A Study of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) Exposures in Paritutu, New Zealand

Phase II: Serum Testing

An Interim Report to the New Zealand Ministry of Health

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GLOSSARY OF TERMS

Term	Description
Air dispersion model	Uses meteorological information and geographical features to estimate how much of a pollutant travels in any given direction, and is deposited at ground level.
Congener	A chemical variant within a family of chemical compounds. Dioxins, furans, and PCBs all have various congeners. TCDD is one congener in the dioxin family.
Detection limit	The amount of chemical, below which, the analytical method cannot provide an accurate measure.
Dioxin	Refers generally to all of the chlorinated dioxin and furan congener families, and sometimes includes certain polychlorinated biphenyls (PCBs).
Furan	A family of compounds similar in structure to dioxins, but usually associated with combustion processes.
Half-life	This is the amount of time required for half of a chemical to leave the body. For TCDD this forms a range of estimated values depending on age, sex, and body fat composition.
Multipathway exposure assessment	An approach to risk assessment that encompasses environmental exposures from air, food, water, and skin contact for a given individual.
PCB	Polychlorinated biphenyl. A type of chemical associated with heavy industrial uses, such as in transformers. Although certain PCBs have dioxin-like toxicity, they have very different routes of entry into the environment from dioxins and furans.
TCDD	Technically, this refers to 2,3,7,8-Tetrachlorodibenzo-p-dioxin – one of the chlorinated dioxin family, and the specific chemical of interest in the current serum study. This particular dioxin congener is a contaminant in the previously existing herbicide 2,4,5-T.
TEQ	Toxic Equivalent: This is the internationally accepted way to express the summed TCDD-like toxic potency of all of the dioxin, furan, and PCB congeners. In this report we use the World Health Organization definition of TEQ, published by Van den Berg et al. (1998)
Toxicokinetic model	The behaviour of a toxic chemical once inside the body. Refers in this case to the elimination rate of TCDD.

SUMMARY

Background

In October 2001 the Ministry of Health (MoH) contracted the Institute of Environmental Science & Research (ESR) to investigate non-occupational exposure to dioxins among residents of Paritutu, a suburb of New Plymouth.

The investigation into suspected exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) related to a point source of production of the herbicide 2-4-5,T, namely the Ivon-Watkins Dow [IWD] plant, now operating as Dow AgroSciences.

Subsequent to community consultation, environmental soil dioxin testing and ethics committee approval, the blood of selected residents was analysed for polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and polychlorinated biphenyls (PCBs).

Methods

Individuals were selected for testing based on spatial, toxicokinetic, and multipathway exposure modelling, particularly individuals most likely to exhibit elevated serum TCDD if significant previous exposure to airborne emissions of TCDD had occurred. The exposure model considered the place, and years, of residence in relation to what was assumed to be the peak time period of any possible exposure (1962-1975).

Individuals were selected from a pool of 830 respondents to advertisements. Of the 830, 31 were selected for testing using the model, and of these, 24 were subsequently able to give blood. The group comprised five demographic subgroups of four to six individuals corresponding to the age/sex strata from the Organochlorines Programme (OCP). These subgroups were formed, based on the modelled prediction of individuals most likely to show a statistically significant elevation in serum TCDD, if previous exposure had occurred. Subjects were excluded from the study if there was a history of possible occupational exposures.

The data on serum TCDD and other dioxin and PCB congeners from the 24 selected individuals were subsequently compared with national serum TCDD data from the Ministry for the Environment's national OCP.

Results

A statistically significant elevation in serum TCDD compared to national TCDD serum concentrations was found in the study group. The mean serum TCDD level for the group was 10.8 pg/g lipid, while the expected national mean for a similar group was 3.5 pg/g lipid.

Mean TCDD elevations in the subgroups ranged from two-fold (7.1 vs. 3.6 pg/g lipid in women aged 50-64) to nearly five-fold (14.6 vs 3.0 pg/g lipid in men aged 65+). These elevations fell within the range predicted by the modelling.

The mean TCDD concentrations in the subgroups were: 6.2 pg/g lipid (females aged 35-49), 7.1 pg/g lipid (females aged 50-64), 17.8 pg/g lipid (females aged 65+), 9.8 pg/g lipid (males aged 50-64), and 14.6 pg/g lipid (males aged 65+). The range of individual TCDD concentrations was 1.3 – 33.3 pg/g lipid. For nine out of the 24 people sampled, the concentrations of TCDD in serum were more than three standard deviations higher than the mean concentration for the relevant age and gender group from the OCP study. The largest difference for any individual was 21.7 standard deviations above the OCP mean.

Although there was a significant elevation in the serum TCDD, the elevation in total serum dioxin toxic equivalents (TEQ) was less pronounced, exceeding three standard deviations above the OCP mean for three individuals, and there was no elevation in PCB (measured as TEQ) compared with the OCP. The average elevation in TEQ was 1.4-fold. TCDD was the only consistently elevated compound, and subtracting the contribution of TCDD to TEQ removed significant differences from the OCP means.

Duration of residence was the key factor in determining the likelihood of measuring an increase in serum TCDD. Only one person, out of 12, who lived in the area less than 20 years in the period 1962 – 1987 showed a significant elevation in TCDD, while eight of 12 living in the area for at least 20 years had highly significant elevations. Consumption of home-grown produce, including home-grown poultry and eggs, did not appear to contribute significantly to elevations in serum TCDD.

Discussion

These findings support the premise that aerial emissions containing TCDD were responsible for the soil and serum dioxin concentrations in Paritutu. Dioxin profiles in the Paritutu environment, its residents and the measured TCDD elevations are most likely not a result of combustion processes, such as incineration. Whether these emissions were a result of regular or more episodic releases cannot be determined by the current study.

The multipathway exposure modelling, in particular duration of residence, successfully predicted elevations in serum TCDD, whereas soil TCDD concentrations alone did not.

Based on the current data, there appear to be a number of findings of particular relevance to assessing the nature of the exposures to dioxins in Paritutu, namely:

- Elevations in serum TCDD reflect primarily duration of residence over the period 1962 – 1987 in areas of modelled soil TCDD in excess of 3.4 pg/g.
- These elevations are, in all probability, due to inhalational exposures from aerial emissions originating from the IWD plant. Present soil contamination is not likely to be the source of the observed serum TCDD levels.
- The areas of modelled elevated soil TCDD form a relatively narrow geographical band around the perimeter of the Dow AgroSciences plant, including approximately 500 domestic residences.
- The elevation in total dioxin TEQ is small relative to TCDD (1.4-fold, on average) and was statistically significant different to the background levels.

The following questions remain unanswered by the study:

- The timing of exposures during the period 1962 to 1987.
- Peak body burdens of the sample group.
- Serum TCDD levels in individuals who resided in areas where soil TCDD exceeded those in this study.
- Whether there was a contribution to TCDD exposure from production of chlorinated phenolic products other than 2,4,5-T.
- Characterising the risk to the health of people significantly exposed.
- Characterising the exposure of residents not included in this study

1. INTRODUCTION AND BACKGROUND

In October 2001 the Ministry of Health (MoH) contracted the Institute of Environmental Science & Research (ESR) to investigate non-occupational exposure to dioxins among residents of Paritutu, a suburb of New Plymouth. ESR conducted the investigation in two phases.

