Potential Dioxin Release Associated with Tire Derived Fuel Use in A Cement Kiln Gallatin County, Montana

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Abstract

Holnam Industries has proposed the use of Tire Derived Fuel (TDF) to supplement its use of coal to fuel its cement kiln, located at Trident Montana. Concerns about dioxin emissions have been raised by local and regional environmental lobby groups. This study presents a mass balance approach to characterizing potential sources of dioxin, both background and cement kiln generated, and discusses the potential environmental mobility and transformation of PCDD/PCDF compounds. Potential receptors and toxicological endpoints are reviewed. The likely health risk associated with dioxin release due to TDF combustion at the Holnam plant is very low, based on comparison of published release rates with likely background dioxin emissions in the Gallatin Valley.

1.0 Introduction

In late October, 2000, Holnam Inc., a cement company with a plant located in Trident MT (Figure 1), announced plans to replace 15% of the coal it uses to fire its cement kiln at Trident, Montana with Tire Derived Fuel (TDF) (Miller, 2000). The proposal would allow the company to reduce its fuel costs (which have increased dramatically in the last year, requiring a shift from natural gas to coal) while disposing of an estimated 615,000 tires per year, or roughly 75% of the scrap tires generated in Montana each year. Wire in the tire oxidizes to contribute iron oxide to the clinker, thereby improving the quality of the produced cement. Use of less coal would reduce particulate release by the facility.

At Trident, TDF would be introduced at the midpoint of the kiln where temperatures range from 760 to 1100 ^{o}C and incinerated rapidly, at the equivalent rate of one tire every 3 seconds. Temperatures are in excess of 1800 ^{o}C at the bottom of the kiln, and are less than 425^{o}F at the point where they enter the electrostatic precipitator on the stack (Prokop, 2000). Cement kiln dust (which meets TCLP criteria for land disposal under RCRA) is placed in on-site land disposal facilities. The Holnam kiln is an older, wet kiln design that is energy inefficient, so that the cost savings associated with TDF use will be significant to the longevity of the operation.

Holnam's proposal met with immediate opposition from local, regional, and national environmental groups, including Montanan's Against Toxic Burning, the Montana Environmental Information Center (MEIC), Greater Yellowstone Coalition (GYC), and the Sierra Club. These groups have cited nationwide concern regarding zinc, chromium, and dioxin/furan emissions associated with scrap tire combustion (Miller, 2000; http://www.meic.org/tires.html), and claim that the company should instead invest in newer, more energy efficient technology to reduce its operating costs.

(Not Shown)

Figure 1. Location of the Holnam Trident Cement Plant, showing Gallatin Valley

$$S_{stack\text{-}coal} + S_{stack\text{-}TDF} + S_{CKD} + [S_{wood} + S_{forest\ fires} + S_{vehicles} + S_{stored}] = P_{air} + P_{water} + P_{soil} + R_{veg} + R_{animals} + R_{humans}$$ ***Equation 1***

The objective of this study is to describe the potential sources (S), pathways (P), receptors (R) and methods of controlling PCDD/PCDF release that could contribute to health risk associated with the combustion of TDF at the Trident plant. These factors are summarized in Figure 2, and in Equation 1.

This study was completed as a case study for a course in Environmental Toxicology taught at the University of Idaho during the Fall semester 2000 and is not intended to represent a comprehensive, quantitative analysis of the risk of TDF combustion at the Holnam plant.

