.3	0.8					0.8
P.03.2.3 Jams and fruit preserves				161.4		161.4	161.4	100				100	
P.03.2.4 Canned/preserved fruit			262.6	1.3		263.9	316.8	83			83	0.4	
P.04.2.1 Preserved vegetables without sauces			498.0	31.5		529.5	529.5	100			94	6.0	
P.04.2.2 Canned/preserved tomatoes			357.8			357.8	359.5	100			100		
P.04.2.3 Canned beans and pulses			989.4			989.4	989.4	100			100		
P.04.2.4 Tomato paste/purees			7.6	28.7	39.5	75.7	76.4	99			10	38	52
P.04.2.5 Pasta sauces (tomato based)				89.2		89.2	137.4	65				65	
P.04.2.6 Pickled vegetables			2.3	143.8		146.2	159.4	91			1.4	90	
P.08.2.3 Preserved meat and meat products			118.3			118.3	118.3	100			100		
P.09.2.4 Preserved fish/seafood without sauce			347.2			347.2	350.9	99			99		
P.09.2.5 Pickled fish and seafood				24.0		24.0	24.0	100				100	
P.11.2.1 Honey				26.6		26.6	41.8	64				64	
P.11.2.2 Ice cream toppings and desert sauces	8.4		22.3	12.0		42.7	94.9	45	8.9		24	13	
P.12.1.01 Mayonnaise				46.6		46.6	71.0	66				66	
P.12.1.02 Vinaigrettes				11.0		11.0	12.1	90				90	
P.12.1.03 Salad dressings				50.9		50.9	67.0	76				76	
P.12.1.04 Ketchup				72.1		72.1	166.1	43				43	
P.12.1.05 Mustard				18.8	0.2	19	22.6	83				83	0.8
P.12.1.07 Soy-based sauces				3.5		3.5	11.7	30				30	
P.12.1.08 Table sauces				136.0		136.0	160.8	85				85	
P.12.1.09 Pasta sauces				89.2		89.2	137.4	65				65	
P.12.1.10 Wet sauces			27.9	219.2		247.0	271.7	91			10	81	
P.12.1.11 Dips				12.9		12.9	111.6	12				12	
P.12.1.12 Liquid stocks and fonds				2.9		2.9	5.9	50				50	
P.12.1.15 Other sauces dressings, etc.				12.1		12.1	136.0	8.9				8.9	
P.12.2.4 Canned/preserved soup			758.3	0.1		758.4	759.4	100			99.9	0.01	
P.13.2.1 Prepared baby food			52.9	130.3		183.2	200.9	91			26	65	
P.13.2.2 Other baby food				11.0		11.0	24.4	45				45	
P.13.3.1 Other nutritional foods		2.5				5.7	20.5	12		12			
P.14.2.1 Carbonates		2398.6				2398.6	4894.4	49		49			

(*continued*)

Table 3. Continued.

FACET food groups	Aerosol can	Beverage can	Food can	Lid	Tube	Total metal	Total all packs	Percentage metal (maximum)	Aerosol can (%)	Beverage can (%)	Food can (%)	Lid (%)	Tube (%)
P.14.2.2 Juices		10.2		2.1		12.4	2932.3	0.4		0.4		0.07	
P.14.2.3 Functional drinks		230.0				230.0	860.9	27		27			
P.14.2.6 Ready-to-drink pre-packed coffee		3.1				3.1	3.1	100		100			
P.15.1.1 Beer		3530.9				3530.9	4791.7	74		74			
P.15.1.2 Cider		201.4				201.4	332.9	61		61			
P.15.1.3 Flavoured alcoholic beverages		1.8				1.8	312.5	0.6		0.6			
P.18.4.2 Canned/preserved pasta			634.6			634.6	636.5	100			100		
P.18.5.06 Canned/preserved ready meals			466.0			466.0	472.2	99			99		
P.18.5.07 Preserved fish/seafood with sauce			347.2			347.2	350.9	99			99		
Total	20.2	6379	4960	1338	71.8	12769	135690	9.4	0.01	4.7	3.7	1.0	0.05

Table 4. Surface area to pack weight ratio of metal parts in contact with food (cm^2 g^{-1}).

FACET food groups	Beverage can	Beverage end	Food can	Food end	Total beverage can area	Total food can area	Lids	Aerosol can	Tube
P.01.1.6 Condensed/evaporated milk			0.7	0.14		0.84			
P.01.1.8 Cream							0.19	1.2	
P.01.2.1 Processed cheese									1.2
P.03.2.3 Jams and fruit preserves							0.16		
P.03.2.4 Canned/preserved fruit			0.7	0.15		0.85	0.14		
P.04.2.1 Preserved vegetables without sauces			0.8	0.17		0.97	0.16		
P.04.2.2 Canned/preserved tomatoes			0.9	0.18		1.08			
P.04.2.3 Canned beans and pulses			1.0	0.19		1.19			
P.04.2.4 Tomato paste/purees			0.9	0.19		1.09	0.17		1.0
P.04.2.5 Pasta sauces (tomato based)							0.16		
P.04.2.6 Pickled vegetables			0.9	0.19		1.09	0.16		
P.08.2.3 Preserved meat and meat products			0.8	0.16		0.96			
P.09.2.4 Preserved fish/seafood without sauce			0.9	0.23		1.13			
P.09.2.5 Pickled fish and seafood							0.22		
P.11.2.1 Honey							0.14		
P.11.2.2 Ice cream toppings and dessert sauces			0.9	0.19		1.09	0.18	0.9	
P.12.1.01 Mayonnaise							0.19		
P.12.1.02 Vinaigrettes							0.03		
P.12.1.03 Salad dressings							0.03		
P.12.1.04 Ketchup							0.02		
P.12.1.05 Mustard							0.21		
P.12.1.07 Soy-based sauces							0.05		
P.12.1.08 Table sauces							0.05		
P.12.1.09 Pasta sauces							0.16		
P.12.1.10 Wet sauces			0.7	0.15		0.85	0.20		
P.12.1.11 Dips							0.17		
P.12.1.12 Liquid stocks and fonds							0.19		
P.12.1.15 Other sauces, dressings etc							0.19		
P.12.2.4 Canned/preserved soup			0.8	0.16		0.96	0.14		
P.13.2.1 Prepared baby food			1.1	0.22		1.32	0.22		
P.13.2.2 Other baby food							0.04		
P.13.3.1 Other nutritional foodstuffs	1.0	0.07			1.07				
P.14.2.1 Carbonates	1.0	0.07			1.07				
P.14.2.2 Juices	1.1	0.09			1.19		0.02		
P.14.2.3 Functional drinks	1.1	0.09			1.19				
P.14.2.6 Ready-to-drink pre-packed coffee	1.1	0.09			1.19				
P.15.1.1 Beer	0.86	0.05			0.91				
P.15.1.2 Cider	0.85	0.05			0.90				
P.15.1.3 Flavoured alcoholic beverages	0.99	0.07			1.06				
P.18.4.2 Canned/preserved pasta			0.9	0.19		1.09			
P.18.5.06 Canned/preserved ready meals			0.9	0.19		1.09			
P.18.5.07 Preserved fish/seafood with sauce			1.0	0.2		1.2			

million to 66 million per size. The surface area to weight ratio for 66 million was 0.157 $cm^2\ g^{-1}$ and for 56 million (the next highest number) was 0.142 $cm^2\ g^{-1}$. Thus, the ratio used here was 0.157 $cm^2\ g^{-1}$, although it is higher than the average of 0.153 $cm^2\ g^{-1}$. The areas of the can ends were added to that of their respective bodies to give a total area for that type of can. Table 4 shows that for cans (bodies plus ends) the ratio is about 1.5–2.0-fold higher than the European Union default ratio of 0.6 $cm^2\ g^{-1}$ (Brands et al. 2007). Conversely, for lids the ratio is lower than the European Union default, being one-quarter to one-third for jar lids and about one-20th for bottle tops.

Linking different types of food cans for each food category

It should be borne in mind that different types of coatings, which may or may not be based on BPA-containing materials, can be used for the same type of can or closure. Food cans are the most diverse. Bodies can be manufactured in three different ways: the simple welded cylinder body of a three-piece can, needing two ends, or a drawn and redrawn (DRD) or a drawn and wall-ironed (DWI) body of a two-piece can that needs just one end added. The opening end may be either easy open (ring pull) or classic (can opener needed) (Oldring & Nehring 2007). So a classic three-piece food can may have one type of coating for the body, another for the non-opening end and yet another for the easy open end, as well as another coating for the side seam stripe (that covers the weld). Some cans are not fully coated (e.g. for some tomato-based products such as soup and canned beans). Furthermore, different types of can (and coatings) may be used for the same foodstuff. A summary of the splits between the different types of food cans (only) for each food group is given in Table 5, along with the split of easy open or classic ends obtained from Euromonitor data. The ratios between classic and easy open ends for food cans will vary country by country, hence the need to use Euromonitor data. Where these data are unavailable the can-makers provided generic European splits as a guideline to fill any data gaps. As a general rule, the light metal packaging industry decided that for a three-piece can the side seam stripe would account for 10% of the area of the body, hence the area of the body is proportionally decreased. It should be noted that not all the food groups in Table 5 are packaged in food cans or food cans and another form of metal packaging, e.g. P.04.2.6 Pickled vegetables has total sales of 159.4 million packs per annum (Table 2), of which 143.8 million are in glass jars and 2.3 million are in food cans (100% three-piece). In the UK, some foodstuffs packaged in light metal packaging are only supplied in jars/bottles with metal closures (e.g. P.12.1.08 Table sauces), whilst others are in beverage cans.