An initial consultation phase (Phase I, see Appendix A) took place between October 2001 and May 2002, resulting in majority agreement of the community consultation group as to the next phase (Phase II), which included:

- seeking consent from the appropriate ethics committee;
- administration of questionnaires to current and former residents who met inclusion criteria;
- identification of a possible high exposure group through the use of a multipathway exposure model;
- discussion and informed consent to participation both for the questionnaire and blood testing;
- taking of venous blood from these individuals;
- analysis of the blood samples for the congeners of dioxin of human significance, and comparison with the levels of the wider NZ population; and
- dissemination of individual, group and comparative results.

The methods for addressing these issues, in concert with findings of the study, are addressed in this Phase II report.

It should be noted that the purpose of this study was to only assess potential exposures to dioxins in the community. Therefore, this report does not include any assessment of possible health effects related to dioxin exposure.

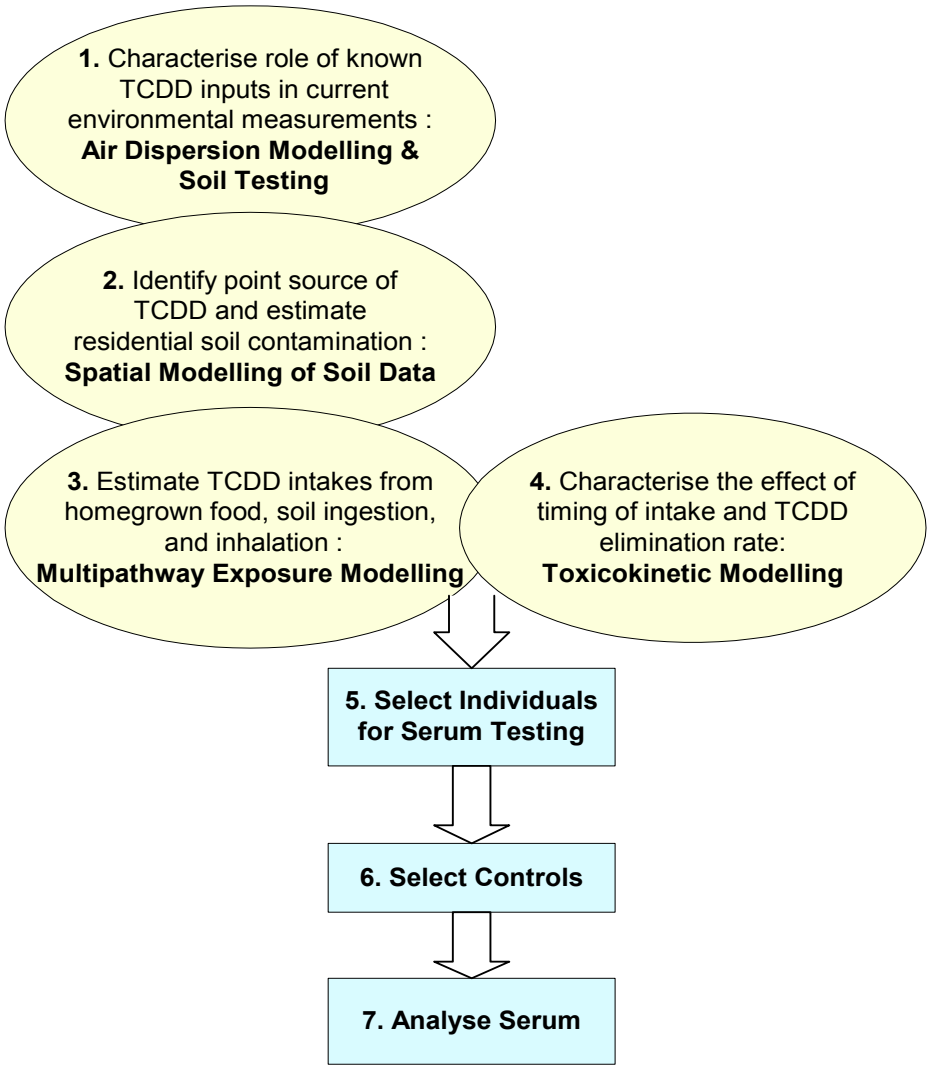
1.1. Ethical Approval

Prior to commencing the project, ethical approval was sought from the Taranaki Regional Ethics Committee. Approval for the study was granted, reference TRK/03/05/014.

2. METHODOLOGY

The general approach to this study included a number of modelling components in order to characterise the Paritutu environment, take account of published reports of TCDD emissions from the IWD plant, construct exposure/uptake scenarios of inhalation and dietary intake at each address, and to take account of individual variations in TCDD elimination rate. These processes are depicted in Figure 1.

Figure 1. Sequence of modelling studies in the estimation of individual dioxin exposures in Paritutu, used as a basis for selection of study participants.



Data from two questionnaires from Paritutu residents were used to support these models as tools to select participants. All details of model development and use are presented in a series of technical Appendices. The general approach to each aspect of the study is described below for the following key areas:

2.1. Air Dispersion and Deposition Model (Appendix B)

Objective: To ascertain the potential role of the IWD liquid and solid waste incinerators, in the observed soil TCDD concentrations.

Inputs/Assumptions: Incinerator parameters (stack height, location, temperatures, etc) and emissions data obtained from Pilgrim 1986, and DSIR 1986. Meteorological data from 1999 was used in the Air Pollution Model (TAPM) model.

Method: The Air Pollution Model (TAPM) developed by the Australian CSIRO was used to develop a meteorological dispersion modelling data set for the Paritutu area.

The USEPA ISC3 air dispersion model was used to estimate ground concentrations and deposition rates of dioxins from the IWD point source.

2.2. Spatial Model (Appendix C)

Objective: To estimate TCDD concentrations in soils in the Paritutu area based on measured soil TCDD data.

Inputs/Assumptions: Soil TCDD test results from Pattle Delamore Partners, Ltd. report to the Ministry for the Environment (2002). For the modelling, we included 34 data points from the PDP 2002 report, and 39 data points from sampling conducted in

- 1985 (Department of Health and IWD);
- 1986 (Ministry of Health); and
- 1997 (Ministry for the Environment).

A 25-year half-life correction was applied to the earlier samples to bring them to approximate 2002 levels for the combined map. In all, 73 measured soil TCDD values served as inputs to the model.

Method: ArcView Geospatial Analyst software was used to conduct Ordinary Kriging of all of the available measured TCDD soil data. The spatial model assisted in the identification of the point source, as well as defining the general area of interest for sampling.

2.3. Multipathway Exposure Model (Appendices B and D)

Objective: To estimate TCDD exposures of residents in Paritutu from:

a) Inhalation of TCDD in air;
b) TCDD in food from home gardens; and
c) Possible ingestion of soil contaminated with TCDD.

