AN UPDATED ASSESSMENT OF THE EXPOSURE OF CANADIANS TO DIOXINS AND FURANS.

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ABSTRACT

Dioxins and furans substituted in the 2,3,7, and 8 positions are highly toxic substances. The governments of Canada and Ontario have recently concluded that human exposure should not exceed 10 pg TEQ/kg bw/d. Updated estimates of average lifetime intakes by Canadian adults of dioxins and furans from all sources are under 10 pg TEQ/kg bw/d. The estimation of exposure calculated from current tissue concentrations in Canadian adults supports this finding. Excessive consumption of some highly contaminated fish and wildlife species may lead to intakes of dioxins and furans that approach or exceed the 10 pg TEQ/kg bw/d value and constitutes a danger to health.

INTRODUCTION

Animal studies confirm that most mammalian species respond in the same qualitative way to dioxins and furans. However, dose-effect relationships vary markedly between species for the various dioxin and furan compounds. The dioxins and furans substituted in the 2, 3, 7 and 8 positions produce several effects in animals that are significant for consideration of human health. Among these are their effects on the reproductive system of non-human primates and rats, their tendency to cause hyperplasia in rodents, their carcinogenic effects on livers in rats and their effects on the immune system in several species.

Studies of human populations indicate that short-term exposure to several milligrams of mixtures of dioxins and furans can lead to a variety of effects on skin, eyes, and sensory and behavioural processes. Most effects have been reported to be reversible, although a return to normal may take several years. High-level exposure of women to furans in contaminated rice-oil may have been responsible for reproductive anomalies and infant mortalities. There is no adequate demonstration that populations have suffered excess cancer as a result of exposure to dioxins and furans. However, the evidence is conflicting and the data are confounded by exposure to other chemicals, incomplete health records, inadequate case identification and small sample size.

Based on a traditional approach which used the no-observed-adverse-effect-levels from animal tests and standard uncertainty factors, the Canadian and Ontario governments concluded that human intakes should be below 10 picograms per kilogram of body weight per day of toxic equivalents averaged over a lifetime. This conclusion assumes that 2,3,7,8-substituted dioxins and furans are non-genotoxic carcinogens for which a threshold dose exists at approximately 1 nanogram toxic equivalents per kilogram of body weight per day. The no-observed-adverse-effect-level for reproduction in rodents is also approximately 1 nanogram of 2,3,7,8-tetrachlorodibenzo-dioxin per kilogram of body weight per day. Humans appear to be less sensitive to dioxins and furans than most laboratory species (especially rats and

monkeys) and the effect threshold values in rodents were based on lifetime exposures. An uncertainty factor of 100 was applied to the no-observed-adverse-effect-level to obtain the 10 pg TEQ/kg bw/d value, to take account of variations in response between individuals and to account for the seriousness of the potential effects. In a recent review, Rozman (1989) reached the same conclusion, deriving Acceptable Daily Intake estimates for 2,3,7,8-tetrachlorodibenzodioxin of 10 pg TEQ/kg bw/d for tumour promotion; 14 pg TEQ/kg bw/d for porphyria; and 21 pg TEQ/kg bw/d for dermal effects.

A recent Federal-Ontario study estimated the average total exposure of Canadian adults and children to dioxin and furan compounds from all possible pathways (Birmingham et al., 1989). These estimates of average Canadian intakes of air, water, soil and food with representative concentrations of dioxins and furans have been updated.

EXPOSURE ESTIMATES

Between 94 and 96 percent of the intake by non-smoking adults is estimated to be from food, with the remainder equally split between air and all other routes (Table 1).