Allocating the different coating chemistries

The types of coating chemistries that can be used for light metal packaging are given in Table 6. Epoxy resins is a generic term used by the light metal packaging industry and refers to epoxies based on epichlorohydrin and BPA. In some cases epoxy resins were/are used as minor components in the formulation to improve the properties of the cured film, such as sterilisation resistance. It should be noted that closure coatings (P.37.5.2) are in fact a system of an epoxy phenolic basecoat and an organosol topcoat, and the extraction of BPA from the entire (base plus top) coating system has been used.

Obtaining representative extraction data for BPA

As part of continual monitoring and in response to brand owner requirements, companies involved have a wealth of in-house data on levels of BPA from different coatings. In most cases, data reported were from extraction into the solvent acetonitrile. These tests were typically performed by total immersion of cut specimens of coated panels in acetonitrile for 24 h at ambient temperature. These extraction conditions are considered to be exhaustive, as demonstrated by using a second and then a third extraction test with fresh solvent which yields little if any additional BPA. For beverage coatings, levels of extraction into relevant food simulants were used. These tests were typically conducted in 10% (v/v) aqueous ethanol solution and/or 3% (w/v) acetic acid solution for 2 h at 100°C. Analysis of the solvent or simulant extracts for BPA was then by HPLC with fluorescence detection in most cases, although some of the providers of data used LC-MS/MS for the analysis. In all cases, the providers of data followed appropriate analytical quality assurance standards.

The results of all these tests for BPA were shared between can-makers and coating suppliers and a range of values were agreed to provide a comprehensive overview of what is considered the worst case. The extraction values for BPA used here are given in Table 6. Individual company participation captured extraction data from a minimum of 60% of the total markets for food can and food can end, beverage can and beverage can end, and glass jar and bottle metal closures. In reality the European situation is represented to a higher degree than 60% because a few multinational coating suppliers and can-makers dominate. The same coatings that are supplied by the multinational coating suppliers and used by the multinational can-makers, are also supplied to and used by the smaller can and closure makers. Therefore, the data obtained are considered to represent over 80% of the European Union market. Indeed CEPE, the European trade association for coating suppliers, brings approximately 85% of this industry together in its membership (CEPE 2013). There is always an unknown about the coatings (if any) on cans

Table 5. Market split of different food can types and food can ends only, along with the area for side seam and three-piece can bodies where a side seam would be used.

	Percentage type of food can[a]			Type food can end by number (millions per annum)		Percentage share food can end type		Area for coating types (cm^2 g^{-1})		
FACET food groups	Percentage three-piece food can	Percentage DWI food can[a]	Percentage DRD food can[a]	Number of easy open ends	Number of classic ends	Percentage easy open ends	Percentage classic ends	Area three-piece food can	Area side seam stripe	Area body
P.01.1.6 Condensed/ evaporated milk	100			67.8		100		0.7	0.07	0.63
P.03.2.4 Canned/ preserved fruit	95	5		189.1	73.5	72	28	0.7	0.07	0.63
P.04.2.1 Preserved vegetables without sauces	100			363.5	134.5	73	27	0.8	0.08	0.72
P.04.2.2 Canned/ preserved tomatoes	100			271.9	85.9	76	24	0.9	0.09	0.81
P.04.2.3 Canned beans and pulses	90	10		751.9	237.5	76	24	1.0	0.1	0.9
P.04.2.4 Tomato paste/purees	50		50	6.3	1.3	82.9	17.1	0.9	0.09	0.81
P.04.2.6 Pickled vegetables	100			2.3		100				
P.08.2.3 Preserved meat and meat products	70		30	86.3	32	73	27	0.9	0.09	0.81
P.09.2.4 Preserved fish/seafood	20		80	302.1	45.1	87	13	0.8	0.08	0.72
P.11.2.2 Ice cream toppings etc	100			15	7.3	67.3	32.7	0.9	0.09	0.81
P.12.1.10 Wet sauces	90	10		23.2	4.7	83.2	16.8	0.7	0.07	0.63
P.12.2.4 Canned/ preserved soup	90	10		606.7	151.6	80	20	0.8	0.08	0.72
P.13.2.1 Prepared baby food	100			49.7	3.2	94	6	1.1	0.11	0.99
P.18.4.2 Canned/ preserved pasta	90	10		526.7	107.9	83	17	0.9	0.09	0.81
P.18.5.06 Canned/ preserved ready meals	80	10	10	372.8	93.2	80	20	0.9	0.09	0.81
P.18.5.07 Preserved fish/seafood with sauce	20		80	302.1	45.1	87	13	1.0	0.1	0.9

Note: [a]For two-piece cans: DWI = drawn and wall-ironed and DRD = drawn and redrawn.

Table 6. Coating categories used in the FACET project and their extraction values (mg dm^{-2}) for BPA (1 mg dm^{-2} = 0.01 mg cm^{-2}).

			BPA (mg dm^{-2})	
37. Can coating chemistry			Minimum	Maximum
37.1. Epoxy	37.1.1. Phenolic		0.00005	0.020
	37.1.2. Anhydride		0.00005	0.012
	37.1.3. Amino	37.1.3.1 Beverage	0.001	0.004
		37.1.3.2 Food	0.00005	0.010
	37.1.4. Acrylate	37.1.4.1 Beverage	0.001	0.004
		37.1.4.2 Food	0.001	0.012
	37.1.5. Other		0.001	0.005
37.2. PVC	37.2.1. Epoxy containing		0.00005	0.005
	37.2.2. Other		0.00005	0.001
37.3. Polyester	37.3.1. Phenolic		0.00005	0.0008
	37.3.2. Amino		0.001	0.002
	37.3.3. Polyurethane		0.001	0.002
	37.3.4. Other		0.001	0.007
37.4. Acrylic			0	0
37.5. Other	37.5.1. Polymer coated		0.001	0.001
	37.5.2. Closures for twist off and push twist (PT)		0.002	0.016

and closures for foods that are imported into the European Union. The major imports are canned fruit, fish and meat (Dionisi & Oldring 2002). From the FACET project it was shown that the majority of the imported fruit cans purchased in eight European Union countries were uncoated, including the ends, which is different from the European industry practice of using internally coated ends on plain (uncoated) cans. Coatings on cans, etc. for fish and meat tend to follow (mimic) European Union coatings, particularly as many of the major European Union suppliers have operations in the Far East, South Africa, etc. Therefore, it was concluded that it is not unreasonable to consider the European Union agreed data as being a 'worst' case representative for a refined deterministic approach because the coatings of imports are either similar to European Union ones or the cans are not coated, thus the data used here are conservative.

The question naturally arises how close is the agreement of these BPA extraction levels (Table 6) with BPA levels based on analytical measurements in foods surveys? A systematic comparison is difficult because food surveys rarely if ever identify the different coating chemistries used or the ratio of the surface area to packed food weight. The possibility also exists that the food may contain some BPA from sources other than the can coating. Nevertheless, some simple comparisons are informative and reassuring.

The largest body of food survey data for BPA was published by EFSA (2013). Seven out of 17 canned food categories had an average BPA concentration above 30 μg kg^{-1}. These were the EFSA food groups Grain and grain-based products, Legumes, nuts and oilseeds, Meat and meat products, Fish and other seafood, Herbs, spices and condiments, Composite food, and Snacks, desserts, and other foods. Four of the canned food categories had average BPA concentrations between 2.7 and 23.5 μg kg^{-1} (Vegetables and vegetable products, Fruit and fruit products, Fruit and vegetable juices, and Milk and dairy products), while the remaining six categories had average BPA concentrations below 1.2 μg kg^{-1}.

Table 4 shows a simplified ratio of surface area to food weight is about 1 g cm^{-2} (or 100 g dm^{-2}) and so 30 μg kg^{-1} in food would correspond to a migration of 3 μg dm^{-2} (or 0.003 mg dm^{-2}). It can be seen in Table 6 that this value sits squarely inside the minimum–maximum concentration ranges given for coatings used for food cans. By the same simplified approach, the lowest food group concentration reported by EFSA, < 1.2 μg kg^{-1}, would correspond to 0.0001 mg dm^{-2} and this either sits within the minimum–maximum ranges in Table 6 or is higher than the minimum value and so the minimum value is conservative. It is concluded that the industry supplied data were 'worst case', which is not surprising as the data were based on extracting solvents or food simulants and not actual foodstuffs.