Inputs/Assumptions: In the assessment the possible intake routes through which residents may have been exposed included:

- Inhalation of particulate and gas phase PCDD/PCDF;
- Ingestion of contaminated soil;
- Ingestion of below-ground vegetables (e.g. potatoes, carrots);
- Ingestion of 'protected' above-ground vegetables and fruits (e.g. sweet corn, citrus, nuts);
- Ingestion of 'exposed' above ground vegetables and fruits (e.g. lettuce, apples); and
- Ingestion of home-grown poultry and eggs.

Produce is defined as either 'protected' or 'exposed' depending upon whether the edible proportion of the fruit or vegetable is likely to have been exposed directly to dioxin congeners either through direct deposition from the air or via vapour uptake by the plant's foliage. For instance, fruits such as oranges whose skins are not generally consumed are classified as 'protected'. The major route of contamination for

'protected' and below ground produce is via root uptake of contaminants present in the soil. As it is possible that some residents could have kept poultry for eggs or (less likely) meat, the additional intakes of dioxins associated with these pathways have also been considered in the assessment.

Total dietary intakes of eggs and poultry are based upon the estimates used in the Organochlorines Programme, for which the fat intakes are the same as those from the National Nutrition Survey and similar to USEPA estimates. In the calculations it is assumed that the typical fat content of eggs is 11.2% and 8.4% for chicken meat.

The MfE Organochlorines Programme assessment of dietary intakes for dioxins and dioxin-like PCBs was used based on diets selected to be representative of the adult New Zealand male population (Buckland et al., 1998). Dietary exposure calculations have been based on a typical 80 kg adult New Zealand male, due to the larger relative intakes of males.

The typical air inhalation rate of $20m^3$/day used is the value recommended by the US EPA (1998) for an adult male. The intake of soil used (25 mg/day for an adult), is the same at that used by the MfE in "Health and Environmental Guidelines for Selected Timber Treatment Chemicals" (MoH, MfE, 1997).

Intakes were calculated assuming that the average resident would be potentially exposed to contaminated soil, produce and air for 350 days in a typical year. The resident is assumed to have been away from the immediate vicinity of the site for the other 15 days and, therefore, not exposed to media contaminated by the plant. This assumption is consistent with the USEPA risk assessment methodology.

Appendices B and D detail the methodology and calculations leading to estimated TCDD intakes. Briefly, the intake scenarios assumed that a typical resident obtained 10% of their daily fruit and vegetables, and chicken and egg intakes from their place of residence. Therefore, 10% of typical dietary produce and poultry intakes was assumed to be contaminated by emissions from the IWD plant. The calculations also assumed that 100% of the air that residents breathe and soil they ingest over the critical time periods is contaminated, approximating exposures for a person who spends most of their day at home. A summary of intake rates used in the multipathway exposure analysis for the study of the incinerator emissions is presented in Appendix D.

Method: The USEPA Human Health Risk Assessment Protocol (1998) (HHRAP) was followed in the multipathway exposure modeling. Exposed and protected above ground produce consumption rates are also based upon the USEPA (1998) HHRAP recommendations. The HHRAP is based on data from the Exposure Factors Handbook (US EPA, 1997). The below-ground produce intake is taken from "Health and Environmental Guidelines for Selected Timber Treatment Chemicals" (MoH, MfE, 1997).

The estimation of airborne TCDD required to result in the measured soil TCDD concentrations was done using two models: USEPA (1998) and McLachlan (1997) models were used to form a range of predicted inhalation rate scenarios and corresponding serum TCDD concentrations.

2.4. Toxicokinetic Model (Appendices E and F)

Objective: To estimate age/gender-specific TCDD elimination half-life rates based on analysis of existing data in order to assist in selecting individuals most likely to show elevated TCDD in 2004 from a past exposure, and also to assist in any back-calculations of original exposure and body burdens. The model predicts the TCDD body burden for New Zealanders aged between 15 and 64 years in the year 2003, based upon an assumed dietary 'background intake' function and changing body composition and dietary intakes over an individual's lifetime.

Inputs/Assumptions: To be effective, the toxicokinetic model required an estimate of the critical time of exposure. We assumed, based on the conclusions reached on the role of waste incinerators in the measured soil TCDD concentrations, that the key period for individual exposures was most likely to be the early period from 1962 to 1975 (Table 1).

Additional elements in the calculation process are presented in detail in Appendix E. There are three major elements used to estimate TCDD body burden at the end of a simulated year:

1. Estimated amount of TCDD in the individual's body at the end of the previous year;

2. Elimination rate of TCDD, defined in terms of a half-life and assumed to be a function of the total percentage lipid content of the body (see peer reviewer comments in Appendix F); and

3. Intake rate of TCDD associated with consuming contaminated food (and any additional exposures defined by the user).

Table 1. 2, 4, 5-T herbicide production volumes at the IWD chemical plant and associated TCDD contaminant levels in the product.

Year	Annual production (tonnes)	TCDD (mg/kg)	Potential TCDD in product (g)
1962	103	1	103
1963	111	1	111
1964	196	1	196
1965	127	1	127
1966	124	1	124
1967	167	1	167
1968	167	1	167
1969	343	1	343
1970	310	1	310
1971	265	1	265
1972	377	1	377
1973	453	0.1	45
1974	563	0.1	56
1975	525	0.1	53

Start IWD operations

Start of reduction in TCDD in 2,4,5-T

1972 Clean Air Act (in force)

Age groups in the model correspond to those in the OCP study to allow calibration of the model. In order to calibrate the model with the OCP serum results, we assumed that the observed TCDD blood lipid concentrations reflect the average TCDD concentration in the total body lipid, as predicted by the toxicokinetic model.

One limitation is the lack of scientific knowledge of the background function with ages over 65. We have assumed that the elimination rate does not change for individuals beyond age 70, due to a lack of data that suggest otherwise.

Method: Dioxin body burdens are calculated on a year-by-year basis, accounting for variations in food (calorific) intake, body weight and body fat. Profiles of male and female body compositions and dietary intakes are constructed for 'typical' New Zealanders aged between 1 and 64 years. These profiles are used to predict typical TCDD intakes based on assumed calorific dietary consumption, TCDD half-life in the body (based on total body fat), and the dilution of total TCDD body burden in total body fat.

The 'background intake' function estimates relative changes in the concentration of TCDD in the New Zealand diet between 1937 and the year 2000. The background intake function focuses on picograms (pg) of TCDD per day, per megajoule of food ingested. The model assumes that the body absorbs all of the TCDD ingested (100%). Using any other absorption rate would proportionally increase the TCDD concentration per megajoule ingested by the inverse of that absorption rate (ie 1 / TCDD absorption rate).

In each gender-specific model, TCDD intakes and elimination rates are simulated for fifty virtual 'individuals.' The TCDD body burdens of each 'individual' are modelled

on a year-by-year basis, taking into account age and time-dependent variations in TCDD intake rates, elimination rates and body dilution. Each 'individual' represents a typical New Zealand male or female aged between 15 and 64 years in the year 2003.

