

## Lessons from the Polybrominated Diphenyl Ethers (PBDEs): Precautionary Principle, Primary Prevention, and the Value of Community-Based Body-Burden Monitoring Using Breast Milk

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Levels of chemicals in humans (body burdens) are useful indicators of environmental quality and of community health. Chemical body burdens are easily monitored using breast milk samples collected from first-time mothers (primiparae) with infants 2–8 weeks of age. Currently, there is no body-burden monitoring program using breast milk in the United States, although ad hoc systems operate successfully in several European countries. In this article we describe the value of such monitoring and important considerations of how it might be accomplished, drawing from our experiences with pilot monitoring projects. Breast milk has several advantages as a sampling matrix: It is simple and noninvasive, with samples collected by the mother. It monitors body burdens in reproductive-age women and it estimates *in utero* and nursing-infant exposures, all important to community health. Time-trend data from breast milk monitoring serve as a warning system that identifies chemicals whose body burdens and human exposures are increasing. Time trends also serve as a report card on how well past regulatory actions have reduced environmental chemical exposures. Body-burden monitoring using breast milk should include educational programs that encourage breast-feeding. Finally, and most important, clean breast milk matters to people and leads to primary prevention—the limiting of chemical exposures. We illustrate these advantages with polybrominated diphenyl ethers (PBDEs), a formerly obscure group of brominated flame retardants that rose to prominence and were regulated in Sweden when residue levels were found to be rapidly increasing in breast milk. A community-based body-burden monitoring program using breast milk could be set up in the United States in collaboration with the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC). WIC has a large number of lactating first-time mothers: It has 6,000 clinics nationwide and serves almost half (47%) the infants born in the United States. Educational programs (e.g., those run by WIC) are needed that encourage breast-feeding, especially in lower-income communities where breast-feeding rates are low and where breast-feeding may help protect the infant from the effects of environmental chemical exposures. Education is also needed about reducing chemical body burdens. A body-burden monitoring program would provide valuable data on time trends, background levels, and community hot spots in need of mitigation and follow-up health studies; develop analytic methods for new chemicals of concern; and archive breast milk samples for future analyses of other agents. **Key words:** body burdens, breast milk, breast-feeding, environmental justice, hot spots, human monitoring, Kazakhstan, persistent organic pollutants, polybrominated diphenyl ethers, precautionary principle, primary prevention, WIC clinics. *Environ Health Perspect* 111:109–114 (2003). [Online 11 December 2002] doi:10.1289/ehp.5438 available via <http://dx.doi.org/>

The health of infants, children, and the community can be improved by increasing breast-feeding rates and by decreasing community “body burdens” (chemical levels in humans). These objectives can be addressed by a program that monitors body burdens using breast milk. Currently, the United States has no body-burden monitoring program using breast milk, although ad hoc systems operate successfully in several European countries. In this article we describe the value of such monitoring and some important considerations of how this might be accomplished, drawing from our experiences with pilot monitoring projects in Kazakhstan and in Stockton, CA. We argue that breast milk is effective in expanding primary prevention

(reducing chemical exposures that harm the fetus, newborn, and child), in no small part because finding industrial chemicals in breast milk has stimulated public response and regulatory action.

### Lessons of the Polybrominated Diphenyl Ethers

Swedish body burden monitoring studies (1,2) for polybrominated diphenyl ethers (PBDEs) make clear that breast milk is a highly visible and socially important sampling matrix. PBDEs have been in use for the past 25 years as flame retardants; as such, they are major, non-chemically bound additives to fabrics, foams, and plastics, comprising up to 30% by weight of polyurethane foams and computer plastics

(3–5). Until recently, PBDEs were considered obscure members of the persistent organic pollutants (POPs) family, whose other members include polychlorinated biphenyls (PCBs), polychlorinated dibenzodioxins and -furans (PCDDs/PCDFs), and organochlorine pesticides (3,6,7). In 1992, exponential increases in PBDEs were found in marine sediment core samples taken from the Swedish coast over a 10-year period (7,8), but the study attracted little attention. Not until similar exponential increases were found in archived samples of Swedish breast milk in 1998 did the presence of PBDEs become known in Sweden and receive worldwide scientific and public attention: PBDE levels in breast milk had been doubling every 5 years over the preceding 25 years, but no one had known about it (Figure 1) (1,2,8).

