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Uncertainty and Variation in Indirect Exposure Assessments: An Analysis of Exposure to TCDD from a Beef Consumption Pathway

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1. Introduction

Recently, regulatory agencies determined that indirect exposures to toxic substances released in air emissions can represent significant sources of risk to public health[1,2]. In recently released documents that discuss the performance of indirect risk assessments[1,2,3,4], EPA has recommended a series of equations and default parameter values that allow an incinerator operator to estimate the point estimate dose received by typical and high end exposed individuals via indirect pathways[1]. However, the doses received from indirect exposure vary greatly in the exposed population and there is considerable uncertainty in the dose estimates. Point estimates of dose cannot provide guidance to decision makers on these factors. In addition, default values, especially when the values are selected to be conservative, can result in estimated doses that exceed the 90th to 95th percentile of the dose distribution by several orders of magnitude[5,6,7]. The tendency for overestimating exposure is increased in indirect risk assessments which involve both a large number of parameters and parameters for which values have a large degree of uncertainty[8,9].

As discussed by EPA and other researchers, it is useful to characterize interpersonal variation and uncertainty in doses predicted for indirect exposure pathways[4,6,8,9,10,11,12]. Interindividual variation is the difference in exposure that occurs between one person and another and can be characterized as the distribution of dose rates in an exposed population. Uncertainty, which occurs due to a lack of complete information on a parameter's value, can be expressed as confidence limits on this dose rate distribution.

This paper presents an analysis of the uncertainty in estimates of lifetime average daily dose rates received by individuals via beef consumption because of indirect exposure to 2,3,7,8-tetrachlorodibenzo-*p*-dioxin (TCDD) emitted from a hypothetical incinerator. This analysis uses a Monte Carlo simulation to characterize the distribution of dose rates in the exposed population and to quantify the uncertainties associated with it.

2. Methods

In this analysis, the parameters used in the indirect exposure models were separated into three categories: constants, uncertainty, and interpersonal variation. First, those parameters, such as stack height and TCDD emissions rates,which were anticipated to be known (with a low degree of uncertainty) by the operator of the facility were treated as point estimates in the model. Second, those parameters, such as the half-life of TCDD and photodegradation rates, for which there is limited knowledge but for which there is a single true value were modeled in the uncertainty portion of the Monte Carlo model. Third, those parameters such as consumption rates and exposure duration,which vary from one individual to another within an exposed population, were modeled in the interindividual variability portion of the Monte Carlo model.

The hypothetical incinerator was assumed to be located on the Gulf Coast of Texas. Facility parameters, such as stack height, emission rate, etc. were adopted from actual hazardous waste incinerators operating in the State of Texas and local topographic and meteorological information were used in modeling. A hypothetical emission rate of 7.6×10^{-10} g/sec was used in the COMPDEP model[1,3)] to calculate the total TCDD deposition rates and the vapor concentrations at a series of receptor points near the facility. The estimated vapor concentration and rates of wet and dry deposition of TCDD were used to predict concentrations in grass and soil at local pasturage which were, in turn, used to estimate the TCDD concentration in the edible portion of beef cattle that grazed there.

This analysis used the methodology in Agency guidance[1,13)] and drew upon work of others[14-19)] to assess indirect exposures. The equations used in this analysis were consistent with those presented in Agency guidance[13)] except that TCDD specific information on biotransfer factors were used[20)], certain equations were modified to consider uncertainty in air models and vapor-to-particulate partitioning, and we included factors, like percent of ranches that raise beef for home consumption and the constancy of incinerator operation, which were not included by EPA. It was also assumed that cattle were raised on pasture but were moved to a "feed lot" and fed a diet of grain in order to increase their weight and improve the quality of the beef prior to slaughter. Due to lower uptake of TCDD by grain than by pasture[16,19)], TCDD levels in beef were assumed to decline during grain feeding as a result of metabolism/excretion of TCDD and dilution as an animal's total weight increases[16,17,20)]. This decline was estimated using the equation used by Fries and Paustenbach[16)] and the elimination rate reported by Jensen et al.[20)].

A two-dimensional Monte Carlo model that separately characterized uncertainty and variation was constructed using the nested loop approach described by Hoffman and Hammonds[10)] and Barry [21)]. The approach used an iterative procedure (the uncertainty loop) to select values from the probability density functions defined for each of the uncertainty parameters. During each iteration of the uncertainty loop, the model used a second nested iterative procedure (the variation loop) to model a distribution of dose rates in the exposed population determined by the selected set of values for the uncertainty parameters (Figure 1). The variation loop also selected a location where the modeled individual lived and used it to determine the appropriate long-term deposition rates and airborne concentrations, as calculated by the COMPDEP model.

The variation loop was repeated until the dose rates for the specified number of individuals were obtained. The model then calculated the summary statistics for the modeled population and stored them for the final output. Once completed, the model returned to the uncertainty loop and selected a new set of values for the uncertainty parameters. A total of 2,000 model iterations were conducted for both the uncertainty and variation loops for the model, resulting in 4,000,000 separate dose rate estimates. The Latin Hypercube sampling method was used to provide efficient sampling of distributions of parameter values. The Monte Carlo model was constructed on the PC-platform using Excel 4.0 macro language (Microsoft Corporation, Seattle WA 1992) and the sampling of parameters from probability density functions was accomplished using @Risk Version 1.12[22)].