Table 7 shows an approximate share of the coatings used for different types of beverage and food cans and ends. This share is on a formulation weight (tonnage) basis. Assuming the same application rates giving the same coverage, these shares will approximate to an area-related basis for the share of the coatings market. It should be borne in mind that this is for a pan-European view and reflects the situation for 2005, to which the Euromonitor data also relate. Aerosols for foodstuffs are coated with either organosols (P.37.2.1 or P.37.2.2) or epoxy phenolics (P.37.1.1). Tubes would use an epoxy-based coating (P.37.1.1).

Table 7. Types of coating used for food and beverage cans and their percentage market share (by volume as wet coatings).

	Epoxy phenolic	Epoxy anhydride	Epoxy amino	Polyester phenolic	Polyester polyurethane	Organosol	Epoxy acrylate beverage
FACET material code	37.1.1	37.1.2	37.1.3.1 37.1.3.2	37.3.1	37.3.3	37.2	37.1.4.1
Beverage cans (%)							
Beverage can bodies							100
Beverage easy open end			45	5		5	45
Food cans (%)							
Three-piece body	60	39			1		
Side stripe	60		3	10		27	
Classic end	60	22		14	1	3	
Easy open end food	37	5		10	18	30	
Drawn/DRD	54			3	10	33	

Market shares of the different coating chemistries

For each coating category given in Table 6, coating companies supplied the amount sold and this was totalled by CEPE to allocate market share data per coating category per company supplying the data. Companies supplied information on the occurrence of BPA (yes/no). Some coatings may or may not contain some substances, e.g. epoxy phenolics (P.37.1.1) always contain epoxies, hence BPA, thus the occurrence is 'yes' with a probability of 1. Each can-maker supplied data on the types and relative amounts of each coating used for each of the different types of coated metal packaging as well as their share of the market for each type of metal packaging. This enabled a comprehensive overview of which chemistries were used for the different types of metal packaging and different foodstuffs. Due to anti-cartel rules these data were compiled by a third party for the FACET project and they cannot be viewed in the FACET tool nor be reproduced here. Creme Global (hereafter referred to as Creme), which was the software provider, linked the information supplied by industry into a pack type (PT coding system) (Oldring et al. 2013). Those pack types relevant to metal packaging are (PT = pack type; M = main – the major part of the packaging in contact with the foodstuffs; C = closure – seal for main, not always applicable), PT1 – M: Aerosol can, PT3 – M: Aerosol can, C: Plastic other, PT8 – M: Beverage can, PT20 – M: Food can, C: Classic, PT21 – M: Food can, C: Easy open, PT35 – M: Glass bottle, C: Metal twist/lever, PT41 – M: Glass jar, C: Metal twist/lever, and PT48 – M: Metal collapsible tube, C: Plastic screw thread.

Refined deterministic estimate of exposure using this information

In order to evaluate whether the output from FACET for exposure to BPA is soundly based and also as an alternative way to help illustrate how these information sources are combined, a refined deterministic approach was also used here.

Outputs from FACET are required in order to be compared with a refined deterministic approach. This ensured that wherever possible the same input data were used for exposure assessments from both FACET and the refined deterministic approach. The food consumption diaries of the UK NDNS in 2000 adult survey (19–64 year olds) (Henderson et al. 2002) were used in FACET to derive the mean, 95th and 97.5th percentile food consumption, for both consumers only (of each food group) and for the total population, for each of the foodstuffs that could be packaged in coated light metal packaging.

The meaning of consumers only is that in any dietary survey (which is normally of a rather short duration) there will be people surveyed who do not consume particular foods during the time of that survey, even though over a longer time period they might. By way of a simple example, during a 5-day survey it may be that only 10% of participants report eating fish. So if the simple per capita fish consumption (i.e. for the whole population) derived from that survey was, say, 10 g day^{-1}, then by simple arithmetic the average consumption for consumers only must be 100 g/person/day. This is not to say that only 10% of the population ever eat fish. It relates only to the duration of the survey. This is a known weakness in dietary surveys because, clearly, if the survey period is extended then simply by chance more of the participants will consume a higher number of the different food types and the difference between the total population estimate and that for consumers only will narrow or even disappear.

Consumers only are a subset of the total population and the number will vary considerably depending on the popularity of the foodstuff. These are shown as g/person/day in Table 8 per food group at Tier 3 and these are only for those 42 food groups that could be packaged in coated

Table 8. Mean, 95th and 97.5th percentile consumptions (g/person/day) for consumers only and the total population for food categories packaged in light metal packaging.

		Total population (g/person/day)				Consumers only (g/person/day)		
Code	FACET food groups	Mean	95th	97.5th	Number of consumers only	Mean	95th	97.5th
P.1.1.6	Condensed/evaporated milk	0.5	0.0	4.3	72	11.2	41.7	48.4
P.1.1.8	Cream	0.5	2.9	6.7	115	7.7	23.8	34.5
P.1.2.1	Processed cheese	1.6	9.3	14.9	323	8.2	22.1	27.9
P.3.2.3	Jams and fruit preserves	3.6	17.7	25.0	655	8.9	26.1	30.1
P.3.2.4	Canned/preserved fruit	4.3	26.9	44.4	261	26.8	82	133
P.4.2.1	Preserved vegetables without sauces	7.2	36.9	53.0	559	20.9	58.6	80.6
P.4.2.2	Canned/preserved tomatoes	2.2	16.1	28.6	135	27.1	57.1	59.5
P.4.2.3	Canned beans and pulses	0.7	0.0	10.1	74	14.7	36.1	49.7
P.4.2.4	Tomato paste/purees	0.0	0.0	0.0	11	2.1	4.4	4.5
P.4.2.5	Pasta sauces (tomato based)	3.4	26.0	37.1	66	24.5	58.0	66.0
P.4.2.6	Pickled vegetables	2.0	10.7	16.6	431	7.4	23.4	29.3
P.8.2.3	Preserved meat and meat products	1.3	9.6	17.5	135	15.7	38.8	57.5
P.9.2.4	Preserved fish/seafood without sauce	5.7	27.1	37.2	545	17.0	48.0	55.5
P.9.2.5	Pickled fish and seafood	0.0	0.0	0.0	0	0.0	0.0	0.0
P.11.2.1	Honey	0.6	2.9	6.9	129	7.5	26.4	31.0
P.11.2.2	Ice cream toppings and dessert sauces	0.2	0.0	2.0	66	3.9	8.8	11.7
P.12.1.1	Mayonnaise	5.4	18.6	36.1	783	11.3	38.0	72.1
P.12.1.2	Vinaigrettes	0.5	2.1	4.3	162	5.4	15.4	27.4
P.12.1.3	Salad dressings	0.2	0.0	1.2	48	6.6	19.0	26.3
P.12.1.4	Ketchup	1.4	4.6	8.1	285	7.9	16.6	41.0
P.12.1.5	Mustard	0.5	1.0	2.1	166	5.4	15.8	60.0
P.12.1.7	Soy-based sauces	0.2	0.0	1.0	79	3.5	17.5	35.5
P.12.1.8	Table sauces	2.3	11.6	21.4	399	9.3	31.0	38.6
P.12.1.9	Pasta sauces	0.2	0.0	0.2	43	8.3	36.7	39.1
P.12.1.10	Wet sauces	13.5	49.8	70.1	954	23.2	67.0	85.2
P.12.1.11	Dips	0.4	0.0	4.3	67	9.4	38.2	50.2
P.12.1.12	Liquid stocks and fonds	0.0	0.0	0.0	0	0.0	0.0	0.0
P.12.1.15	Other sauces, dressings and condiments	0.4	0.0	7.0	62	11.1	25.1	28.8
P.12.2.4	Canned/preserved soup	10.4	60.7	97.6	272	62.1	123.1	182.2
P.13.2.1	Prepared baby food	0.0	0.0	0.0	0	0.0	0.0	0.0
P.13.2.2	Other baby food	0.1	0.0	0.0	4	24.3	47.1	47.1
P.13.3.1	Other nutritional foodstuffs	6.4	13.6	21.9	739	2.9	8.0	13.0
P.14.2.1	Carbonates	133.0	569.4	717.0	1021	212.5	673.3	866.7
P.14.2.2	Juices	56.0	239.3	316.8	805	113.4	317.9	366.7
P.14.2.3	Functional drinks	0.0	0.0	0.0	0	0.0	0.0	0.0
P.14.2.6	Ready-to-drink pre-packed coffee	0.0	0.0	0.0	0	0.0	0.0	0.0
P.15.1.1	Beer	217.3	1126.8	1632.4	713	497.0	1700.8	1974.6
P.15.1.2	Cider	19.7	3.8	164.0	84	383.3	1744.0	2677.5
P.15.1.3	Flavoured alcoholic beverages	10.0	39.3	140.8	86	188.7	576.7	736.5
P.18.4.2	Canned/preserved pasta	2.8	22.2	46.5	118	39.3	114.4	117.2
P.18.5.6	Canned/preserved ready meals	17.7	71.8	105.4	751	38.5	109.4	129.8
P.18.5.7	Preserved fish/seafood with sauce	0.3	0.0	0.0	27	20.2	40.4	46.8

Notes: The number of consumers only for a specific food item is given. The total number of people surveyed was 1631.

metal and are listed in Table 3. For certain food groups in the total population the 95th percentile is zero whilst the mean is non-zero. This is not an error. It is because fewer than 95% of the population consume that food group. If, for example, only 2% are consumers of that food group (during the period of the survey) then there are by definition no consumers below the 97.5th percentile. But as some food has been consumed (in this example by just 2% of the people surveyed) there will be a non-zero mean.

