A Monte Carlo Analysis of Exposures and Cancer Risks from 2,3,7,8-Tetrachlorodibenzo-p-Dioxin in Soil at Residential and Industrial Sites

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Introduction

In the United States and many other industrialized countries, the occurrence of elevated levels of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) in soil has been considered a potentially significant public health concern[1,2]. In the United States, the 1 ppb cleanup level typically has been invoked as the dividing line between acceptable and unacceptable levels of TCDD in residential and industrial soils[1]. This guideline was based on the Times Beach, MO risk assessment conducted by Kimbrough et al.[3] in response to public health concerns arising from potential exposures to contaminated residential soil.

Until recently, quantitative risk assessments have often been accused of being too dependent upon the repeated use of worst-case assumptions, which yield risk estimates which are unrealistic and of little use in decision-making[4,5,6]. This problem is primarily due to a reliance on the repeated use conservative single point estimates for various exposure parameters[5,6]. For example, Kimbrough et al.[3] recognized the uncertainties associated with many of the assumptions used in the Times Beach risk assessment and specifically identified several critical exposure estimates that were not likely to be encountered. Increasingly, risk assessments incorporate quantitative uncertainty analyses in order to integrate all of the available data regarding human contact with chemicals in the environment and to characterize any uncertainties[5,6,7].

These advances in quantitative risk assessment methodologies, as well as more recent information regarding the histopathology interpretation of the Kociba et al.[8] bioassay and the environmental fate and half-life of TCDD in soil, enable risk assessors to more precisely estimate the range of acceptable concentrations of TCDD in soil. For example, Paustenbach et al.[9] recently reported that 20 ppb in residential soils and between 131 and 582 ppb in industrial soils were found to pose a lifetime cancer risk that did not exceed 1 in 100,000 for the most likely exposed individual. In this paper, we re-evaluated TCDD uptake and the corresponding cleanup levels for residential or industrial soils. Probability distributions of the key exposure parameters used in that study were incorporated into a Monte Carlo analysis and used to predict the range and probability of TCDD uptake and corresponding soil concentrations.

Methods

As described in Paustenbach et al.[9], exposure to TCDD in soils was evaluated for ingestion of soil, dermal contact, inhalation and ingestion of airborne particles, and the consumption of fish exposed to TCDD through surface runoff. Uptake through other pathways (e.g., vapor inhalation, ingestion of surface water or groundwater) were not evaluated since their contributions are insignificant compared to other routes of exposure[1,10]. The concentration of TCDD was assumed to be distributed uniformly across the soil surface. Restrictions on direct contact with soil due to vegetative cover or pavement were not considered. Exposures to contaminated residential soil were adjusted each year to reflect changes in the residual concentration of TCDD due to degradation. Exposures to industrial soil were estimated similarly, with the exception that fish consumption was only considered to occur among individuals residing off-site.

The distributions of various exposure parameters were adopted from several well-referenced sources[6,7,11,12,13]. Each Monte Carlo simulation was comprised of 5,000 iterations using uniformly distributed ranges to describe the plausible upper or lower bounds of most parameters. In some cases, specified values derived from laboratory studies were randomly selected with equal probability. Because the runoff of soil-bound chemicals to a stream is not well characterized using the USLE model, the uncertainty analysis did not include probability distributions for the parameters used to estimate soil runoff to a neighboring stream.

Results

The results of the analysis for the residential scenario are presented in Figure 1. The concentrations of TCDD in residential soil which could plausibly produce a 10^{-5} cancer risk ranged from 85 to 3 ppb. The expected mean result from the 5000 iterations of the Monte Carlo model was 18 ppb. These results suggested that the lifetime incremental cancer risks for 75 % or 95 % of the population would be less than 1 in 100,000 if the concentration of TCDD in soil were no greater than 12 ppb and 7 ppb, respectively.

The results of the analysis for the industrial scenario are presented in Figure 2. The concentrations of TCDD in industrial soil, when fish consumption by off-site individuals was considered, ranged from approximately 56,000 to 14 ppb (10^{-5} risk). For a worker engaged only in outdoor activities for 8 h, the expected mean result from the Monte Carlo model was 327 ppb (10^{-5} risk) and soil concentrations at the 50th, 75th, and 95th percentiles (10^{-5} risk) were approximately 171, 93, and 44 ppb, respectively. For a worker employed indoors during an 8 h workday, the expected mean result was 3,035 ppb (10^{-5} risk) and soil concentrations at the 50th, 75th, and 95th percentiles (10^{-5} risk) were approximately 2,026, 1,208, and 625 ppb, respectively.

A sensitivity analysis of the various parameters used in the exposure assessments for the residential and industrial scenarios was conducted to determine the most critical exposure factors. In order of importance, the factors that were most influential in the exposure estimates were (1) exposed skin contact rate with soil, (2) fraction of soil derived from the site, (3) exposed skin surface area, (4) half-life of TCDD in soil, and (5) dermal bioavailability.