A gender-specific profile describing typical dietary intakes, body weight and percentage total body fat over an individual's lifecycle was constructed using national and international data. Each individual is assumed to follow the same life history regarding dietary energy intakes and body composition. An individual's body and intake characteristics are assumed to be constant over each year modelled. Though these assumptions are crude, they allowed us to make an initial screening/prioritisation ranking of individual participants so that objective decisions could be made regarding individual selections for serum testing.

2.5. Selection of Candidates for Serum Testing

Objective: To use predictions of individual TCDD intake, combined with estimated age/sex specific TCDD elimination rates, to derive a list of individuals having the best chance of showing elevations in serum TCDD in 2004 from an exposure 30-40 years ago, in comparison with national averages and estimated variances for the individual age/sex strata.

Inputs/Assumptions: Uniform body fat percentage was assumed for each of the age/sex groups. It was also assumed that all participants were exposed through non-occupational means.

Two questionnaires were developed to provide input to the multipathway and toxicokinetic modelling. Questionnaire One is more pertinent to the selection process and provides data for the geo-spatial and multipathway exposure modelling. Questionnaire Two provides more detailed data relevant to the multipathway exposure and toxicokinetic modelling of the half-life of TCDD in the body. Questionnaire Two also provided information on some possible exclusion variable information, such as previous employment at the IWD plant, history of extensive use of herbicides, etc. These data assist with interpreting and explaining individual results, particularly the ratio of TCDD to total TEQ.

Method: The sum of residential inhalation and dietary intake exposures, using modelled air concentrations of TCDD as described in the Multipathway Exposure Model (above). Subsequent application of an age/sex specific elimination rate (see Toxicokinetic Model above), based on assumption of peak exposure period 1962-1975. Comparison of estimated serum TCDD in 2004 with OCP results for that age/sex stratum.

2.6. Selection of Controls and Statistical Comparisons (Appendices G, H, and J)

Objective: To select a control group for the comparison of Paritutu resident TCDD serum concentrations.

Inputs/Assumptions: The national OCP study was conducted in 1997, representing a large number of New Zealanders grouped into pooled substrata. This information was assessed, and national, rather than regional (lower North Island), means and variances

were selected for use since it was felt that these were a more robust measure for comparison (larger sample numbers; minimises any effect that New Plymouth samples might have on pooled substrata).

Method: Appendices G and H describe the statistical issues surrounding the estimation of variance from pooled substrata and the use of additional NZ-specific control data from Hannah et al. (1994). Means and estimated 95% confidence intervals for each stratum are shown in Appendix G.

2.7. Serum Analyses

Sera were analysed for all seven of the 2,3,7,8-substituted chlorinated dioxins and the eight 2,3,7,8-substituted chlorinated furans as well as ten coplanar and mono-ortho PCBs thought to contribute to dioxin-like activity. The list of congeners tested for is shown in Appendix N. All sera were sent in sealed insulated containers via Federal Express courier to the Axys Analytical Services laboratory, in Sydney, BC, Canada for testing. The Axys laboratory met WHO criteria for chlorinated dioxins and PCB measurements in human blood (Appendix I). One quality control sample was sent to the US Center for Disease Control in Atlanta, Georgia, USA. The QC sample was taken from an individual not in the subgroups, but living in an area of modelled high soil TCDD during the relevant time period. This individual agreed to donate twice the volume of blood (400 mL) relative to that donated by the other individuals in the study. The QC result for this sample, which happened to also be the lowest serum TCDD in the study, was within 94% of the TEQ estimate for this individual and the difference in TCDD results between the two laboratories was 0.67 pg/g lipid, which was taken to represent a confirmatory result.

The Axys laboratory used high-resolution gas chromatography coupled with high-resolution mass spectrometry to analyse for the full spectrum of chlorinated dioxins and furans and PCBs relevant to characterising an individual TCDD TEQ according to the WHO 1998 TEF scheme. Detection limits for TCDD were typically 0.1 pg/g lipid. Serum lipids were also measured by this laboratory.

3. RESULTS

3.1. Serum TCDD Concentrations

The serum TCDD concentrations for each study subgroup are shown in Table 2. As discussed above and in Appendices G and H, the best basis for comparison was the MfE 1997 OCP survey. The national mean values and estimated variances from the MfE OCP study were used for comparison (see Appendix H for detailed discussion). Table 3 shows the individual subgroup PCDD/F and PCB TEQ results, using Toxic Equivalence Factors from WHO (WHO 1998). Table 4 shows the influence of TCDD on the elevated PCDD/F TEQ values. The TEQ elevations in all three Paritutu female age groups disappear when TCDD is subtracted. For the males, there remains a diminished but significant increase in the 65+ age group, however, the slight elevation in TEQ in the 50-64 age group males is not significant. Therefore, across all groups TCDD is the major driving factor in total PCDD/F TEQ differences from national mean values.

Table 2: Mean serum TCDD levels: Paritutu and Ministry for the Environment 1997 Organochlorines Programme survey.

Age group	Sample size (Paritutu)	Sample size (MfE)	Paritutu TCDD (pg/g lipid) Mean [95% CI]	MfE TCDD (pg/g lipid) Mean [95% CI]
Male				
50-64	6	170	**9.8** [1.3, 18.3]	**2.5** [0.5, 4.6]
65+	4	139	**14.6** [0, 35.4]	**3.0** [0.6, 5.4]
Total	10		**11.7**[SD = 9.99]	
Female				
35-49	5	368	**6.2** [0.63, 11.8]	**2.1** [0, 5.3]
50-64	4	255	**7.1** [0, 14.40]	**3.6** [0, 11.3]
65+	4	242	**17.8** [4.97, 30.62]	**5.9** [0, 14.3]
Total	13		**10.0**[SD = 7.58]	
All ages	23		**10.8**[SD = 8.54]	

SD = standard deviation.
95% CI = lower and upper 95% confidence interval around the mean.

Table 3a. Mean Serum Total PCDD/F and PCB TEQ: Paritutu and Ministry for the Environment 1997 Organochlorines Programme survey.

Age group	Paritutu PCDD/F TEQ (pg/g lipid) Mean [95% CI]	MfE PCDD/F TEQ (pg/g lipid) Mean [95% CI]	Paritutu PCB TEQ (pg/g lipid) Mean [95% CI]	MfE PCB TEQ (pg/g lipid) Mean [95% CI]
Male				
50-64	**24.7** [10.22, 39.18]	**13.9*** [12.87, 14.93]	**7.6** [3.09, 12.11]	**6.2** [6.18, 6.22]
65+	**33.6** [7.98, 59.22]	**14.8** [12.92, 16.68]	**12.5** [9.00, 16.00]	**8.0** [7.98, 8.02]
Female				
35-49	**15.4** [2.90, 27.90]	**12.7** [11.79, 13.61]	**5.5** [1.65, 9.35]	**6.5** [6.52, 6.68]
50-64	**18.4** [6.94, 29.86]	**16.7** [15.34, 18.06]	**7.5** [0.50, 14.50]	**7.1** [7.01, 7.19]
65+	**35.6** [19.37, 51.83]	**23.7** [22.00, 25.40]	**9.7** [3.02, 16.38]	**10.0** [9.94, 10.06]
All ages	**24.3** [SD = 13.7]		**8.1** [SD = 4.2]	

SD = standard deviation

95% CI = lower and upper 95% confidence interval around the mean

Table 3b. Percent contribution of TCDD to mean serum total PCDD/F TEQ: Paritutu and Ministry for the Environment 1997 Organochlorines Programme survey.

