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Dietary Estimates of Dioxins Consumed in U.S. Department of Agriculture–Regulated Meat and Poultry Products†

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ABSTRACT

The U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) examined whether levels of dioxin-like compounds (DLCs) measured in FSIS-regulated meat and poultry products indicate possible concern for U.S. public health based on usual and recommended consumption patterns of meat and poultry for the U.S. population. The FSIS estimated daily dietary exposures and compared them with the reference dose (RfD) established by the U.S. Environmental Protection Agency (EPA) for potential noncancer risks from 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), assuming that all measured DLCs were represented by the RfD (i.e., not just TCDD alone). The estimates indicate that a typical U.S. adult daily exposure of DLCs from FSIS-regulated products is below the EPA-established RfD. Only children consuming chronic average daily servings of meat or poultry products containing the highest measured levels of DLCs may exceed the RfD. If one follows the recommendations from the 2010 *Dietary Guidelines for Americans,* all expected exposures to DLCs from FSIS-regulated products are estimated to be well below the RfD.

Over the past two decades, the U.S. Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) along with its Federal partners, the U.S. Environmental Protection Agency (EPA) and the U.S. Food and Drug Administration, conducted three surveys at 5-year intervals for ''dioxins'' in four FSIS-regulated products: beef, pork, chicken, and turkey *(4, 5, 9, 13, 24, 25)*. ''Dioxins'' are a group of toxic chemical compounds (dioxin-like compounds; DLCs) that share certain chemical structures and biological characteristics; 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) is the representative or reference dioxin of the group. These surveys monitored DLCs (17 toxic polychlorinated dibenzo-p-dioxins [PCDDs] and polychlorinated dibenzofurans [PCDFs] and 4 nonortho-polychlorinated biphenyls [no-PCBs]) in domestic meat and poultry to provide statistical information on the current concentrations of DLCs in the four food product classes *(5)*.

DLCs are environmental contaminants, and continuous low-level exposure of the U.S. population to this group of compounds remains a concern. Primary sources of new DLCs in the environment include industrial emissions, backyard burning of trash, and forest fires *(17)*. DLCs break down very slowly in the environment. As a result, past releases of DLCs from both man-made and other sources still exist in the environment *(17)*. Most human exposure to DLCs occurs through the diet, specifically from the animal fats associated with eating beef, pork, poultry, fish, milk, and dairy products, with small amounts of exposure coming from breathing air containing trace amounts of DLCs, inadvertent ingestion of soil containing DLCs, and dermal contact with DLC-contaminated media *(8, 16, 21)*. Because diet is a major exposure pathway and animal products account for an important component of the diet, surveys to evaluate DLCs in meat and poultry products have been conducted. The results from the most recent survey *(5)* were used in the exposure estimates presented here.

In 2012, the EPA released a report: *EPA's Reanalysis of Key Issues Related to Dioxin Toxicity and Response to NAS Comments*, volume 1 *(11, 21)*. The report includes reviews and summarized the available data on noncancer effects of TCDD *(21, 22)*. Adverse noncancer effects associated with oral TCDD exposure include hepatic, neurological, immunological, reproductive, endocrine, and developmental effects. Two human epidemiological studies *(1, 10)* were chosen as the basis for deriving a reference dose (RfD) for TCDD. The EPA determined that the RfD for chronic oral exposure is 7×10^{-10} mg/kg-day based on decreased sperm count and motility in men exposed to TCDD as boys and increased thyroid stimulating hormone in newborns exposed to TCDD in utero *(21, 22)*.

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† Trade names are necessary to report factually on available data; however, the U.S. Department of Agriculture neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

TABLE 1. *Mean dioxin exposure from beef, based on beef consumption*

Study group	Amt of beef consumed (g/kg/day)[a]	Mean beef TEQ (pg/g)[b]	Nonlean beef			Lean beef		
			% fat[c]	Mean DLC exposure (pg/kg of bw/day)[d]	Comparison with the RfD[e]	% fat[c]	Mean DLC exposure (pg/kg of bw/day)[f]	Comparison with the RfD[e]
Whole population	0.77	0.659	19.24	0.098	0.139	6.16	0.031	0.045
Birth to 1 yr	0.34	0.659	19.24	0.043	0.062	6.16	0.014	0.020
1–2 yr	1.38	0.659	19.24	0.175	0.250	6.16	0.056	0.080
3–5 yr	1.42	0.659	19.24	0.180	0.257	6.16	0.058	0.082
6–12 yr	1.11	0.659	19.24	0.141	0.201	6.16	0.045	0.064
13–19 yr	0.83	0.659	19.24	0.105	0.150	6.16	0.034	0.048
20–49 yr	0.73	0.659	19.24	0.093	0.132	6.16	0.030	0.042
Females 13–49 yr	0.6	0.659	19.24	0.076	0.109	6.16	0.024	0.035
≥50 yr	0.58	0.659	19.24	0.074	0.105	6.16	0.024	0.034

[a] Value from Table 11-5 in the EPA *Handbook (20).*
[b] Mean TEQ is the mean sum TEQ per gram of lipid *(5, 13).*
[c] Value from Table 11-38 in the EPA *Handbook (20).*
[d] Amount of beef consumed × mean beef TEQ × fat % in nonlean beef.
[e] Mean exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of body wt/day (7×10^{-10} mg/kg of body wt/day) *(21, 22).*
[f] Amount of beef consumed × mean beef TEQ × fat % in lean beef.

