Assessment of Potential Risks to the General Population from Exposure to Dioxins and Furans as a Result of Use and Disposal of Pulp and Paper Mill Sludge

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ABSTRACT: The potential carcinogenic risks to the general population from exposures to dioxins and furans were examined as a result of sludge management practices used at kraft and sulfite pulp and paper mills that employ chlorine bleaching. Three types of potential carcinogenic risks were estimated: maximum exposed individual (MEI) risks, typical individual risks, and population risks. Estimates of potential MEI risks exceeded 1×10^{-6} for 15 of the 21 exposure pathways examined. Scenarios on which these MEI risks were based are hypothetical; there is no direct evidence that these exposures actually occur.

INTRODUCTION: This assessment focused on potential carcinogenic risks to the general population as a result of disposal and use of pulp and paper mill sludge from kraft and sulfite pulp and paper mills that employ chlorine bleaching. Using the Toxicity Equivalency Factor (TEF) values formally adopted by the United States Environmental Protection Agency in 1987, 2,3,7,8-tetrachloro-p-dibenzodioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF) generally accounted for more than 90 percent of the dioxin toxic equivalents (TEQ) found in samples of pulp and paper mill sludge analyzed as part of the Five-Mill Study[(1)] and the 104-Mill Study.[(2)] Consequently, risks estimated from disposal and use of these types of sludges were based on exposures to these two dioxin congeners. Table 1 presents the distribution of 2,3,7,8-TCDD and 2,3,7,8-TCDF sludge concentrations for all bleached kraft and sulfite pulp and paper mills for which sludge concentrations were reported as part of the 104-Mill Study.[(3)]

Table 1. Distribution of 2,3,7,8-TCDD and 2,3,7,8-TCDF Sludge Concentrations for All Plants in the 104-Mill Study[a]

Distribution descriptor	2,3,7,8-TCDD concentration (ng/kg or ppt)	2,3,7,8-TCDF concentration (ng/kg or ppt)	Distribution descriptor	2,3,7,8-TCDD concentration (ng/kg or ppt)	2,3,7,8-TCDF concentration (ng/kg or ppt)
100th percentile	3,800	17,100	25th percentile	12	34
95th percentile	680	2,940	10th percentile	3	6
90th percentile	293	1,760	5th percentile	1.9	2.4
75th percentile	119	799	Mean	162.9	885.4
50th percentile	51	158	Standard Deviation	464.7	2,303

[a]Based on data from 79 pulp and paper mills. Source: (3)

Pulp and paper mill sludge management practices considered in this assessment include landfilling, surface impoundment, land application, and distribution and marketing. Approximately 2.5 million metric tons of pulp and paper mill sludge are generated annually.[(3)] Landfilling is the most common method of disposal of this sludge, accounting for 44 percent of the total pulp and paper mill sludge generated annually.[(3)] About 75 percent of all mills that landfill pulp and paper mill sludge dispose of this sludge on-site; the remaining 25 percent dispose of the sludge in municipal landfills.[(3)] Surface impoundment is the next most common method of disposal of pulp and paper mill sludge accounting for 24 percent of the total pulp and paper mill sludge generated annually.[3] About 12 percent of the total pulp and paper mill sludge generated annually is land-applied.[3] Of the amount of pulp and paper mill sludge that is land-applied, roughly 80 percent is applied to forest land, about 10 percent is applied to reclaimed mine sites, and the remaining 10 percent is applied to land used for agriculture.[3] The amount of sludge incinerated is approximately equal to the amount that is land-applied on an annual basis.[3] About 8 percent of the total pulp and paper mill sludge generated annually was reportedly distributed and marketed as a soil amendment.[3]

METHODOLOGY: In assessing potential carcinogenic risks to the general population from pulp and paper mill sludge management practices, 21 exposure pathways were examined. The exposure pathways considered for each sludge management practice are presented in Table 2. Two approaches were used to estimate potential risks to the general population from exposure to 2,3,7,8-TCDD and 2,3,7,8-TCDF as a result of pulp and paper mill sludge management practices. The primary difference in these two approaches is the distribution of pulp and paper mill sludge concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF used to estimate risks.