Table 1 UPDATED ESTIMATES OF CANADIAN INTAKE OF DIOXINS AND FURANS (AFTER BIRMINGHAM ET AL., 1989)

Substrate/ Medium	Estimated Intake* (picograms toxic equivalents per kilogram of body weight per day)			
	Adult[1]	Child[2]	Infant[3]	Neonate[4]
Food*	0.49[5] to 2.0[6]	1.18[5] to 4.78[6]	2.6[5] to 10.7[6]	165
Air	0.04	0.07	0.1	0.04
Soil	0.01	0.027 to 0.03	0.34 to 0.38	-
Water	<0.01 to 0.05	<0.01 to 0.07	<0.002 to 0.11	-
Consumer[7] Products:	<0.01	<0.01	<0.01	<0.01
Total Estimated Intake:	0.56 to 2.1	1.3 to 5.0	3.1 to 11.0	165
Exposure Period:	53 years	14 years	2.5 years	0.5 years

[1] Adult differs slightly from quoted reference due to small differences in calculations and an assumed body weight of 70 kilograms. Adult consumes daily average amounts of air (20m³), water (1.5L), soil (0.02g), and food from age 17 to 70 years.
[2] Child: Weighs 33 kilograms: Breathes 15m³ air: Intake 1 litre water, 0.02 gm soil, 113% of adult food.
[3] Infant: Weighs 13 kilograms: Breathes 10m³ air: Intake 0.6 litre water, 0.1 gm soil, 100% of adult food.
[4] Neonate: Weighs 5 kilograms: Breathes 1m³ air: Intake 750 millilitres of breast milk (3% fat) containing 36.5 picograms toxic equivalents per gram of fat (Ryan et al., 1985).
[5] Lower end of all ranges assumes a reported Not Detectable = 0.
[6] Upper end of all ranges assumes a reported Not Detectable = Limit of Detection.
[7] Does not include intake from cigarette smoking.
* Food intakes based on Nutrition Canada survey (Health and Welfare Canada, 1977).
* All toxic equivalents (TEQ) based on NATO (1988).

Adults exposed to similar concentrations of dioxins and furans as shown in Table 1 but who also consume fish contaminated with dioxins and furans in excess of current Canadian guidelines could increase their daily total intake considerably to between 3.6 and 5.1 pg TEQ/kg bw. Adults exposed to higher than average air borne emissions due to their proximity to an old technology incinerator could increase their daily total intake marginally to between 0.72 and 2.3 pg TEQ/kg bw.

The average daily intake of dioxins and furans over a lifetime can be calculated from Table 1 by adding total intakes during the exposure periods of neonates, infants, children, and adults, and then dividing the total by 70 years (Table 2). This estimate of 2.0 to 4.2 pg TEQ/kg bw/d is based on assumptions that are likely to overestimate exposure in the interest of protecting human health.

Table 2 ESTIMATED LIFETIME INTAKE OF PCDD AND PCDF

Substrate/Media	Estimated Intake[1] (picograms toxic equivalents per kilogram of body weight per day)		
	Adult A[2]	Adult B[3]	Adult C[4]
Food	1.88 - 4.03	4.16 - 6.30	1.88 - 4.03
Air	0.05	0.05	0.17
Soil	0.025-0.027	0.025-0.027	0.025-0.027
Water	<0.01 - 0.05	<0.01 - 0.05	<0.01 - 0.05
Consumer Products	<0.01	<0.01	<0.01
Total Estimated Lifetime Intake[5]	2.0 - 4.2	4.3 - 6.4	2.1 - 4.3

[1] These estimates represent the lifetime average daily intake calculated by dividing the total estimated intakes for each life stage (See Table 1) by the 70 year exposure period. The estimates in this table are based on the upper range of average national values and conservative assumptions that overestimate rather than underestimate exposures. These estimates are only approximations and not absolute values. TEQ values are based on NATO (1988).

[2] Adult A is an average 70 kg adult consuming average amounts of air, water, soil and food from the age of 17 to 70 years.

[3] Adult B is similar to Adult A except that consumption of fish contaminated with PCDDs and PCDFs is in excess of current Canadian guidelines.

