Assessment of Dietary Exposure to Some Persistent Organic Pollutants in the Republic of Karakalpakstan of Uzbekistan

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A 1999 study heightened long-standing concerns over persistent organic pollutant contamination in the Aral Sea area, detecting elevated levels in breast milk and cord blood of women in Karakalpakstan (western Uzbekistan). These findings prompted a collaborative research study aimed at linking such human findings with evidence of food chain contamination in the area. An international team carried out analyses of organochlorine and organophosphate pesticides, polychlorinated biphenyls (PCBs), polychlorinated dibenzo-*p*-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) on samples of 12 foods commonly produced and consumed in Karakalpakstan. Analysis consistently detected long-lasting organochlorine pesticides and their metabolites in all foods of animal origin and in some vegetables such as onions and carrots—two low-cost components of many traditional dishes. Levels of PCBs were relatively low in all samples except fish. Analyses revealed high levels of PCDDs and PCDFs (together often termed "dioxins") in sheep fat, dairy cream, eggs, and edible cottonseed oil, among other foodstuffs. These findings indicate that food traditionally grown, sold, and consumed in Karakalpakstan is a major route of human exposure to several persistent toxic contaminants, including the most toxic of dioxins, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). Intake estimations demonstrate that consumption of even small amounts of locally grown food may expose consumers to dioxin levels that considerably exceed the monthly tolerable dioxin intake levels set by the World Health Organization. Data presented in this study allow a first assessment of the risk associated with the consumption of certain food products in Karakalpakstan and highlight a critical public health situation. *Key words:* **Aral Sea, Central Asia, dioxins, exposure assessment, food, organochlorine pesticides, PCBs, persistent organic pollutants, Uzbekistan.** *Environ Health Perspect* **111:1306–1311 (2003). doi:10.1289/ehp.5907 available via *http://dx.doi.org/* [Online 14 April 2003]**

Soviet-era introduction of cotton monoculture in Central Asia in the 1950s began a 40-year history of intensive agricultural chemical use. Karakalpakstan, an autonomous republic within Uzbekistan, bordering the Aral Sea, was no exception. During the 1970s and 1980s, insecticide and herbicide application rates there averaged 21 kg/hectare, compared with only 5 kg/hectare throughout the Soviet Union during the same period (Bakhritdinov 1991). In addition, several compounds that were used are now banned because of their toxicity, and other agents were of doubtful origin and low chemical grade (Hooper et al. 1998). Given the persistent nature of these agents, many researchers, public health practitioners, and residents of the affected communities are concerned that this historically intensive application of toxic and low-grade agricultural chemicals is having an adverse effect on the health of the area population (Crighton et al. 2003).

Numerous studies carried out in agricultural regions of Uzbekistan (Bakhritdinov 1991; Crighton et al. 2003; Iskanderov 1986; O'Hara et al. 2000, 2001; Shafer et al. 2001; Small 1999; Small et al. 2001; Smith 1991) have documented a wide range of serious health problems. Findings potentially related to environmental health and toxicology include elevated levels of developmental retardation, malabsorption, hypothyroidism, immunodeficiency, and chronic renal and lung diseases among area children (Jensen et al. 1997). At this point, however, a firm scientific link between agrochemical use and health outcomes has yet to be established. Nonetheless, evidence of elevated human exposure has kept concerns high.

Recent analysis of breast milk and cord blood of women and children in Karakalpakstan showed elevated levels of hexachlorobenzene (HCB), hexachlorocyclohexane (HCH), *p,p′*-dichlorodiphenyldichloroethylene (*p,p′*-DDE) and of the most toxic of dioxins, 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (2,3,7,8-TCDD). Dioxins in breast milk were 2.5 times the levels found in the Ukraine, and maternal 2,3,7,8-TCDD body burdens were 5 times higher than in The Netherlands (Ataniyazova et al. 2001).

The primary sources of exposure to such pesticides and dioxins in the region had yet to be clearly identified. Karakalpakstan drinking water has been found to be contaminated with dichlorodiphenyltrichloroethane (DDT) and γ-HCH at concentrations higher than standards for Uzbekistan as well as recommended international standards (Binnie & Partners 1996). However, because of the generally high fat solubility and very low water solubility of the pollutants in question, one might expect exposure from contaminated drinking water to be less important than exposure via food consumption, especially fatty foods. For example, investigations performed in the United States have found a direct relationship between serum dioxin and furan levels and consumption of beef and eggs contaminated with varying concentrations of polychlorodibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs)—collectively referred to as "dioxins" (Goldman et al. 2000). A study in neighboring Kazakhstan lends weight to this concern over exposure via contaminated food. That study detected elevated levels of 2,3,7,8-TCDD in animal fat samples (Hooper et al. 1998).