Potential dioxin/furan sources include TDF combustion as well as coal combustion at the plant; background anthropogenic contributions, such as fossil fuel combustion in vehicles and open burning; and natural sources, such as forest fires, all of which affect dioxin release (of course, with variable frequency and magnitude) in Gallatin County. A final source is comprised of the reservoirs of attenuated or bioaccumulated dioxin that was released previously and stored in various environmental compartments, such as soil. Potential sources include stack gases as well as cement kiln dust (CKD). PCDD/PCDF compounds have not been reported in the clinker product for any TDF burning facilities (USEPA, 2000a) Fate of any released dioxins are considered based on the physical and chemical characteristics of the cogeners likely to be associated with each source, for air, water, soil, and biological media. Potential receptors include vegetation, fisheries, wildlife, and humans; toxicological endpoints are discussed for receptors. Potential control options, including plant operation criteria, are discussed. Potential release of PCDD/PCDF associated with TDF combustion is estimated based on published data and reviewed with emphasis on existing background conditions. This study considers the primary zone of potential impact to be the Gallatin Valley. As dioxins (and related compounds) are persistent, bioaccumulative toxins (PBT's) which occur both naturally and as a result of anthropogenic activity, much of the debate about potential dioxin release due to TDF combustion at Trident will center on the potential concentration of the source and on dilution (ie: compliance with regulatory standards at the point source), rather than on biotransformation or attenuation of these compounds. Related environmental health risks associated with alternative disposal of scrap tires (which include highly toxic uncontrolled open combustion) are not addressed in this review.

2.0 Background

A variety of issues must be discussed to set the stage for this case study. These include the nature and use of TDF; description and understanding of PCDD/PCDF; the hydrogeologic and physiographic setting of the plant site; and state and federal air and water quality regulations. These are discussed briefly below.

2.1. What is Tire Derived Fuel (TDF)?: TDF is defined as a scrap tire, shredded or whole, composed principally of hydrocarbons and steel with a range in metal content (zinc, iron, chromium, cadmium, and lead) that will burn to release between 28 and 31 Mbtu/ton (ASTM, 1999). TDF also contains an average of 0.149% chlorine, at an average value much lower than existed prior to the early 1980's, when tubeless tires used a chlorobutyl innerliner (Salay, 2000). Comprehensive information on the chemistry and operational use of this fuel is provided elsewhere and will not be presented here (ASTM, 1999; Scrap Tire Management Council, 1992; http://www.rma.org/scraptires) TDF is currently in use at 53 cement kilns in several states (STC; Texas Air Control Board; Oklahoma DEQ Air Quality Board), including the northwestern states of Idaho, Oregon and Washington, where its approval is based on a large body of scientific evidence according to the MT DEQ (Miller, 2000) and the Scrap Tire Management Council, a lobby organization afiliatated with the Rubber Manufacturers Association (http://www.rma.org/scraptires). An estimated 100 million scrap tires are burned each year in the United States, with 37 million burned as supplementary fuel in cement kilns. (Schrama et al, 1995; USEPA, 1999a).

2.2. What are PCDD/PCDF Compounds? Polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) are halogenated aromatic hydrocarbons that are byproducts of combustion below 400^{o}C and chemical processes in the presence of chlorine. PCDD/PCDF are persistent, bioaccumulative toxins that are known animal carcinogens and probable human carcinogens. They are also linked to a variety of non-cancer effects (see Section 5). The dioxin and furan compounds have similar physical and chemical properties, due to their similar structure, but their environmental mobility and toxicity varies significantly depending on the specific cogener. Various cogeners are referenced in terms of toxic equivalents to the toxicity of 2,3,7,8 -tetrachlorodienzo-p-dioxin, which is established as a reference standard with a TEF value of 1.0. The TEF values for various compounds are multiplied by the concentration of each to yield a TEQ, which can be summed to estimate total dioxin or furan toxicity. Dioxins occur naturally, primarily due to forest fires, but are released in larger concentrations by anthropogenic activities, including commercial and municipal waste incineration, household trash burning, fossil fuel combustion, paper production, and other industrial processes (EPA, 2000a), although source control programs have reduced concentrations by 80% over the past 20 years. EPA (2000b) suggests that only 7 of the 75 PCDD cogeners and 10 of the 135 PCDF cogeners have dioxin-like (ie:, or 2378-TCDD, like) toxicity. These are the compounds listed in Table 1.