Age group	Paritutu % PCDD/F TEQ from TCDD	MfE % PCDD/F TEQ from TCDD
Male		
50-64	39.7	18.0
65+	43.5	20.3
Female		
35-49	40.3	16.5
50-64	38.6	21.6
65+	50.0	24.9

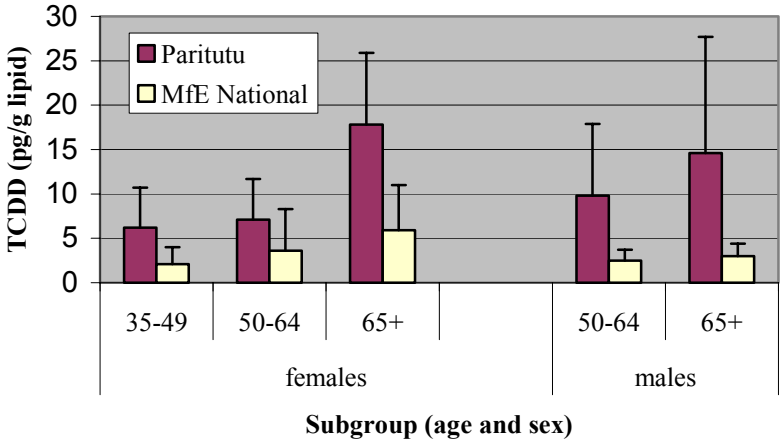
Table 4. Mean serum total PCDD/F with TCDD subtracted: Paritutu and Ministry for the Environment 1997 Organochlorines Programme survey.

Age group	Paritutu PCDD/F TEQ w/o TCDD (pg/g lipid) (Mean, SD)	MfE PCDD/F TEQ w/o TCDD (pg/g lipid) (Mean)
Male		
50-64	**15.0** (6.9)	**11.4***
65+	**19.0** (5.0)	**11.8**
Female		
35-49	**9.2** (5.6)	**10.6**
50-64	**11.4** (3.1)	**13.1**
65+	**17.8** (5.8)	**17.8**
All ages	**24.3** (13.7)	

* = Estimated standard deviations for the OCP study TEQ w/o TCDD values were not available.

Figure 2 below illustrates the elevations in serum TCDD in all subgroups tested. The female 50-64 age group elevation compared with the MfE control group was not statistically significant. It should be noted that females were expected to present greater variability in serum TCDD than males, which results in relative difficulties discerning elevations from background in a small sample size. Despite this, statistically significant elevations were seen in the female 35-49, and 65+ age groups.

Figure 2. Serum TCDD in Paritutu study subjects (means and standard deviations).

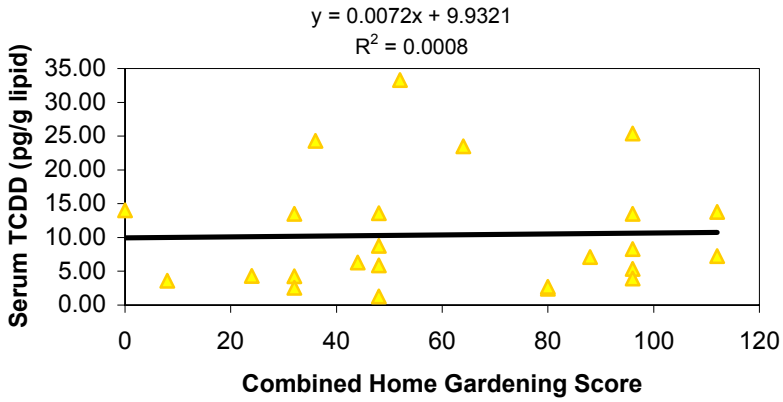


3.2. Role of Home Grown Produce as a Route of Exposure

The Questionnaires collected information on the home produce consumption history of each study participant, including the type and extent of edible vegetation grown above and below ground, and also recollections of home grown poultry and egg consumption in the years of past residence. While all but one of the participants described some level of home vegetable/fruit gardening, only six raised chickens for eggs, and none for poultry meat.

There did not appear to be a contribution of home gardening on the level of serum TCDD in the participants (Figure 3). In addition, although a small increase in serum TCDD was seen in the six subjects who kept poultry for home grown eggs (12.7 pg/g serum, vs 9.6 pg/g serum), this increase is not statistically significant and was similar to the degree expected by the length of residence, which was also greater in these six individuals. Therefore, we conclude that home gardening was not an important route of exposure for the observed serum TCDD levels.

Figure 3. Serum TCDD vs Home Gardening



3.3. Spatial Analysis of Paritutu Soil Dioxin Levels and the Role of Waste Incinerators

The spatial analysis of measured soil TCDD concentrations in 2002 (and previously) showed that the TCDD in the soils around Paritutu most likely originated from the IWD plant (Appendix C). A Krig function using Geospatial Analyst software showed a strong degree of spatial autocorrelation of soil TCDD concentrations, the highest occurring at the IWD plant, with a rapid decline South of the IWD plant. The highest residential TCDD soil concentration predicted by the Krig function was 106 pg/g, with a total of 37 addresses predicted to be above 40 pg/g. The highest modelled soil concentration at a residence for which we were able to obtain a serum sample in this study was 42.9 pg/g soil.

The predicted soil TCDD concentrations from air dispersion modelling (at a 5 cm soil depth) emanating from the liquid waste incinerator emissions over the 1975-79 period were, maximally, in the range of 0.2-0.6 ng TEQ/kg (Appendix B). In contrast, the contours from the actual measured soil TCDD concentrations are in the range 100-300 ng TEQ/kg over the same area. The measured concentrations of TCDD in soil are, therefore, between 150 and 1500 times higher than those predicted by air dispersion and multipathway modelling.

