Infant Exposure to Chemicals in Breast Milk in the United States: What We Need to Learn From a Breast Milk Monitoring Program

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The presence of environmental chemicals in breast milk has gained increased attention from regulatory agencies and groups advocating women's and children's health. As the published literature on chemicals in breast milk has grown, there remains a paucity of data on parameters related to infant exposure via breast-feeding, particularly those with a time-dependent nature. This information is necessary for performing exposure assessments without heavy reliance on default assumptions. Although most experts agree that, except in unusual situations, breast-feeding is the preferred nutrition, a better understanding of an infant's level of exposure to environmental chemicals is essential, particularly in the United States where information is sparse. In this paper, we review extant data on two parameters needed to conduct realistic exposure assessments for breast-fed infants: *a*) levels of chemicals in human milk in the United States (and trends for dioxins/furans); and *b*) elimination kinetics (depuration) of chemicals from the mother during breast-feeding. The limitations of the existing data restrict our ability to predict infant body burdens of these chemicals from breast-feeding. Although the data indicate a decrease in breast milk dioxin toxic equivalents over time for several countries, the results for the United States are ambiguous. Whereas available information supports the inclusion of depuration when estimating exposures from breast-feeding, the data do not support selection of a specific rate of depuration. A program of breast milk monitoring would serve to provide the information needed to assess infant exposures during breast-feeding and develop scientifically sound information on benefits and risks of breast-feeding in the United States. *Key words*: breast milk, chlorinated organic chemicals, depuration, dioxin, monitoring program, time trends. *Environ Health Perspect* 109:75–88 (2001). [Online 20 December 2000]
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It has been known since the 1950s that environmental chemicals are present in breast milk (*1*), but this issue has gained attention over the past few years. For example, the U. S. Environmental Protection Agency (U.S. EPA) noted that indicators of potentially high childhood chemical exposure include chemicals in breast milk and proposed chemicals in breast milk as candidates for testing under the Children's Health Chemical Testing Program (*2*,*3*). In an address to the National Women's Health Leadership Summit, the U.S. EPA (*4*) announced that they had

> set tougher new standards for burning municipal waste—one of the largest sources of dioxin, which accumulates in human tissue and breast milk.…

Further, the Endocrine Disruptor Screening and Testing Advisory Committee recommended that the U.S. EPA screen and potentially test "representative mixtures to which large … segments of the population are exposed," including breast milk (*5*). Groups advocating for women's and children's health have also focused on chemicals in breast milk (*6*,*7*).

Although research has provided information on the types of chemicals likely to be found in breast milk and on the toxicologic aspects of many of these chemicals, there are few data on parameters related to infant exposure via breast-feeding, including those with a time-dependent nature. This type of information is necessary for performing exposure assessments without heavy reliance on default assumptions or on the limited databases currently available. In addition, data collected longitudinally provide information on trends in breast milk chemical levels, which indicate whether controls on sources of contaminants are effective. Without this type of information, it will continue to be difficult to provide a scientifically based and consistent message to interested parties (e.g., doctors, nurses, lactation specialists, and new mothers) on the risks and benefits of breast-feeding and to compare these to formula-feeding.

In this paper, we review the extant data on two of the parameters needed to conduct realistic exposure assessments for breast-feeding infants, the first step in risk/benefit analyses and subsequent formulation of risk/benefit messages. In particular, we focus on what is known about the levels of chemicals in human milk in the United States and the elimination kinetics (depuration) of chemicals from the mother during breast-feeding. Information on, and uncertainties associated with, other breast-feeding–related parameters have been discussed elsewhere (*8*).

Levels and Trends of Environmental Chemicals in Breast Milk in the United States

Chlorinated organic pesticides, polychlorinated biphenyls (PCBs), and polychlorinated dioxins and furans have been the focus of the majority of studies on environmental chemicals in breast milk. We describe the database of published studies of these chemicals in breast milk in the United States and use this database of dioxin and furan concentrations in breast milk to explore whether any trends in concentrations of environmental chemicals (from selected countries and the United States) can be discerned. The discussion on trends is limited to dioxins, which have been examined more fully than most other chemicals [with the possible exception of trichlorobis(*p*-chlorophenyl)ethane (DDT) and its metabolites, reviewed by Smith (*9*)].

Levels

Figure 1 presents data on concentrations of organochlorine pesticides in breast milk from the United States, plotted by year [pre-1986 data: Jensen and Slorach (*10*); post-1985 data: Kostyniak et al. (*11*), Jensen and Slorach (*10*), Mattison et al. (*12*)]; data for DDT and metabolites reviewed by Smith (*9*) have not been included. Figure 2 shows PCB data for breast milk from the United States [pre-1986 data: Jensen and Slorach (*10*); post-1985 data: Hong et al. (*13*), Kostyniak et al. (*11*), Mattison et al. (*12*)]. Data normalized by lipid level (milligrams per kilogram, lipid

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basis) were included in Figures 1 and 2. For studies that collected data over more than 1 year, either the midpoint (for a range of more than 2 years) or the first year was plotted. Information on dioxins and furans in breast milk in the United States is shown in Figure 3.

Given the significant restrictions on manufacture, use, or release of the chemicals shown in Figures 1–3, it is unlikely that pre-1985 data are representative of current breast milk levels. Focusing on data from 1985 forward, the largest databases in the United States are for PCBs and dioxins/furans (Figures 2 and 3). The PCB data derive from studies of women residing in New York [98 donors, Kostyniak et al. (*11*); 50 donors, Hong et al. (*13*)] and Arkansas [942 donors, Mattison et al. (*12*)]. The dioxin data are derived from breast milk samples from women residing in Binghamton, New York [22 samples pooled to one sample, World Health Organization (WHO) (*14*); Schecter et al. (*15*)], Los Angeles, California [21 donors pooled to one sample, WHO (*14*)], Los Angeles County [24 donors pooled, as cited in Jensen and Slorach (*10*)]; and Tennessee [nine donors pooled to one sample, Schecter et al. (*16*)].

Because the data describing levels of environmental chemicals in breast milk from women residing in the United States are geographically limited and from generally small populations, they cannot be considered representative of current breast milk levels of women in the United States in general.

Trends

Because of worldwide attention on dioxins/furans and their reduced release into the environment, it is expected that breast milk levels would be declining in the United States. The analysis presented here suggests that this is the case for many countries. The international databases on dioxins/furans in breast milk were used to explore the extent of breast milk dioxin data and to determine whether any trends in concentrations over time are evident (Table 1). Breast milk data were collected for the years 1970–1998 from published sources. Data were available from the following countries: Austria, Belgium, Canada, Denmark, Finland, Germany, Hungary, Japan, the Netherlands, Norway, Pakistan, Spain, Sweden, United Kingdom, United States, the former Soviet Union, Ukraine, and Yugoslavia. Extremely limited data or data for one year only were available from the following countries: Albania, China, Croatia, Czech Republic, France, India, Italy, Kazakhstan, Lithuania, New Zealand, Poland, Russia, Slovak, South Africa, and Thailand. For breast milk samples collected before 1989, we used a combination of data from a compilation by Jensen and Slorach (*10*) and primary literature. For breast milk samples collected after 1988, data were all from primary literature. We assembled the following information: date, country, number of donors, dioxin and furan congener concentration, toxic equivalency factors (TEF) value, percent lipid, description of sampling location/population, and reference; not all information was available for each sample. We calculated total toxic equivalents (TEQs) for dioxins and furans combined. For the purposes of this paper, "dioxin TEQs" refer to dioxin and furan TEQs combined. We used international TEF (I-TEF) values and WHO TEF values (Table 2) to calculate the TEQs of the dioxins and furans in breast milk (our values are based on I-TEF values).

Because sampling and analysis protocols can substantially impact the results of a breast milk sampling program and because the data assessed in this analysis derive from studies conducted with varied protocols, the comparability of study results is questionable. For example, variation in the time of breast milk sampling (including time postpartum and time of day), the age of the mother, and the number of previously breast-fed children can produce inconsistent interstudy results. In addition, most countries lack adequate numbers of breast milk samples for the data to be considered representative of the entire country. Regardless, the data assembled here represent the preponderance of published data on dioxin in breast milk.

Uncertainties in the breast milk dioxin database, in addition to those mentioned above, impact its usefulness in ascertaining trends in data over time. We describe some of the shortcomings of the reported data below.

Date of sampling. In many cases, the actual year that breast milk sampling was conducted was not provided. In these instances, we used the year of publication for the sake of consistency. However, this clearly biases the time frame of sampling (which was likely to have occurred from 1 to several years before publication) and increases uncertainty in the time-trend analysis. This is particularly important because the preponderance of the data span approximately 15 years; uncertainty regarding the sampling year can clearly impact the results.

In some cases, sampling occurred over a period of more than 1 year. For the purposes of this analysis, if the sampling time frame was 2 years, we used the earlier reported year. If the sampling time frame was > 2 years, we used the midpoint in time.

Congener concentration measurements. In some cases, study authors did not report data for each specific congener, but rather provided summations of certain congeners, particularly for the 2,3,7,8-pentachlorinated dibenzofurans. For these congeners, we used the more conservative TEF of 0.5. Non-reported congeners were considered to have a value of zero. For data reported as "nondetect," and for which detection limits were provided, we used the detection limit as the concentration value.