3.0 Results

The results of the Monte Carlo model of the uncertainty and variability in the population of individuals who live on ranches within the 400 km^2 area are given in Table 1 and Figure 2. The dose rates for the population range from 0.0004 to 0.2 fg/kg-day for the 5th and the 95th percentiles of the population, respectively (as measured by the 50th percentiles of the uncertainty distributions), or 2.5 orders of magnitude. This variation occurred because of the differences in the locations of the farms where individuals live, the individuals' body weights, their beef consumption rates, and their durations of exposure. The 90 percent confidence limits (the 5th and 95th percentiles in the uncertainty distribution of the dose rate) for the dose rate of the median individual in the exposed population ranged from 0.006 to 0.02 fg/kg-day, slightly more than one-half of an order of magnitude. The doses from the 90th percent lower confidence limit (LCL) of the 5th percentile of the dose rate distribution to the 90th percent upper confidence limit of the uncertainty (UCL) for the 95th percentile of the dose distribution ranged from 0.0002 to 0.3 fg/kg-day, approximately three orders of magnitude.

4. Discussion and Conclusions

The results of this analysis suggest that exposures to TCDD via consumption of beef by ranchers living near a hazardous waste incinerator could have a total uncertainty of three orders of magnitude and that this uncertainty is dominated by interindividual variation. This finding is consistent with McKone's[23)] finding that variation is more important than uncertainty for compounds where there is direct information on the biotransfer rates. The model suggests that additional information on key parameters will not reduce the uncertainty in the dose received by an exposed population below 2-3 orders of magnitude because of the inherent variability in individual dose rates. This finding indicates that exposure estimates which involve a large number of parameters that have large uncertainty or a high degree of interindividual variation can result in a wide range of scientifically supportable exposure estimates[24)].

Nested Monte Carlo models of uncertainty and variation can provide considerable insight into the uncertainty in the range of doses received by populations exposed during indirect exposure analyses. This analysis suggests that while both uncertainty and interindividual variation are significant in indirect exposures, the total uncertainty is dominated by variation. In addition, these findings demonstrate the high variability that can result in point estimate dose estimates, depending upon the parameters that are selected for the assessment. As a result, the use of point estimate default parameters to derive dose estimates do not provide an adequate description of the range of doses received from indirect exposures. Consequently, it is recommended that estimates derived using current EPA defaults be confirmed by probabilistic analysis of the range of doses that could occur prior to making risk management decisions.

5. References

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Figure 1. Monte Carlo Model of Uncertainty and Variation of Indirect Exposure in a Local Population

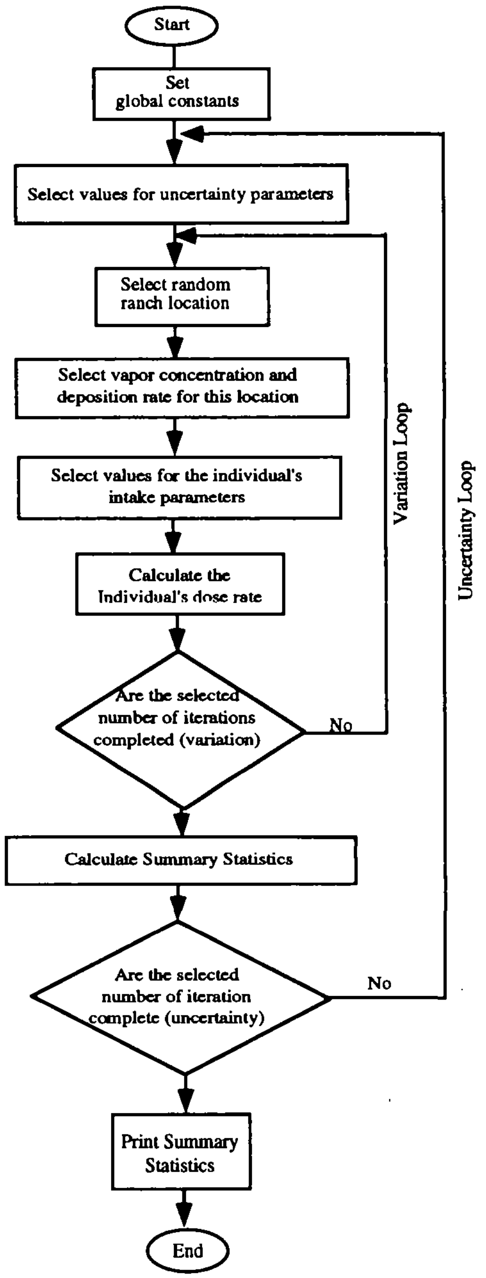

Table 1. Uncertainty and Variation in Dose Rate (fg/kg-day) from Indirect Exposure to TCDD

Variation / Uncertainty	5.0 %'ile	10.0 %'ile	25.0 %'ile	50.0 %'ile	75.0 %'ile	90.0 %'ile	95.0 %'ile
5.0 %'ile	0.0002	0.0004	0.002	0.006	0.02	0.05	0.08
10.0 %'ile	0.0002	0.0005	0.002	0.007	0.02	0.06	0.1
25.0 %'ile	0.0003	0.0006	0.002	0.009	0.03	0.08	0.1
50.0 %'ile	0.0004	0.0008	0.003	0.01	0.04	0.1	0.2
75.0 %'ile	0.0005	0.001	0.004	0.02	0.05	0.1	0.2
95.0 %'ile	0.0007	0.002	0.005	0.02	0.07	0.2	0.3

Figure 2. Variation and Uncertainty in Dose Rates (fg/kg-day) of the Exposed Population