To help clarify the role of the food chain in human exposure to these pollutants in Karakalpakstan, Médecins sans Frontières (MSF), which has been working in the area since 1997, in collaboration with the World Health Organization's (WHO's) European Centre for Environment and Health, initiated a study to measure the levels of contamination from dioxins (PCDDs/PCDFs), polychlorinated biphenyls (PCBs), and certain organochlorine and organophosphate pesticides in foods commonly consumed in Karakalpakstan. In this article we describe the findings of this research.

Materials and Methods

Food sample collection. In February 2001, a trained technician, under supervision of the

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Karakalpak Veterinary Authority, collected samples from the same three towns (Nukus, Chimbay, and Kanlikul) in Karakalpakstan where toxicologic investigation of human breast milk and maternal and cord blood had recently been carried out (Ataniyazova et al. 2001). The study team chose food types for sampling based both on their capacity to accumulate organochlorine pesticides and dioxins and on patterns of food consumption in Karakalpakstan known from a recent household dietary assessment carried out in Nukus (MSF 2001).

Thirty-six food samples (1 sample of 12 food types from each of the three towns) were cross-sectionally sampled according to internationally recognized sampling methods, specified by the Codex Alimentarius Commission (1999). At the central market of each town, technicians collected a sample of six locally grown/produced foods of animal origin [1.5 kg each of fatty beef, fatty sheep meat, chicken fat, and fish (sazan—a freshwater fish of the carp family), 36 eggs, and 1.5 L of dairy cream] and a sample of six locally grown/produced foods of plant origin (1.5 L of cottonseed oil and 3 kg each of onions, carrots, potatoes, rice, and flat bread). To obtain the required amount for each sample, technicians collected portions from four or five randomly selected sellers and then pooled them. Randomization of sellers was accomplished by identifying all sellers of each food item present on the day of sampling and randomly selecting four or five of them. Samples are considered representative of all commercially available produce in these towns, because each central market is the sole official fresh produce outlet.

Contamination and deterioration were avoided by adhering to the sampling instructions of the Codex Alimentarius Commission (1999). All samples were collected in a 3-day period during the winter month of February and were placed in clean, inert glass containers, sealed with a lid and thick aluminum foil. Containers, lids, and foil were rinsed with analytical grade acetone before use. Samples were stored and monitored in a freezer at –18°C within 2–3 hr of collection. Frozen samples were packed in insulated containers with dry ice and shipped by air to the laboratories, where they arrived still frozen 5–7 days after collection.

Analytical procedures. Chemisches Landes und Staatliches Veterinäruntersuchungsamt (Münster, Germany) performed analyses on foods of animal origin for PCDDs/PCDFs (17 congeners from tetra- to octachlorinated), PCBs (19 congeners), and several organochlorine pesticides. The German lab analyzed dioxins and coplanar PCBs using capillary gas chromatography/high-resolution mass spectrometry at a resolution of 10.000 in the selected ion-monitoring mode. Nonplanar PCBs were analyzed using combined capillary gas chromatography/low-resolution mass spectrometry. Organochlorine pesticides were analyzed by capillary gas chromatography/electron capture detection on two capillary columns of different polarity.

Istituto Zooprofilattico Sperimentale dell'Abruzzo e del Molise (Teramo, Italy) performed analyses on foods of plant origin for the same congeners of PCDDs/PCDFs and PCBs. The Italian laboratory analyzed foods of plant origin for several additional organochlorine pesticides and also tested for several organophosphorus pesticides and three related products: phosalone, trichlorfon, and thiram. The Italian laboratory analyzed PCDDs/PCDFs using a modification of U.S. Environmental Protection Agency (EPA) Method 1613 (U.S. EPA 1994a). Modifications consisted of *a*) extraction by Accelerated Solvent Extractor 200 (Dionex, Sunnyvale, CA, USA), a system working under high pressure and temperature to improve fat extraction; and *b*) extract purification using the automatic Power Prep system (Fluid Management System, Inc., Waltham, MA, USA), equipped with three cleanup columns: acid/base silica, alumina, and carbon. PCBs were analyzed according to U.S. EPA Method 1668 (U.S. EPA 1999), modified in the extraction step with use of the Accelerated Solvent Extractor 200. Organochlorine and organophosphorus pesticides were analyzed using in-house validated methods developed for foodstuffs and animal feed. Phosalone, trichlorfon, and thiram were analyzed following validated procedures.

All methods applied have been validated by a number of national and international quality assurance studies and proficiency tests. Moreover, both laboratories are accredited according to internationally recognized quality control schemes.