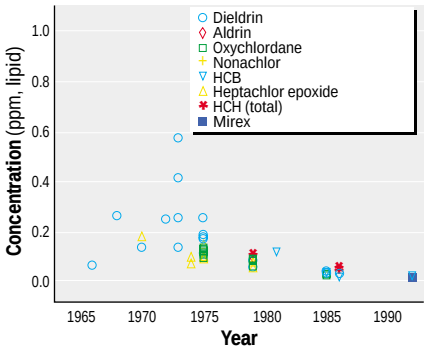

Figure 1. Concentrations of environmental chemicals (organochlorine pesticides and metabolites) in breast milk from the United States (ppm, lipid basis). Abbreviations: HCB, hexachlorobenzene; HCH, hexachlorocyclohexane. DDT and metabolites are not shown. Pre-1985 data from Jensen and Slorach (*10*); data post-1985 from Kostyniak et al. (*11*), Jensen and Slorach (*10*), and Mattison et al. (*12*).

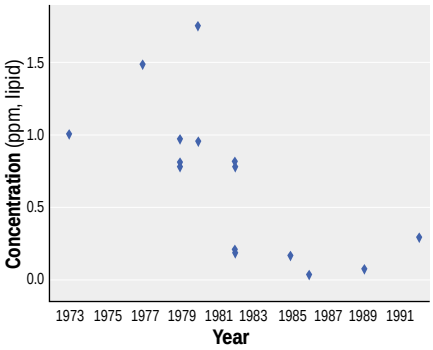

Figure 2. Concentrations of PCBs in breast milk from the United States (ppm, lipid basis) Pre-1985 data from Jensen and Slorach (*10*); data post-1985 from Hong et al. (*13*), Kostyniak et al. (*11*), and Mattison et al. (*12*).

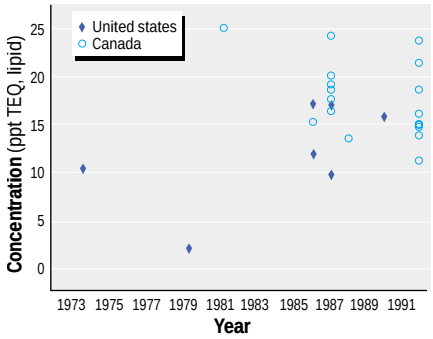

Figure 3. Dioxins/furans in breast milk (ppt TEQ, lipid basis) for the United States and Canada. Data from Table 1 I-TEF values.

Measure of central tendency. Because the dioxin breast milk concentrations are not necessarily normally distributed, the median, geometric mean, or other statistic might be the preferred measure of central tendency (*9*). In addition, it is not clear that central tendency is of primary interest; for example, frequencies of extreme (high or low) concentrations may be more important. However, the arithmetic mean was the most commonly reported measure; thus, for consistency, we used arithmetic means in this analysis.

Sources of variability. Most samples represent a different number of donors (due to pooling). In addition, a certain amount of laboratory variability is associated with the analytical results of each sample. Thus, the samples have different inherent variability; therefore, care is required in interpreting apparent trends.

The results of this analysis indicate an international decline in concentration of dioxin in breast milk over time (Figure 4). High levels of dioxin TEQs in breast milk from the early 1970s are from mothers residing in areas in Vietnam that had been sprayed with Agent Orange, a defoliant contaminated with dioxins, during the Vietnam war. If we focus on the data from the 1980s and 1990s, it is more difficult to discern a trend in breast milk dioxin levels. This is likely due, in part, to the general paucity of data and the uncertainties in the database described above. By examining the data from each country individually, a clearer picture emerges. Breast milk dioxin data from several countries seem to suggest a decline in levels over time (including Austria, Belgium, Denmark, Finland, Germany, Hungary, Japan, the Netherlands, Norway, Pakistan, Sweden (*42*), the United Kingdom, Ukraine, Vietnam, and Yugoslavia); Figure 5 shows

Table 1. Compilation of published international data on dioxin TEQs in breast milk.

Year	Country	No. donors /samples[a]	Location (description)	Reference	Dioxin TEQs: I-TEF (ppt, lipid basis)	Dioxin TEQs: WHO-TEF (ppt, lipid basis)
1992	Albania	10/1	Tirana	(*17*)[b]	4.8	–
1992	Albania	10/1	Librazhd	(*17*)	3.8	–
1986	Austria	54/1	Vienna	(*14*)[c]	17.7	19.7
1986	Austria	51/1	TulIn	(*14*)	19.3	21.8
1992	Austria	13/1	Vienna (urban)	(*17*)	10.7	–
1992	Austria	21/1	TulIn (rural)	(*17*)	10.9	–
1992	Austria	13/1	Brixlegg (industrial)	(*17*)	14.0	–
1987	Belgium	1	Rural	(*14*)	34.4	39.1
1987	Belgium	1	Industrial	(*14*)	41.5	46.6
1987	Belgium	1	Urban	(*14*)	39.3	43.6
1992	Belgium	9	5 Flemish provinces	(*18*)	35.0	40.7
1992	Belgium	8/1	Brabant Wallou	(*17*)	20.8	–
1992	Belgium	20/1	Liege	(*17*)	27.1	–
1992	Belgium	6/1	Brussels	(*17*)	26.6	–
1981	Canada	200/1[d]	Whole country	(*19*)	24.7	29.3
1986	Canada	100[e]	Whole country	(*19*)	15.1	18.0
1987	Canada	19/1	Maritime	(*14*)	16.2	19.0
1987	Canada	34/1	Québec	(*14*)	18.9	22.8
1987	Canada	32/1	Ontario (north and east)	(*14*)	17.4	20.5
1987	Canada	44/1	Ontario (Toronto and southwest)	(*14*)	18.4	21.9
1987	Canada	31/1	Prairies	(*14*)	19.8	23.7
1987	Canada	23/1	British Columbia	(*14*)	24.0	28.9
1989	Canada	105[f]	Northern Québec	(*20*)	19.2	–
1989	Canada	96[f]	Southern Québec	(*20*)	13.3	–
1992	Canada	20/1	Maritimes	(*17*)	11.0	–
1992	Canada	20/1	Québec	(*17*)	13.6	–
1992	Canada	20/1	Ontario	(*17*)	18.3	–
1992	Canada	20/1	Prairies	(*17*)	14.8	–
1992	Canada	20/1	British Columbia	(*17*)	15.8	–
1992	Canada	100/1	All provinces	(*17*)	14.6	–
1992	Canada	12/1	Gaspe	(*17*)	23.4	–
1992	Canada	4/1	Basse Côte-Nord	(*17*)	14.7	–
1992	Canada	4/1	Ungave Bay	(*17*)	14.5	–
1992	Canada	5/1	Hudson Bay	(*17*)	21.1	–
1994	China	50/1	Rural	(*21*)	2.7	3.1
1992	Croatia	10/1	Krk	(*17*)	8.4	–
1992	Croatia	13/1	Zagreb	(*17*)	13.5	–
1992	Czech Republic	11/1	Kladno	(*17,22*)	12.4	13.3
1992	Czech Republic	11/1	Uherské Hradištìě	(*17,22*)	18.5	20.0
1985	Denmark	2	Copenhagen	(*10*)	69.3	84.0
1986	Denmark	10[g]	NP	(*14*)	17.6	20.2
1986	Denmark	42/1	NP	(*14*)	17.7	20.6
1992	Denmark	48/1	7 different cities	(*17*)	15.2	–
1991	East Germany	499[f]	17 regions of former GDR	(*23*)	23.2	27.5
1987	Finland	38/1	Helsinki	(*14*)	18.1	20.8
1987	Finland	31/1	Kuopio	(*14*)	15.8	18.5
1987	Finland	37	Kuopio	(*24*)	20.1	–
1987	Finland	47	Helsinki	(*24*)	26.3	–
1992	Finland	10/1	Helsinki	(*17*)	21.5	–
1992	Finland	24/1	Kuopio	(*17*)	12.0	–
1993	Finland	28	Kuopio	(*24*)	13.6	–
1993	Finland	14	Helsinki	(*24*)	19.9	-

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data for Germany, Norway (for ease of graphing, one value > 100 ppt in 1985 was omitted), the Netherlands, and Japan. [Norén and Lundén (*42*) observed a decline in dioxin and furan levels in breast milk from mothers in the Stockholm region from 1972 to 1985. Between 1985 and 1989, however, they reported that this trend did not continue. The European Union data for Sweden reported for the early 1990s also suggested a plateau in the dioxin levels (see data for Sweden in Table 1).]