One approach used the distribution of concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF reported in the 104-Mill Study data base to be present in sludge for each management practice to estimate risks to the general population from each pulp and paper mill sludge management practice considered.[3,4] In the future, however, these mills could employ sludge management practices different from those reported in the 104-Mill Study data base. The distribution of 2,3,7,8-TCDD and 2,3,7,8-TCDF concentrations in pulp and paper mill sludge handled by each management practice could change, and the estimates of risks from these practices would, therefore, also change. Consequently, a second approach based on the distribution of sludge concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF from all pulp and paper mills in the 104-Mill Study data base was used to assess risk to the general population from each sludge management practice.

Using the second approach, these practices could be compared so that those with which the highest risks were associated could be determined without considering the influence of differences in concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in pulp and paper mill sludge. This second approach, also referred to as the "generic" approach, estimated typical individual risks based on mean concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in sludge and estimated MEI risks based on 90th percentile concentrations of these two dioxin congeners. The mean and 90th percentile concentrations of 2,3,7,8-TCDD in pulp and paper mill sludge were 163 ppt and 293 ppt, respectively; the mean and 90th percentile concentrations of 2,3,7,8-TCDF were 885 ppt and 1,760 ppt, respectively.[3]

Various mathematical models were used to estimate concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF in environmental media. These include the Seasonal Soil (SESOIL) model for fate and transport in soil;[5] the Analytical Transport One-, Two-, and Three-Dimensional (AT123D) model for fate and transport in aquifers;[6] and the Industrial Source Complex Long-Term (ISCLT) dispersion model for fate and transport in air.[7] A detailed discussion of the methods and assumptions used to estimate environmental releases and concentrations of 2,3,7,8-TCDD and 2,3,7,8-TCDF from pulp and paper mill sludge in environmental media is provided in the risk assessment for disposal and use of pulp and paper mill sludge prepared under the guidance of the Office of Toxic Substances and the Office of Solid Waste of the United States Environmental Protection Agency.[3]

RESULTS AND DISCUSSION: Three types of potential carcinogenic risks were estimated: maximum exposed individual (MEI) risks, typical individual risks, and population risks. Estimates of potential general population cancer risks associated with each pulp and paper mill sludge management practice are presented in Table 2. These estimates were based on the generic approach. In general, risks estimated by the two approaches differed by no more than an order of magnitude. In all cases, exposure to 2,3,7,8-TCDF was assumed to be one-tenth the exposure to 2,3,7,8-TCDD based on the toxicity equivalency factor method.[8] Estimates of risks were based on the EPA slope factor of 1.6×10^{-4} $(pg/kg\text{-}day)^{-1}$. Estimates of potential MEI risks exceeded 1×10^{-6} for 15 of the 21 exposure pathways examined. The exposure pathway with the greatest potential MEI risk was ingestion of fish from surface water contaminated by runoff from landfills, surface impoundments, and land application sites. Estimates of MEI risk from this pathway ranged from 10^{-1} to 10^{-2} Ingestion of surface water contaminated by runoff from landfills, surface impoundments, and land applica-

Table 2. Estimates of Potential General Population Cancer Risks Associated with Each Pulp and Paper Mill Sludge Management Practice