Estimating dietary intake. In April 2001, as part of ongoing drought impact surveillance, MSF completed a dietary assessment in the city of Nukus among 101 households living near the central market. A trained local researcher conducted the cross-sectional survey, collecting information from an adult household member on household food consumption in the previous month, as well as household demographic and socioeconomic characteristics. Every other house along a path starting at the market was visited, with vacant houses skipped.

The food consumption data derived from the Nukus survey are combined with this study's laboratory analysis results and assumptions regarding typical body weight and food fat content derived from standard food tables for Uzbekistan (Pokrovskiy 1977) to calculate estimates of average monthly intake of several tested chemicals. The assumed fat contents for meats, high by North American standards, are typical for Central Asia, where animal fat is highly prized and regularly consumed.

Results

Of the 18 PCB congeners analyzed, 12 are the PCB congeners judged by the WHO to have dioxin-like toxicity. Analysis results for dioxins and these 12 dioxin-like PCB congeners are expressed as toxic equivalents (WHO-TEQ), calculated using the toxic equivalency factors (TEF) proposed by the WHO (Van den Berg et al. 1998). If specific dioxins or PCB congeners could not be detected, their contribution to total toxicity was calculated as zero and as one-half the value of the respective limit of detection (LOD).

The other six analyzed "indicator" PCB congeners (PCB congeners 28, 52, 101, 138, 153, and 180) do not contribute to these calculations of total toxicity. Results for these congeners are expressed as micrograms per

Table 1. TEQs (ng-TEQ/kg fat) for PCDDs/PCDFs and dioxin-like PCBs in samples of animal origin.

	PCDDs/PCDFs		PCBs		Total	
Sample	TEQ	(1/2 LOD)	TEQ	(1/2 LOD)	TEQ	(1/2 LOD)
Sheep fat						
Nukus	28.90	28.91	0.79	0.88	29.70	29.79
Chimbay	2.01	2.01	1.41	1.72	3.41	3.73
Kanlikul	2.53	2.53	1.93	1.99	4.46	4.52
Beef fat						
Nukus	0.74	0.74	0.56	0.63	1.30	1.37
Chimbay	1.27	1.27	1.16	1.50	2.43	2.77
Kanlikul	0.56	0.57	0.54	0.74	1.11	1.31
Chicken fat						
Nukus	8.74	8.74	5.40	5.55	14.14	14.29
Chimbay	10.17	10.17	8.06	8.14	18.24	18.32
Kanlikul	15.20	15.20	10.64	10.79	25.84	25.99
Fish						
Nukus	4.87	4.87	12.28	12.58	17.15	17.46
Chimbay	2.07	2.07	6.61	6.91	8.69	8.99
Kanlikul	3.61	3.61	6.27	6.58	9.88	10.19
Eggs						
Nukus	0.74	0.74	0.30	0.49	1.04	1.23
Chimbay	34.37	34.37	3.21	3.50	37.58	37.87
Kanlikul	4.05	4.05	4.19	4.48	8.25	8.54
Dairy cream						
Nukus	3.15	3.15	1.09	1.12	4.24	4.27
Chimbay	2.52	2.52	0.95	0.98	3.47	3.50
Kanlikul	0.91	0.91	0.55	0.58	1.46	1.49

kilogram of fat for foods of animal origin and as nanograms per kilogram fresh weight for foods of plant origin. All other congener-specific results are expressed as nanograms per kilogram of fat for foods of animal origin or nanograms per kilogram fresh weight for foods of plant origin. Fresh weight is used for foods of plant origin because of their low fat content.

Because of the high concentrations of pesticides detected in many food samples, these results are expressed as milligrams per kilogram of fat (foods of animal origin) and milligrams per kilogram fresh weight (foods of plant origin), rather than as micrograms or nanograms per kilogram.

Foods of animal origin. **PCDDs/PCDFs.** Several sheep fat and egg samples and all chicken fat samples had dioxin levels well above maximum levels set by European legislation for these foods: 3 ng-TEQ/kg fat for sheep and eggs and 2 ng-TEQ/kg fat for chicken (European Commission 2001). In one egg sample, total dioxin toxicity was as high as 34.37 ng-TEQ/kg fat. Dioxin levels found in beef fat and dairy cream were lower (Table 1).