The FSIS estimated average daily dietary exposures to DLCs from its regulated products for comparison with the RfD. The dietary exposure estimates are reported here and compared with the RfD. This direct comparative study indicates very few circumstances in which consumption of meat and poultry products in the United States would result in exposure that would exceed the RfD.

MATERIALS AND METHODS

Two approaches for dietary ingestion rates were used. The first incorporated mean ingestion rates from the EPA's *Exposure Factors Handbook: 2011 Edition (20)* that are based on 2003 through 2006 data from the National Health and Nutrition Examination Survey (NHANES) database. The mean ingestion rates (or consumption patterns) in the EPA *Handbook* represent typical (or usual) dietary ingestion rates for the U.S. population. The second approach incorporated the consumption recommendations from the USDA Food Patterns in the *Dietary Guidelines for Americans 2010 (15)* because they are recommendations for a healthy diet. Ingestion rates based on these two approaches were separately combined with the DLC concentrations in various meat and poultry products (beef, pork, chicken, and turkey) from the USDA dioxin survey *(5)* to estimate dietary exposures to DLCs from the FSIS regulated meat and poultry products. The estimated dietary exposures to DLCs from each approach were then compared with the RfD.

For the estimated dietary exposures, estimates for only beef are presented here in Tables 1 through 7 because the beef estimates are higher than those for the other three food product classes for all scenarios examined. The estimates for pork, chicken, and turkey can be found in Supplemental Tables 1 through 7 on the USDA Web site *(14).*

TABLE 2. *Highest dioxin exposure from beef, based on beef consumption*

Study group	Amt of beef consumed (g/kg/day)[a]	Highest beef TEQ (pg/g)	Nonlean beef			Lean beef		
			% fat[c]	Highest DLC exposure (pg/kg of bw/day)[d]	Comparison with the RfD[e]	% fat[c]	Highest DLC exposure (pg/kg of bw/day)[f]	Comparison with the RfD[e]
Whole population	0.77	4.857	19.24	0.720	1.028	6.16	0.230	0.329
Birth to 1 yr	0.34	4.857	19.24	0.318	0.454	6.16	0.102	0.145
1–2 yr	1.38	4.857	19.24	1.290	1.842	6.16	0.413	0.590
3–5 yr	1.42	4.857	19.24	1.327	1.896	6.16	0.425	0.607
6–12 yr	1.11	4.857	19.24	1.037	1.482	6.16	0.332	0.474
13–19 yr	0.83	4.857	19.24	0.776	1.108	6.16	0.248	0.355
20–49 yr	0.73	4.857	19.24	0.682	0.975	6.16	0.218	0.312
Females 13–49 yr	0.6	4.857	19.24	0.561	0.801	6.16	0.180	0.256
≥50 yr	0.58	4.857	19.24	0.542	0.774	6.16	0.174	0.248

[a] Value from Table 11-5 in the EPA *Handbook (20).*
[b] Highest TEQ is the highest sum TEQ per gram of lipid *(5, 13).*
[c] Value from Table 11-38 in the EPA *Handbook (20).*
[d] Amount of beef consumed × highest beef TEQ × fat % in nonlean beef.
[e] Highest exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of body wt/day (7×10^{-10} mg/kg of body wt/day) *(21, 22).*
[f] Amount of beef consumed × highest beef TEQ × fat % in lean beef.

TABLE 3. *Dioxin exposure from beef as one of several protein foods sources; mean recommended calories and mean TEQ*

Study group	Mean calories[a]	Recommended amt of protein foods (oz/day)[a]	Recommended amt of meat, poultry, eggs (oz/day)[b]	Meat as % of all meat, poultry, eggs[c]	Recommended amt of meat (oz/day)[d]	Beef as % of all meat[e]	Recommended amt of beef per day[f]		Body wt (kg)[h]	Amt of beef consumed (g/kg/day)[i]	Mean beef TEQ (pg/g)[j]	% fat in lean beef[k]	DLC exposure based on recommended consumption (pg/kg of bw/day)[l]	Comparison of DLC exposure with the RfD[m]
							Ounces	Grams[g]						
1–2 yr	1,000	2.0	1.4	49.05	0.7	67	0.47	13.310	11.4	1.17	0.659	6.16	0.047	0.068
3–5 yr	1,400	4.0	2.7	49.05	1.3	67	0.89	25.288	18.6	1.36	0.659	6.16	0.055	0.079
6–12 yr	1,800	5.0	3.4	49.05	1.7	67	1.13	31.943	31.8	1.00	0.659	6.16	0.041	0.058
13–19 yr	2,600	6.5	4.4	49.05	2.2	67	1.46	41.260	71.6	0.58	0.659	6.16	0.023	0.033
20–49 yr	2,600	6.5	4.4	49.05	2.2	67	1.46	41.260	80	0.52	0.659	6.16	0.021	0.030
Females 13–49 yr	1,800	5.0	3.4	49.05	1.7	67	1.13	31.943	70[n]	0.46	0.659	6.16	0.019	0.026
≥50 yr	2,000	5.5	3.7	49.05	1.8	67	1.22	34.605	80	0.43	0.659	6.16	0.018	0.025
U.S. adults, usual intake	2,000	5.5			2.5[o]	67	1.68	47.486	80	0.594	0.659	6.16	0.024	0.034
U.S. recommended intake	2,000	5.5			1.8[o]	67	1.21	34.190	80	0.427	0.659	6.16	0.017	0.025