At the time of the Swedish study (1), few measurements of PBDEs had been made in the United States in either biota or humans. Indeed, no comparable time-trend data exist to this day. Two recent studies (9,10) from our laboratory indicated the need for more body burden monitoring in the United States and the value of using breast milk. One study reported that women in the San Francisco Bay, California, region had the highest PBDE body burdens in the world, 6- to 10-fold higher than levels reported for Europeans (Figure 2A) (9). Results from a second study showed that PBDE levels in San Francisco Bay harbor seals had been doubling every two years and had increased 100-fold over the past decade (Figure 2B) (10). Both studies used samples of adipose tissue rather than breast milk. In contrast to the Swedish breast milk study, both generated limited public and regulatory response. Comparing responses from the Swedish and U.S. public has its limitations, but it seems fair to say from these time-trend studies that “When breast milk speaks, people listen!” Significantly, the presence of strontium 90 in breast milk and

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other foods in the United States was a major contributor to the ban on atmospheric nuclear testing (11).

Several lessons can be learned from the Swedish breast milk study. Most important is that breast milk occupies a special place in the public mind: People seem unconsciously to invoke the precautionary principle more readily for chemicals in breast milk than for those in blood, urine, or fat. Because breast milk speaks loudly, catching the public's attention, body burden data from breast milk can serve as an effective warning system for new chemicals in need of regulatory attention (e.g., PBDEs) (12). Time-trend data serve as a report card on the effectiveness of past regulatory strategies to lower community body burdens. These data tell us that regulation works: Body burdens of PCBs and polychlorinated dioxins/furans in the Swedish breast milk study decreased 50% in the 20-year period (1972–1992) following regulation (Figure 1) (1). Time trends showed further that the Swedish responses to PBDEs were effective: PBDE body burdens began to trend downward following the phaseout of the penta-PBDE flame retardant in the late 1990s (Figure 1) (2).

## Advantages of Body-Burden Monitoring

Primary prevention seeks to reduce the public's exposures to toxic chemicals. A monitoring system can help with primary prevention if we initiate mitigation measures when increases in specific chemicals are found. Different chemicals require different systems. Many industrial organic chemicals are volatile, water-soluble, or rapidly transformed (environmentally degraded or metabolized by biota), and reside only briefly in biota or humans. Because body burdens are transient, it makes sense to monitor these chemicals by monitoring levels in matrices (e.g., urban air or water) that are significant sources of shared exposures for major populations.

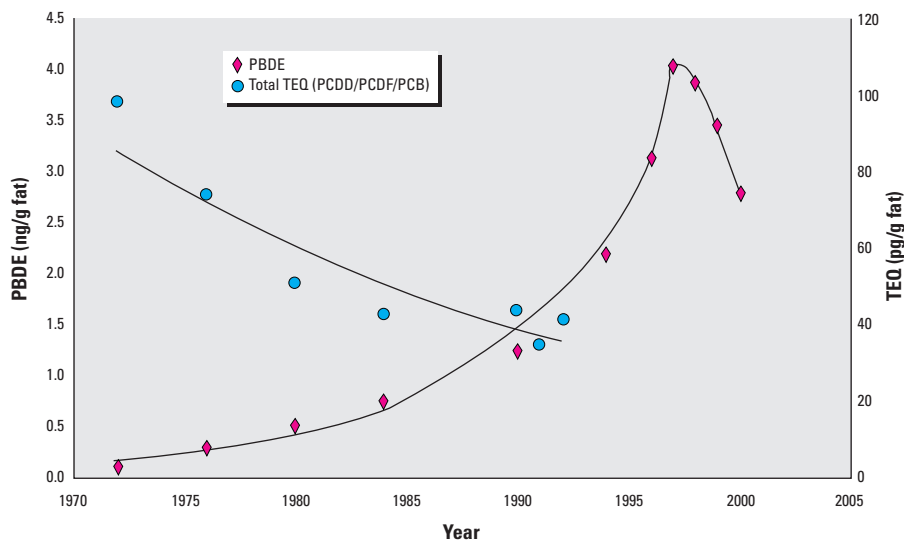
In contrast, other chemicals (e.g., POPs) are relatively nonvolatile or sparingly soluble in water, and neither air nor water is the major source of human exposure. POPs are lipophilic and stable; they bioaccumulate in the fat of biota and humans and biomagnify up the food chain. Humans are near the top of this ecologic food pyramid, with breast-fed infants at the very peak. POP chemicals need to be monitored because several adverse health effects in humans have been linked to POP exposures, including cancer (13,14) and altered infant sex ratio (15,16) with 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD), neurodevelopmental cognitive-motor deficits with PCBs (17–20), and shortened duration of lactation with *o,p*-DDE (21). POPs are suspected of acting as pseudo-hormones [e.g.,