Although each of the 17 analyzed congeners was found at detectable levels in almost all samples, dioxin contamination was dominated by 2,3,7,8-TCDD. Although this congener typically contributes < 30% to total TEQ, samples of animal origin analyzed in this study revealed a TCDD share of up to 90%. In one egg and one sheep fat sample, concentrations of this most toxic dioxin congener (TEF = 1) were almost 30 ng/kg fat. 1,2,3,7,8-Pentachlorodibenzo-*p*-dioxin was also present but to a lesser extent (mean concentration in chicken = 3.13 ng/kg fat). All fish samples showed a similar profile of contamination. Within the group of PCDD congeners, octachlorodibenzo-*p*-dioxin (OCDD) dominated, with levels ranging from 20 to 54 ng/kg fat, followed by 1,2,3,4,6,7,8-heptachlorodibenzo-*p*-dioxin (HpCDD), with 2.2–6.6 ng/kg fat. However, because of their low TEFs, these two congeners did not contribute significantly to total TEQ values. As typical for fish, the highest contribution to total TEQ in these samples came from 2,3,7,8-TCDD, 2,3,7,8-tetrachlorodibenzofuran, and 2,3,4,7,8-pentachlorodibenzofuran.

Dioxin-like PCBs. The contribution of the 12 dioxin-like PCBs to total toxicity differed by food item. TEQ values typically doubled for dairy products, meat, and eggs, whereas for fish, high PCB contamination increased TEQ by a factor of 3–4 (Table 1).

PCB 126, the most toxic dioxin-like congener, was detected in all food samples of animal origin in concentrations ranging from 2.0 to 108.6 ng/kg fat. Fish and chicken samples had the highest dioxin-like PCB levels.

Indicator PCBs. Fish also had the highest levels of the six indicator PCB congeners. Each congener was detected in all three fish samples, with high levels of PCB 28 (mean, 46 µg/kg fat) and PCB 52 (67 µg/kg fat); medium levels of PCB 101 (mean, 21.6 µg/kg fat), PCB 138 (mean, 20.8 µg/kg fat), and PCB 153 (mean, 13.3 µg/kg fat); and lower concentrations of PCB 180 (mean, 6.5 µg/kg fat). Eggs showed a similar pattern of contamination but at a lower level.

In contrast with these results, all fatty matrices (dairy cream and chicken, sheep, and beef fat) showed very low levels for each indicator congener. PCBs 28, 52, and 180 were below the LODs in most analyzed samples, and the other congeners (PCBs 101, 138, and 153) generally ranged from only 0.1 to 2 µg/kg fat. PCBs 138 and 153 were found only in higher concentrations in chicken fat (means = 7 µg/kg fat and 5.1 µg/kg fat, respectively).

Table 2. Organochlorine pesticides (mg/kg fat) in samples of animal origin.

Sample	HCB	α-HCH	β-HCH	γ-HCH	*p,p′*-DDE	*p,p′*-DDT
Sheep fat						
Nukus	0.140	0.034	0.186	0.006	0.198	< 0.002
Chimbay	0.012	0.070	0.114	0.006	0.066	< 0.002
Kanlikul	0.014	0.080	0.134	0.006	0.084	< 0.002
Beef fat						
Nukus	0.006	0.066	0.114	0.006	0.066	< 0.002
Chimbay	< 0.001	0.056	0.088	0.004	0.008	< 0.002
Kanlikul	0.008	0.020	0.076	< 0.002	0.014	< 0.002
Chicken fat						
Nukus	< 0.001	0.266	0.520	0.068	0.214	0.022
Chimbay	< 0.001	0.188	0.540	0.054	0.374	0.026
Kanlikul	< 0.001	0.336	0.736	0.094	0.290	0.016
Fish						
Nukus	0.006	0.048	0.047	0.020	1.009	0.025
Chimbay	0.003	0.014	0.065	0.011	0.061	< 0.002
Kanlikul	0.004	0.033	0.118	0.018	0.147	< 0.002
Eggs						
Nukus	< 0.001	< 0.002	< 0.005	< 0.002	0.031	< 0.002
Chimbay	0.019	0.028	0.318	0.016	0.098	0.009
Kanlikul	0.003	< 0.002	0.065	< 0.002	0.065	< 0.002
Dairy cream						
Nukus	0.031	0.043	0.252	0.004	0.115	< 0.002
Chimbay	0.023	0.044	0.200	0.004	0.069	< 0.002
Kanlikul	0.004	0.030	0.045	0.003	0.024	< 0.002

Organochlorine pesticides. Of the compounds examined, only HCB, the three isomers of HCH, *p,p′*-DDT, and its metabolite *p,p′*-DDE were found at detectable levels. The remaining analyzed compounds, oxychlordane, heptachlor epoxide, *trans*-nonachlor, and dieldrin, were below LODs in all samples.

All samples revealed the presence of the metabolite *p,p′*-DDE but low levels of *p,p′*-DDT (Table 2). In addition, the most persistent HCH isomers, β-HCH and α-HCH, were detected in 16 of 18 samples. Except for one sample of mutton from Nukus (0.140 mg/kg fat), HCB levels in all samples were below or just above the detection limit of 0.001 mg/kg fat.