2.3. What is the environmental setting of the Trident Plant? The Trident plant site is located in the floodplain of the Missouri River. It lies in the northwest corner

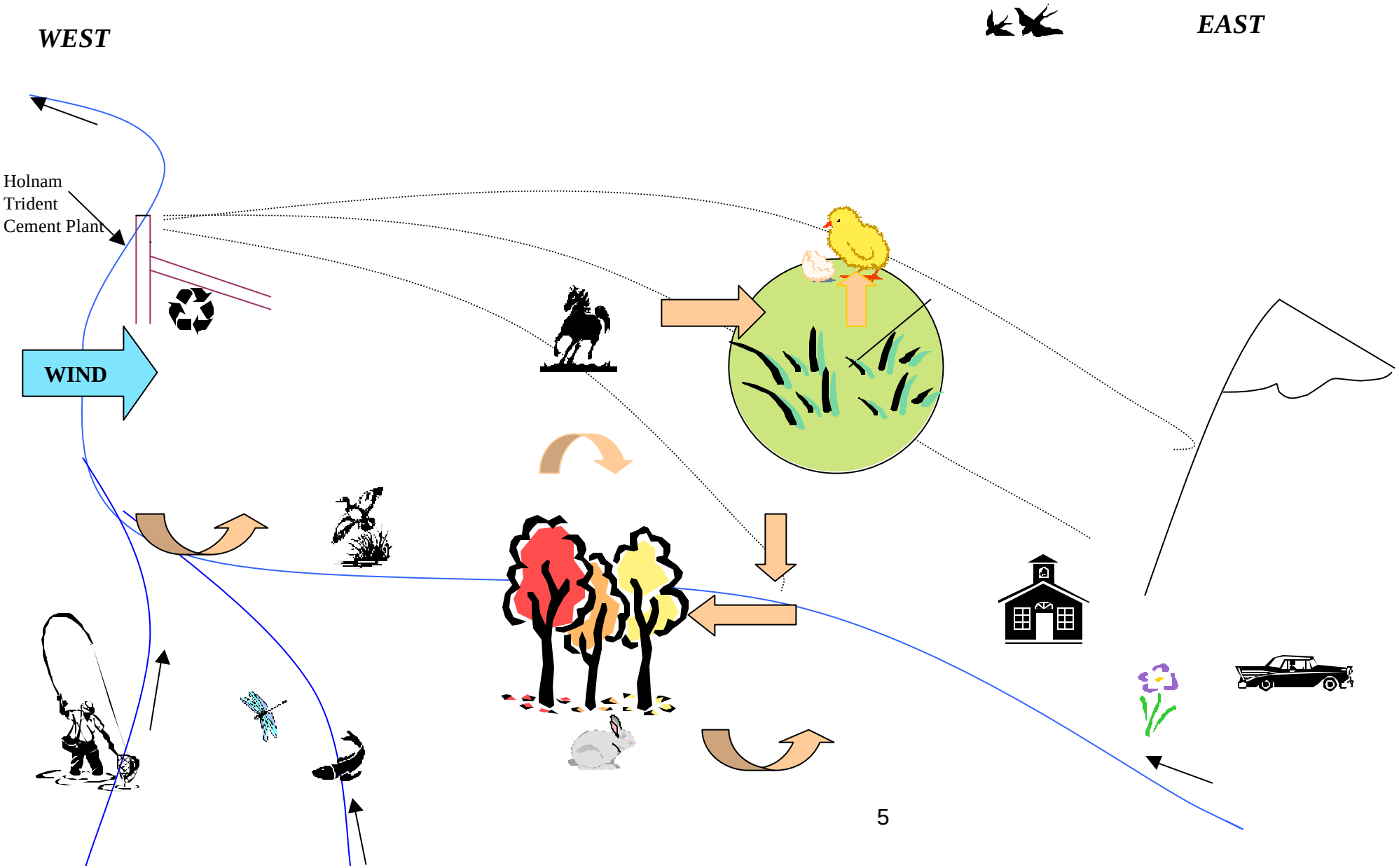
of Gallatin County, immediately upwind of the Missouri River headwaters comprised of the three drainages, the Jefferson, the Madison, and the Gallatin Rivers. The county is essentially defined by the Gallatin River drainage basin, and is a fault-bounded graben bordered by the Bridger Mountains to the East, the Gallatin Range to the southeast, the Madison Range to the southwest, the Tobacco Root Mountains to the west, and the Story Hills to the northwest, as shown in Figure 1 (USGS, 1960). For the purposes of this study, it is assumed that the majority of air deposition will be contained in the Gallatin Valley due to the presence of Bridger Mountains at the eastern (downwind) end of the valley. Groundwater occurs in shallow aquifers in glacial and fluvial deposits, including quaternary alluvium in the existing floodplains. Deeper bedrock aquifers exist in Mesozoic limestones (USGS, 1960). The area is home to a wide variety of world-class fisheries, and has thriving populations of birds and wildlife. Some endangered species live in the Gallatin Valley, alongside a variety of livestock and of course, people, many of whom are drawn to the valley by the quality of the environment.