Germany, with its rich database, seems to provide the most compelling evidence for a decline in breast milk dioxin levels over time (*43,44*). For example, Fürst and Wilmers (*43*), in their analysis of approximately 1,000 breast milk samples from North Rhine-Westphalia, reported that dioxin TEQ levels decreased from 34 ppt (lipid based) in 1989 to 14.2 ppt in 1996, about a 60% decline. The data for Japan (*30*), Norway, and the United Kingdom also provide convincing evidence for a decrease in breast milk dioxin levels. Iida et al. (*30*) reported a slight decline in PCDD TEQs in breast milk from 1994 to 1996; their data are not aggregated (i.e., dioxin and furan data were not combined) and their assessment did not include dioxin data from the 1980s. The data from Canada, the Czech Republic, France, Spain, and the United States are more ambiguous, whereas those from Italy and Lithuania suggest an increase in dioxin levels in breast milk. Craan and Haines (*45*) summarized Canadian breast milk data collected over 25 years by Health Canada, including data for dioxin, and reported the following decline in dioxin TEQs (ppt, lipid basis): 24.7 ppt for 1981–1982; 15.6 ppt for 1986–1987; and 14.5 ppt for 1992. For Canada (Figure 3), the decline indicated by the data reported by Craan and Haines (*45*) is obscured by additional province-specific data reported by

Table 1. *Continued*

Year	Country	No. donors /samples[a]	Location (description)	Reference	Dioxin TEQs: I-TEF (ppt, lipid basis)	Dioxin TEQs: WHO-TEF (ppt, lipid basis)
1990	France	15	Paris	(*25,26*)	20.3	23.4
1992	Germany	56	Northrhine-Westphalia	(*24*)	20.5	–
1992	Germany	10/1	Berlin	(*17*)	16.6	–
1993	Germany	78	Northrhine-Westphalia	(*24*)	20.9	–
1994	Germany	50	Northrhine-Westphalia	(*24*)	17.2	–
1995	Germany	38	Northrhine-Westphalia	(*24*)	16.1	–
1996	Germany	22	Northrhine-Westphalia	(*24*)	14.1	–
1997	Germany	9	Northrhine-Westphalia	(*24*)	12.0	–
1984	Germany, FRG	5[f]	NP	(*10*)	33.1	39.2
1984	Germany, FRG	94[f]	Münster	(*10*)	30.5	35.8
1985	Germany, FRG	193[f]	Northrhine-Westphalia	(*14*)	27.9	32.7
1985	Germany, FRG	79	Northrhine-Westphalia	(*14*)	32.0	37.7
1985	Germany, FRG	30[g]	West Berlin	(*10*)	32.0	39.0
1987	Germany, FRG	35[d]	Oldenburg	(*14*)	35.8	39.1
1987	Germany, FRG	40/1	West Berlin	(*14*)	32.4	39.1
1987	Germany, FRG	35[f]	West Berlin	(*14*)	33.4	40.5
1987	Germany, FRG	23/1	Recklinghausen	(*14*)	33.2	40.0
1987	Germany, FRG	10[f]	Recklinghausen	(*14*)	30.9	36.7
1987	Germany, FRG	14[f]	Weiden	(*14*)	30.6	36.4
1987	Germany, FRG	9[f]	Rheinfelden	(*14*)	37.4	45.0
1987	Germany, FRG	6[f]	Flensburg	(*14*)	31.9	37.7
1987	Hungary	100/1	Budapest	(*14*)	9.6	9.9
1987	Hungary	50/1	Szentes	(*14*)	11.8	12.3
1992	Hungary	20/1	Budapest	(*17*)	8.6	–
1992	Hungary	10/1	Scentes	(*17*)	7.8	–
1987	India	7/1	Bombay	(*14*)	6.7	7.2
1976	Italy	3[g]	Seveso	(*10*)	13.0	13.0
1987	Italy	9/1	Pavia	(*27*)	31.5	36.4
1987	Italy	9/1	Rome	(*27*)	21.8	25.3
1987	Italy	27/1	Florence	(*27*)	28.8	33.6
1987	Italy	14/1	Milan	(*27*)	18.8	21.0
1980	Japan	265/7	Osaka	(*10*)	50.9	57.7
1987	Japan	3/1	Fukuoka Prefecture	(*14*)	21.2	22.4
1987	Japan	3/1	Fukuoka Prefecture	(*14*)	27.4	29.0
1991	Japan	9	NP in English	(*28*)	13.6	16.4
1994	Japan	15	Fukuoka	(*29*)	15.6	18.8
1995	Japan	51	Western Japan	(*30*)	18.0	21.8
1995	Japan	44	Western Japan	(*30*)	13.2	15.7
1996	Kazakhstan	97/40	NP	(*31*)	20.5	22.6
1992	Lithuania	12/1	Palanga (coastal)	(*17*)	16.6	–
1992	Lithuania	12/1	Anykshchiai (rural)	(*17*)	14.4	–
1992	Lithuania	12/1	Vilnius city (urban)	(*17*)	13.3	–
1993	Lithuania	12/1	Palanga (coastal)	(*32*)	16.9	18.5
1993	Lithuania	12/1	Anykshchiai (rural)	(*32*)	14.6	16.4
1993	Lithuania	12/1	Vilnius (urban)	(*32*)	13.8	15.1
1985	Netherlands	3[g]	NP	(*10*)	110.0	131.3
1985	Netherlands	18[g]	Amsterdam	(*10*)	43.1	57.2
1987	Netherlands	13/1	Urban	(*14*)	37.8	45.8
1987	Netherlands	13/1	Rural	(*14*)	40.0	48.4
1988	Netherlands	10 pools of 10 samples	All regions	(*24*)[h]	34.2	–

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Liem et al. (*17*). A smoothed fit (least squares) through the data for the Western European countries also suggests an overall decline (Figure 6). In contrast, Figure 3, which includes dioxin/furan data for the United States, reveals the limit of our knowledge of what constitutes a "representative" level of dioxins/furans in U.S. breast milk and whether levels in the United States are declining.

In summary, for many of the countries for which dioxin TEQs in breast milk have been reported, the data indicate a decrease in breast milk dioxin TEQs over time. For countries with ambiguous results, including the United States, it is possible that an improved database (e.g., greater number of samples collected over time from a broader geographic area with appropriate sampling and analysis protocols) might reveal similar future reductions in breast milk dioxin TEQs.

Generally speaking, extremely limited data on organic environmental chemicals in breast milk in the Unites States have been reported in the published literature. In fact, as reported by Hooper (*46*), "…more is known about the breast milk contamination and body burdens of the mother, infant, and child living in Ukraine or Kazakhstan than, for example, about similar groups living in California." Further, the limited data available in the United States do not provide information on chemicals that are only now beginning to receive attention [e.g., polybrominated biphenyl ethers (*47*)]. Although we can draw inferences from breast milk data from other countries, the paucity of breast milk data for the United States limits the confidence in our ability to assess infants' exposures, risks, and benefits from breastfeeding, to compare these risks and benefits to formula feeding, and to reach conclusions about the effectiveness of contaminant source controls.

Table 1. *Continued*

Year	Country	No. donors /samples[a]	Location (description)	Reference	Dioxin TEQs: I-TEF (ppt, lipid basis)	Dioxin TEQs: WHO-TEF (ppt, lipid basis)
1991	Netherlands	209	Groningen/Rotterdam	(*33*)	28.7	33.2
1992	Netherlands	168	Rotterdam/Groningen	(*24*)	30.0	–
1992	Netherlands	176	Rotterdam/Groningen	(*24*)	30.2	–
1992	Netherlands	17/1	Whole country	(*17*)	22.5	–
1993	Netherlands	103	All regions	(*24*)	23.5	–
1998	Netherlands	10 pools of 9–13 samples	All regions	(*24*)	34.2	–
1987	New Zealand	2	Auckland	(*14*)	6.4	7.6
1987	New Zealand	20[f]	Christchurch, Auckland	(*34*)	16.5	19.7
1987	New Zealand	17[f]	Canterbury, Northland	(*34*)	18.1	21.9
1986	Norway	11[f]	Tromsø	(*14*)	16.1	18.3
1986	Norway	10[f]	Hamar	(*14*)	15.2	17.4
1986	Norway	10[f]	Skien/Porsgrunn	(*14*)	19.8	22.3
1992	Norway	10/1	Hamar (rural)	(*32*)	9.5	10.8
1992	Norway	10/1	Tromsø (coastal)	(*32*)	10.3	11.8
1993	Norway	10/1	Skien/Porsgrunn (industrial)	(*32*)	12.8	14.6
1990	Pakistan	7/1	Karachi	(*16*)	15.2	17.7
1992	Pakistan	14/1	Lahore	(*17*)	3.9	–
1986	Poland	5[f]	Bytom	(*14*)	23.0	25.8
1992	Russia	1	Arkhankelsk	(*17*)	15.2	–
1992	Russia	1	Karhopol	(*17*)	5.9	–
1992	Slovak	10/1	Michalovce	(*17*)	15.2	–
1992	Slovak	10/1	Nitra	(*17*)	12.6	–
1990	South Africa	6/1	NP	(*16*)	8.5	10.2
1990	South Africa	18/1	NP	(*16*)	12.9	15.5
1990	Spain	13	Madrid	(*25*,*26*)	13.3	17.7
1992	Spain	19/1	Bizkaia	(*17*)	19.4	–
1992	Spain	10/1	Gipuzkoa	(*17*)	25.5	–
1996	Spain	15/1	Tarragona	(*35*)	12.0	13.9
1972	Sweden	227/4	Stockholm	(*10*)	33.7	37.8
1976	Sweden	245/4	Stockholm	(*10*)	30.2	33.4
1980	Sweden	340/4	Stockholm	(*10*)	19.8	22.5
1984	Sweden	102/2	Stockholm	(*36*)	15.0	-
1984	Sweden	4[f]	Umeå	(*10*)	21.1	24.1
1987	Sweden	10[f]	Sundsvall	(*14*)	22.6	26.3
1987	Sweden	10[f]	Gothenburg	(*14*)	22.8	26.3
1987	Sweden	10[f]	Uppsala	(*14*)	22.4	25.8
1987	Sweden	10[f]	Borlänge	(*14*)	20.4	23.5
1990	Sweden	60/3	Stockholm	(*36*)[i]	17.0	–
1991	Sweden	60/3	Stockholm	(*36*)[i]	13.0	–
1992	Sweden	40/2	Stockholm	(*36*)[i]	18.0	–
1987	Thailand	3/1	Bangkok	(*14*)	5.2	6.2
1987	United Kingdom	20/1	Birmingham	(*37*)	37.2	43.9
1987	United Kingdom	20/1	Glasgow	(*37*)	29.1	34.9
1988	United Kingdom	40	Birmingham	(*24*)[h]	37.0	–
1988	United Kingdom	40	Glasgow	(*24*)[h]	29.1	–
1989	United Kingdom	?/2	Wales	(*24*)	33.0	39.2
1992	United Kingdom	20/1	Birmingham	(*17*)	17.9	–
1992	United Kingdom	23/1	Glasgow	(*17*)	15.2	–
1993	United Kingdom	20/1	Birmingham	(*37*)	21.0	25.3
1993	United Kingdom	20/1	Glasgow	(*37*)	21.0	25.2