[a] Based on recommendations from the USDA *Guidelines (15),* specifically Appendices 6 and 7 (http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm).
[b] Based on recommendations from the USDA *Guidelines (15),* specifically Appendix 7 at http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm. For example, for a 1,000-calorie diet, 10 oz/week is divided by 7 days/week.
[c] Personal communication *(12).*
[d] Meat as % of all meat, poultry, and eggs × recommended amount of meat, poultry, and eggs.
[e] Beef represents 67% of the ''meats'' subgroup, i.e., beef, ground beef, beef liver, and beef luncheon meats. From the USDA Food Patterns (http://www.cnpp.usda.gov/Publications/USDAFoodPatterns/ItemClustersAndRepFoods.pdf).
[f] Recommended amount of meat × beef as a % of all meat.
[g] Conversion from ounces to grams at 28.35 g/oz.
[h] Value for body weight (bw) from Table 8-1 in the EPA *Handbook (20).*
[i] Recommended amount of beef per bw.
[j] Mean sum TEQ per gram of lipid *(5, 13).*
[k] Value from Table 11-38 in the EPA *Handbook (20).*
[l] Amount of beef consumed × mean beef TEQ × fat % in lean beef.
[m] Exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of bw/day (7×10^{-10} mg/kg of bw/day) *(21, 22).*
[n] Average, taken from Table 8-5 in the EPA *Handbook (20).*
[o] Usual and recommended U.S. intake for meat portion of protein foods is taken from Table 5-1 in the *Guidelines (15)* for a 2,000-calorie diet.

TABLE 4. *Dioxin exposure from beef as one of several protein foods sources; mean recommended calories and highest TEQ*

Study group	Mean calories[a]	Recommended amt of protein foods (oz/day)[a]	Recommended amt of meat, poultry, eggs (oz/day)[b]	Meat as % of all meat, poultry, eggs[c]	Recommended amt of meat (oz/day)[d]	Beef as % of all meat[e]	Recommended amt of beef per day[f]		Body wt (kg)[h]	Amt of beef consumed (g/kg/day)[i]	Highest beef TEQ (pg/g)[j]	% fat in lean beef[k]	DLC exposure based on recommended consumption (pg/kg of bw/day)[l]	Comparison of DLC exposure with the RfD[m]
							Ounces	Grams[g]						
1–2 yr	1,000	2.0	1.4	49.05	0.7	67	0.47	13.310	11.4	1.17	4.857	6.16	0.349	0.499
3–5 yr	1,400	4.0	2.7	49.05	1.3	67	0.89	25.288	18.6	1.36	4.857	6.16	0.407	0.581
6–12 yr	1,800	5.0	3.4	49.05	1.7	67	1.13	31.943	31.8	1.00	4.857	6.16	0.301	0.429
13–19 yr	2,600	6.5	4.4	49.05	2.2	67	1.46	41.260	71.6	0.58	4.857	6.16	0.172	0.246
20–49 yr	2,600	6.5	4.4	49.05	2.2	67	1.46	41.260	80	0.52	4.857	6.16	0.154	0.220
Females 13–49 yr	1,800	5.0	3.4	49.05	1.7	67	1.13	31.943	70[n]	0.46	4.857	6.16	0.137	0.195
≥50 yr	2,000	5.5	3.7	49.05	1.8	67	1.22	34.605	80	0.43	4.857	6.16	0.129	0.185
U.S. adults, usual intake	2,000	5.5			2.5[o]	67	1.68	47.486	80	0.594	4.857	6.16	0.178	0.254
U.S. recommended intake	2,000	5.5			1.8[o]	67	1.21	34.190	80	0.427	4.857	6.16	0.128	0.183

[a] Based on recommendations from the USDA *Guidelines (15),* specifically Appendices 6 and 7 (http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm).
[b] Based on recommendations from the USDA *Guidelines (15),* specifically Appendix 7 at http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm. For example, for a 1,000-calorie diet, 10 oz/week is divided by 7 days/week.
[c] Personal communication *(12).*
[d] Meat as % of all meat, poultry, and eggs × recommended amount of meat, poultry, and eggs.
[e] Beef represents 67% of the ''meats'' subgroup, i.e., beef, ground beef, beef liver, and beef luncheon meats. From the USDA Food Patterns (http://www.cnpp.usda.gov/Publications/USDAFoodPatterns/ItemClustersAndRepFoods.pdf).
[f] Recommended amount of meat × beef as a % of all meat.
[g] Conversion from ounces to grams at 28.35 g/oz.
[h] Value for body weight (bw) from Table 8-1 in the EPA *Handbook (20).*
[i] Recommended amount of beef per bw.
[j] Highest TEQ per gram of lipid *(5, 13).*
[k] Value from Table 11-38 in the EPA *Handbook (20).*
[l] Amount of beef consumed × highest beef TEQ × fat % in lean beef.
[m] Exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of bw/day (7×10^{-10} mg/kg of bw/day) *(21, 22).*
[n] Average, taken from Table 8-5 in the EPA *Handbook (20).*
[o] Usual and recommended U.S. intake for meat portion of protein foods is taken from Table 5-1 in the *Guidelines (15)* for a 2,000-calorie diet.