2.4. What air and water quality regulations apply to Holnam Trident?

Montana regulates scrap tire disposal, collection and storage under its solid waste management program, and allows landfill disposal, but makes no provision for use or restriction of TDF, provided its use meets pertinent state and federal air and water quality regulations (USEPA, 1999). The Holnam facility is regulated under site specific state air quality guidelines, but will soon be held to the more stringent monitoring and performance standards of the federal Maximum Available Control Technology (MACT) program, recently enacted by US EPA in response to Clean Air Act and Resource Conservation and Recovery Act legislation (Prokop, 2000). Due to its conversion to coal from natural gas, the facility has experienced recent problems complying with particulate standards.

As an MSHA regulated facility that meets TCLP standards for Cement Kiln Dust (CKD), Holnam is permitted to land disposal of CKD in onsite repositories, if such disposal does not degrade surface or groundwaters of the state of Montana. As such, the facility is held to the stringent Montana non-degradation standards, known as WQB-7.

Figure 2. Conceptual Model of Potential Dioxin Release, Fate, Transport and Toxicological Endpoints, Holnam Trident Cement Plant.



3.0 Source: Potential Formation and Release of Dioxin

As indicated in Equation 1, several sources of PCDD/PCDF compounds affect health risk in the Gallatin Valley, only one of which is the subject of current public scrutiny. These include fossil fuel combustion in vehicles, wood combustion, forest fires, barrel burning of household wastes, in addition to the combustion of coal at the Holnam plant. The relative significance of these sources has been calculated in Table 2. Forest fire contribution (which includes prescribed burning of forests and agricultural wastes) was calculated using EPA published values of 9.43 metric tons/acre burned, over an estimated 500,000 acres (based on recent local fire and controlled burn land use patterns), at a published PCDD/PCDF release rate of 2E-09 g/kg of wood burned. Similarly, woodstove contributions were predicted based on an estimate of 50% of 10,000 households burning 2000 kg of wood annually in wood stoves that release PCDD/PCDF concentrations of 2E-09 g/kg of wood burned. This value is based on a population of 65,500 in the dominantly rural Gallatin Valley. Likewise, barrel burning was estimated by assuming that 30% of the rural valley population burns the EPA estimated 62% of its 616 kg/person/year of solid waste at a PCDD release rate of 7.28E-8 g/kg. Fossil fuel contributions were estimated by assuming that one third of the population drives 30,000 km each year, at a PCDD/PCDF emission rate of 2.6E-12 g/km. This process of estimate indicates a background release rate of 0.65 g TEQ PCDD/PCDF annually in the Gallatin Valley, including existing emissions from Holnam based on EPA- reported values for non-TDF combustion (2000a). It is important to note thatthe company monitoring data indicate that this value is actually lower,, but the EPA data were used for purposes of consistency in comparison. It should be emphasized that the background estimates of PCDD/PCDF release in the Gallatin Valley presented here have been calculated based on several assumptions and should be evaluated accordingly.