as estrogens, anti-estrogens, or, with PBDEs, as thyroid hormone mimics (6)] by a variety of mechanisms, including interfering with hormone synthesis or metabolism, carrier protein concentrations, carrier protein function, and transcriptional activation. If so, even trace levels of POPs may produce significant biologic effects.

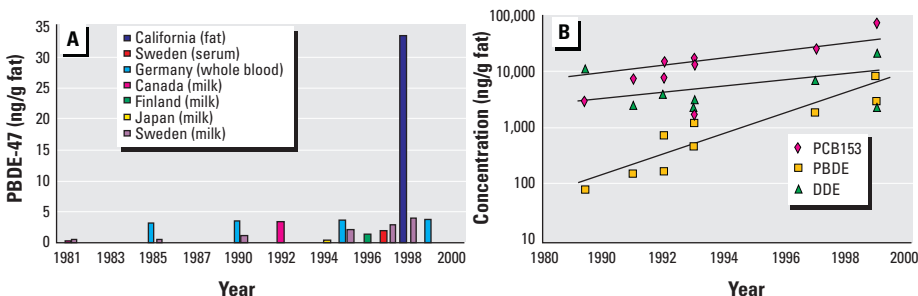
Although dietary animal fat is the major source for many POPs, nondietary sources may be significant for others (e.g., PBDEs). For example, polyurethane foam, as found in sofas, contains penta-PBDEs up to ~30% by weight (5,22). The foam crumbles at the surface and disperses into dust after 4 weeks of sun exposure at ambient summer conditions (5,22), and the nonchemically bound PBDEs may leach or volatilize from the dust particles. Variable diets within a population hamper our ability to predict POP body burdens from residue levels measured in foods. Monitoring POPs in environmental sentinel biota (e.g., fish, shellfish, raptor birds) can alert us to new chemicals, but dietary differences between biota and humans again limit the predictive value of these data for levels or time trends in humans.

For POPs, direct measurement of body burdens seems the best means of tracking human exposures. Such measurements are, in fact, multimedia monitoring, as they integrate exposures from all sources and pathways. Optimally, a human body burden monitoring program would accomplish five objectives: establish background levels; identify chemicals or regions in need of mitigation or follow-up health studies (hot spots); examine changes of body burdens over time (time trends); develop analytic methods for new persistent chemicals of interest; and systematically archive samples for future studies of new chemicals of concern.

Regarding the second objective, identifying problem chemicals, given the difficulties and complexities of health studies, the lessons learned from DDT and the PCBs should encourage us to take precautionary action (mitigation) to reduce levels of POPs with toxic effects when we find their levels increasing in breast milk. PBDEs, like PCBs before them, fulfill the three elements of the precautionary principle: plausibility of harm, scientific uncertainty that is difficult to resolve, and the benefits of precautionary action (23,24).



**Figure 1.** Organohalogen compounds in breast milk in Sweden. Data from Norén and Mieronyté (1) and Guvenius and Norén (2).



**Figure 2.** High and increasing levels of PBDEs in California. (A) PBDE levels in humans' regional comparisons. (B) Persistent organic pollutants in harbor seals from San Francisco Bay.

## Advantages of Community-Based Monitoring

Communities are centers of social, cultural, and political activity and thus are the logical places within which body burden monitoring and breast-feeding education can be linked. Communities have the energy and political will as well as the responsibility to transform the finding of elevated community body burdens into demands for mitigation and/or regulation to limit exposures.