The number of consumers only is given in Table 8, whereas the total population in the survey was 1631. In some instances, although packaging has been recorded for a particular food group, no consumption of that food appears in the food consumption diaries. This occurred for five food groups, namely: P.09.2.5 Pickled fish and seafood, P.12.1.12 Liquid stocks and fonds, P.13.2.1 Prepared baby food, P.14.2.3 Functional drinks, and P.14.2.6 Ready-to-drink pre-packed coffee. As this

assessment was for 19–64 year olds, it was not surprising that prepared baby food was not consumed by them. In contrast, for P.13.2.2 Other baby foods, which includes any other products marketed for babies such as baby rusks, teething biscuits, baby fruit juices, etc., consumption is reported by four consumers only with a mean of 24.3 g. For the total population (n = 1631) the mean is 0.1 g day^{-1} (i.e. 4 × 24.3/1631), but clearly there is no 95th or 97.5th percentile consumption figure. A similar situation exists for P.04.2.4 Tomato paste/purees with only 11 reported consumers. As a summary 10 food groups had fewer than 50 consumers and nine food groups had between 50 and 100 reported consumers of a total of 1631 participants in the survey.

As an aside, and to show that the tool was working correctly, the consumption of prepared baby food in the 1–4 year olds was from 48 to 145 g/person/day depending on age. The most likely explanation for the lack of consumption events being recorded for the four other food groups is the limitations of dietary surveys. As far as National dietary surveys go, the UK NDNS surveys are considered to be good since they survey approximately 2000 individuals over 4–7 days. Many other national surveys have fewer participants and/or fewer days. Notwithstanding the above average quality of the UK surveys, the fact that no eating occasions for four food groups were recorded indicates the limitations of surveys in general. Depending on the importance of the food group, consumption figures at high percentiles can be very unreliable since the survey has limited statistical power with few or even no consumers out at the high percentiles.

For the UK 19–64 year olds, the FACET tool was run for all food groups, at Tier 3, recorded as being in light metal packaging (and metallic tubes). Packaging (or consumer) loyalty was set (Oldring et al. 2013). In brief this means that, not withstanding market share, if the probabilistic model 'decides' on the first eating occasion that the food item (or group) is packaged in metal (e.g. a canned beer rather than a bottled beer) then all subsequent consumptions of that food item (group) by that individual would be taken to be canned too. The FACET reports used for this exercise did not show the 95th percentile, hence these data along with amount of food consumed at the various percentiles were extracted independently from the output data from FACET. The exposures to BPA (mg/person/day) for each food group (packaged in metal) at the mean, 95th and 97.5th percentiles were obtained for both total population and consumers only and these are given in Table 9, except for those where no food consumption was recorded. For each food group, the exposure for each packaging type (as a PT code) is given. In Table 9, if a foodstuff could be packaged in more than one type of packaging (e.g. P.12.1.10 Wet sauces; food can or jar with metal lid) and each had a substantial market share, then the exposures from all types of metal packaging for that food group were added (note that rounding errors may give a slightly different total), because the packaging of the food consumed is unknown and a consumer may or may not differentiate between them. If for a food group no exposure was recorded for more than one packaging type, then the PT codes have been combined for convenience.

It should be noted that the FACET reports contain exposures to foodstuffs at Tier 1. For lower tier exposure estimates, calculations can be run in FACET at Tier 3 by the user. The advantage of using Tier 3 (the highest level of refinement with the most detailed food description) is that it can be more food group and more packaging specific, unlike Tier 1 which covers a much wider range of packaging types at a higher (coarser) level of food classification. Thus, exposure to foodstuffs only reported at the first tier will not necessarily match those values in the tables here. In the case of P.13.3.1 Other nutritional foodstuffs, whilst reportedly being packaged in beverage cans there is no link to them being consumed in beverage cans in this survey. In reality this has negligible effect on any exposure assessment because of the low consumption.

Refined deterministic approach

A refined deterministic exposure assessment was only made for food groups that were more than 50% packaged in metal. These 20 food groups are listed in Tables 10 and 11, where those food groups that have greater than 50% packaged in metal are shown along with pack types, percentage (by number) market share, area to weight (cm^2 g^{-1}) ratio, and the minimum and maximum levels of extractable BPA for the coatings assigned to that metal packaging. Although P.14.2.1 Carbonates are significant contributors to exposure to BPA (Table 9), less than 50% are packaged in metal, thus it is questionable to use this foodstuff category for comparison of a refined deterministic estimate of exposure for carbonates to that from FACET, because of the relatively low market share compared with some of the other foodstuffs used in this verification exercise. For a 'pure exposure assessment' then this contribution would be considered, but this exercise is, in significant part, a verification of the FACET probabilistic tool.

These data are used in the refined deterministic approach, along with the food consumption statistics for the total population (Table 10) and consumers only (Table 11). For food groups packaged in food cans it is necessary to consider the contribution from cans with classic and easy open ends, because the amount of food consumed is the important parameter. Therefore, the exposures to BPA per food group packaged in a food can with either classic or easy open end are totalled per food group. In essence and for simplicity only three coating types were assigned, namely: epoxy phenolics

Table 9. BPA exposure estimates (mg/person/day) from FACET for all foodstuffs packaged in metal.

		Total population			Consumers		
FACET food groups	Pack[a]	Mean	95th	97.5th	Mean	95th	97.5th
P.1.1.6 Condensed/evaporated milk (100% packed in metal)	PT20	0	0	0	0	0	0
	PT21	0	0	0.0003	0.0007	0.0029	0.0031
	Total	0	0	0.0003	0.0007	0.0029	0.0031
P.1.1.8 Cream (3.8% packed in metal)	PT41	0	0	0	0	0	0
	PT1/3	0	0	0	0	0	0
	Total	0	0	0	0	0	0
P.1.2.1 Processed cheese (0.8% packed in metal)	PT48	0	0	0	0	0	0
P.3.2.3 Jams and fruit preserves (100% packed in metal)	PT41	0	0.0002	0.0004	0.0001	0.0004	0.0005
P.3.2.4 Canned/preserved fruit (83% packed in metal)	PT20	0.0001	0	0.0006	0.0004	0.0027	0.0034
	PT21	0.0002	0.0006	0.0022	0.0012	0.0054	0.0083
	Total	0.0003	0.0006	0.0028	0.0016	0.0081	0.0117
P.4.2.1 Preserved vegetables without sauces (94% packed in metal)	PT20	0.0001	0.0006	0.0017	0.0004	0.0025	0.0042
	PT21	0.0004	0.0021	0.0035	0.0011	0.0043	0.0067
	Total	0.0005	0.0027	0.0052	0.0015	0.0068	0.0109
P.4.2.2 Canned/preserved tomatoes (99.5% packed in metal)	PT20	0	0	0	0.0006	0.0030	0.0044
	PT21	0.0001	0.0004	0.0013	0.0015	0.0052	0.0062
	Total	0.0002	0.0004	0.0013	0.0021	0.0082	0.0106
P.4.2.3 Canned beans and pulses (100% packed in metal)	PT20	0	0	0	0.0003	0.0016	0.0021
	PT21	0	0	0.0003	0.0008	0.0034	0.0038
	Total	0	0	0.0003	0.0011	0.0050	0.0059
P.4.2.4 Tomato paste/purees (99% packed in metal)	PT20	0	0	0	0	0	0
	PT21	0	0	0	0.0001	0	0.0001
	PT41	0	0	0	0	0	0
	PT48	0	0	0	0	0	0
	Total	0	0	0	0	0	0.0001
P.4.2.5 Pasta sauces (tomato based) (65% packed in metal)	PT41	0	0.0002	0.0003	0.0002	0.0006	0.0009
P.4.2.6 Pickled vegetables (90% packed in metal)	PT20	0	0	0	0	0	0
	PT21	0	0	0	0	0	0
	PT41	0	0.0002	0.0002	0.0001	0.0004	0.0006
	Total	0	0.0002	0.0002	0.0001	0.0004	0.0006
P.8.2.3 Preserved meat and products (100% packed in metal)	PT20	0	0	0	0.0005	0.0024	0.0035
	PT21	0.0001	0.0002	0.0008	0.0009	0.0029	0.0047
	Total	0.0001	0.0002	0.0008	0.0014	0.0053	0.0082
P.9.2.4 Preserved fish/seafood without sauce (99% packed in metal)	PT20	0	0	0.0001	0	0.0002	0.0006
	PT21	0.0001	0.0006	0.0013	0.0004	0.0020	0.0029
	Total	0.0001	0.0006	0.0014	0.0004	0.0023	0.0035
P.11.2.1 Honey (64% packed in metal)	PT1	0	0	0.0002	0	0.0001	0.0002
	PT41	0	0	0	0	0	0.0001
	Total	0	0	0.0002	0	0.0001	0.0003
P.11.2.2 Ice cream toppings and desert sauces (45% packed in metal)	PT1/3, PT41	0	0	0.0002	0	0.0001	0.0003
P.12.1.01 Mayonnaise (66% packed in metal)	PT41	0	0.0001	0.0001	0	0.0001	0.0002
P.12.1.02 Vinaigrettes (90% packed in metal)	PT35	0	0	0	0	0.0001	0.0002
P.12.1.03 Salad dressings (76% packed in metal)	PT35	0	0	0	0	0.0001	0.0001
	PT41	0	0	0	0	0	0
	Total	0	0	0	0	0.0001	0.0001
P.12.1.04 Ketchup (43% packed in metal)	PT35	0	0	0	0	0	0.0001
P.12.1.05 Mustard (89% packed in metal)	PT35	0	0	0	0	0	0
	PT41	0	0	0	0	0.0001	0.0001
	PT48	0	0	0	0	0	0
	Total	0	0	0	0	0.0001	0.0001
P.12.1.07 Soy-based sauces (30% packed in metal)	PT35	0	0	0	0	0	0