TABLE 5. *Dioxin exposure from beef as one of several protein foods sources; highest recommended calories and mean TEQ*

Study group	Highest calories[a]	Recommended amt of protein foods (oz/day)[a]	Recommended amt of meat, poultry, eggs (oz/day)[b]	Meat as % of all meat, poultry, eggs[c]	Recommended amt of meat (oz/day)[d]	Beef as % of all meat[e]	Recommended amt of beef per day[f]		Body wt (kg)[h]	Amt of beef consumed (g/kg/day)[i]	Mean beef TEQ (pg/g)[j]	% fat in lean beef[k]	DLC exposure based on recommended consumption (pg/kg of bw/day)[l]	Comparison of DLC exposure with the RfD[m]
							Ounces	Grams[g]						
Children 1–2 yr	1,000	2.0	1.4	49.05	0.7	67	0.47	13.310	11.4	1.17	0.659	6.16	0.047	0.068
Females 3–5 yr	1,600	5.0	3.4	49.05	1.7	67	1.13	31.943	18.3	1.75	0.659	6.16	0.071	0.101
Males 3–5 yr	1,600	5.0	3.4	49.05	1.7	67	1.13	31.943	18.8	1.70	0.659	6.16	0.069	0.099
Females 6–12 yr	2,200	6.0	4.1	49.05	2.0	67	1.36	38.598	31.7	1.22	0.659	6.16	0.049	0.071
Males 6–12 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	31.9	1.29	0.659	6.16	0.053	0.075
Females 13–19 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	65.9	0.63	0.659	6.16	0.025	0.036
Males 13–19 yr	3,200	7.0	4.9	49.05	2.4	67	1.60	45.253	77.3	0.59	0.659	6.16	0.024	0.034
Females 20–49 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	77.1	0.54	0.659	6.16	0.022	0.031
Males 20–49 yr	3,000	7.0	4.9	49.05	2.4	67	1.60	45.253	90.5	0.50	0.659	6.16	0.020	0.029
Females ≥50 yr	2,200	6.0	4.1	49.05	2.0	67	1.36	38.598	77.5	0.50	0.659	6.16	0.020	0.029
Males ≥50 yr	2,800	7.0	4.9	49.05	2.4	67	1.60	45.253	89.5	0.51	0.659	6.16	0.021	0.029
U.S. adults, usual intake	2,000	5.5			2.5[n]	67	1.68	47.486	80	0.594	0.659	6.16	0.024	0.034
U.S. recommended intake	2,000	5.5			1.8[n]	67	1.21	34.190	80	0.427	0.659	6.16	0.017	0.025

[a] Based on recommendations from the USDA *Guidelines (15),* specifically Appendices 6 and 7 (http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm).
[b] Based on recommendations from the USDA *Guidelines (15),* specifically Appendix 7 at http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm. For example, for a 1,000-calorie diet, 10 oz/week is divided by 7 days/week.
[c] Personal communication *(12).*
[d] Meat as % of all meat, poultry, and eggs × recommended amount of meat, poultry, and eggs.
[e] Beef represents 67% of the ''meats'' subgroup, i.e., beef, ground beef, beef liver, and beef luncheon meats. From the USDA Food Patterns (http://www.cnpp.usda.gov/Publications/USDAFoodPatterns/ItemClustersAndRepFoods.pdf).
[f] Recommended amount of meat × beef as a % of all meat.
[g] Conversion from ounces to grams at 28.35 g/oz.
[h] Value for body weight (bw) from Tables 8-3, 8-4, and 8-5 in the EPA *Handbook (20).*
[i] Recommended amount of beef per bw.
[j] Mean sum TEQ per gram of lipid *(5, 13).*
[k] Value from Table 11-38 in the EPA *Handbook (20).*
[l] Amount of beef consumed × mean beef TEQ × fat % in lean beef.
[m] Exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of bw/day (7×10^{-10} mg/kg of bw/day) *(21, 22).*
[n] Usual and recommended U.S. intake for meat portion of protein foods is taken from Table 5-1 in the *Guidelines (15)* for a 2,000-calorie diet.