As with other public health interventions (e.g., clean water and proper sanitation to prevent infectious diseases), primary prevention for environmental health occurs collectively at the community, state, and/or national levels, not at the individual level. Preventive measures are introduced that lead to cleaner air, water, food, and the like and that limit the public's exposure to noxious factors.

An effective monitoring program would identify communities with significant exposures and query highly exposed individuals to identify potential major sources/pathways of human exposure. Time-trend data would assess the effectiveness of mitigation strategies. Some of our monitoring efforts, therefore, should focus on potential hot spots (e.g., underserved or under-resourced populations living in heavily industrialized areas at-risk for environmental chemical exposures). A number of low-income communities concerned about environmental justice have stepped forward and asked that their community body burdens be characterized (25).

## Advantages of Individual versus Pooled Data

In all but the most extreme cases, physicians cannot predict the health consequences of an individual's POPs body burden, nor can they offer a means of lowering this burden. Thus, from a treatment standpoint, POP residue data

are of limited use to the individual. From a public health standpoint, however, individual data are extremely useful to the community because they give us ranges and distributions of POP body burdens not provided by pooled samples. However, to prevent potential adverse social or economic consequences, data from individuals must be kept strictly confidential.

## Advantages of Exposure Registry

One solution is to report publicly only community-wide summary data with ranges and distributions and to maintain confidential individual data in a registry. This protocol protects the individual, emphasizes the community basis of the monitoring, and focuses responsibility for action on the community.

In a manner similar to cancer or birth defects registries, exposure registries of body burden data would characterize spatial (hot spots) and temporal (time trends) patterns as well as normative backgrounds, except that body burden data, not diagnoses of disease or defects, are recorded. Just as data from health registries have been used to intervene and prevent morbidity, data from a body burden registry can be used to develop rational strategies to lower (prevent, mitigate, or remediate) chemical exposures.

## Advantages of Breast Milk

Three tissue options—adipose, blood, or breast milk—are available to monitor for trace POPs body burdens, and all require chemically clean collection procedures. Adipose tissue is poorly suited for routine monitoring because sample collection requires surgical intervention.

The significant advantage of blood is that diverse populations can be sampled—male, female, young, and old. However, blood has

several disadvantages: Samples must be collected under chemically clean and strictly sterile conditions to minimize the risk of transmission of infectious disease among sample donors, collectors, and lab analytic personnel. A phlebotomist is required, preferably in a hospital or clinic setting, and correct disposal of blood-contaminated materials (e.g., needles, bandages, vacutainers, tops) is necessary. Serum samples must be prepared onsite, requiring clinical centrifuges and equipment to transfer serum from vacutainers to chemically clean jars. Because the fat content of blood (0.3–0.5%) is one-tenth that of milk (3–5%), the volume of blood required for chemical analysis is 10 times greater than the volume of breast milk.

In contrast, breast milk is a convenient and noninvasive alternative matrix for measuring body burdens of POPs. Donors are selected according to the World Health Organization (WHO) criteria, namely healthy first-time mothers (primiparae) with healthy infants 2–8 weeks of age (26). These criteria standardize the interindividual measurement of body burdens by limiting donors to mothers with no prior breast-feeding episodes (which lower body burdens) and by collecting samples early in lactation (which limits the length of lactation before sampling). Samples are easily collected: First-time mothers hand-express milk into chemically clean jars and refrigerate, as if collecting and storing milk for their infant. Collection occurs in the mother's home and at her own pace. An obvious drawback is that only lactating women can be sampled, which decreases the diversity of the sampled population. However, body burdens in young lactating women should reasonably approximate community body burdens of similarly young men and women arising from environmental chemical exposures. Moreover, breast milk is ideally suited for monitoring POP body burdens in reproductive-age women, and in estimating body burdens for subpopulations whose health is critical to the future economic well-being of the community, and from whom blood samples are difficult to obtain: namely, the fetus and the breast-fed infant or young child. A difficulty with breast milk is that a potential donor needs to be contacted during pregnancy to determine whether she wishes to participate, and samples are collected 2–8 weeks after birth to adhere to the WHO protocol.