continued, next page

Depuration of Environmental Chemicals from Breast Milk during Lactation

The typical procedure for estimating intakes of environmental chemicals by nursing infants involves selecting a daily volume of breast milk consumed (typically approximately 800 mL/day) and multiplying this value by an empirical or modeled concentration of a chemical in breast milk. The advantage to this approach is the simplicity of the computation. However, the limitations are clear—these estimates do not account for variability in exposure, and more importantly, there is no recognition that a woman's stores of lipophilic chemicals in adipose tissue and breast milk are depleted over the duration of lactation. In fact, the depuration of chemicals due to breast-feeding is a critical, yet poorly characterized, parameter in evaluating infant exposure to chemicals in breast milk (*8*). It is not clear which factors may influence elimination kinetics; for example, it is likely that some of the following would influence depuration: initial chemical concentration, age of the mother, parity, volume of milk consumed by infant, supplementation with formula or solid foods, and properties of individual chemicals.

A few previous efforts to model concentrations of lipophilic compounds in breast milk have incorporated the depuration process by estimating the decline in chemical concentration over the duration of breast-feeding. For example, LaKind et al. (*8*) incorporated depuration rates of 30, 50, or 70% over 6 months for 2,3,7,8-TCDD. Patandin et al. (*48*) used a 20% decrease in dioxin/PCB body burden of the breast-feeding mother to calculate a weekly decrease of 1.7% in dioxin/PCB concentration in breast milk (modeled as $\int_0^T e^{-0.017t}\,dt$). Sullivan et al. (*49*) modeled the decrease in dioxin in breast milk as first order elimination. Kreuzer et al. (*50*) reported a good correlation between modeled and published values of TCDD in mother's milk by assuming an approximately 70% decline in the levels of TCDD in milk after 6 months of daily breast-feeding.

Table 1. *Continued*

Year	Country	No. donors /samples[a]	Location (description)	Reference	Dioxin TEQs: I-TEF (ppt, lipid basis)	Dioxin TEQs: WHO-TEF (ppt, lipid basis)
1993	United Kingdom	20/1	Cambridge	(*37*)	23.8	28.6
1992	Ukraine	5/1	Kiev no. 1	(*17*)	11.0	–
1992	Ukraine	5/1	Kiev no. 2	(*17*)	13.3	–
1993	Ukraine	50/1	Dniprodzerzhinsk	(*38*)	8.1	9.2
1993	Ukraine	50/1	Dniprodzerzhinsk	(*38*)	11.7	13.2
1993	Ukraine	51/1	Kyiv	(*38*)	8.0	9.0
1993	Ukraine	49/1	Kyiv	(*38*)	10.1	11.3
1973	United States	3[f]	NP	(*10*)	10.3	10.8
1979	United States	103[f]	NP	(*10*)	2.0	2.0
1986	United States	7/1	Binghamton	(*15*)	11.9	14.5
1986	United States	22/1	Binghamton	(*14*)	17.0	20.0
1987	United States	47[f]	Los Angeles	(*10*)	9.6	9.1
1987	United States	21/1	Los Angeles	(*14*)	16.8	20.2
1990	United States	9/1	Tennessee	(*16*)	15.6	18.8
1988	USSR	1	Moscow	(*16*)	20.7	23.8
1988	USSR	5	Baikalak	(*16*)	10.9	12.3
1988	USSR	4	Irkutak	(*16*)	18.3	20.0
1988	USSR	10	Novosibirak	(*16*)	12.2	14.0
1988	USSR	4	Kachung	(*16*)	9.7	10.8
1970	Vietnam	18[f]	NP	(*10*)	484.0	484.0
1970	Vietnam	NP	NP	(*10*)	111.0	111.0
1973	Vietnam	3[f]	South Vietnam	(*10*)	140.3	140.0
1973	Vietnam	9[f]	South Vietnam	(*10*)	153.6	154.2
1986	Vietnam	2/1	Tan Uyen	(*14*)	28.1	30.4
1986	Vietnam	2/1	Tan Uyen	(*14*)	10.0	10.7
1986	Vietnam	2/1	Tan Uyen	(*14*)	20.1	22.7
1986	Vietnam	3/1	Gan Gio	(*14*)	13.8	14.9
1986	Vietnam	2/1	Long Xuyen	(*14*)	7.3	8.3
1986	Vietnam	15/1	Ho Chi Minh	(*14*)	22.4	25.0
1986	Vietnam	8/1	Ho Chi Minh	(*14*)	16.8	19.6
1986	Vietnam	38/1	Ho Chi Minh	(*14*)	19.2	22.0
1986	Vietnam	28/1	Hanoi	(*14*)	9.3	10.7
1986	Vietnam	12/1	Song Be Province	(*14*)	32.7	36.6
1990	Vietnam	4/1	Binh Long	(*16*)	15.3	18.6
1990	Vietnam	5/1	Vung Tau	(*16*)	22.7	27.8
1990	Vietnam	4/1	Tay Ninh	(*16*)	28.5	35.1
1990	Vietnam	4/1	Song be Province	(*16*)	12.6	14.8
1991	Vietnam	16[f]	South	(*39*)	16.2	18.1
1981	Yugoslavia	50/1	Zagreb	(*10*)	20.1	22.4
1985	Yugoslavia	17/1	Zagreb	(*10*)	19.0	21.8
1986	Yugoslavia	14/1	Krk	(*14*)	12.5	13.6
1987	Yugoslavia	41/1	Zagreb	(*14*)	12.1	13.3

Abbreviations: ?, unknown; FRG, Federal Republic of Germany; NP, not provided; USSR, Union of Soviet Socialist Republics. Published data that included TEQ values are incorporated in this table. Otherwise, we calculated dioxin TEQs using published concentration data and TEF values shown in Table 2.

[a]The number of women participating in the study (in many cases, the participants' breast milk was combined, or pooled, to make a fewer number of samples; for example,10/1 represents 10 women who provided breast milk samples that were pooled to make one sample for analysis. [b]North Atlantic Treaty Organization, Committee on the Challanges of Modern Society TEF values were used (*40*); these values are the same as the I-TEF values except for 1,2,3,4,6,7-heptaCDD, which is 0.1. This is not expected to result in substantially different TEQ values from the I-TEF model. [c]A TEF of 0.5 was used for 2,3,7,8-pentaCDF. [d]Arithmetic mean of duplicate analysis of pooled sample from 200 donors. [e]Weighted geometric mean of 100 samples. [f]Mean value. [g]Values reported as means and ranges of congeners; mean values were used for this analysis. [h]TEQs were calculated using the Nordic TEF model, which differs from the I-TEF model by assigning a value of 0.01 to 1,2,3,7,8-penta-CDF (*14*). [i]Nordic TEFs were used to calculate TEQs (*14*).

In this review of the published literature on depuration of environmental chemicals in breast milk, we describe the uncertainties associated with the available information. Our focus is on lipophilic environmental chemicals, and each section below describes the database for a particular chemical or group of chemicals (studies are described in chronological order).

Dioxins/Furans

Fürst et al. (*51*) collected milk samples from one mother for 1 year after the birth of her second child and analyzed the samples for dioxins and furans. The mother provided breast milk samples during week 1, week 5, weeks 10–13, and weeks 52–60 postpartum. The analytical results are presented in Figures 7 (dioxins) and 8 (furans). OctaCDD is reduced by approximately 50% between the first and fifth weeks; the other congeners decline by 15–30% (*51*). Fürst et al. (*51*)

> cautiously conclude that a strong mobilization of … PCDDs and PCDFs takes place within the first few weeks after delivery.

In addition, 168 women provided breast milk samples and information on the period of lactation when the sample was collected. On average, the levels of dioxins and furans in mothers breast-feeding their second child (74 samples) were 20–30% lower than mothers breast-feeding their first child (79 samples). Generally, Fürst et al. (*51*) found the greatest decline for organochlorines, including PCBs and pesticides, during the transition from colostrum to ripe human milk (the authors did not provide data for these chemicals).