(*continued*)

Table 9. Continued.

FACET food groups	Pack[a]	Total population			Consumers		
		Mean	95th	97.5th	Mean	95th	97.5th
P.12.1.08 Table sauces (85% packed in metal)	PT35	0	0.0001	0.0002	0.0001	0.0003	0.0006
P.12.1.09 Pasta sauces (65% packed in metal)	PT41	0	0	0	0	0.0001	0.0002
P.12.1.10 Wet sauces (91% packed in metal; 10%	PT20	0	0	0	0	0	0
in food cans and 81% in jars with a metal	PT21	0.0001	0.0001	0.0009	0.0002	0.0008	0.0020
closure)	PT41	0.0001	0.0005	0.0010	0.0002	0.0009	0.0013
	Total	0.0002	0.0006	0.0019	0.0004	0.0016	0.0033
P12.1.11 Dips (12% packed in metal)	PT41	0	0	0	0	0.0001	0.0001
P.12.1.15 Other sauces dressings etc. (8.9% packed in metal)	PT41	0	0	0	0	0	0
P.12.2.4 Canned/preserved soup (100% packed in	PT20	0.0001	0	0.0009	0.0007	0.0042	0.0062
metal)	PT21	0.0007	0.0047	0.0068	0.0040	0.0115	0.0171
	Total	0.0008	0.0047	0.0078	0.0047	0.0157	0.0233
P.13.2.2 Other baby food (45% packed in metal)	PT20, PT21 PT41	0	0	0	0	0	0
P.14.2.1 Carbonates (49% packed in metal)	PT8	0.0019	0.0117	0.0166	0.0030	0.0148	0.0203
P.14.2.2 Juices (0.4% packed in metal)	PT8, PT35	0	0	0	0	0	0
P.15.1.1 Beer (74% packed in metal)	PT8	0.0037	0.0217	0.0330	0.0086	0.0348	0.0494
P.15.1.2 Cider (61% packed in metal)	PT8	0.0003	0	0.0015	0.0057	0.0208	0.0228
P.15.1.3 Flavoured alcoholic beverages (0.6% packed in metal)	PT8	0	0	0	0.0003	0	0
P.18.4.2 Canned/preserved pasta (99.7% packed in	PT20	0.0001	0	0	0.0007	0.0044	0.0068
metal)	PT21	0.0002	0.0006	0.0024	0.0026	0.0100	0.0112
	Total	0.0002	0.0006	0.0024	0.0033	0.0144	0.0180
P.18.5.6 Canned/preserved ready meals (99%	PT20	0.0003	0.0020	0.0041	0.0007	0.0043	0.0061
packed in metal)	PT21	0.0010	0.0053	0.0084	0.0022	0.0088	0.0116
	Total	0.0013	0.0074	0.0125	0.0028	0.0131	0.0176
P.18.5.7 Preserved fish/seafood with sauce (99%	PT20	0	0	0	0	0.0002	0.0003
packed in metal)	PT21	0	0	0	0.0002	0.0009	0.0012
	Total	0	0	0	0.0002	0.0011	0.0014

Notes: 0 = 0.0000.
[a]PT 1 and 3 aerosol, PT8 beverage can, PT20 food can, classic end, PT21 food can easy open end, PT35 glass bottle, metal closure, PT41 glass jar, metal closure; and PT48 tube.

(P.37.1.1) for food cans and ends, epoxy acrylate beverage (P.37.1.4.1) for beverage cans, and closure coatings (P.37.5.2) for metal lids. This is a conservative assumption. The consumption of foodstuffs in aerosols or tubes was considered insufficient to be used for this verification exercise (see Table 6 for further details of coating chemistries). For convenience and to be conservative, it was assumed that both easy open and classic ends for food cans as well as side seam stripes were coated with the same epoxy phenolic coating as the can body. For food group P.12.1.10 Wet sauces the market shares, surface areas to weight and different levels of extractable BPA were used for food cans and closures (PT21/PT41). An average of the surface areas and market shares cannot be used because the amount of extractable BPA is different for the different coatings. The mean, 95th and 97.5th percentiles for PT21 were added to the mean, 95th and 97.5th percentiles, respectively, for PT41 to give an overall summary, although this simple summation of values is not rigorous from a statistical viewpoint.

Results and discussion

Estimate of consumer exposure to BPA using the FACET tool

In Table 10 the exposures for the total population only have been derived using the amount of food consumed per statistic (mean, 95th and 97.5th percentiles) and the minimum and maximum extractible levels of BPA. This gives a range for each consumption statistic. It would be anticipated that any (probabilistic) FACET exposure assessment for the same food group and same statistic would lie somewhere within this (refined deterministic) range. For food group P.12.1.10 Wet sauces the minimum and maximum exposures from being packaged in food cans or jars with metal closures is given and then the third row gives the exposure assuming consumption (pro rata) from the ratio of cans and jars. Similarly the same has been done for consumers only and these results are shown in Table 11. It should be noted that it is statistically incorrect to sum the mean, 95th or 97.5th percentiles over a range of foods as it leads to an unrealistic aggregation of exposure.

Table 10. Refined deterministic assessment of exposure for the total population to BPA from light metal packaging for those metal packs with significant market shares.