Disposal practice/exposure pathway	MEI risk[a] (lifetime^{-1})	Typical risk[a] (lifetime^{-1})	Exposed population[b]	Population risk[c] (cases/year)
Landfills				
Ingestion exposure from drinking surface water contaminated by surface runoff	7×10^{-4}	5×10^{-8}	6,980,000	5×10^{-3}
Ingestion exposure from fish caught in surface water contaminated by runoff	5×10^{-2}	8×10^{-8}	14,200,000	2×10^{-2}
Inhalation exposure to air contaminated by volatilization from landfills	5×10^{-7}	1×10^{-9}	12,800,000	2×10^{-4}
Ingestion exposure from drinking ground water contaminated by leachate	1×10^{-9}	1×10^{-10}	19,000	3×10^{-8}
Surface impoundments				
Ingestion exposure from drinking surface water contaminated by surface runoff	2×10^{-3}	7×10^{-8}	2,330,000	2×10^{-3}
Ingestion exposure from fish caught in surface water contaminated by runoff	1×10^{-1}	1×10^{-7}	4,760,000	7×10^{-3}
Inhalation exposure to air contaminated by volatilization from surface impoundments	1×10^{-6}	5×10^{-8}	7,100,000	5×10^{-3}
Ingestion exposure from drinking ground water contaminated by leachate	3×10^{-8}	5×10^{-10}	6,000	4×10^{-8}
Distribution and marketing				
Dermal exposure from contact with soil	1×10^{-4}	3×10^{-8}	3,500,000	1×10^{-3}
Exposure from direct ingestion of soil	1×10^{-4}	3×10^{-7}	3,500,000	1×10^{-2}
Inhalation exposure to air contaminated by volatilization from soil	6×10^{-7}	5×10^{-8}	3,500,000	3×10^{-3}
Inhalation exposure to soil particulates	2×10^{-7}	5×10^{-9}	3,500,000	3×10^{-4}
Dietary exposure from produce grown in gardens	2×10^{-8}	5×10^{-11}	3,500,000	3×10^{-6}
Land application				
Dermal exposure from contact with soil	4×10^{-5}	3×10^{-7}	40	2×10^{-7}
Exposure from direct ingestion of soil	4×10^{-5}	1×10^{-6}	40	7×10^{-7}
Inhalation exposure to air contaminated by volatilization from soil	2×10^{-4}	1×10^{-5}	40	7×10^{-6}
Inhalation exposure to soil particulates	4×10^{-6}	7×10^{-7}	40	4×10^{-7}
Ingestion exposure from drinking surface water contaminated by surface runoff from agricultural land application	2×10^{-3}	3×10^{-7}	333,000	1×10^{-3}
Ingestion exposure from drinking surface water contaminated by surface runoff from land application to mines/forests	3×10^{-3}	3×10^{-7}	833,000	4×10^{-3}
Ingestion exposure to fish contaminated by surface runoff from agricultural land application	1×10^{-1}	5×10^{-7}	679,000	4×10^{-3}
Ingestion exposure to fish contaminated by surface runoff from land application to mines/forests	2×10^{-1}	5×10^{-7}	1,700,000	1×10^{-2}
Dietary exposure from produce, meat, and dairy products grown in amended soil	1×10^{-2}	2×10^{-10}	240,000,000	7×10^{-4}
Ingestion exposure from drinking ground water contaminated by leaching from soil	$<3\times10^{-7}$	$<3\times10^{-7}$	NA[d]	NA[d]

[a]Risks presented were calculated using the EPA unit risk estimate for 2,3,7,8-TCDD and the TEQ method. This unit risk estimate was derived using the EPA carcinogenic slope factor for 2,3,7,8-TCDD (1.6×10^{-4} $(pg/kg/d)^{-1}$).

[b]Estimates of exposed population are based on typical risk.

[c]Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy].

[d]Not applicable.

tion sites resulted in MEI risks on the order of 10^{-3}. For land application of pulp and paper mill sludge, the second highest MEI risk resulted from ingestion of produce, meat, and dairy products grown on sludge-amended soil; the MEI risk estimated from this pathway was roughly 10^{-2}. The subsistence farmer (i.e., farmer that grows all or almost all food required by the farm family) represented the MEI for this exposure pathway. Most of the exposure pathways examined for land application of pulp and paper mill sludge resulted in MEI risks greater than 1×10^{-6}.

The only typical individual risk estimated to be greater than 10^{-6} occurs as the result of inhalation of dioxin vapors from sludge applied to agricultural land; the typical individual risk estimated from this exposure pathway was on the order of 10^{-5}. Population risks for pathways with typical individual risks greater than 10^{-6} were estimated to be very low because of the small population sizes associated with these estimates of typical risk. As with the MEI risk estimates, consumption of fish from surface water contaminated by surface runoff poses the highest population risk due to the large number of people potentially exposed; the population risk estimated from this exposure pathway was on the order of 10^{-2} excess cancer cases per year.

Because of a lack of site-specific data, hypothetical scenarios were examined; there is no direct evidence that the MEI exposure scenarios depicted actually occur. Because scant information was available regarding sludge management practices at sites receiving pulp and paper mill sludge, estimates of potential individual risk were based on exposure scenarios that depicted poor sludge management practices. For example, estimates of both typical and MEI risks assumed that runoff from landfills and surface impoundments was not controlled and would enter receiving streams used as sources of drinking water and fish ingested by humans. More sound management practices would tend to mitigate these risks. Also, because the location and hydrogeologic characteristics of the sites are not well known, generic data were used for parameters on the topography and geology of each site, the hydrology of nearby surface water bodies, the distance of each site from surface water, the land area of each site, and the quantity of sludge received at each site. Values assumed for these parameters in each typical scenario were different from those used in each MEI scenario. Assumptions used for each scenario to determine typical individual and MEI risks are presented in the risk assessment for disposal and use of pulp and paper mill sludge.[3]

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