Foods of plant origin. **PCDDs/PCDFs.** Of the 18 samples, only 8 had detectable levels of any examined congener. No congeners were detectable in carrots, onions, or potatoes. Almost all samples presented low dioxin toxicity—from 0.01 to 0.05 ng-TEQ/kg fresh weight using the one-half LOD calculation method (Table 3). Only one cottonseed oil sample presented an intermediate toxicity level (0.99 ng-TEQ/kg fresh weight) because of a quantifiable level of 2,3,7,8-TCDD contamination.

OCDD was the most common congener detected in seven samples, including cottonseed oil, bread, and rice (ranging between 0.021 and 2.75 ng/kg fresh weight). One bread sample presented traces of 1,2,3,4,6,7,8-heptachlorodibenzofuran (0.010 ng/kg fresh weight), and another had detectable levels of 1,2,3,4,6,7,8-HpCDD (0.112 ng/kg fresh weight). These two congeners were also detected in small amounts in the same cottonseed oil sample containing the highest OCDD concentration. 2,3,7,8-TCDD was detected in a separate cottonseed oil sample (0.664 ng/kg fresh weight) that had no other detectable congeners.

Dioxin-like PCBs. Of the foods of plant origin, cottonseed oil exhibited the greatest toxicity from dioxin-like PCB contamination, containing 0.0109–0.0190 ng-TEQ/kg fresh weight when only detected congeners were considered (Table 3). This contamination was primarily from PCB congeners 77, 105, and 118. Overall, the dioxin-like PCB congeners 105 and 156 were the most common, being detected in 14 and 12 of the 18 samples, respectively. PCB 126 was found in 1 onion sample (0.19 ng/kg fresh weight), giving this sample the highest non–cottonseed oil TEQ value (0.0191 ng-TEQ/kg fresh weight).

Indicator PCBs. As with dioxins and dioxin-like PCBs, cottonseed oil was the food of plant origin most contaminated by indicator PCB congeners. Although all six congeners were at detectable levels in cottonseed oil, concentrations tended to decrease from the lowest to highest chlorinated isomers. In particular, two of the three oil samples had very high levels of PCB 28 (531.78 and 433.95 ng/kg

fresh weight) and PCB 52 (85.71 and 66.02 ng/kg fresh weight). Concentrations of PCBs 101, 138, 153, and 180 were much lower (1.07–21.67 ng/kg fresh weight).

In bread and rice, with only a few exceptions, all six congeners were generally detected at low levels (from 2 to 6 ng/kg fresh weight). Carrots, onions, and potatoes were the least contaminated products, tending to be contaminated only with the lowest chlorinated isomers, PCBs 28 and 52. PCB 28 was detected in all vegetable samples except one onion sample (from 0.44 to 1.93 ng/kg fresh weight). Similar levels of PCB 52 were found in only four samples (two carrot, one potato, and one onion sample).

Organochlorine pesticides. The highest concentrations of organochlorine pesticides were found in onions and carrots (Table 4). These items also had the largest spectrum of contamination. γ-HCH, α-HCH, and α-endosulfan were almost ubiquitous, whereas other substances (e.g., dieldrin, aldrin, DDT, heptachlor, and methoxychlor) were less so. It is remarkable that endrin, a cyclodiene compound, was found in bread, whereas potatoes were positive for β-HCH.

All samples were below detection limits for heptachlor, heptachlor epoxide, *o,p′*-DDE, β-endosulfan, dieldrin, endrin, *o,p′*-DDT, and methoxychlor.

Organophosphorus pesticides and similar products. All samples were found to be below the LODs for the analyzed compounds: mevinphos, dimethoate, parathion methyl, malathion, phosalone, trichlorfon, phorate, parathion ethyl, azinphos methyl, azinphos ethyl, fenchlorphos, diazinon, and fenthion.

Exposure assessment. Table 5 presents an estimate of the average monthly intake of dioxins and dioxin-like PCBs among Karakalpakstan residents and the data used in this estimation, including assumed food fat contents and food consumption amounts. Because levels of dioxin and dioxin-like PCBs in almost all food samples of plant origin were below the LOD, this estimation only includes cottonseed oil and foods of animal origin. Although only the most contaminated foods are considered in this partial estimate, total intake is almost three times higher than the provisional tolerable monthly intake standard of 70 pg-TEQ/kg body weight/month determined by the World Health Organization [Joint Food and Agriculture Organization (FAO)/WHO Expert Committee on Food Additives (JECFA) 2001; WHO International Programme on Chemical Safety (WHO/IPCS) 1989]. This result is particularly worrying considering that consumption of animal protein in Karakalpakstan is already very low compared with international standards (e.g., meat and fish consumption is one-half that reported for the Russian Federation and one-eighth of that in the United States; (FAO 2001).