[4] Adult C is similar to Adult A except that he/he lives in close proximity to an incineration/combustion source.

[5] These estimates have been rounded off to two (2) significant figures because of the uncertainty in the data.

Data from a recent report (Muto and Takizawa, 1989) suggest tobacco smoking as another pathway of general population exposure to dioxins. The potential exposure of a person who smokes 20 cigarettes a day is 0.5 pg TEQ/kg bw/d (this assumes that a 70 kilogram person inhales 1 litre of smoke per cigarette (Rickert et al., 1986) containing dioxins at the concentration of 1.8 nanograms toxic equivalents per cubic metre (Muto and Takizawa, 1989), and that uptake is 100%). This estimate is preliminary in that it does not consider sidestream smoke, the potential presence of furans, nor the differences between the experimental protocol and actual smoking. This pathway has not been included in the above estimates of general population exposure because of these uncertainties. Nonetheless, this calculation indicates that smoking may contribute significantly to dioxin and furan exposure.

Intake via breast milk during the first half year of life is estimated to be relatively high (Table 1). This estimate was based on levels of dioxins and furans in Canadian adipose tissue. Subsequent analyses of human milk reduce this estimate by approximately one half, to 70 pg TEQ/kg bw/d. Although estimated intakes for neonates would still exceed 10 pg TEQ/kg bw/d, breast feeding only occurs for a short part of the life span (i.e., less than 4%) and lower exposures throughout the remainder of the life span reduce lifetime exposure to below the 10 pg value. The concentrations of dioxins and furans in target organs are not expected to be dramatically increased as a consequence of breast feeding because of the rapid increase in the amount of the infant's fatty tissue. The known benefits of breast feeding currently outweigh any potential risk that may be associated with dioxins and furans in breast milk.

Daily intakes of PCDDs and PCDFs by Canadians can also be estimated by taking reported levels for PCDDs and PCDFs in human adipose tissue and applying pharmacokinetic principles. The levels of PCDDs and PCDFs in human adipose tissue are assumed to represent a dynamic equilibrium between uptake, retention and elimination. Animal studies indicate that these processes are adequately described using first order kinetics. Such a model can be found in Appendix 1 of the Ontario Ministry of the Environments' Scientific Criteria Document (OME, 1985).

To calculate the daily intake, we need to estimate:

(a) the average Canadian adipose tissue steady state concentration of PCDDs and PCDFs.
The mean concentration of total PCDD and PCDF for all Canadian adipose tissue samples reported by Ryan et al, (1985) is 1131 ppt. This represents about 32.3 ppt of 2,3,7,8-T_4CDD toxic equivalents. The mean concentration of 2,3,7,8-TCDD in these samples was 4.5 ppt.

(b) the total body burden.
A 70 kg individual is assumed to be 20% adipose tissue, i.e., 14 kg fat. The liver, estimated to weigh 1.5 kg, is assumed to have one third the wet weight concentration of adipose tissue of PCDD and PCDF (Ryan et al, 1985). Hence, its contribution is equivalent to 0.5 kg adipose tissue. The rest of the tissue in the individual (55.5 kg) is assumed to have PCDD and PCDF concentrations 100-fold less than that found in adipose or liver. Consequently the rest of the body reduces to about 0.56 kg for an overall total body weight for body burden calculation purposes of 15.06 kg fat.

(c) the elimination half-life of PCDDs and PCDFs.
Poiger, Schlatter and Wendling (1988) reported an estimate of 9.5 years (whole body) to 11.5 years (adipose) for a single human subject ingesting isotope-labelled 2,3,7,8-T_4CDD. Gorski et al., (1984) investigating the case of a young girl exposed to pentachlorophenol, reported half-lives of 3.5, 3.2 and 5.7 years for H_6CDD, H_7CDD and O_8CDD respectively. H_7CDF and O_8CDF were reported to have half-lives of 1.8 years or less. Pirkle et al., (1987) reported a mean half-life of 7.1 years for serum 2,3,7,8-TCDD in Vietnam veterans. The value of 7.1 years is used as a representative half-life.