In a study on fecal elimination of dioxins and furans in a 3-month-old breast-fed infant, four samples of breast milk were collected from the mother (details on collection, such as sampling time, were not provided) (*52*). A general decline in levels of some of the congeners of dioxins and furans over time are observable in Figures 9 and 10.

Hori (*53*) provided minimal information on levels of dioxins and furans in breast milk lipid from one mother 4–26 weeks after delivery. No information on collection of breast milk samples was provided. PCDDs (TEQs, lipid basis) decreased from 29 ppt at 6 weeks to 21 ppt at 26 weeks, and PCDFs decreased from 18 ppt at 6 weeks to 12 ppt at 26 weeks (Figure 11).

Schecter et al. (*54*) describe the results of a study of dioxins and furans in the breast milk of a somewhat less typical mother who breast-fed one child for 16 months and then breast-fed twins for over 2 years. The first breast milk sample was collected in February 1992, after the mother had nursed her first child for about 1 year. The second sample was collected in March 1993 (approximately 3 months after the birth of the twins), and the last in September 1995. [Schecter et al. (*54*) also provided data from March 1993 to December 1993; however, these are averages of 10 samples over that time period.] From March 1993 to September 1995, the total PCDDs, PCDFs, and PCDDs/PCDFs in milk (TEQs, lipid basis) decreased by 70%, 66%, and 69%, respectively (Table 3). Schecter et al. (*55*) postulated that the increase in dioxins and furans between December 1994 and September 1995 may have been caused by a decrease in breast-feeding and by a decreased intake of dioxins from food.

Abraham et al. (*56*,*57*) studied the intake and fecal elimination of chemicals, including dioxins and furans, in infants. Two samples

Table 2. I-TEFs and the more recent WHO-TEFs for dioxins and furans (*41*).

	I-TEF	WHO-TEF
Dioxins		
2,3,7,8-TCDD	1.0	1.0
1,2,3,7,8-PentaCDD	0.5	1.0
1,2,3,4,7,8-HexaCDD	0.1	0.1
1,2,3,6,7,8-HexaCDD	0.1	0.1
1,2,3,7,8,9-HexaCDD	0.1	0.1
1,2,3,4,6,7,8-HeptaCDD	0.01	0.01
1,2,3,4,6,7,8,9-OctaCDD	0.001	0.0001
Furans		
2,3,7,8-TCDF	0.1	0.1
1,2,3,7,8-PentaCDF	0.05	0.05
2,3,4,7,8-PentaCDF	0.5	0.5
1,2,3,4,7,8-HexaCDF	0.1	0.1
1,2,3,6,7,8-HexaCDF	0.1	0.1
1,2,3,7,8,9-HexaCDF	0.1	0.1
2,3,4,6,7,8-HexaCDF	0.1	0.1
1,2,3,4,6,7,8-HeptaCDF	0.01	0.01
1,2,3,4,7,8,9-HeptaCDF	0.01	0.01
1,2,3,4,6,7,8,9-OctaCDF	0.001	0.0001

Abbreviations: CDD, chlorinated dibenzo-*p*-dioxin; CDF, chlorinated dibenzofuran.

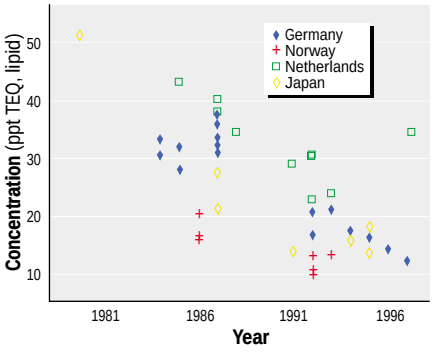

Figure 5. Trends in dioxin/furan concentrations (ppt TEQ, lipid basis) in breast milk for Germany, Norway, the Netherlands, and Japan. Data from Table 1.

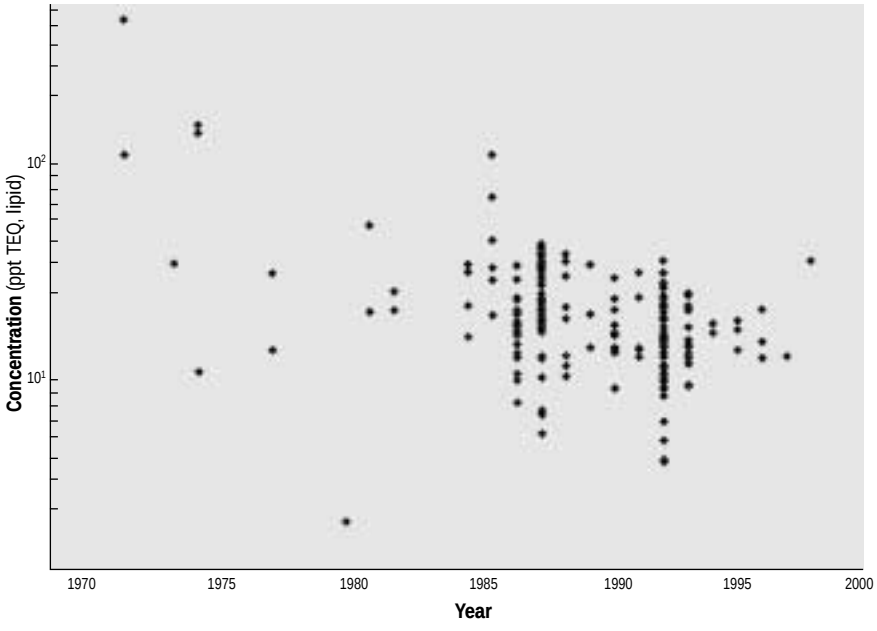

Figure 4. Trends in dioxin/furan concentrations in breast milk for all countries (ppt TEQ, lipid basis). Data from Table 1.

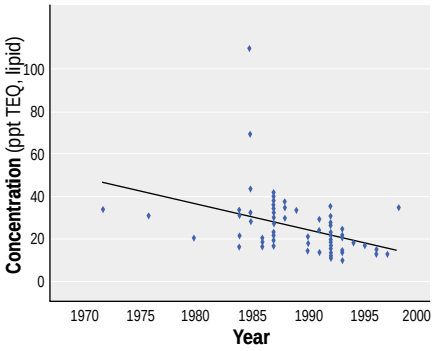

Figure 6. Trends in dioxin/furan concentrations in breast milk (ppt TEQ, lipid basis) for Western Europe. Data from Table 1.

of mother's milk (at least 100 mL each) were obtained by pumping empty the whole breast. Reported results (Table 4) indicate that for the dioxins, octaCDD and heptaCDD appear to increase over the course of 5 months, whereas the concentrations of the remaining congeners stay relatively constant (*56*). In contrast, the level of octaCDF appears to decrease while the other furan congeners remain essentially unchanged.

Abraham et al. (*57*) studied two breast-fed infants (as well as one formula-fed infant, which is not discussed here). Mother's milk (two samples during each sampling period) was obtained by emptying the entire milk content in the breast by pump. The levels measured in the diet of two infants are not shown here because, after the first month's measurements, the level of dioxins and furans reported in their diets included those measured in foods other than breast milk, including vegetables and rice pudding prepared with cow's milk.

In reviewing the above dioxin/furan studies, it is clear that information reported to date is not sufficient to confidently derive depuration rates for dioxins and furans or to make generalizations about the factors which might influence elimination kinetics (Table 5). For example, the limited information on breast milk sample collection methodologies does not permit an evaluation as to whether representative samples were obtained. Further, there was only one woman included in each study, with little information on such factors as age and parity, and not all studies examined depuration immediately postpartum [for certain studies (*52,56*), analysis of elimination kinetics was not the intent of the research].

PCBs and Polybrominated Biphenyls

To assess whether levels of polybrominated biphenyls changed in breast milk over time, Brilliant et al. (*58*) studied one woman over 3 months, but they provided no information on sampling methodology for this individual. The authors noted day-to-day variations but no trend in concentrations.

A study to examine long-term excretion of PCBs in mother's milk was conducted with a woman who was occupationally exposed to PCBs (Kanechlor 300 and 500) through work in a capacitor factory (*59,60*). Before giving birth, the subject underwent 2 years of fasting treatment for PCB intoxication. The authors reported an approximately 76% decrease in PCB levels in milk 16 months after delivery and described a half-life of 8 months for PCBs in breast milk (breast milk was used for study purposes only) (Figure 12).

Hofvander et al (*61*) collected breast milk samples from 18 mothers at 3 months postpartum and from 23 other mothers at 6 months postpartum. The mean levels of PCBs in the 3- and 6-month groups were comparable. It is difficult to interpret the results of this study because breast milk from two separate groups of women was sampled and only mean values were provided.

Mes and Lau (*62*) examined the change in PCB levels in the milk of one woman during the course of lactation. They reported that despite fluctuations, the PCB congener content remained relatively constant in the milk during lactation, except for those congeners with six and seven chlorine atoms in the molecule. Mes and Lau (*62*) reported a statistically significant increase in the hexachlorobiphenyl content of the breast milk.