Because α-HCH, β-HCH, and γ-HCH are known to accumulate in adipose tissue, their observed prevalence in beef and chicken fat, dairy cream, and cottonseed oil samples is expected. A first assessment of human exposure to these contaminants in Karakalpakstan was also performed using study findings and available food consumption data (MSF 2001). Estimated monthly intake levels for the predominant HCH isomers range from 1 to 60 μg/month for α-HCH and from 2 to 140 μg/month for β-HCH, depending on food type. High intake levels are also estimated for γ-HCH from onion consumption (about 17 μg/month) and for HCB from carrot consumption (7 μg/month).

Discussion

To assess the degree of exposure to persistent organic pollutants in Karakalpakstan and to begin developing concrete guidelines and recommendations regarding measures to reduce the risk to human health, this study examined contamination of several common foods. Because sampling was performed at sites all located in proximity to the Aral Sea area, and no remarkable systematic differences were observed between these sites, results provide a fair picture of the contaminant exposure profile for the general population living in the Aral Sea area. This region includes Republic of Karakalpakstan of Uzbekistan as well as the Khoresm region of Uzbekistan, Kizylorda district (southern Kazakhstan), and Dashovuz district (Turkmenistan).

The most noteworthy findings of this research are elevated levels of α-HCH, β-HCH, γ-HCH, and *p,p′*-DDE as well as high dioxin levels, especially the most toxic dioxin, 2,3,7,8-TCDD. As expected, the highest levels of contamination were found in foods with elevated lipid content such as sheep and chicken fat, eggs, and cottonseed oil. Given that these foods are widely consumed in the Karakalpak diet, these results are of great concern.

Levels of α-HCH, β-HCH, and *p,p′*-DDE in some samples of animal origin exceeded the maximum residue limits established by European legislation (European Commission 1997, 1999a, 1999b). For example, chicken fat showed β-HCH levels 2–3 times higher than this limit.

Detection of *p,p′*-DDE, a stable DDT metabolite, indicates past use of DDT. However, the ratio of *p,p′*-DDE to *p,p′*-DDT indicates that DDT may not have been applied recently.

An important finding is the simultaneous presence of α-HCH and β-HCH together with γ-HCH—the only HCH isomer with insecticide activity. In contrast to α-HCH and β-HCH, γ-HCH bioaccumulates to a lesser degree in mammals. Because of the high persistence and bioaccumulation of α-HCH and β-HCH, technical HCH mixtures were banned in almost all developed countries more than 25 years ago, but application of γ-HCH is still allowed for specific purposes. Compared with the West, the levels of β-HCH in most food samples analyzed in this study, especially in the chicken samples, were considerably elevated. This suggests that a technical HCH mixture rather than pure γ-HCH has been applied in the region in the years preceding Uzbekistan's ban on HCH use.

Other studies have reported the presence of β-HCH in rather high quantities in local water supplies (e.g., Binnie & Partners 1996). It can

Table 3. TEQs (ng-TEQ/kg fresh weight) for PCDDs/PCDFs and dioxin-like PCBs for samples of plant origin.

	PCDDs/PCDFs		PCBs		Total	
Sample	TEQ	(1/2 LOD)	TEQ	(1/2 LOD)	TEQ	(1/2 LOD)
Cottonseed oil						
Nukus	0.0002	0.26	0.0109	0.0779	0.01	0.34
Chimbay	0.66	0.99	0.0190	0.1055	0.68	1.10
Kanlikul	0.003	0.12	0.0111	0.0791	0.01	0.20
Rice						
Nukus	ND	0.05	0.0010	0.0119	0.001	0.06
Chimbay	0.00001	0.02	0.0014	0.0109	0.001	0.03
Kanlikul	0.00001	0.01	0.0006	0.0149	0.001	0.02
Carrots						
Nukus	ND	0.03	ND	0.0067	ND	0.04
Chimbay	ND	0.03	0.0001	0.0082	0.0001	0.04
Kanlikul	ND	0.02	0.0003	0.0084	0.0003	0.03
Potatoes						
Nukus	ND	0.02	ND	0.0091	ND	0.03
Chimbay	ND	0.05	0.0001	0.0101	0.0001	0.06
Kanlikul	ND	0.03	0.0001	0.0102	0.0001	0.04
Onions						
Nukus	ND	0.02	0.0000	0.0083	0.0000	0.03
Chimbay	ND	0.02	0.0001	0.0062	0.0001	0.03
Kanlikul	ND	0.03	0.0191	0.0206	0.02	0.05
Bread						
Nukus	0.001	0.02	0.0005	0.0124	0.002	0.03
Chimbay	0.00002	0.02	0.0008	0.0101	0.001	0.03
Kanlikul	0.0001	0.01	0.0007	0.0144	0.001	0.02