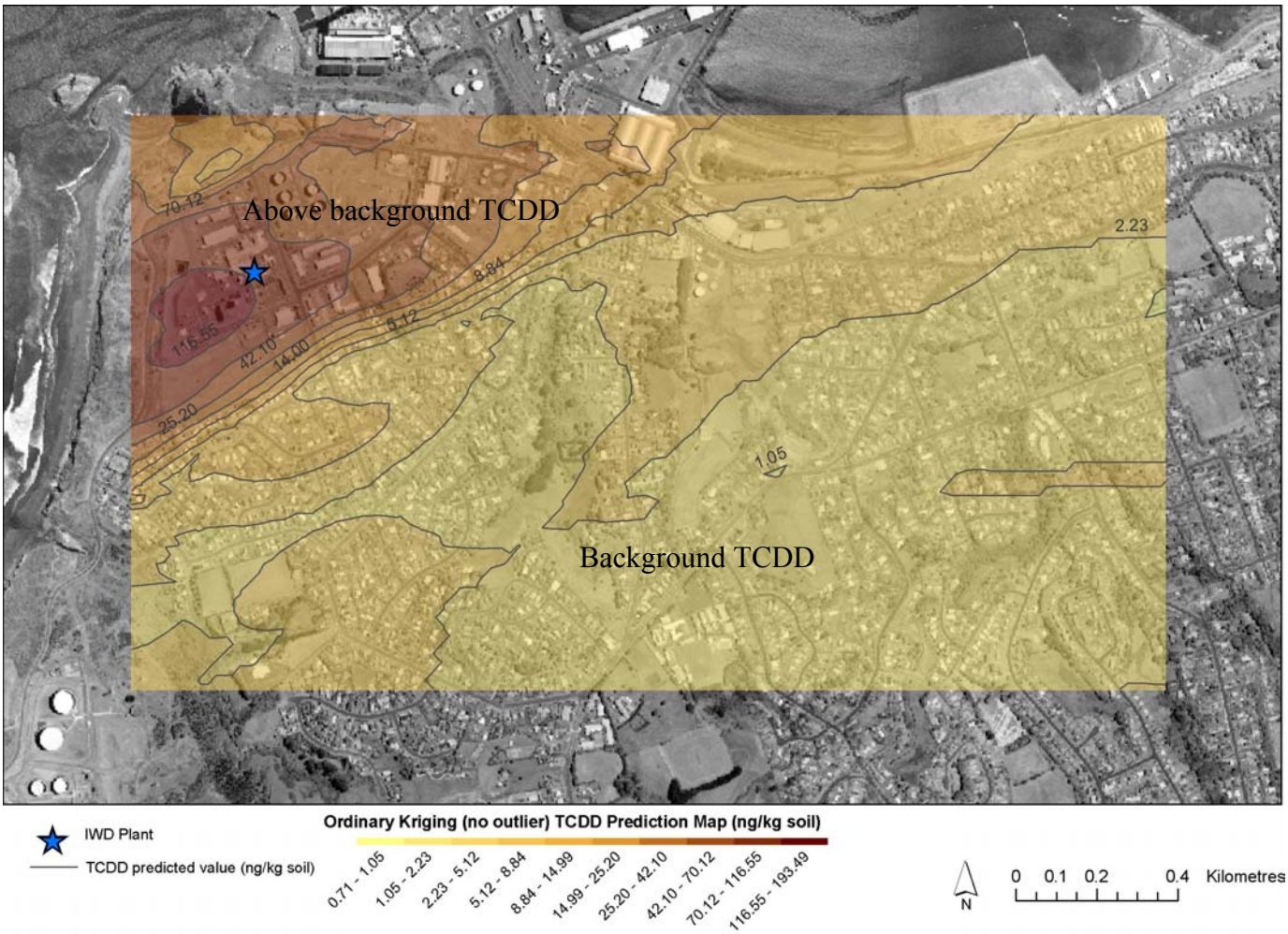
The spatial analysis of the 2002 soil testing data is broadly consistent with a plume of TCDD emanating from the IWD plant, and extending to approximately 1000 meters, predominantly to the East, and approximately 400 meters to the South. The geostatistical model (Figure 4) illustrates this pattern, showing the highest concentrations outside the plant immediately east of the plant boundary.

This pattern of soil concentrations is not consistent with the dispersion/deposition modelling of emissions from the incinerator stacks. The model predicts much lower concentrations overall, and the highest concentrations in soils on Mt Moturoa, with relatively low concentrations immediately east of the IWD plant.

The main conclusion was that the soil TCDD most likely originated predominantly from emissions that took place in years prior to the incineration operations as a result of one or more airborne releases from the site, or possibly from fugitive emissions from routine operations. One can reasonably hypothesize that such emissions would

be proportional to the combined measure of production volume and TCDD contaminant level in the product. Based on these assumptions, the critical period of interest was assumed to be 1962-1975.

Figure 4. Prediction of soil TCDD concentrations in Paritutu areas above background for New Zealand are lightest yellow and background for New Plymouth is one shade darker.



The modelled soil concentrations shown in Figure 4 correspond to a breakdown in addresses as shown in Table 5. There are over 500 addresses in the study area that are predicted to have soil TCDD concentrations in excess of 3.4 pg/g which was the lowest soil concentration in the current study that was associated with elevated serum TCDD after long term residence. Duration of residence was a key factor in the TCDD elevations found. Of the 12 people who had lived in the area for less than 20 years from 1962-1987 only one was demonstrably elevated (14 pg/g), and the next highest serum result in this group was only moderately elevated at 7.1 pg/g. The mean serum TCDD level in the 11 subjects living less than 20 years in the area was 5.0 pg/g. In contrast, those 13 people having lived at least 20 years in the area from 1962-1987 had a mean serum TCDD level of 14.9 pg/g lipid.

Table 5. Areas of Modelled 2,3,7,8-TCDD Soil Contamination, and Observed Elevations in Serum TCDD, per Year of Residence at the Address.

Soil TCDD (estimated – 2002 values)	**Number of Addresses That Occur in Study Area**	**Geographic Category**	**Observed mean increase in 2004 serum TCDD (pg/g) over background per year residence time up to 1987**
0 – 3.39	1,679	Background	0 (assumed)
3.4 - 10	444	Area A	0.40
10 – 20	52	Area B	0.44
20 +	41		0.51

3.4. Toxicokinetic Model

The toxicokinetic model developed for TCDD, estimated the expected magnitude of TCDD retention in subgroups, and helped inform the selection of individuals most likely to be able to show a significant elevation in 2004 (Appendices E, F). For the purposes of participant selection, this model included age and sex-dependent TCDD background intake and half-life functions.

The toxicokinetic model can also be used to help back-calculate the extent of historical exposure, based on the individual serum lipid TCDD in 2004, as it includes parameters that affect the elimination half-life of TCDD in the body, such as body fat content, breastfeeding, dietary patterns, and sudden weight loss. These parameters were collected from individuals via questionnaire before they were selected for serum testing. The model encounters difficulties in estimating TCDD half-life in obese individuals; there is virtually no reliable information in the international literature on TCDD half-life in persons over the age of 70. Upon consultation with Professor Dale Hattis (Clark University, USA), the model was refined to provide a best fit to the empirical data available and estimated the half-lives for elderly people (Appendices E, F).

It should be noted that the uncertainties in estimating half-life for obese and elderly individuals was only a potential complication for forecasting the precise degree of serum TCDD elevation in 2004. These issues would not be expected to result in an increase in the probability of a false positive result, but could result in a false negative, or introduce such variability that a very large sample size would be needed to detect a statistically significant difference from controls. This did not turn out to be the case in the current study.