Mes et al. (*63*) sampled breast milk from 16 women during eight intervals of a 98-day lactation period. The milk samples were collected over a 24-hr period. Data were reported on a whole milk basis as averages of all samples collected at a given time during lactation; we used lipid levels to convert the whole milk values to lipid-corrected values (Table 6). Even after lipid correction, there is no obvious trend in these data.

Rogan and colleagues (*64,65*) studied breast milk from the mothers of 856 children and reported a decline in the PCB levels, on average, by about 20% after 6 months (Table 7). The authors did not describe breast milk sampling procedures. Forty-three percent of the women were primiparous, and the median time for breast-feeding was 29 weeks.

Fooken and Butte (*66*) collected breast milk samples from five women and examined variations in PCB levels during lactation. Monthly samples were actually composed of a mixture of weekly, manually collected breast milk samples (equal volumes of samples from one woman dating from the month of lactation were combined). The authors found either no changes in residue level over time or fluctuations with no observable trends.

Galetin-Smith et al. (*67*) examined the levels of PCBs in colostrum and milk samples

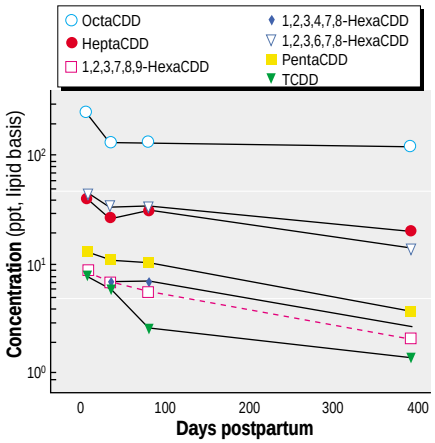

Figure 7. Log concentrations of dioxin congeners (ppt, lipid basis) in the breast milk of one woman up to 392 days postpartum. Data from Fürst et al. (*51*).

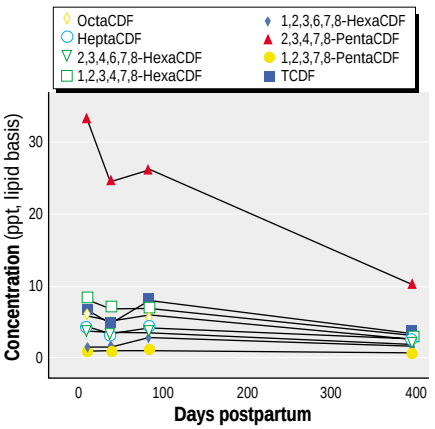

Figure 8. Concentrations of furan congeners (ppt, lipid basis) in the breast milk of one woman up to 392 days postpartum. Data from Fürst et al. (*51*).

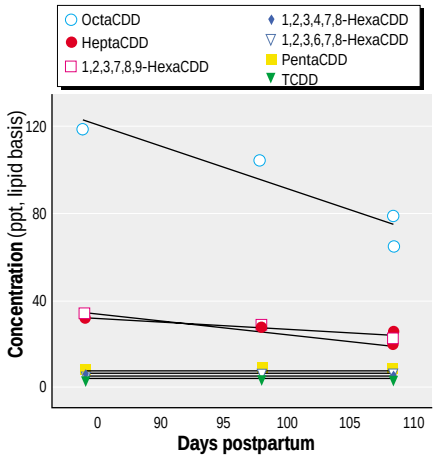

Figure 9. Concentrations of dioxin congeners (ppt, lipid basis) in breast milk of one woman up to 16 weeks pastpartum. Data from Jödicke et al. (*52*).

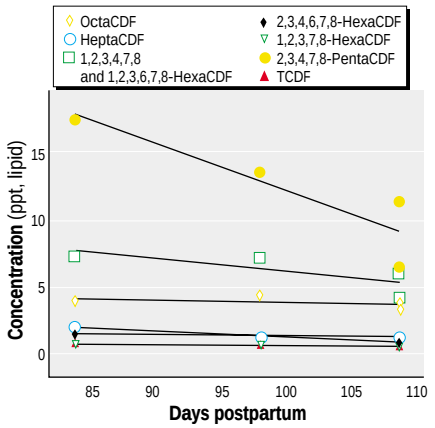

Figure 10. Concentrations of furan congeners (ppt, lipid basis) in breast milk of one woman up to 16 weeks postpartum. Data from Jödicke et al. (*52*).

from seven women. They provided no information on collection methodology. PCB levels were a summation of PCB congeners 28, 52, 101, 118, 138, 153, 170, and 180 from a 1:1 mixture of Arochlor 1254 and 1260. It was difficult to discern any common trend among these women except for an increase in PCBs from the colostrum samples to the first milk sample. However, the authors reported that PCBs showed an increase of 6% per month.

Hori (*53*) provided minimal information on the levels of PCBs in breast milk lipid from one mother 4–26 weeks after delivery. No information on collection of breast milk samples was provided. Coplanar PCBs (TEQs, lipid basis) decreased from 50 ppt at 6 weeks to 32 ppt at 26 weeks (Figure 13).

In a study on the intake and fecal elimination of chemicals in infants, Abraham et al. (*56*) reported depuration data on three PCBs. Two samples of a mother's milk (at least 100 mL each) were obtained by pumping empty the whole breast. The authors reported increases in concentrations of PCB 138 and PCB 180, but there was no obvious trend in the data for PCB 153 (Table 8).

The research by Schecter et al. (*55*) on a mother breast-feeding twins was described in "Dioxins/Furans." Schecter et al. (*55*) also analyzed breast milk samples for PCB congeners. Concentrations of total PCBs are shown in Table 9 (the concentrations of individual PCB congeners detected in breast milk lipid decreased from 52% to 95% over the study duration).

Kostyniak et al. (*11*) analyzed breast milk samples from lactating female members and spouses of male members of the New York State Angler Cohort. The samples were analyzed for 77 PCB congeners and several pesticides. Approximately half of the population was primiparous, and the parity of the remaining women was ≥ 2. Breast milk samples were collected after the second morning feeding (hindmilk was collected). The study was not longitudinal—in other words, the authors did not analyze concentrations of PCBs in breast milk over time for individual women. However, they performed Spearman rank correlations for the total months of lactation (over a lifetime) and the PCB concentrations in breast milk fat for all 98 study participants and reported negative correlation. For primiparous women, Kostyniak et al. (*11*) reported a significant negative correlation for total PCBs and five PCB congeners.

Information reported to date on depuration of PCBs is not sufficient to confidently derive depuration rates for this group of chemicals or to make generalizations about the factors that might influence elimination

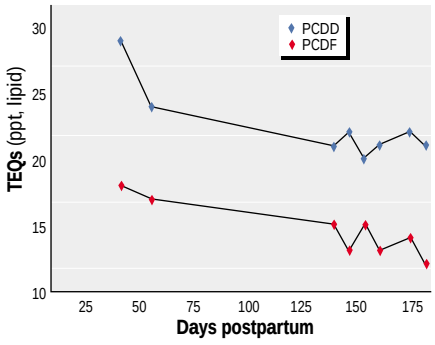

Figure 11. Concentration of dioxin and furan TEQs in breast milk (ppt, lipid basis) from one mother 4–26 weeks after delivery. Data from Hori (*53*).

Table 3. Concentrations of dioxins/furans in one mother's breast milk over 3 years of lactation.

Congener (ppt, lipid basis)	Sampling date				
	Feb 1992[a]	Mar 1993[b]	Jul 1994	Dec 1994	Sep 1995
Dioxins					
1,2,3,4,6,7,8,9-OctaCDD	147.0	201.4	72.2	85.9	126.3
1,2,3,4,6,7,8-HeptaCDD	38.0	59.1	13.5	14.6	30.2
1,2,3,4,7,8/					
1,2,3,6,7,8-HexaCDD	29.0	35.7	9.3	10.4	12.4
1,2,3,7,8,9-HexaCDD	4.5	4.47	0.93	1.0	2.4
1,2,3,7,8-PentaCDD	4.8	5.2	1.0	1.1	1.7
2,3,7,8-TCDD	3.3	2.70	0.7	0.5	(0.4) ND
Furans					
1,2,3,4,6,7,8,9-OctaCDF	NA	NP	(0.59) ND	(0.54) ND	NP
1,2,3,4,7,8,9-HeptaCDF	NA	NP	0.21	0.16	NP
1,2,3,4,6,7,8-HeptaCDF	40.0	6.0	1.9	2.20	3.0
1,2,3,4,7,8/					
1,2,3,6,7,8-HexaCDF	24.0	7.7	2.21	2.14	2.7
1,2,3,7,8,9-HexaCDF	NA	NP	(0.1) ND	(0.1) ND	NP
2,3,4,6,7,8-HexaCDF	21.0	1.35	0.37	0.43	1.1
1,2,3,7,8-PentaCDF	NA	NP	0.13	0.10	NP
2,3,4,7,8-PentaCDF	4.4	4.8	0.79	0.68	1.6
2,3,7,8-TCDF	1.7	1.09	(0.52)	(0.30)	(0.5)

Abbreviations: NA, not available; NP, not provided; ND, not detected. Values shown in parentheses indicate the detection limit. Reprinted from Schecter et al. (*54,55*) with permission from Elsevier Science.
[a]Before birth of twins. [b]Three months postpartum.