FACET food groups	Pack type[a]	Area (cm^2 g^{-1})	Percentage metal	BPA levels (mg dm^{-2})		Food consumed (g/person/day) for the total population			Total population exposure (mg/person/day)[b]					
									Minimum (mg/person/day)			Maximum (mg/person/day)		
				Minimum	Maximum	Mean	95th	97.5th	Mean	95th	97.5th	Mean	95th	97.5th
1.1.6 Condensed/evaporated milk	PT20/21	0.84	100	0.00005	0.02	0.5	0	4.3	0	0	0	0.0001	0	0.0007
3.2.3 Jams and fruit preserves	PT41	0.16	100	0.002	0.016	3.6	17.7	25	0	0.0001	0.0001	0.0001	0.0005	0.0006
3.2.4 Canned/preserved fruit	PT20/21	0.85	83	0.00005	0.02	4.3	26.9	44.4	0	0	0	0.0007	0.0046	0.0075
4.2.1 Preserved vegetables without sauces	PT20/21	0.97	94	0.00005	0.02	7.2	36.9	53	0	0	0	0.0014	0.0072	0.0103
4.2.2 Canned/preserved tomatoes	PT20/21	1.08	100	0.00005	0.02	2.2	16.1	28.6	0	0	0	0.0005	0.0035	0.0062
4.2.3 Canned beans and pulses	PT20/21	1.19	100	0.00005	0.02	0.7	0	10.1	0	0	0	0.0002	0	0.0024
4.2.5 Pasta sauces (tomato based)	PT41	0.16	65	0.002	0.016	3.4	26	37.1	0	0.0001	0.0001	0.0001	0.0007	0.0009
4.2.6 Pickled vegetables	PT41	0.16	90	0.002	0.016	2	10.7	16.6	0	0	0.0001	0.0001	0.0003	0.0004
8.2.3 Preserved meat and meat products	PT20/21	0.96	100	0.00005	0.02	1.3	9.6	17.5	0	0	0	0.0002	0.0018	0.0034
9.2.4 Preserved fish/seafood without sauce	PT20/21	1.13	99	0.00005	0.02	5.7	27.1	37.2	0	0	0	0.0013	0.0061	0.0084
12.1.2 Vinaigrettes	PT35	0.03	91	0.002	0.016	0.5	2.1	4.3	0	0	0	0	0	0
12.1.8 Table sauces	PT35	0.05	85	0.002	0.016	2.3	11.6	21.4	0	0	0	0	0.0001	0.0002
12.1.10 Wet sauces PT21/PT41 10.3/80.7	PT20/21	0.85	10	0.00005	0.02	14	49.8	70.1	0	0	0	0.0023	0.0085	0.0119
	PT41	0.2	81	0.002	0.016	14	49.8	70.1	0.0001	0.0002	0.0003	0.0004	0.0016	0.0022
12.1.10 PT20 and 21/PT41 average ratio of 10.3/80.7[c]						14	49.8	70.1	0	0.0002	0.0002	0.0006	0.0022	0.0030
12.2.4 Canned/preserved soup	PT20/21	0.96	100	0.00005	0.02	10	60.7	97.6	0	0	0	0.0020	0.0117	0.0187
15.1.1 Beer	PT8	0.91	74	0.001	0.004	217	1127	1632	0.0020	0.0103	0.0149	0.0079	0.0410	0.0594
15.1.2 Cider	PT8	0.9	61	0.001	0.004	20	3.8	164	0.0002	0	0.0015	0.0007	0.0001	0.0059
18.4.2 Canned/preserved pasta	PT20/21	1.09	100	0.00005	0.02	2.8	22.2	46.5	0	0	0	0.0006	0.0048	0.0101
18.5.6 canned/preserved ready meals	PT20/21	1.09	99	0.00005	0.02	18	71.8	105	0	0	0.0001	0.0039	0.0157	0.0230
18.5.7 Preserved fish/seafood with sauce	PT20/21	1.2	99	0.00005	0.02	0.3	0	0	0	0	0	0.0001	0	0

Notes: 0 = 0.0000.

[a]PT 8 beverage cans, PT 20/21 food cans with either classic or easy open ends, PT 35 glass bottle metal closure (small area), PT 41 metal closure for glass jars (larger area).

[b]Minimum and maximum calculated exposures relate to the minimum and maximum levels of extractable BPA (see Table 6).

[c]For 12.1.10 Wet sauces the contribution from coated metal packaging comes from either food cans (PT20 or PT21) or metal closures on jars (PT41). The exposure has been calculated using the ratio of market shares for cans and closures of 10.3/80.7.

Table 11. Refined deterministic assessment of exposure to BPA (consumers only) from light metal packaging for those metal packs with significant market shares.

FACET food groups	Pack type[a]	Area (cm^2 g^{-1})	Percentage metal	BPA levels (mg dm^{-2})		Food consumed (g/person/day) for the total population			Consumers only exposure (mg/person/day)[b]					
									Minimum (mg/person/day)			Maximum (mg/person/day)		
				Minimum	Maximum	Mean	95th	97.5th	Mean	95th	97.5th	Mean	95th	97.5th
1.1.6 Condensed/evaporated milk	PT20/21	0.84	100	0.00005	0.02	11	41.7	48.4	0	0	0	0.0019	0.0070	0.0081
3.2.3 Jams and fruit preserves	PT41	0.16	100	0.002	0.016	8.9	26.1	30.1	0	0.0001	0.0001	0.0002	0.0007	0.0008
3.2.4 Canned/preserved fruit	PT20/21	0.85	83	0.00005	0.02	27	82	133	0	0	0.0001	0.0046	0.0139	0.0226
4.2.1 Preserved vegetables without sauces	PT20/21	0.97	94	0.00005	0.02	21	58.6	80.6	0	0	0	0.0041	0.0114	0.0156
4.2.2 Canned/preserved tomatoes	PT20/21	1.08	100	0.00005	0.02	27	57.1	59.5	0	0	0	0.0059	0.0123	0.0129
4.2.3 Canned beans and pulses	PT20/21	1.19	100	0.00005	0.02	15	36.1	49.7	0	0	0	0.0035	0.0086	0.0118
4.2.5 Pasta sauces (tomato based)	PT41	0.16	65	0.002	0.016	25	58	66	0.0001	0.0002	0.0002	0.0006	0.0015	0.0017
4.2.6 Pickled vegetables	PT41	0.16	90	0.002	0.016	7.4	23.4	29.3	0	0.0001	0.0001	0.0002	0.0006	0.0008
8.2.3 Preserved meat and meat products	PT20/21	0.96	100	0.00005	0.02	16	38.8	57.5	0	0	0	0.0030	0.0074	0.0110
9.2.4 Preserved fish/seafood without sauce	PT20/21	1.13	99	0.00005	0.02	17	48	55.5	0	0	0	0.0038	0.0108	0.0125
12.1.2 Vinaigrettes	PT35	0.03	91	0.002	0.016	5.4	15.4	27.4	0	0	0	0	0.0001	0.0001
12.1.8 Table sauces	PT35	0.05	85	0.002	0.016	31	38.6	0	0	0	0	0	0	0
12.1.10 Wet sauces PT21/PT41 10.3/80.7	PT20/21	0.85	10	0.00005	0.02	67	85.2	0	0.0039	0.0114	0.0145	0	0	0
	PT41	0.2	81	0.002	0.016	67	85.2	0.0003	0.0007	0.0021	0.0027	0.0001	0.0003	0.0003
12.1.10 PT20 and 21/PT41 average on ratio of 10.3/80.7[c]						67	85.2	0.0003	0.0010	0.0029	0.0037	0.0001	0.0002	0.0003
12.2.4 Canned/preserved soup	PT20/21	0.96	100	0.00005	0.02	123.1	182	0.0001	0.0119	0.0236	0.0350	0	0.0001	0.0001
15.1.1 Beer	PT8	0.91	74	0.001	0.004	1701	1975	0.0180	0.0181	0.0619	0.0719	0.0045	0.0155	0.0180
15.1.2 Cider	PT8	0.9	61	0.001	0.004	1744	2678	0.0241	0.0138	0.0628	0.0964	0.0034	0.0157	0.0241
18.4.2 Canned/preserved pasta	PT20/21	1.09	100	0.00005	0.02	114.4	117	0.0001	0.0086	0.0249	0.0255	0	0.0001	0.0001
18.5.6 Canned/preserved ready meals	PT20/21	1.09	99	0.00005	0.02	109.4	130	0.0001	0.0084	0.0238	0.0283	0	0	0
18.5.7 Preserved fish/seafood with sauce	PT20/21	1.2	99	0.00005	0.02	40.4	46.8	0	0.0048	0.0097	0.0112			

Notes: 0 = 0.0000.

[a]PT8 beverage can, PT20/21 food can with either a classic or easy open end, PT35 glass bottle, metal closure (small area), PT41 glass jar, metal closure (larger area).

[b]Minimum and maximum calculated exposures relate to the minimum and maximum levels of extractable BPA (see Table 6).

[c]For 12.1.10 Wet sauces the contribution from coated metal packaging comes from either food cans (PT20 or PT21) or metal closures on jars (PT41). The exposure has been calculated using the ratio of market shares for cans and closures of 10.3/80.7.

Tables 12 and 13 show comparisons between exposures from the FACET output for the UK 19–64 year olds per food group at Tier 3, for which there is a relatively high proportion of foodstuffs packaged in cans or jars/bottles with metal closures, and the minimum and maximum exposures obtained deterministically using the minimum and maximum levels for BPA. The values from FACET lie within the range of the refined deterministic ones. Due to the fact that not every food group has 100% market share in metal and that various coatings (including non-BPA based) could be used, the values from FACET are not exactly midway because the FACET exposure model uses market share of different coatings and occurrence probability of BPA in those coatings, whereas the refined-deterministic approach assumes the food groups are all packed in light metal packaging, with epoxy-based coatings. The refined deterministic approach only used three basic types of coating and used food cans: beverage cans, large closures for metal jars and small closures for bottles. Indeed, the agreement is considered good and sufficient to verify the FACET model when concentration data are used as inputs in this example.