TABLE 6. *Dioxin exposure from beef as one of several protein foods sources; highest recommended calories and highest TEQ*

Study group	Highest calories	Recommended amt of protein foods (oz/day)[a]	Recommended amt of meat, poultry, eggs (oz/day)[b]	Meat as % of all meat, poultry, eggs[c]	Recommended amt of meat (oz/day)[d]	Beef as % of all meat[e]	Recommended amt of beef per day[f]		Body wt (kg)[h]	Amt of beef consumed (g/kg/day)[i]	Highest beef TEQ (pg/g)[j]	% fat in lean beef[k]	DLC exposure based on recommended consumption (pg/kg of bw/day)[l]	Comparison of DLC exposure with the RfD[m]
							Ounces	Grams[g]						
Children 1–2 yr	1,000	2.0	1.4	49.05	0.7	67	0.47	13.310	11.4	1.17	4.857	6.16	0.349	0.499
Females 3–5 yr	1,600	5.0	3.4	49.05	1.7	67	1.13	31.943	18.3	1.75	4.857	6.16	0.522	0.746
Males 3–5 yr	1,600	5.0	3.4	49.05	1.7	67	1.13	31.943	18.8	1.70	4.857	6.16	0.508	0.726
Females 6–12 yr	2,200	6.0	4.1	49.05	2.0	67	1.36	38.598	31.7	1.22	4.857	6.16	0.364	0.520
Males 6–12 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	31.9	1.29	4.857	6.16	0.387	0.553
Females 13–19 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	65.9	0.63	4.857	6.16	0.187	0.268
Males 13–19 yr	3,200	7.0	4.9	49.05	2.4	67	1.60	45.253	77.3	0.59	4.857	6.16	0.175	0.250
Females 20–49 yr	2,400	6.5	4.4	49.05	2.2	67	1.46	41.260	77.1	0.54	4.857	6.16	0.160	0.229
Males 20–49 yr	3,000	7.0	4.9	49.05	2.4	67	1.60	45.253	90.5	0.50	4.857	6.16	0.150	0.214
Females ≥50 yr	2,200	6.0	4.1	49.05	2.0	67	1.36	38.598	77.5	0.50	4.857	6.16	0.149	0.213
Males ≥50 yr	2,800	7.0	4.9	49.05	2.4	67	1.60	45.253	89.5	0.51	4.857	6.16	0.151	0.216
U.S. adults, usual intake	2,000	5.5			2.5[n]	67	1.68	47.486	80	0.594	4.857	6.16	0.178	0.254
U.S. recommended intake	2,000	5.5			1.8[n]	67	1.21	34.190	80	0.427	4.857	6.16	0.128	0.183

[a] Based on recommendations from the USDA *Guidelines (15),* specifically Appendices 6 and 7 (http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm).
[b] Based on recommendations from the USDA *Guidelines (15),* specifically Appendix 7 at http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm. For example, for a 1,000-calorie diet, 10 oz/week is divided by 7 days/week.
[c] Personal communication *(12).*
[d] Meat as % of all meat, poultry, and eggs × recommended amount of meat, poultry, and eggs.
[e] Beef represents 67% of the ''meats'' subgroup, i.e., beef, ground beef, beef liver, and beef luncheon meats. From the USDA Food Patterns (http://www.cnpp.usda.gov/Publications/USDAFoodPatterns/ItemClustersAndRepFoods.pdf).
[f] Recommended amount of meat × beef as a % of all meat.
[g] Conversion from ounces to grams at 28.35 g/oz.
[h] Value for body weight (bw) from Tables 8-3, 8-4, and 8-5 in the EPA *Handbook (20).*
[i] Recommended amount of beef per bw.
[j] Highest TEQ per gram of lipid *(5, 13).*
[k] Value from Table 11-38 in the EPA *Handbook (20).*
[l] Amount of beef consumed × highest beef TEQ × fat % in lean beef.
[m] Exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of bw/day (7×10^{-10} mg/kg of bw/day) *(21, 22).*
[n] Usual and recommended U.S. intake for meat portion of protein foods is taken from Table 5-1 in the *Guidelines (15)* for a 2,000-calorie diet.

TABLE 7. *Mean dioxin exposure from beef as the sole protein food consumed*

Study group	Recommended amt of protein foods[a]		Body wt (kg)[c]	Amt of protein foods consumed (g/kg/day)[d]	Mean beef TEQ (pg/g)[e]	% fat in lean beef[f]	DLC exposure based on recommended consumption (pg/kg of bw/day)[g]	Comparison of DLC exposure with the RfD[h]
	Ounces	Grams[b]						
1–2 yr	2.0	56.700	11.4	4.97	0.659	6.16	0.202	0.288
3–5 yr	4.0	113.400	18.6	6.10	0.659	6.16	0.247	0.354
6–12 yr	5.0	141.750	31.8	4.46	0.659	6.16	0.181	0.259
13–19 yr	6.5	184.275	71.6	2.57	0.659	6.16	0.104	0.149
20–49 yr	6.5	184.275	80	2.30	0.659	6.16	0.094	0.134
Females 13–49 yr	5.0	141.750	70[i]	2.03	0.659	6.16	0.082	0.117
≥50 yr	5.5	155.925	80	1.95	0.659	6.16	0.079	0.113

[a] Based on recommendations from the USDA *Guidelines (15),* specifically Appendices 6 and 7 (http://www.cnpp.usda.gov/DGAs2010-PolicyDocument.htm).
[b] Conversion from ounces to grams at 28.35 g/oz.
[c] Value for body weight (bw) from Table 8-1 in the EPA *Handbook (20).*
[d] Recommended amount of protein foods per bw.
[e] Mean sum TEQ per gram of lipid *(5, 13).*
[f] Value from Table 11-38 in the EPA *Handbook (20).*
[g] Amount of beef consumed × mean beef TEQ × fat % in lean beef.
[h] Exposure ÷ RfD for dioxin. RfD for dioxin = 0.7 pg/kg of bw/day (7×10^{-10} mg/kg of bw/day) *(21, 22).*
[i] Average, taken from Table 8-5 in the EPA *Handbook (20).*