ND, no congeners detected.

be hypothesized that animal exposure to such pesticides could be from consumption of such waters and/or contaminated feeds, and/or possibly via inhalation of polluted dust disseminated by strong winds off the desiccated Aral Sea seabed (O'Hara et al. 2000). Traces of HCH isomers found in onions, potatoes, carrots, and rice could also result from contact with contaminated water or soil, but further investigations are needed to clarify exposure pathways.

The negligible concentrations of organochlorine pesticides in cottonseed oil samples and the relatively high levels in sheep fat, chicken fat, and eggs indicate that animal fat rather than vegetable oil is a more important dietary source of organochlorine pesticide residues.

Dietary dioxin exposure for a typical Karakalpak resident is estimated to be almost three times higher than the level that WHO considers safe. Although the estimated dioxin dietary intake value indicates excessive exposure, the following limitations have to be considered. The number of food samples examined was small, and levels of dioxin contamination varied considerably in some foods. Also, monthly food consumption data used in the estimation were collected only in Nukus and may not fully represent average food intake for the entire Karakalpak population. At the same time, such dietary exposure may only begin to describe the total body burden on local residents consuming contaminated water sources and breathing air containing contaminated dust.

The sources of observed dioxin contamination are unclear. Karakalpakstan has little suspect industrial development and no large waste incinerators. A realistic hypothesis is that water and food have been contaminated with 2,3,7,8-TCDD from use of 2,4,5-trichlorophenoxyacetic acid (a component of Agent Orange), a phenoxy acid herbicide that often contains dioxin and related compounds as impurities. Although use of dioxin-contaminated 2,4,5-trichlorophenoxyacetic acid defoliant in cotton cultivation has been documented in neighboring Kazakhstan (Hooper et al. 1998) and hypothesized in a recent study on prenatal dioxin exposure in the study area (Ataniyazova et al. 2001), no official data confirming use of this substance in Uzbekistan are currently available.

Concerns related to the potential hormonal, immunomodulatory, and carcinogenic effects of persistent organic pollutant exposure has been highlighted by many studies (e.g., Sonnenschein and Soto 1998; Vos et al. 1997–1998).

Concern over the effects of organochlorine pesticides on hormonal functions arises from their ability to promote irreversible modifications before maturation of homeostatic systems and during periods of genetic imprinting. Moreover, a few organochlorine pesticides are known to exert reproductive toxicity or have an adverse effect on human lactation performance. Examples of the latter are DDT and its metabolite DDE (Gladen et al. 1999; Rogan et al. 1987), which together with β-HCH are known to suppress lactation. Exposure to these "environmental estrogens" leads to a reduction in the amount of breast milk and fat content and is potentially harmful to infants, especially in deprived conditions (Amador et al. 1994; Perez-Escamilla 1993). A recent study has shown an average decline in both the initiation and the duration of breast-feeding over the last 10 years in Karakalpakstan (Ataniyazova et al. 2001). Thus, this potential impact of toxic chemical exposure may already be contributing to high regional childhood morbidity and mortality, because breast-feeding is recognized as the optimal method of infant feeding (Howie et al. 1990; Lanting et al. 1994).

Dioxins share with organochlorine pesticides both developmental and reproductive toxicity, but their range of biologic properties is definitely much broader. Of particular concern is immunosuppression that can result in increased incidence and severity of infectious diseases and allergies, as well as some types of cancer (Repetto and Baliga 1996). Specifically, dioxin-like compounds may reduce $CD4^+$ (lymphocyte) T helper cells. In this regard, there is some evidence of reduced T-cell–mediated immune response among Karakalpak women during their reproductive cycle (Ataniyazova 1998).

Experimental evidence demonstrates that 2,3,7,8-TCDD can promote cancer in many sites of the human body, such as lung, liver, gastrointestinal system, thyroid, breast, endometrium, and soft tissues (IARC 1997; U.S. EPA 1994b, 2000). Although official statistics for the incidence of malignant neoplasms in Karakalpakstan and Uzbekistan are 65.1 and 70.8 per 100,000 population, respectively (Ministry of Health of the Republic of Uzbekistan 2001), cancer mortality in Karakalpakstan is higher than overall national mortality rates—45.3 and 39.0 per 100,000 population, respectively (WHO 2000). Because

Table 4. Organochlorine pesticides (mg/kg fresh weight) in samples of plant origin.