In FACET there is the capability to obtain in the report as defaults the overall mean, 90th and 97.5th percentile exposures to a substance from selected packaging for each survey, in addition to each selected food group. This has now been modified to the 95th rather than the 97.5th percentile. To obtain other percentiles it is necessary to preselect them before undertaking an exposure assessment. Exposures were run with packaging (consumer) loyalty (rather than brand loyalty) and the values obtained

Table 12. Comparison of refined deterministic estimate (RD) of exposure to BPA with FACET output (mg/person/day) for UK NDNS 19–64 year olds, 2000 survey, for total population (not all canned/jarred foodstuffs are included).

		Exposure to BPA of total population (mg/person/day)								
		Mean			95th			97.5th		
FACET food groups	Code	RD minimum	FACET	RD maximum	RD minimum	FACET	RD maximum	RD minimum	FACET	RD maximum
Condensed/evaporated milk	1.1.6	0	0	0.0001	0	0	0	0	0.0003	0.0007
Jams and fruit preserves	3.2.3	0	0	0.0001	0.0001	0.0002	0.0005	0.0001	0.0004	0.0006
Canned/preserved fruit	3.2.4	0	0.0003	0.0007	0	0.0006	0.0046	0	0.0028	0.0075
Preserved vegetables without sauces	4.2.1	0	0.0005	0.0014	0	0.0027	0.0072	0	0.0052	0.0103
Canned/preserved tomatoes	4.2.2	0	0.0002	0.0005	0	0.0004	0.0035	0	0.0013	0.0062
Canned beans and pulses	4.2.3	0	0.0001	0.0002	0	0	0	0	0.0003	0.0024
Pasta sauces (tomato based)	4.2.5	0	0	0.0001	0.0001	0.0002	0.0007	0.0001	0.0003	0.0009
Pickled vegetables	4.2.6	0	0	0.0001	0	0.0002	0.0003	0.0001	0.0002	0.0004
Preserved meat and meat products	8.2.3	0	0.0001	0.0002	0	0.0002	0.0018	0	0.0008	0.0034
Preserved fish/seafood without sauce	9.2.4	0	0.0001	0.0013	0	0.0006	0.0061	0	0.0014	0.0084
Vinaigrettes	12.1.2	0	0	0	0	0	0	0	0	0
Table sauces	12.1.8	0	0	0	0	0.0001	0.0001	0	0.0002	0.0002
Wet sauces food can[a]	12.1.10	0	0.0002	0.0023	0	0.0006	0.0085	0	0.0019	0.0119
Wet sauces closure[a]	12.1.10	0.0001	0.0002	0.0004	0.0002	0.0006	0.0016	0.0003	0.0019	0.0022
Wet sauces food plus closure average[a]	12.1.10	0	0.0002	0.0006	0.0002	0.0006	0.0022	0.0002	0.0019	0.0030
Canned/preserved soup	12.2.4	0	0.0008	0.0020	0	0.0047	0.0117	0	0.0078	0.0187
Beer	15.1.1	0.0020	0.0038	0.0079	0.0103	0.0217	0.0410	0.0149	0.0330	0.0594
Cider	15.1.2	0.0002	0.0003	0.0007	0	0	0.0048	0.0015	0.0015	0.0059
Canned/preserved pasta	18.4.2	0	0.0002	0.0006	0	0.0006	0.0157	0	0.0024	0.0101
Canned/preserved ready meals	18.5.6	0	0.0013	0.0039	0	0.0074	0	0.0001	0.0125	0.0230
Preserved fish/seafood with sauce	18.5.7	0	0	0.0001	0	0	0	0	0	0
Total of means		0.0022	0.0081	0.0193						

Notes: 0 = 0.0000.

[a]The contribution from wet sauces (12.1.10) comes from cans and metal closures. Separate values are given for the exposure from each, but the exposure is the average pro rata according to the market shares of cans and jars. Thus, the total exposure is reduced.

are given in Table 14. Note that the total exposure values in Table 14 do not simply equal the sum of all the individual food groups listed in Table 12 (total population) and Table 13 (consumers only). This is because for Table 12 the arithmetic sum of the mean is 0.0081 mg/person/day whereas in Table 14 the corresponding value is 0.0097 mg/person/day. The small difference is because only those food groups with more than 50% market share in light metal packaging are listed in Table 12, whereas in Table 14 it is the sum of all food groups. In contrast there is no summation in Table 13 because it is inappropriate to sum exposure values from two or more different food groups for consumers only, because the consumers are different. For example, consumers only of

Table 13. Comparison of refined deterministic estimate (RD) of exposure to BPA with FACET output (mg/person/day) for UK NDNS 19–64 year olds, 2000 survey, for consumers only (not all canned/jarred foodstuffs are included).

		Exposure to BPA of consumers only (mg/person/day)								
		Mean			95th			97.5th		
FACET food groups	Code	RD minimum	FACET	RD maximum	RD minimum	FACET	RD maximum	RD minimum	FACET	RD maximum
Condensed/evaporated milk	1.1.6	0	0.0007	0.0019	0	0.0029	0.0070	0	0.0031	0.0081
Jams and fruit preserves	3.2.3	0	0.0001	0.0002	0.0001	0.0004	0.0007	0.0001	0.0005	0.0008
Canned/preserved fruit	3.2.4	0	0.0016	0.0046	0	0.0081	0.0139	0.0001	0.0117	0.0226
Preserved vegetables without sauces	4.2.1	0	0.0015	0.0041	0	0.0068	0.0114	0	0.0109	0.0156
Canned/preserved tomatoes	4.2.2	0	0.0021	0.0059	0	0.0082	0.0123	0	0.0106	0.0129
Canned beans and pulses	4.2.3	0	0.0011	0.0035	0	0.0050	0.0086	0	0.0059	0.0118
Pasta sauces (tomato based)	4.2.5	0.0001	0.0002	0.0006	0.0002	0.0006	0.0015	0.0002	0.0009	0.0017
Pickled vegetables	4.2.6	0	0.0001	0.0002	0.0001	0.0004	0.0006	0.0001	0.0006	0.0008
Preserved meat and meat products	8.2.3	0	0.0014	0.0030	0	0.0053	0.0074	0	0.0082	0.0110
Preserved fish/seafood without sauce	9.2.4	0	0.0004	0.0038	0	0.0023	0.0108	0	0.0035	0.0125
Vinaigrettes	12.1.2	0	0	0	0	0.0001	0.0001	0	0.0002	0.0001
Table sauces	12.1.8	0	0.0001	0.0001	0	0.0003	0.0002	0	0.0006	0.0003
Wet sauces food can[a]	12.1.10	0	0.0004	0.0039	0	0.0016	0.0114	0	0.0033	0.0145
Wet sauces closure[a]	12.1.10	0.0001	0.0004	0.0007	0.0003	0.0016	0.0021	0.0003	0.0033	0.0027
Wet sauces food plus closure average[a]	12.1.10	0.0001	0.0004	0.0010	0.0002	0.0016	0.0029	0.0003	0.0033	0.0037
Canned/preserved soup	12.2.4	0	0.0047	0.0119	0.0001	0.0157	0.0236	0.0001	0.0233	0.0350
Beer	15.1.1	0.0045	0.0086	0.0181	0.0155	0.0348	0.0619	0.0180	0.0495	0.0719
Cider	15.1.2	0.0034	0.0057	0.0138	0.0157	0.0208	0.0628	0.0241	0.0229	0.0964
Canned/preserved pasta	18.4.2	0	0.0033	0.0086	0.0001	0.0144	0.0249	0.0001	0.0180	0.0255
Canned/preserved ready meals	18.5.6	0	0.0028	0.0084	0.0001	0.0131	0.0238	0.0001	0.0176	0.0283
Preserved fish/seafood with sauce	18.5.7	0	0.0002	0.0048	0	0.0011	0.0097	0	0.0014	0.0112

Notes: 0 = 0.0000.
[a]The contribution from wet sauces (12.1.10) comes from cans and metal closures. Separate values are given for the exposure from each, but the exposure is the average pro rata according to the market shares of cans and jars. Thus, the total exposure is reduced.

Table 14. Estimates of exposure from FACET for BPA emanating from canned foodstuffs for different percentiles for UK 19–64 year olds.

	Mean	90th percentile	97.5th percentile
Population (mg/person/day)	0.00973	0.0235	0.0466
Consumers-only (mg/person/day)	0.00978	0.0236	0.0466
Population (mg kg^{-1} bw day^{-1})	0.00013	0.00029	0.00059
Consumers only (mg kg^{-1} bw day^{-1})	0.00013	0.00029	0.00059

beer (n = 713; Table 8) are not the same individuals as consumers only of cider (n = 84; Table 8).

The levels of exposure to BPA emanating from light metal packaging using conservative assumptions are well below the TDI of 0.05 mg kg^{-1} body weight day^{-1} (EFSA 2006) even for the highest percentile consumers (Table 14) taking into account the assumption that the European Union consumer average body weight is 60 kg.