TEQ in meat and poultry products. Because people are not exposed exclusively to TCDD in their diets, the RfD is assumed to apply to the total toxic equivalent quotient (TEQ) for exposure to DLCs. To obtain a TEQ for a food product, the concentration of each DLC is multiplied by its toxicity equivalence factor. The resulting value for all DLCs are summed to obtain a TEQ. This TEQ multiplied by the food consumption rate provides the total TEQ associated with that food product *(5, 6).* This approach is consistent with assessments of human health risks posed by exposure to mixtures of TCDD and DLCs, including PCDDs, PCDFs, and no-PCBs *(19).* This study and the survey incorporated the consensus mammalian toxicity equivalence factors developed by the World Health Organization *(23).*

A survey of TCDD and DLCs in domestic meat and poultry was conducted by the USDA from September 2007 to September 2008 *(5).* Seventeen toxic PCDD and PCDF congeners and four no-PCB congeners were measured in 510 beef (steer and heifer), market hog, young chicken, and young turkey fat samples. From this survey, TEQs were determined for each sample, and mean TEQs are used here in the estimates of dietary exposure. The highest TEQs for each product class were identified from the survey and are used here for determining estimates.

Consumption (ingestion) rates based on dietary intake. The EPA's *Handbook (20)* rates for the consumption (ingestion) rates for meats in the U.S. population were based on the EPA analysis of consumption data from the 2003 through 2006 NHANES *(2).* The NHANES dietary interview, ''What We Eat in America,'' consisted of 24-h intake data collected on two nonconsecutive days from each survey participant. The EPA's analysis of the NHANES data provided distributions of intake rates for various age groups, from children to adults, normalized by body weight. The data set was designed to be representative of the U.S. population and includes 4 years of combined intake data. The age groups in the present study's corresponding tables followed the *Handbook* age groups.

The *Handbook* provides ingestion rates for beef, pork, and poultry, but intake rates are not listed for specific types of poultry (e.g., chicken and turkey). Because the USDA survey provides DLC concentrations for chicken and turkey instead of total poultry, it was necessary to partition the intake rate for poultry into separate intake rates for chicken and turkey. Crème Food Exposure Assessment Software *(3)* was used to partition poultry consumption (see Supplemental Table 8 *(14)*). This proportionality was then applied for the chicken and turkey estimates to better align with the FSIS food product classes and the Food Patterns in the *Guidelines (15).* Crème software is on a secure server that has fast turnaround times with consumption data such as that from NHANES, with no data preparation needed. This software can perform a food consumption assessment with the current NHANES data implementing open source methods to generate both acute and lifetime (chronic) consumption estimates *(3).* However, for the present study, the Crème software was used simply as an interface to access NHANES data and was not used for any exposure calculations.

The fat percentage also was considered in the exposure estimates because DLCs accumulate in the lipid portion of foods. Thus, dietary exposures were estimated for both lean and nonlean meats and poultry. The fat percentages in nonlean and lean meats and poultry were taken from the EPA *Handbook.*

Consumption rates based on the *Guidelines*. The USDA and U.S. Department of Health and Human Services *Dietary Guidelines for Americans 2010 (15)* provides recommended dietary patterns (the USDA Food Patterns) for various groups within the U.S. population based on caloric intake and activity level. Usual and recommended U.S. intakes corresponding to a 2,000-calorie adult diet also are included. The proportional breakout within food categories of the overall recommended Protein Foods Intakes for adults is based on the NHANES ''What We Eat in America'' 2001 through 2004 results *(15),* as are the usual intakes. The age groups in the corresponding tables followed the age and calorie groups from the *Guidelines.*

These dietary estimates are based on various combinations of input values to estimate different exposure scenarios. Because in the *Guidelines* intake recommendations are grouped for several

types of Protein Foods (e.g., meat, poultry, and eggs), this group was broken into its meat versus poultry components and then into beef, pork, chicken, and turkey components. This specificity was necessary to match the components directly with those in the USDA dioxin survey *(5)*. The estimates could then be calculated for each of these four food product classes at mean and highest TEQs and mean and highest caloric intakes (highest caloric intake corresponds to a recommended active healthy lifestyle). Estimates were made for mean caloric intakes with beef, pork, chicken, or turkey as the sole daily protein food consumed for comparison with the estimated recommended amount.

Comparison with the RfD. As a final comparison, the estimated exposures for all four food classes were compared with the EPA RfD. This calculated value is similar to the hazard quotient, which provides the ratio of exposure to a substance to a toxicity value selected for the risk assessment for that substance *(18)*. A ratio greater than 1 is of potential concern; a ratio less than 1 indicates that noncancer risks would not be expected.

RESULTS

Two groups of estimates were calculated in this study. The first group of estimates reflects exposures based on actual consumption patterns from the EPA's *Handbook* (Tables 1 and 2). The second group of estimates reflects exposures based on recommendations in the *Guidelines* (Tables 3 through 7). The dietary estimate calculations and formulas are found in each table.