## Advantages of Women, Infants, and Children Clinics

The Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) Clinics provides access to a significant cross-section of pregnant, soon-to-be lactating, first-time mothers from lower-income, at-risk populations in the United States. WIC has 6,000 clinics

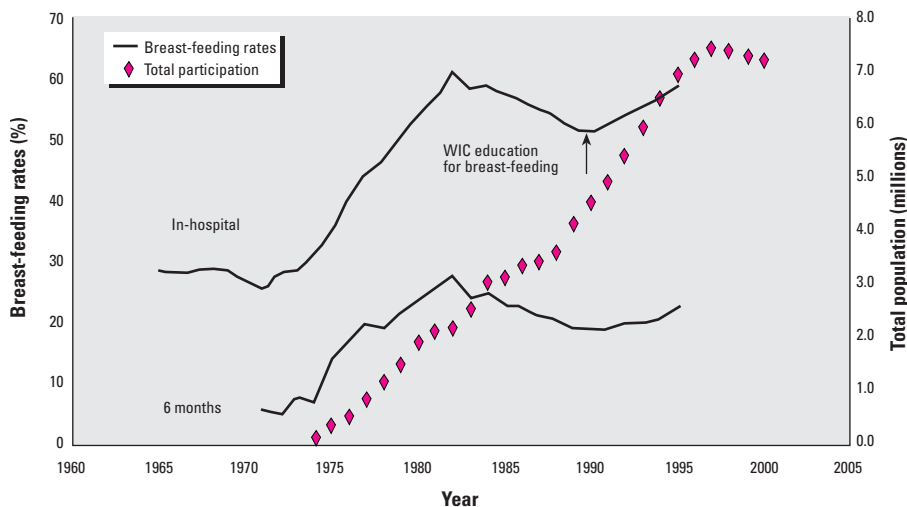


Figure 3. U.S. breast-feeding rates and WIC participants.

nationwide and serves 7 million persons (pregnant or postpartum women, infants, and children up to age 5) in families that meet the low-income eligibility guidelines (27). Currently, 62% of infants born in California and 47% of all babies born in the United States are served by the WIC clinics (27,28).

## Value of Breast-Feeding Education

For some POP chemicals (e.g., PCBs), breast-fed infants take in much greater (50-fold higher) amounts than adults on a body weight basis (29–31). This poses a dilemma for new mothers and public health officials. Should we limit breast-feeding?

First, the health benefits for the breast-fed infant are well documented and include decreased rates of diarrhea and of respiratory, ear, and urinary tract infections as well as increased immune surveillance (32). Second, the health problems documented in infants from POP chemical exposures (e.g., neurodevelopmental deficits, altered sex ratio) seem to be caused not by chemicals in breast milk (lactational exposures) but by *in utero* exposures or paternal factors—that is, by the chemical body burdens of the mother and father, or the community's body burden (15,16,19). The female-biased infant sex ratio reported from TCDD exposures in Seveso is linked to the TCDD body burden of the father, not the mother nor to lactational exposures (15,16). The neurodevelopmental deficits seen in offspring whose mothers are in the highest 10th percentile of “background” PCB levels appear to arise from *in utero* rather than lactational exposures, as the most severe deficits are seen in nonbreast-fed infants (19,20).

Finally, one study (33,34) suggests that chemicals in breast milk should encourage rather than discourage breast-feeding. Breast milk appears to reduce the severity of the effects on the infant from the mother's body burdens and, to some extent, rescue the infant from these effects. In the PCB–neurodevelopmental study, infants and children who were breast-fed outperformed bottle-fed offspring on the neurodevelopmental tests, suggesting that breast-feeding decreased the health risks stemming from *in utero* PCB exposures (33,34). Breast milk is known to contain factors that stimulate the development of the immune system and brain in the infant (32), and it may also have evolved factors that help ameliorate fetal damage caused by *in utero* exposures. Because we are descendants of herbivorous primates with a long history of ingestion of plant defense substances, *in utero* damage likely has a long history as well and did not begin with exposures to modern xenobiotics. An evolutionary advantage would be gained by those primates whose breast milk conferred to the infant the

gift of restoration as well as the wealth of other benefits. Several studies have indicated that breast-fed daughters have a 25% lower breast cancer incidence than nonbreast-fed daughters (35,36), consistent with breast milk reversing *in utero* damage.