Using the values in (a), (b), (c) and the OME (1985) model, the estimated daily intakes for Canadians are as follows:

Total PCDDs and PCDFs	- 65.1 pg/kg body wt./day
2,3,7,8-T_4CDD alone	- 0.26 pg/kg body wt./day
2,3,7,8-T_4CDD toxic equivalents	- 1.86 pg/kg body wt./day

RISK ASSESSMENT

Both of the foregoing exposure estimates indicate that average Canadian lifetime intakes are currently below 10 pg TEQ/kg bw/d. However, these substances bioaccumulate in the food chain, and concern for the health of human populations living in some areas where shellfish are highly contaminated has already necessitated closure of the affected fisheries near some pulp and paper mills that use chlorine bleaching. Exposures are estimated to approach or exceed 10 pg TEQ/kg bw/d for persons consuming highly contaminated fish in quantities well in excess of the general population norm. Furthermore, there is considerable uncertainty associated with the estimates of exposure, as they do not consider other sources that may contribute significantly to exposure, such as cigarette smoking. Finally, some toxic dioxins and furans are very persistent, and their continued release into the environment will unnecessarily prolong exposure, with a resultant increase in the risk to the health of high-exposure sub-populations.

These considerations led the Minister of National Health and Welfare to conclude that polychlorinated dibenzodioxins and polychlorinated dibenzofurans may enter the environment in quantities which constitute a danger to human health. They are considered "toxic" as defined under Section 11(c) of the Canadian Environmental Protection Act.

REFERENCES

Birmingham, B., Gilman, A., Grant, D., Salminen, J., Boddington, M., Thorpe, B., Wile, L, Toft, P. and Armstrong, V., 1989. PCDD/PCDF multimedia exposure analysis for the Canadian population: detailed exposure estimation. Chemosphere 19 (1-6): 637-642.

Gorski, T., Konopka, L. and Brodzki, M. 1984. Persistence of some polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans of pentachlorophenol in human adipose tissue. Roczn. Pzh. 35: 297-301.

Health and Welfare Canada, 1977. Nutrition Canada, Food Consumption Patterns Report, Health Protection Branch, National Health and Welfare, Ottawa, Ontario.

Muto, H. and Takizawa, Y., 1989. Dioxins in cigarettte smoke. Arch. Environ. Health 44:171-174.

NATO, (North Atlantic Treaty Organization), 1988. International Toxicity Equivalency Factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds. Pilot study on international information exchange on dioxins and related compounds. Committee on the Challenges of Modern Society. #176: 26 pp.

OME (Ontario Ministry of the Environment), 1985. Scientific Criteria Document for Standard Development No. 4-84: Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs).

Pirkle, J.L., Wolf, W.H., Patterson, Jr., D.G., Needham, L.L., Micheal, J.E., Miner, J.C. and Peterson, M.R., 1987. Proc. 7th Intl. Conf. on Dioxins and Related Compounds. Chemosphere.

Poiger, H., Schlatter, C. and Wendling, J.M., 1988. Pharmacokinetics of 2,3,7,8-TCDD in man: An update. Proc. 8th Intl. Conf. on Dioxins and Related Compounds. Chemosphere.

Rickert, W.S., Collishaw, N.E., Bray, D.F. and Robinson, J.C., 1986. Estimates of maximum or average cigarette tar, nicotine, and carbon monoxide yields can be obtained from yields under standard conditions. Prevent. Med. 15: 82-91.

Rozman, K., 1989. A critical view of the mechanism(s) of toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin: implications for human safety assessment. Dermatosen 37(3): 81-92.

Ryan, J.J., Lizotte, R. and Lau, B.P.-Y., 1985. Chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans in Canadian human adipose tissue. Chemosphere 14: 697-706.