Discussion and Conclusions

The advances in our ability to assess human exposure to TCDD-contaminated soil have significant implications for setting risk-based cleanup levels for TCDD in residential and industrial soils. Improvements in quantitative risk assessment methodologies, as well as more recent information regarding the risk-specific dose for TCDD[14,15] and the environmental fate and half-life of TCDD in soil, enable risk assessors to determine acceptable concentrations of TCDD in soil with greater confidence. This assessment could be improved if a probability distribution for the risk specific dose (10^{-5}) were incorporated. Also, in light of recent questions about whether cancer is the most sensitive adverse effort, the analysis would benefit from consideration of the possible developmental and immune hazards.

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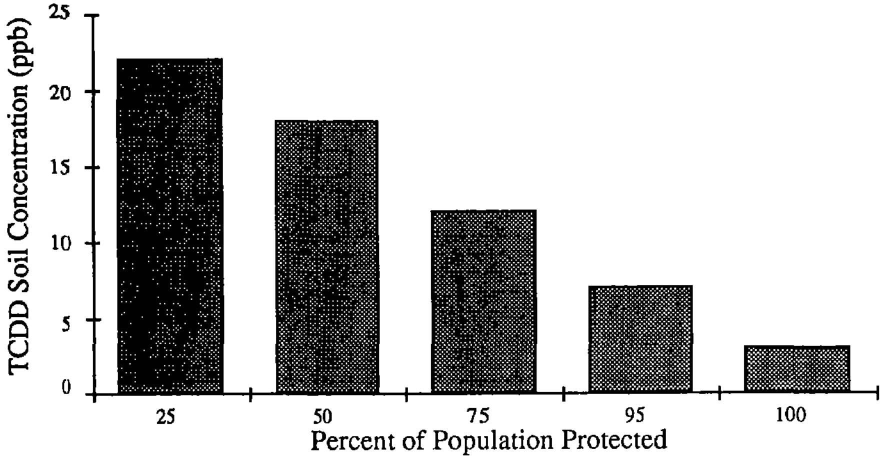
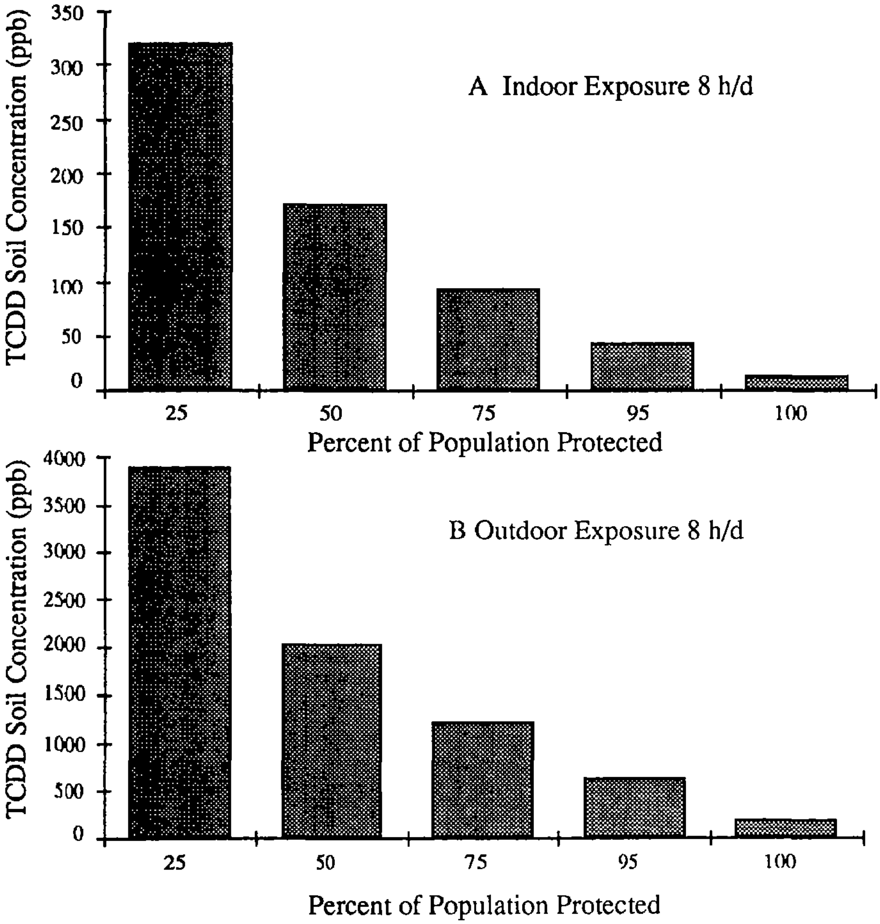


Figure 1. Range of TCDD concentrations in residential soil that could plausibly be associated with a 1 in 100,000 increased cancer risk. These estimates were based on Monte Carlo model.



Figures 2a and b. Range of TCDD concentrations in industrial soils which could plausibly be associated with a 1 in 100,0000 incremental cancer risk. These esimates were based on a Monte Carlo model.