Counterintuitive as it sounds, it may be that the higher the mother's chemical body burden, within limits, the greater are the health benefits conveyed to her infant by her breast milk and the more important it is for her to breast-feed, to help reverse any transplacental damage to the fetus. It may be that xenobiotics in breast milk are not particularly harmful. It may be that these contaminants cause significant harm only when they reside in the community, sequestered in the mother and father before conception, to later affect the health of the developing fetus.

An oft-cited disadvantage of using breast milk to monitor body burdens is that information on contaminants in breast milk discourages mothers from breast-feeding. It is not clear, however, that breast-feeding rates are lower in the United States than in other industrialized nations because of fear of contaminants, nor is it clear that talk of contaminants discourages breast-feeding. In southern Kazakhstan, mothers are aware of environmental contamination, but breast-feeding is nearly universal (37–39). Likewise, in Sweden and Norway, awareness of contaminants is high, but breast-feeding rates are higher than in the United States (80–90% vs. 65–70%) (40). It is, however, clear that any body-burden monitoring using breast milk should be accompanied by breast-feeding education programs that describe the advantages of breast milk, the disadvantages of infant formula, and the importance of breast-feeding for communities with higher body burdens.

Thus, an added benefit of monitoring body burdens through breast milk is that educational components can encourage and support the practice of breast-feeding and stress the importance of lowering chemical body burdens. The community learns that environmental chemicals are in everyone, not just the lactating mother and that reducing chemical body burdens is everyone's responsibility. They learn that a mother can reflect the community's body burden of environmental chemicals by donating a sample of breast milk early in her first lactation. And they learn that scientific evidence suggests that breast-feeding is even more important in communities with higher chemical body burdens.

WIC runs educational programs that have increased breast-feeding rates in lower-income populations. Breast-feeding was universal in the United States in 1900, declined to 22% in 1972, and is now at 60% for hospital-based initiation and 20% for 6 months postpartum, with many of the latter supplementing with

formula (Figure 3) (41,42). Breast-feeding rates are lower among lower-income populations (41–43), but WIC educational programs introduced in 1989–1995 markedly increased breast-feeding in WIC participants and dramatically improved the national breast-feeding rates because so many mothers were being served by WIC (Figure 3) (42).

Lactation consultants in California suggest that the low prevalence of breast-feeding among low-income participants in the WIC programs is linked to the dispensing of free infant formula as well as to the belief by some ethnic immigrant groups that infant formula builds the larger and healthier children they see in the United States (44). Several factors have enabled infant formula, with \$3 billion in mass-market revenues and with powdered formula in double-digit sales growth (45), to secure a niche in the medical care system that allows in-hospital marketing to new mothers: Contracts with hospitals give a formula company the exclusive marketing rights to new mothers in the hospital in exchange for free infant formula for the hospital (44,46). Free samples of infant formula are given to new mothers in maternity wards in hospitals, and breast-feeding mothers are given reduced-cost coupons when they leave the hospital as inducement to change (44,46). Hospitals give infant formula to nonbreast-fed babies rather than breast milk from archived milk banks. Although the Baby-Friendly Hospital Initiative aims to eliminate these practices, they are still prevalent in many hospitals nationwide (46).

For the infant and young mother, the use of infant formula can be just as addictive—as difficult to reverse—as cigarette smoking. Lactation, once ceased, cannot simply be reinitiated, and infants, once introduced to pacifiers and bottle feeding, adopt the muscular sucking movements used in bottle-feeding, which are different from those used in breast-feeding and are difficult to reverse. Habituated soon after birth to these motions, the infant may prefer the bottle, where flow rate is higher and feeding impulses are satiated more rapidly. With lower demand, the mother's supply of milk diminishes, and lactation spirals downward until breast-feeding ceases.

Education programs can counteract the effect of infant formula on breast-feeding.