Mean dioxin exposure based on consumption. Table 1 presents the mean DLC exposure from consumption of beef, based on U.S. consumption rates. DLC exposure from consumption of pork, chicken, and turkey are presented in Supplemental Table 1. Exposure from each food product class was estimated using the same approach. For example, for beef, the daily beef consumption (based on chronic exposure) was combined with the mean beef TEQ (from the USDA survey results) and the percentage of fat associated with beef to estimate a mean U.S. population exposure to dioxins in beef. This calculation applies to consumption of both nonlean and lean beef. Because the EPA's *Handbook* provides consumption rates for different age groups, estimates for the different age groups were calculated in addition to those for the population as a whole. Females 13 to 49 years of age are in a separate category to represent women of child-bearing age. The age group of 50 years and older represents the aging population.

Mean exposure to DLCs was compared with the RfD. The comparisons for each age group and the population as a whole revealed that DLC exposure from consumption of any one of these food product classes on a daily basis is below the RfD recommended by the EPA. Beef consumption provided the highest level of exposure. Children (1 to 2 years and 3 to 5 years of age) have the highest relative exposure to dioxins (e.g., about 25% of the RfD), probably because of their lower weights. Consumption of lean product significantly reduces the relative exposure to DLCs in the diet; when there is less fat (lipid) the reservoir for DLC accumulation is reduced. For example, for children 1 to 2 years of age the ratio of beef-associated DLC exposure to the RfD dropped from 0.25 (consumption of nonlean beef) to 0.08 (consumption of lean beef).

Highest dioxin exposure based on consumption. Table 2 examines a possible high-end exposure to DLCs from consumption of beef (the other three food product class exposures are presented in Supplemental Table 2). Table 2 differs from Table 1 in the use of the highest TEQ values from the USDA survey; the highest TEQ is based on the single highest value found for each product. This presumes that people are eating any one of these product classes with the highest amount of DLCs (found in a single survey point) on a daily basis.

The estimates indicate that beef provides more exposure to DLCs in the diet than do the other three food product classes. Based on the high-end exposure, the whole population is exposed to DLCs in nonlean beef at the RfD level. Children would be exposed to dioxins in beef at almost twice the RfD. Consumption of lean beef lowers all the DLC exposures from beef to below the RfD for all age groups. Exposure to DLCs from consumption of pork, chicken, or turkey at their highest respective TEQ is below the RfD for both nonlean and lean products. Children still have the highest relative exposure (e.g., almost half the RfD for nonlean chicken for children 1 to 2 years of age).

Dioxin exposure based on the *Guidelines*. Tables 3 through 7 examine several scenarios using the recommended intakes from the *Guidelines (15)*. Tables 3 through 6 provide estimates for DLC exposure from beef consumed as one of several Protein Foods as designated in the *Guidelines*. Table 7 assumes that beef is the sole daily Protein Food consumed for comparison with the other scenarios. The same scenario estimates for pork, chicken, and turkey are presented in Supplemental Tables 3 through 7. Table 3 specifically lists the mean number of calories for the designated age groups found in the *Guidelines*. The bottom row of each table (except Table 7) provides the usual U.S. adult intake and the recommended *Guidelines* intake for a 2,000-calorie diet. These data provide a comparison for the different age groups. For the highest calorie intakes in Tables 5 and 6, the age groups are broken down further by gender because their caloric needs differ with active lifestyles.

When the mean TEQ values for dioxins in beef, pork, chicken, and turkey are used with the recommended number of calories and amounts of Protein Foods, the exposure to DLCs for all age groups fell well below the RfD (Table 3 and Supplemental Table 3). Similar to the pattern displayed in the other tables, beef intake for children was responsible for the highest relative exposure to DLCs (e.g., about 8% of the RfD for children 3 to 5 years of age). The usual and recommended intakes of beef for adults as part of 2,000-calorie diet is estimated to be about 2 to 4% of the RfD. When the highest TEQ is used with the recommended number of calories, the DLC exposure for all age groups increased several fold (Table 4). The highest exposure estimated was for children 3 to 5 years of age, for which exposure to DLCs in beef was estimated to be about 60% of the RfD (up from the 8% estimate with the mean TEQ). The

DLC exposure associated with the other three food product classes also increased to 1 to 9% of the RfD for all age groups (Supplemental Table 4).

Table 5 pairs the mean TEQ with the highest recommended number of calories to estimate the likely DLC exposure based on *Guidelines* for individuals with a high level of physical activity, e.g., equivalent to walking three or more miles per day. A similar pattern is found for children; beef consumption is estimated to result in the highest relative DLC exposure (at about 10% of the RfD) for both females and males. The DLC exposure from the usual and recommended adult beef intake as part of a 2,000-calorie diet is 2 to 4% of the RfD. The exposure to DLCs from pork, chicken, and turkey is estimated to be much lower than that from beef (Supplemental Table 5).