The 'drivers' of exposure to BPA from light metal packaging can be derived from Table 9 for UK 19–64 year olds, only. Considering consumers only and the 97.5th percentile consumer, the main 'drivers' of exposure are (mg/person/day): P.15.1.1 Beer (0.049), P.12.2.4 Soup and P.15.1.2 Cider (both 0.023), P.14.2.1 Carbonates (0.02), P.18.4.2 Preserved pasta and P.18.5.6 Preserved ready meals (both 0.018), P.03.2.4 Canned fruit (0.012), P.04.2.1 Canned vegetables (0.011) and P.04.2.4 Canned tomatoes (0.010). All others are below 0.010 with many < 0.0001. Other percentiles or total population can be treated in a similar manner to determine the relevant 'drivers' of exposure. It should be noted that in the more recent software release of FACET the drivers of exposure are automatically generated in the report at food group Tier 1.

A comparison of the FACET estimate for BPA with a recent estimate performed by EFSA

During the journal's reviewing stage of this paper, EFSA published a new estimate of exposure to BPA (EFSA 2013). EFSA used a deterministic not a probabilistic approach. For food, the average exposure was assessed based on combining average concentrations in different groups of foods and beverages, with average consumption data for those food and beverage groups. Estimates of high exposure were based on average concentration and high consumption. The aim was to estimate the mean and the highest 95th percentile among all European Union countries, meaning that estimates were made for each country separately and the highest results (the 'highest country') were taken forward.

EFSA used two different scenarios to allow for the fact that few of the national dietary surveys in the EFSA Comprehensive Database have information on what the food was packaged in. In Scenario 1, only foodstuffs, specifically codified as canned in the dietary survey, were assigned the corresponding occurrence level for BPA. In Scenario 2, any foodstuff, at FoodEx level 4, which has been codified as canned in at least one national survey, was always considered to be consumed as canned in all dietary surveys considered in the EFSA Comprehensive Database. Scenario 2 was chosen for the total exposure estimation, although it was recognised that this might overestimate the dietary exposure.

For a comparison with this work, where UK adults aged 19–64 years are considered, the three relevant age groups considered by EFSA are: men aged 18–45 years; women aged 18–45 years; and other adults aged 45–65 years.

Using Scenario 2, average dietary exposure from food and beverages for these three groups was estimated by EFSA to be in the range 126–132 ng kg^{-1} bw day^{-1}. Similarly, high (95th percentile) dietary exposure from food and beverages for the same three groups of adults was in the range 335–388 ng kg^{-1} bw day^{-1}. Under Scenario 2, EFSA found that canned products dominated in all surveys, with the percentage contribution to BPA from canned foods mainly ranging between 75% and 90%.

From this work (Table 14) the estimates for the population mean, the 90th and 97.5th percentiles are 130, 290 and 590 ng kg^{-1} bw day^{-1} dietary exposure to BPA from light metal packaging, respectively. These figures from the FACET tool are very similar to the EFSA estimates for exposure from canned food and beverages. Scenario 2 used by EFSA is conservative in that any food canned in at least one national survey is always considered to be consumed as canned in all dietary surveys. In contrast, the FACET tool used actual market share data for the proportion of foods packed in light metal packaging and the different coating chemistries used, some releasing BPA and some not, and assumed packaging loyalty. On the other hand, the FACET tool made conservative assumptions about release concentrations of BPA from coatings and on surface area to weight ratios whereas the EFSA calculations drew upon a large database on BPA concentrations measured in food and beverages. Also, the FACET results presented here are for the UK only. The close agreement between the (conservative) estimate from FACET and the (conservative) estimates by EFSA, at the mean and also at high percentiles, is satisfactory.

Conclusions

This paper is a demonstration that the results from the FACET tool for a particular migrant (BPA) for a specific population (UK 19–64 year olds) are reliable, lying as they do between minimum and maximum values obtained using a refined deterministic approach. The recent EFSA draft opinion (EFSA 2013) on exposure to BPA from different sources showed that canned foodstuffs were a major contributor and compared results from various models, including those from FACET. The results from FACET were overall conservative.

This demonstration could aid the acceptance of FACET as a reliable tool for estimating dietary exposure by industry, regulators and risk assessors across Europe. A summary of how FACET is foreseen to progress has been given (Oldring et al. 2013). Both the packaging usage and food consumption data are dated with packaging usage coming from 2005 and food consumption from 2000. Assessing trends over time, as both diet and packaging

usage changes, could be the subject of a further research project using the FACET tool.

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References

Brands B, Castle L, Duffy E, Franz R, Garcia L, Gibney M, Hart A, Oldring PKT. 2007. Guidance for exposure assessment of substances migrating from food packaging materials. Brussels, Belgium: ILSI Europe.

Castle L, Hart A, Holmes MJ, Oldring PKT. 2006. Approach to stochastic modelling of consumer exposure for any substance from canned foods using simulant migration data. Food Addit Contam. 23:528–538.

CEPE. 2013. About CEPE. [Internet]. [cited 2013 Mar 17]. Available from: http://www.cepe.org

Dionisi G, Oldring PKT. 2002. Estimates of per capita exposure to substances migrating from canned foods and beverages. Food Addit Contam. 19:891–903.

EC. 2011. Commission Implementing Regulation (EU) No 321/2011 of 1 April 2011 amending Regulation (EU) No. 10/2011 as regards the restriction of use of bisphenol A in plastic infant feeding bottles. Off J Eur Union. L87:1–2.

EFSA. 2006. Opinion of the Scientific Panel on Food Additives, Flavourings, Processing Aids and Materials in Contact with Food on a request from the Commission related to 2,2-bis(4-hydroxyphenyl)propane (Bisphenol A). EFSA J. 428:1–75.

EFSA. 2010. Scientific opinion on bisphenol A: evaluation of a study investigating its neurodevelopmental toxicity, review of recent scientific literature on its toxicity and advice on the Danish risk assessment of bisphenol A. EFSA J. 8:1829.

EFSA. 2012. Bisphenol A: EFSA launches full re-evaluation focussing on exposure and possible low dose effects. [Internet]. [cited 2013 Mar 17]. Available from: http://www.efsa.europa.eu/en/press/news/120424.htm

EFSA. 2013. Draft Scientific Opinion on the risks to public health related to the presence of bisphenol A (BPA) in foodstuffs – part: exposure assessment. Endorsed for public consultation. [Internet]. [cited 2013 Oct 1] . Available from: http://www.efsa.europa.eu/en/consultationsclosed/call/130725.pdf

Goodson A, Summerfield W, Cooper I. 2002. Survey of bisphenol A and bisphenol F in canned foods. Food Addit Contam. 19:796–802.

Hearty A, Gibney MJ, Vin K, Leclercq C, Castle L, O'Mahony C, Oldring PKT, Volatier JL, McKevitt A, Tennant D, McCamara C, Kettlitz B. 2011. The FACET project: a chemical exposure surveillance system for Europe. Food Sci Technol. 25:26–29.

Henderson L, Gregory J, Swan G. 2002. The National Diet and Nutrition Survey: adults aged 19 to 64 years. Volume 1: types and quantities of foods consumed. London: HMSO.

Holmes MJ, Hart A, Northing P, Oldring PKT, Castle L, Stott D, Smith G, Wardman O. 2005. Dietary exposure to chemical migrants from food contact materials: a probabilistic approach. Food Addit Contam. 22:907–919.

Northing P, Oldring PKT, Castle L, Mason PASS. 2009. New hierarchical classification of food items for the assessment of exposure to packaging migrants: use of hub codes for different food groups. Food Addit Contam. 26:534–562.

Oldring PKT, editor. 1997. Waterborne & solvent based epoxies and their end user applications. London: Wiley.

Oldring PKT, Castle L, Franz R. 2009. Exposure to substances from food contact materials and an introduction to the FACET project. Dtsch Lebensm Rundsch. 105:501–507.

Oldring PKT, Castle L, Hart A, Holmes MJ. 2006. Migrants from food cans revisited – application of a stochastic model for a more realistic assessment of exposure to bisphenol A diglycidyl ether (BADGE). Packag Technol Sci. 19:121–137.

Oldring PKT, Nehring U. 2007. Packaging materials, 7. Metal packaging for foodstuffs. Brussels, Belgium: ILSI Europe.

Oldring PKT, O'Mahony C, Dixon J, Vints M, Megehan J, Dequatre C, Castle L. 2013. Development of the FACET exposure tool to assess migrants from food packaging. Food Addit Contam Part A. [Internet]. 22. Available from: http://www.tandfonline.com/doi/abs/10.1080/19440049.2013.862348

The Office for National Statistics. UK statistics authority publication hub. Gateway to UK national statistics. [cited 2013 Oct 2]. Available from: http://www.statistics.gov.uk