- The community needs to know that the breast-fed baby is a healthier baby (32); that the POP body burdens of the community adversely affect the health of infants and children; that breast-feeding rescues the infant from some of these effects (33,34); and that breast-feeding is important in at-risk communities with significant body burdens.
- Medical professionals need awareness and training in lactation problems and their treatment (32,46). Lactation consultants

argue that infant formula too often is the first, rather than the last, option recommended by pediatricians when new mothers have lactation dysfunction (44).

- Legislators need to know that proper breast-feeding facilities (a comfortable place and scheduled times) should be made available at each workplace, where working, breast-feeding mothers can collect and refrigerate milk for their infants. Also, the United States may take a lesson from Sweden and Norway, where mothers have 1-year paid maternity leave, contributing to their higher breast-feeding rates (47).

## Examples of Body-Burden Monitoring Using Breast Milk

We have conducted community-based monitoring studies to measure body burdens of POPs using breast milk as the sampling matrix (37–39,48). These studies have established background levels, identified hot spots, and triggered follow-up health outcome studies (49,50). Breast milk donors are selected according to the WHO criteria (26), and standardized consent forms, exposure assessment questionnaires, and sample collection and storage protocols are used (37–39). Donors are recruited from WIC Clinics or maternal and child health clinics.

**Stockton, California.** Because TCDD-contaminated fish were reported in waterways adjoining a superfund site in Stockton, body burdens of TCDD were assessed in fish-eating residents of the region (48). In collaboration with local WIC programs, primiparae were recruited from ethnic groups (Laotians, Vietnamese, Cambodians, and Hmong) who were reported to have breast-feeding rates of 25–35% and to consume significant quantities of local fish. However, breast-feeding prevalence was low (5–10%), as was consumption of local fish. The TCDD body burdens were also low, and this limited study ( $n = 40$ ) could find no apparent relationship between fish consumption and TCDD levels (48).

**Kazakhstan.** In an initial countrywide survey, breast milk samples were collected from 100 primiparae residing in one of seven major population centers (37). Levels of POP body burdens were generally similar to those found in western Europe or the United States. However, a hot spot of TCDD (body burdens up to 212 pg/g lipid) was found in a cotton-growing region in southern Kazakhstan. In this region, body burdens of TCDD and  $\beta$ -hexachlorocyclohexane averaged 10-fold higher than levels found in European or U.S. populations (37–39).

The unique congener pattern [TCDD was the major (70–80%) contributor to the toxic equivalent (TEQ) (38,39)] suggested that the community was exposed to a TCDD-contaminated stock of the herbicide

2,4,5-trichlorophenoxyacetic acid (2,4,5-T), similar to the defoliant Agent Orange that was used in Vietnam. The Soviets produced a TCDD-contaminated 2,4,5-T defoliant beginning in 1960. Agricultural chemicals were heavily sprayed on cotton fields from airplanes, and defoliants were applied two weeks before cotton harvest. Food in the region is home grown, and the food supply appears widely contaminated with TCDD (39,51). Although the TCDD levels are 10- to 100-fold higher than U.S. levels, the TEQs from dioxins/furans and coplanar PCBs are only twice the U.S. levels (38).

## Conclusion

The solution to the problem of chemical body burdens—the chemicals in our bodies, our blood, and our breast milk—is the same as the solution to the problem of chemicals in our environment—our air, water, and food. Rather than restrict our activities (breathing, drinking, eating, or breast-feeding) or introduce substitutes (bottled air or water or infant formula), the solution is to safeguard the health of our infants and children by controlling and limiting our chemical body burdens and by encouraging breast-feeding.

Breast milk is a valuable matrix for monitoring body burdens of POPs. It provides data on background levels, hot spots, and time trends that we need to develop policies to limit chemical exposures. Most important, chemical contaminants in breast milk matter to people, and community involvement can lead to actions that limit chemical exposures. Breast milk is invaluable to the infant as a source of nutrition and health, so breast-feeding should be encouraged. Community-based programs to monitor body burdens of POPs using breast milk could be implemented in the United States in collaboration with WIC programs. Such programs emphasize that increasing breast-feeding rates and decreasing POP body burdens are both important ways to improve the health of the infant and child.

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