Sample	HCB	α-HCH	β-HCH	γ-HCH	*p,p′*-DDE	*p,p′*-DDT	α-Endosulfan
Cottonseed oil							
Nukus	< 0.002	< 0.002	< 0.004	< 0.002	< 0.003	< 0.005	< 0.001
Chimbay	< 0.002	< 0.002	< 0.004	0.017	< 0.003	< 0.005	0.012
Kanlikul	< 0.002	< 0.002	< 0.004	0.009	< 0.003	< 0.005	< 0.001
Rice							
Nukus	< 0.001	0.001	< 0.001	0.001	< 0.001	< 0.001	0.005
Chimbay	< 0.001	0.001	< 0.001	0.001	< 0.001	< 0.001	0.002
Kanlikul	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003
Carrots							
Nukus	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.002
Chimbay	0.004	0.009	< 0.001	0.003	< 0.001	< 0.001	0.002
Kanlikul	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003
Potatoes							
Nukus	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Chimbay	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Kanlikul	< 0.001	< 0.001	0.001	< 0.001	< 0.001	< 0.001	0.009
Onions							
Nukus	0.002	< 0.002	0.003	0.006	0.003	< 0.005	< 0.001
Chimbay	0.003	0.006	0.002	0.015	< 0.003	0.019	0.006
Kanlikul	0.002	0.003	0.007	0.008	< 0.003	< 0.005	< 0.001
Bread							
Nukus	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Chimbay	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.005
Kanlikul	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.003

Table 5. Estimate of average monthly dioxin and dioxin-like PCB intake based on contamination in selected foods.

Food item	Average TEQs[a] (pg-TEQ/g fat)	Consumption (kg food item/ person/month)	Fat content (%)	Monthly intake (pg-TEQ/kg body weight[b]/month)
Sheep	12.52	0.97	50[c]	101
Beef	1.61	0.97	50[c]	13
Chicken	19.40	0.16	44[c]	23
Fish	11.90	0.66	2.6[d]	3.4
Eggs	15.92	0.46	11[d]	13
Dairy cream/milk	3.05	6.10	10[c]	31
Cottonseed oil	0.24	1.60	100[d]	6.5
Total				191

[a]For each food item, values are calculated as mean TEQ of all samples, treating values < LOD as zero; results are expressed according to the WHO approach (Van den Berg et al. 1998). [b]Estimated average body weight for an adult, 60 kg. [c]From standard food tables for Uzbekistan (Pokrovskiy 1977). [d]Based on the fat content of analyzed samples.

there are no detailed studies linking cancer and other diseases with dioxin exposure in the region, more epidemiologic data are required to understand the relationship between dietary intake of dioxins and the associated risks for the population in the Aral Sea area.

Conclusions

The results of this study indicate that a number of commonly consumed food items in Karakalpakstan contain high levels of α-HCH, β-HCH, γ-HCH, DDE, and dioxins, especially the most toxic dioxin, 2,3,7,8-TCDD. Among samples analyzed, the highest contamination levels were detected in foods with elevated lipid contents such as sheep and chicken fat, eggs, and cottonseed oil—all important local foods. Given these levels of contamination and known regional dietary patterns, high specific exposure that exceeds recommended international tolerable intake standards is evident. Such exposure may be contributing to the morbidity patterns in Karakalpakstan reported by a number of sources. Further toxicologic research is required to better understand the implications of exposure to these pollutants in the Aral Sea area.

Regardless of the provisional nature of these results, the study team has begun to promote the following policy recommendations to the Uzbekistan Government and international donors.

First, sources of contamination should be better quantified and exposure risks should be reduced through the following actions: *a*) compilation of a complete inventory of obsolete pesticides currently in storage and a thorough record of past applications (quantity, type, and duration of application); *b*) mapping of highly contaminated sites (including storage areas of obsolete pesticides); *c*) review of stockpile disposal options; *d*) evaluation of remediation methods for contaminated sites; *e*) identification of suitable substitutes for harmful substances still in use; *f*) an extensive public education campaign; and *g*) national legislative reform to support all the above, including Uzbekistan ratification of the Stockholm Convention on Persistent Organic Pollutants.

Second, although this study and others provide some provisional data, not enough is known about the environmental fate of historical pesticide use and its current impact on human health. Research should therefore be conducted to document the environmental transformation and fate of certain pesticides and to assess their health impact. Environmental analysis should evaluate the degradation and environmental behavior of parent pesticides and their degradation or transformation products. Health impact assessments should focus initially on pregnant women and newborn children because they are most vulnerable to these toxic substances.

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