3.5. Statistical Considerations and Analyses

The variability of dioxin/furan blood lipid congener concentrations in the New Zealand population was estimated based upon results from the 1997 MfE organochlorine blood serum sampling programme. In the 1997 survey, due to the relatively small volumes of blood collected from participants (compared to volumes needed for testing), blood samples were pooled into larger sample units. Each sample was pooled in one of 80 strata used to categorise the sample population. Each stratum was defined with respect to gender, ethnicity, age, and locality. Individuals who were likely to have been occupationally exposed to organochlorines were excluded from the blood pooling. Each individual contributed an equal volume to the total pool blood serum volume.

The optimal age/gender subgroups in this study were selected based on the best statistical chance of identifying small elevations in TCDD compared with appropriate subgroups from the 1997 MfE survey. Table 4 illustrates the comparison groups selected.

Table 6. Population TCDD concentrations and estimated variances from the 1997 OCP and Hannah et al., 1994 studies.

Group	Age range	Survey	Mean	Est. Std Dev	95%ile
Females	15-24	MfE	1.1	0.4	1.8
	20-29	Hannah	1.8	0.5	2.5
	25-34	MfE	1.5	1.4	3.8
	30-39	Hannah	2.2	0.7	3.4
	35-49	MfE	2.1	1.9	5.1
	40-60	Hannah	3.8	1.5	6.3
	50-64	MfE	3.6	4.7	11.4
	65+	MfE	5.9	5.1	14.3
Males	15-24	MfE	1	1.1	2.9
	20-29	Hannah	1.3	0.07	1.4
	25-34	MfE	1.2	1.2	3.1
	30-39	Hannah	1.8	0.4	2.5
	35-49	MfE	1.8	1.6	4.5
	40-60	Hannah	2.1	1.1	3.8
	50-64	MfE	2.5	1.2	4.5
	65+	MfE	3	1.4	5.4

Shaded cells indicate those subgroups used as background for comparison with Paritutu serum samples.

Individuals from the age/gender strata shown in Table 4 were selected for the study based on their modelled elevated serum TCDD using the multipathway exposure parameters (inhalation rate, dietary intake, and soil ingestion) discussed above and detailed in Appendices B and C. The primary basis for the modelled serum TCDD was the amount of time an individual spent at an address and the estimated average air concentration and modelled soil TCDD concentrations at that address. Additional factors were considered, including intakes of home produce and poultry/eggs at the address.

The estimated air concentrations giving rise to observed and modelled soil TCDD concentrations were provided by two models: one from the USEPA (1998), and another by McLachlan (1997). These two models employ quite different assumptions regarding TCDD deposition rates into soil organic matter, and, therefore, provide different resulting air concentrations. These different predictions translated into a range of predicted inhalation exposures for the residents, and a corresponding range of modelled serum TCDD concentrations (see Table 7). The McLachlan model resulted in the best predictions of actual measured serum TCDD.

Table 7. Descriptive statistics on subgroups selected for serum testing.

1997 age group	Average age in 1997	Average Modelled Soil TCDD (pg/g soil)	Years of residence in study area post-1962	Average BMI in 2004	Range of modelled increase in serum TCDD (pg/g lipid)
Females					
35-49 (n = 5)	44.8	12.9	15.2	25.7	0.7 – 90.4
50-64 (n = 4)	55.5	11.1	16	29.1	0.7 – 39.3
65+ (n = 4)	72.3	5.5	30.8	26.3	1.1 – 65.8
Males					
35-49 (n = 1)*	40	42.9	7	27.4	1.6 – 40.6
50-64 (n = 6)	58.0	6.6	28.3	30.5	0.5 – 19.5
65+ (n = 4)	71.5	14.1	26.8	28.7	0.6 – 134.4

* Quality control sample – not included in the statistical analysis for age groups.

Subjects residing for longer periods of time in the Paritutu area tended to have higher TCDD concentrations, and also to have TCDD concentrations that were more accurately predicted by the exposure model (Figures 5a and 5b). The McLachlan/Lorber model gave a significantly positive association with measured serum TCDD in all 24 subjects (Figure 5a). The ability of the models to predict serum TCDD in the 13 subjects who lived in the area through to 2003 is shown in Figure 5b. The high outlier in this group influences the overall fit considerably, but removal of this point does not affect the slope term greatly and still results in a statistically significant positive linear relationship between predicted and observed TCDD (r = 0.52).

Figure 5a. Measured vs. predicted serum TCDD in all Paritutu study subjects.

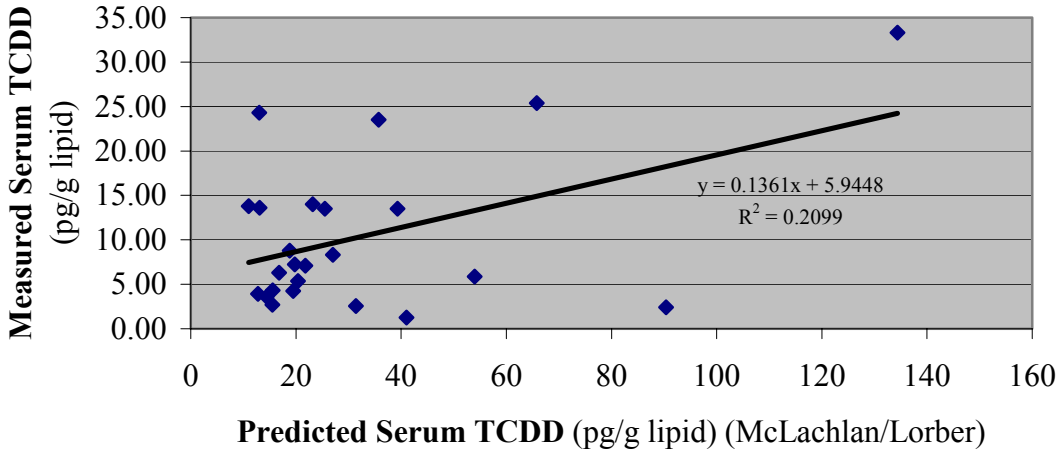
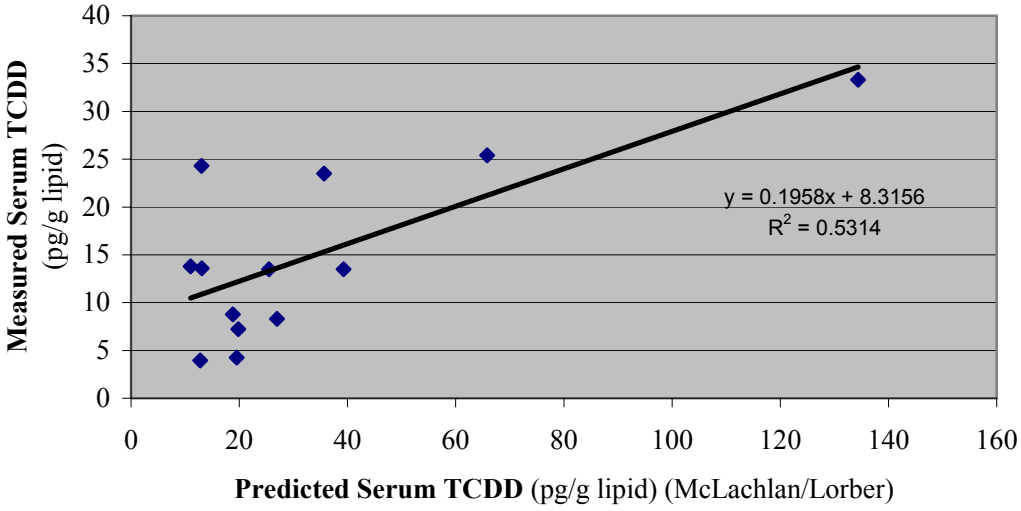


Figure 5b. Measured vs. predicted serum TCDD in long-term resident Paritutu study subjects.