Table 4. Concentrations (ppt, lipid basis) of dioxins/furans in one mother's breast milk at 1 and 5 months postpartum.

Congener (ppt, lipid basis)	Month 1		Month 5
	Sample 1	Sample 2	
Dioxins			
1,2,3,4,6,7,8,9-OctaCDD	60.38	66.75	84.66
1,2,3,4,6,7,8-HeptaCDD	14.15	15.10	18.47
1,2,3,6,7,8-HexaCDD	24.26	24.08	25.06
1,2,3,4,7,8-HexaCDD	2.42	2.35	2.14
1,2,3,7,8,9-HexaCDD	1.78	1.93	2.21
1,2,3,7,8-PentaCDD	7.95	7.39	7.82
2,3,7,8-TCDD	1.92	1.86	1.65
Furans			
1,2,3,4,6,7,8,9-OctaCDF	5.30	4.93	1.51
1,2,3,4,6,7,8-HeptaCDF	5.81	6.18	5.41
1,2,3,4,7,8/			
1,2,3,6,7,8-HexaCDF	7.08	7.68	8.98
2,3,4,6,7,8-HexaCDF	0.80	0.60	1.65
1,2,3,7,8-PentaCDF	0.28	0.29	0.33
2,3,4,7,8-PentaCDF	20.59	19.27	18.66
2,3,7,8-TCDF	0.90	1.05	0.42

Reprinted from Abraham et al. (*56*) with permission from Elsevier Science.

Table 5. Synopsis of study data provided on parameters potentially influencing elimination kinetics of dioxins/furans (presented in chronological order).

Study	No. of Women	Study duration (postpartum)	Breast milk sampling method	Donor age (years)	Parity	Supplementation information
Fürst et al. (*51*)	1	1–60 weeks	NP	NP	2	NP
Jödicke et al. (*52*)	1	13–16 weeks	NP	28	NP	NP
Hori (*53*)	1	4–26 weeks	NP	NP	1	NP
Schecter et al. (*54*)	1	Pre-[a] and 2 years	NP	36	3	NP
Abraham et al. (*56*)	1	1 and 5 months	Emptying whole breast	NP	NP	Supplemented at 5 months

NP, not provided.
[a]Mother breast-fed one child for 16 months and then breast-fed twins for 2 years.

kinetics (Table 10). As with the dioxin/furan studies, limited information on breast milk sample collection methodologies does not permit an evaluation as to whether representative samples were obtained. Pooling of samples, small sample sizes, and minimal data on such factors as age and parity further limit our ability to quantify depuration.

Chlorinated Organic Pesticides

Curley and Kimbrough (*68*) analyzed breast milk samples from five women in one of the first explorations of organochlorine concentrations in breast milk at various times during lactation and provided mean concentrations. The mean total DDT concentrations increased during lactation; this was not considered statistically significant because of a large individual variation (*68*).

Bakken and Seip (*69*) analyzed colostrum and breast milk from three women for hexachlorobenzene (HCB), benzene hexachloride (BHC), and total DDT for up to 9–16 weeks postpartum. Wide fluctuations were seen; in one woman, BHC increased more than 4 times over the course of 4 days, from 8.6 to 40.8 ppb. The authors generally found the highest concentrations in colostrum, with declining values at later sampling times. Bakken and Seip (*69*) did not indicate whether breast milk was sampled in a way that would account for diurnal variations or for variability in lipid content (results were on a whole milk basis).

De Bellini et al. (*70*) analyzed human milk for organochlorine chemicals from 13 women over 30 days. They found increases in *p,p´*-DDT and *p,p´*-DDE and decreases in heptachlor epoxide, hexachlorocyclohexane (HCH), and dieldrin (*63,70*).

Yakushiji et al. (*59*) examined long-term excretion of PCBs in mother's milk. They also examined *p,p´*-DDE, but provided no data. However, the authors described a half-life of 8 months for *p,p´*-DDE in breast milk.

Krauthacker et al. (*71*) determined concentrations of DDT and metabolites from 34 breast milk samples collected 3–5 days postpartum and from 37 samples obtained at later times (up to 55 weeks postpartum). They provided no information on specific sampling methodology, other than that breast milk was manually expressed. Concentrations were given as means on a whole milk basis. According to the authors, the ranges of concentrations were large for samples collected over the 55-week-period and overlapped completely. Krauthacker et al. (*71*) concluded that the concentration of *p,p´*-DDE at the beginning of lactation was not significantly different from that from later lactation periods.

Hofvander et al. (*61*) collected breast milk samples from 18 mothers at 3 months postpartum and from 23 other mothers at 6 months postpartum. The mean levels of organochlorine compounds (DDT/metabolites, HCB, HCH, and dieldrin) in the 3- and 6-month groups were comparable. The results of this study cannot be used to draw conclusions about depuration because breast milk from two separate groups of women were sampled, introducing considerable uncertainty.

Andersen and Orbék (*72*) studied organochlorine levels in human breast milk in Denmark; although data were not provided, the authors noted that the content of HCB in milk fat declined slowly with the time of postpartum sampling but that there was no similar decline in levels of DDE, DDT, dieldrin, or PCBs.

Mes et al. (*63*) sampled breast milk from 16 women during eight intervals of a 98-day lactation period. The milk samples were collected over a 24-hr period at different times during each feeding, and if possible, from alternating breasts. The authors reported the following conclusions: *a*) a general downward trend in residue concentrations in breast milk was interrupted by sporadic increases; *b*) most residues showed a statistically nonsignificant increase in residue levels during the first 30 days; and *c*) during lactation, a statistically

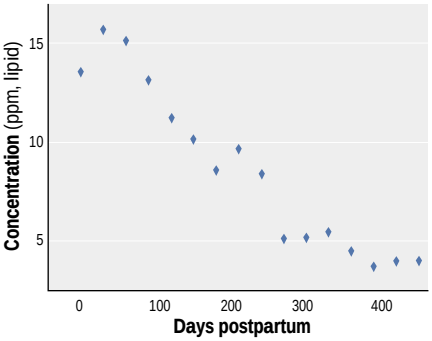

Figure 12. Depuration of PCBs from an occupationally exposed woman (ppm, lipid basis). Data from Yakushiji et al. (*59*).

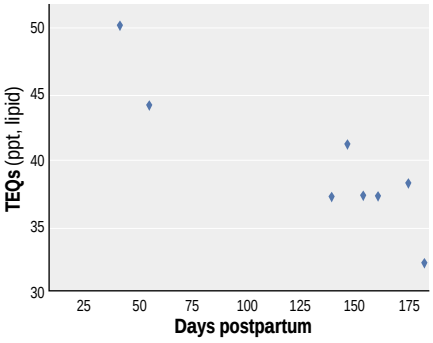

Figure 13. Concentrations of coplanar PCB TEQs in breast milk (ppt, lipid basis) from one mother 4–26 weeks after delivery. Data from Hori (*53*).

Table 6. Chlorinated hydrocarbon residues in whole breast milk samples from 16 women up to 98 days postpartum.

PCB residue	Days following parturition							
	7	14	28	42	56	70	84	98
ppb, whole milk	23.3	29.7	25.6	23.6	25.9	22.8	23.4	28.1
ppb, lipid basis	879.3	804.9	691.9	768.7	752.9	745.1	809.7	749.3
Percent fat	2.65	3.69	3.70	3.07	3.44	3.06	2.89	3.75

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Table 7. PCB concentrations in breast milk (ppm, lipid basis).

Sampling time	No. of breast milk samples	Median PCB level	95th percentile PCB level	Maximum PCB level	Percent less than quantitation limit
Birth	733	1.77	3.91	16.00	13
6 weeks	617	1.53	3.44	14.80	6
3 months	498	1.46	3.35	15.00	9
6 months	362	1.38	2.90	17.10	12
9 months	62	1.18	2.70	3.20	6
1 year	101	1.17	2.34	2.54	11
18 months	32	1.02	2.55	3.28	16

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Table 8. Concentrations (ppb, lipid basis) of PCBs in one mother's breast milk at 1 and 5 months postpartum.

PCB	Month 1		Month 5
	Sample 1	Sample 2	
PCB 138	74	79	100
PCB 153	177	202	194
PCB 180	108	121	139

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Table 9. Concentrations of total PCBs in one mother's breast milk over 2 years of lactation with percent decrease (ppb, lipid basis)

	Sampling time					Percent decrease
	3/93[a]	6/93	9/93	12/93	9/95	
Total PCBs	285	172	156	80	63	78

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[a]Three months postpartum.

significant decrease was observed for HCB, oxychlordane, transnonachlor, β-HCH, *p,p´*-DDE, and *p,p´*-DDT.

Rogan and and colleagues (*64*,*65*) studied breast milk from mothers of 865 children and reported a decline in the levels of DDE, on average, by about 20% after 6 months (Table 11). Breast milk sampling procedures were not described.

Klein et al. (*73*) studied the elimination kinetics of several organochlorine compounds from day 2 to day 10 of breast-feeding (30 volunteers). DDT was below the level of detection in all samples. The authors noted a rapid decrease in the DDE concentration over time; the other chemicals, with the exception of heptachlor, showed a linear decrease over the study duration (Figure 14).