Table 6 and Supplemental Table 6 display the highest recommended number of calories for a high level of physical activity to estimate DLC exposure based on the highest TEQ for each food product class. The highest TEQ is based on the single highest value found for each food product. This approach presumes that people are eating any one of these products with the highest amount of DLCs (found in a single survey point) on a daily basis. Even with the high-end DLC concentration and highest calorie intake, none of the estimated values for the individual products exceeded the RfD for any age group. However, the DLC exposure from each product class represented a higher percentage of the RfD than seen in Table 5. For example, exposure estimates for children reached almost 80% of the RfD for beef intake.

In Table 7 and Supplemental Table 7, the mean TEQ is paired with the recommended amount of Protein Foods from the *Guidelines,* assuming that each food product class is the sole source of Protein Foods. This scenario uses the same approach as shown in Table 1 but with the *Guidelines* recommendations for Protein Food consumption. Values for only lean meat and poultry are considered in Table 7 and Supplemental Table 7 because the *Guidelines* recommend consumption of leaner products. All exposure estimates fell below the RfD, with beef consumption associated with the highest relative DLC exposure in children (e.g., almost 40% for children 3 to 5 years of age).

DISCUSSION

The estimates of DLC TEQ exposures from the consumption of meat and poultry were compared with the EPA-established RfD for TCDD *(22)* to evaluate the potential for a noncancer health concern from consumption of these food products. The exposure estimates indicate that a typical U.S. dietary exposure to DLCs from each of the FSIS-regulated meat and poultry products would be below the EPA RfD. The values calculated for nonlean products all fell well below the RfD for all age groups. Beef consumption is the largest contributor to DLC exposure among the four food product classes examined here (exposure about 10-fold greater than the other three individual food product classes). However, the Protein Foods examined here represent only a portion of a person's total diet. DLCs can be found in other products (e.g., fish), which may add to the DLC burden. Because the *Guidelines* recommend eating less solid fat, which includes animal fats, estimates also were calculated for lean products. For these lean products, the DLC exposure dropped considerably to about one-third of the exposure associated with nonlean products because of the difference in fat percentage. Thus, less animal fat in the diet would be advantageous for lowering possible DLC exposures because DLCs are concentrated in animal fat.

When using the highest DLC exposure from the four food product classes in the calculations, the estimated DLC exposures increased from that associated with the typical diet. Only when consuming nonlean beef with the highest measured concentration of DLCs are most people exposed to a chronic daily DLC concentration estimated at up to twice the RfD. These larger estimates associated with beef consumption, particularly in children, contribute to the whole population estimate at the RfD. However, a person is unlikely to eat a daily diet of meat and poultry products containing the highest concentrations of DLCs for a chronic exposure. The highest TEQ for each food product was well above its mean, indicating that the highest TEQ is likely to be rarely encountered on a continual basis. The ratio of mean TEQ to highest TEQ for each food product class indicate that the amount of DLCs in the fat of these samples tended to skew toward the lower end of the range: 0.659/4.857 pg/g for beef, 0.16/1.367 pg/g for pork, 0.174/1.281 pg/g for chicken, and 0.611/4.597 pg/g for turkey. A scenario representing a diet that includes an extremely large amount of meat and/or poultry combined with the mean concentration of DLC in each product was not examined here because this occurrence was assumed to be even less likely than eating a typical diet with a high amount of DLCs. As seen for the typical diet estimates, the estimates for the highest exposure in the diet drop when lean products are consumed.

According to the EPA definition, ''the RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime'' *(22)*. The uncertainty about who may be at risk from a daily oral exposure ranges over an order of magnitude, suggesting that 0.7 pg/kg-day is not an exact value when a sensitive individual or subgroup may be at risk from DLC exposure. Determining the effects of DLCs at or around the RfD depends on how sensitive the person or population is to the effects of DLCs. Not every person exposed at the RfD or even twice the RfD, with its built-in uncertainty factors accounting for variability, would be expected to be at appreciable risk of deleterious effects (i.e., be sensitive). Combined with the unlikelihood that someone will consume a daily diet of meat and poultry products with the maximum measured DLC concentration, DLC exposure from meat and poultry at the RfD will be unlikely and difficult to ascertain an appreciable health risk.

Following the dietary pattern established in the USDA Food Patterns based on the *Guidelines,* all exposures to

DLCs from FSIS-regulated products were estimated to be well below the RfD. Even when the highest measured DLC concentration was used with the highest daily calorie recommendation, the estimates were below the RfD; this approach might be thought of as a possible ''worst-case'' scenario based on recommended intakes. As seen with the typical dietary estimates in the other tables, beef consumption was the most important contributor to high concentrations of DLCs. These estimates using the USDA Food Patterns highlight the importance of eating less animal fat.

Lorber et al. *(7)* estimated an average U.S. adult DLC intake for several types of exposure (inhalation, soil ingestion, soil dermal contact, water ingestion, and consumption of animal products) at about 0.5 pg/kg-bw-day (for a 70-kg adult). This estimate included the most recent meat and poultry DLC concentrations from Huwe et al. *(5),* the same values used for the calculations reported here. When looking at the typical mean consumption for adults (e.g., in Table 1 and the last two rows of Tables 3 and 5), the DLC exposure was estimated to be below this average adult exposure. However, the contribution of meat and poultry consumption to total DLC exposure cannot be overlooked because animal fat is a major contributor to DLC exposure *(21)*. A diet lower in animal fat would likely reduce one's potential exposure to DLCs.

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