3.6. Responses to the Questionnaires

A total of 830 questionnaires were sent out (Appendix L), as a number of people had requested questionnaires for partners and immediate family. A letter was sent with the questionnaires requesting the return of the completed questionnaire and consent form to participate in the study by the 30th September 2003. A reminder letter was sent on the 25th September 2003. The selection process is described in Table 8.

Of the 830 questionnaires and information packets initially mailed out, 377 questionnaires were returned, giving a response rate of 45%. Fifteen declined to participate, and 438 remained outstanding, despite being sent reminder letters. Of the 377 returned questionnaires, 146 people were selected and sent the Questionnaire 2 package (see Appendix M) that included a consent form for giving blood. At this time the 231 people not selected were informed of this in writing.

3.7. The group selected for testing

Thirty-one people were selected for serum testing, however, we were only able to obtain blood samples from 24 of these individuals. Blood was taken from the 24 subjects on the 23rd-27th February 2004. For seven of the 31 that were unable to be sampled; two could not be contacted; two were not given consent to participate by their GP for health reasons; and, on the day of collection, three people had a haemoglobin level below NZ Blood service guidelines (Hb < 110 *g/l* using a Hemocue machine). These individuals who could not give blood included the highest predicted TCDD level in the study (a female aged 65+), and the highest estimated male in the 50-64 age group.

The overall average age of the 13 women and 11 men who gave blood was 65.7 years in 2004. Further statistics on the subgroups included for testing are described in Table 8:

Table 8. Overview of the Paritutu study subject selection process

	N
People registering an interest (before advertising)	151
Total people registering an interest (after advertising)	809#
Information packs and questionnaires mailed out *(Questionnaire 1)*	830
Questionnaire 1 returned	377
Modelling, initial Selection, (*sent Questionnaire 2*)	146
Questionnaire 2 returned	134
Modelling, ranking and selection	31
Blood collected and tested	24

includes original 151.

Of the 146 of the second questionnaires sent, 134 were returned. At this point, 5 people declined to participate, and 7 remained outstanding, despite being reminded by letter and a follow up phone call.

Each individual gave 120 - 200 mL blood, which was clotted and centrifuged at the hospital and serum separated and stored at –20C. The QC sample from the male in the 35-49 age group was sent to both Axys and the US Center for Disease Control in Atlanta via overnight courier. This individual gave 400 mL blood to accommodate the sample size needs for both labs. Samples were sent via Federal Express to the Axys laboratory, Sydney, BC, Canada, who confirmed receipt of the intact samples.

4. DISCUSSION

This study has demonstrated elevations in serum TCDD in selected residents of Paritutu, significantly above that of the general New Zealand population. .

The mean measured TCDD serum concentration was 10.8 pg/g lipid. The expected national mean for a similar group would be approximately 3.5 pg/g lipid (based on 1997 data).

Nine of the 24 individuals sampled had TCDD levels that were more than three standard deviations from the OCP mean for the relevant age/gender group.

Mean elevations in serum TCDD ranged from 1.8 to 4.9 fold, depending on age and gender. The mean elevation in serum PCDD/F TEQ was 1.4-fold. This elevation was primarily due to the elevation in TCDD. Subtracting TCDD from the total TEQ removed any statistically significant elevations in TEQ among both women and men. The serum PCB TEQ was not significantly elevated in any group by comparison with national background values.

The evidence suggests that TCDD body burdens are falling internationally; for example lipid adjusted TCDD levels in the USA, Canada, Germany, and France were estimated to be approximately 2 pg/g lipid in 2000, and are likely less than that in 2004 (Aylward and Hays, 2002). Therefore, the use of the 1997 OCP data for comparison is likely to underestimate the true relative magnitude of TCDD elevation in the study group over the general population.

The elevation in serum TCDD was usefully characterised by multipathway exposure and toxicokinetic modelling, most especially when using the air/soil TCDD deposition rate assumptions from McLachlan (1997).

Elevations in serum TCDD increased linearly as a function of soil TCDD concentration and duration of residence; the average annual increase being between 0.40 and 0.51 pg/g lipid per year of residence up to 1987 (based on the assumption that any possible inhalational exposure ceased in 1987).

The geographic distribution of TCDD in soil identifies the IWD plant as the source. However, the air dispersion and multipathway exposure modelling based on available data (i.e. incinerator operations and estimates of TCDD released from the 1986 ‘bursting disc failure’) underestimates the observed soil TCDD concentrations by 150-1500 fold. One can reasonably conclude therefore, that the elevated TCDD in soil and sera is not a result of combustion processes associated with incineration.

Although the participants in this study were chosen to optimise the chance of detection of serum TCDD elevations from a previous exposure, the soil spatial modelling indicates that there could be individuals with greater exposures than those represented by the current study group.

The following can reasonably be concluded, based on the data and the information currently available:

- Selected individuals in Paritutu have been exposed to 2,3,7,8-TCDD.
- The resulting (statistically significant) elevations in serum TCDD are a function of soil TCDD, duration of residence from 1962 to 1987, age and gender.
- The mean dioxin TEQ was consequently elevated, but to a lesser extent.
- TCDD was responsible for any elevation seen in TEQ above national means.
- Inhalation was the primary route of exposure.
- Exposures occurred throughout the period 1962 – 1987.
- Exposures were not the result of a single release of material.

The following can reasonably be excluded, based on the data and the information currently available:

- Incineration as the source of exposure.
- Exposure to people born after 1987.
- Significant current ongoing inhalational exposure.
- Soil contamination as a source of serum TCDD elevations.

The following remain unanswered by the study:

- The timing of exposures during the period 1962 to 1987.
- Peak body burdens of the sample group.
- Serum TCDD levels in individuals who resided in areas where soil TCDD exceeded those in this study.
- Whether there was a contribution to TCDD exposure from production of chlorinated phenolic products other than 2,4,5-T.
- Characterising the risk to the health of people significantly exposed.
- Characterising the exposure and risks of residents not included in this study

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