Fooken and Butte (*66*) collected breast milk samples from five women and examined variations in organochlorine residue levels (HCH, HCB, *p,p´*-DDT, and *p,p´*-DDE) during lactation. Month-mix samples were composed of breast milk samples that were collected weekly. The authors found no changes in residue level over time, and there were no observable trends in the fluctuations.

Galetin-Smith et al. (*67*) examined the levels of *p,p´*-DDT, *o,p´*-DDE, and *p,p´*-DDE in colostrum and milk samples from seven women. No information was provided on collection methodology. The authors reported a 3%/month decrease in levels of *p,p´*-DDE during lactation, but noted that this result was only marginally statistically significant because individual variation was pronounced. DDT increased 3%/month. Greater variability would be anticipated in these results because they were reported on a whole milk, rather than a lipid, basis.

Abraham et al. (*56*), in their study of the intake and fecal elimination of chemicals in infants, reported depuration data on HCB. The authors obtained two samples of mother's milk (at least 100 mL each) at 1 month and 5 months postpartum by pumping empty the whole breast. The HCB concentrations decreased by approximately 8% over 5 months.

Schecter et al. (*55*) analyzed DDE and HCB in the breast milk from a mother nursing twins. The authors reported a 92% decrease in HCB in breast milk lipid over approximately 30 months of lactation; DDE in breast milk lipid declined by 81% during the same time period.

Information on depuration of organochlorine pesticides is not sufficient to confidently derive depuration rates for this group of chemicals or make generalizations

Table 10. Synopsis of study data provided on parameters that potentially influence elimination kinetics of PCBs and/or chlorinated organic pesticides (COPs) (presented in chronological order).

Study/ chemical group	No. of women	Study duration	Breast milk sampling method	Donor age (years)	Parity	Supplementation information
Curley and Kimbrough (*68*) COP	5	3–96 days postpartum	Manual expression	20–33	1–4	NP
Bakken and Seip (*69*) COP	3	Over 3–12 days; time postpartum not provided	NP	NP	NP	NP
De Bellini et al. (*70*) COP	13	6–30 days postpartum	NP	20–39	> 1	NP
Brilliant et al. (*58*) PCB	1	Over 3 months; time postpartum not provided	Manual expression	NP	NP	NP
Yakushiji et al. (*59*) PCB, COP	1	16 months postpartum	NP	36	1	Milk expressed for study purposes only
Krauthacker et al. (*71*) COP	25 (37 samples)	3–5 days to 55 weeks postpartum	Manual expression	18–32	NP	NP
Hofvander et al. (*61*) PCB, COP	18 and 23 (2 groups)	At 3 or 6 months postpartum	Nipple cleaning, complete milk extraction with electric pump from one or both breasts	21–35	NP	NP
Andersen and Orbék (*72*) COP	57	4–113 days postpartum	24-hr representative samples, either fore- or hindmilk or mixture	NP	NP	NP
Mes and Lau (*62*) PCB	1	98 days postpartum	NP	NP	NP	NP
Mes et al. (*63*) PCB, COP	16	98 days postpartum	Manually expressed; 24-hr representative sample, alternate between breasts and before and after feedings, if possible	Mean = 35	NP	NP
Rogan et al. (*65*) PCB, COP	807	Up to 18 months postpartum	NP	16–41	1 (43%)	NP
Klein et al. (*73*) COP	39	2–10 days postpartum	NP	NP	NP	NP
Fooken and Butte (*66*) PCB, COP	5	Up to 5 and 9 months postpartum	Manual expression	23–36	1 or 2	NP
Galetin-Smith et al. (*67*) PCB, COP	7	Up to 8 months postpartum	NP	NP	NP	Diluted lemon juice
Hori (*53*) PCB	1	4–26 weeks postpartum	NP	NP	1	NP
Abraham et al. (*56*) PCB, COP	1	1 and 5 months postpartum	Emptying whole breast	NP	NP	Supplementation by 5 months with vegetable pap
Schecter et al. (*55*) PCB, COP	1	Pre- and 2 years postpartum	NP	NP	3	NP
Kostyniak et al. (*11*) PCB	98	Not longitudinal	Express 2 oz milk after second morning feeding, either manually or with a pump	NP	1, > 2	NP

NP, not provided.

about the factors that might influence elimination kinetics (Table 10). An additional complication involves comparing different classes of chemicals. As stated above, limited information on breast milk sample collection methodologies does not permit an evaluation as to whether representative samples were obtained. Pooling of samples, small sample sizes, and minimal data on factors such as age and parity further limit our ability to quantify depuration.

In summary, several factors could potentially influence reported depuration rates. These include the number of previous children nursed, initial body burden of the mother, diet, sampling methodology, amount of lipid in breast milk, and the amount of milk consumed by the infant. There are, at present, insufficient existing data to explore whether these factors play a role in rates of depuration. Without this type of information, the discrepancies in the reported rates of depuration cannot be resolved. Thus, the available information supports the inclusion of depuration when estimating infant exposure to environmental chemicals from breast milk, but the data do not support the selection of a specific rate of depuration.

Conclusions

Environmental chemicals in human milk have been studied since the 1950s, when the pesticide DDT was first detected in breast milk (*1*). These studies are the main source of information with which to estimate health benefits and risks to an infant who is breast-fed rather than formula-fed. Each of these studies has strengths and weaknesses; taken individually, many provide snapshots of concentrations of environmental chemicals in the breast milk of a small population at one time and place. It is difficult to make widely applicable statements about levels of environmental chemicals in breast milk from these studies because of a lack of consistent sampling methodologies and reporting of the results.

Although most experts in the fields of pediatric health and lactation agree that, except in unusual situations, breast-feeding is the preferred nutrition for infants, a better understanding of an infant's level of exposure to environmental chemicals is essential, particularly in the United States where there is relatively little information. Considering both the levels of chemicals in breast milk of women residing in the United States and the kinetics of elimination of those chemicals during lactation, existing data are extremely limited. Shortcomings of published studies include inconsistent sampling and analysis protocols, incomplete reporting of sampling methods, nonrepresentative sampling (geographic, parity, age), duration of sampling, limited number of study participants, and the number and types of chemicals analyzed.

These limitations restrict our ability to predict infant body burdens, particularly during the early days and weeks of lactation. A carefully planned and executed program of breast milk sampling and analysis would serve to provide the information needed to assess infant exposures during breast-feeding and to provide consistent and scientifically sound information on benefits and risks of breast-feeding in the United States.

Increased sampling of breast milk is necessary to provide a better basis for characterizing the levels of chemicals in breast milk; therefore, a program should be initiated in the United States to sample and analyze breast milk. This type of program would provide information on current levels of environmental chemicals in breast milk and enable the development of a scientifically based and consistent message to interested parties (e.g., doctors, nurses, lactation specialists, and new mothers) on the risks and benefits of breast-feeding.

The objectives and goals of a breast milk monitoring program for women in the United States are as follows:

- Information should be obtained on women from diverse geographic regions of the United States and from different socioeconomic and demographic backgrounds. For example, the United States could be divided into four compartments: Northeast, Southeast, Northwest, and Southwest. Samples should be collected from both rural and urban locations.
- Previous studies should be extended by testing for an increased number of environmental chemicals in breast milk. In addition to the chemicals discussed in this paper, analytes should include certain heavy metals as well as other chemicals with significant lipid solubility and long biological half-life.
- Longitudinal information should be obtained during the course of lactation so that the decrease in concentration of the chemical over time can be assessed. Lactating women should be enrolled in the study on a longitudinal basis, donating samples on a monthly basis (or more frequently in the first 2 months) and then every 2–3 months if lactation continues. Recruitment of participants may be aided by lactation consultants.
- Harmonization of sampling and analysis protocols should be promoted to improve the comparability of the results. Studies should include harmonized sampling and analysis protocols, such as protocols for collecting breast milk samples, gathering information on study participants relevant to the study (e.g., mother's smoking status, age, parity, dietary information, occupational exposure information, infant dietary supplementation), reporting of breast milk data, and reporting of methodologic information.

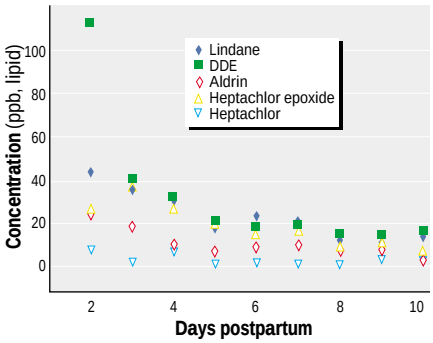

Figure 14. Elimination kinetics of organochlorine compounds (ng/g) from day 2 to day 10 of breast-feeding (30 volunteers). Data from Klein et al. (*73*).

Table 11. DDE concentrations in breast milk from birth to 18 months postpartum (ppm, lipid basis).

Sampling time	No. of samples	Median DDE level	95th percentile DDE level	Maximum DDE level	Percent less than quantitation limit
Birth	733	2.43	6.72	25.4	< 1
6 weeks	617	2.19	5.84	25.7	< 1
3 months	498	2.07	5.51	23.4	1
6 months	362	1.85	4.69	22.5	1
9 months	62	1.39	4.91	11.7	0
1 year	101	1.51	3.37	12.7	0
18 months	32	1.29	4.44	11.9	0

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