Polychlorinated PCDD/PCDF (PCDD, or dioxin/furans) are byproducts of the combustion of organic compounds. Air emissions from relatively low temperature, open tire fires are highly toxic, with high concentrations of criteria pollutants (NOx, SOx, CO, and VOCs) as well as hazardous air pollutants including polynuclear aromatic hydrocarbons, dioxins, furans, hydrogen chloride, benzene, PCB's and metals. Optimum temperatures for dioxin/furan production have been shown to be 200 to 450 ^{o}C (EPA, 2000a), which may occur in open fires, home woodstoves, and during cooling of high temperature combustion byproducts (such as cement kiln dust).

Dioxin formation requires a source of chlorine and organic matter, as well as a specific range of temperatures. Three principal mechanisms of dioxin generation as a combustion byproduct have been identified as 1) dioxin presence in source material, 2) thermal breakdown and reorganization of precursor aromatic hydrocarbons, and 3) de novo synthesis on fly ash in the presence of carbon, hydrogen, chlorine and transition metal catalysts (EPA, 2000a). As dioxin concentrations are typically higher downstream of the furnace in cement kilns, this suggests that PCDD/PCDF compounds

form via the latter two processes, particularly where temperatures are above 450^{o}F. Studies reviewed by EPA in its recent reassessment of dioxin indicate that although chlorine is needed for dioxin formation in combustion systems, chlorine level in feed is not the dominant controlling factor for PCDD/PCDF emissions in monitored facilities, which are more strongly affected by combustion process characteristics and air pollution control equipment. This relationship has also been proven in laboratory experiments, which indicate that PCDD/PCDF formation is independent of chlorine content in feed at concentrations less than 1 percent (EPA, 2000a).

Cogeners produced by organic combustion vary within a kiln, with more highly chlorinated and more toxic compounds occurring in kiln waste while a broad spectrum of cogeners ranging from tetra- to octa- PCDD/PCDF compounds were measured in stack gases, suggested that post-combustion formation in waste is an important process (EPA, 2000a). Oxidation of hydrogen chloride gas catalyzed by copper chloride appears to be another important source reaction.

Although chlorine concentrations are very low in TDF, by most reports 0.149% (US EPA, 1991; Scrap Tire Council, 1992) , its presence raises the possibility of PCDD formation and the ugly fear of dioxin release in the Gallatin Valley. Due to the very high in-situ monitoring equipment cost (in excess of $1 million) needed to conduct a test burn on site, Holnam has not conducted a test burn at its facility. The Trident kiln burns at temperatures ranging from 760 to 1900^{o}C below the proposed midkiln point of TDF introduction. Holnam is therefore relying on performance monitoring data and process analyses from other TDF burning kilns operated under similar conditions by Holnam and other corporations around the US, along with tests completed by various state and federal agencies. Results of such tests are summarized in Table 1.

Also summarized in Table 1 are the observed range in emissions for 28 cement kilns, energy service, pulp and paper plant, and miscellaneous incinerator facilities reported in a comprehensive study funded by the California Integrated Waste Management Board Study (Dames and Moore, 1997). These facilities were operated under both baseline (fossil fuel) and TDF-supplemented conditions. Dioxin data were reported for eighteen tests at eleven facilities, seven of which were cement kilns. Mean total dioxin emissions were significantly lower in TDF kiln emissions, although this was not true for all dioxin compounds. The range in concentrations between facilities was significant, as shown in Table 1, reflecting the importance of combustion process management. There was little variance between minimum and maximum values reported for baseline and TDF facilities, though, indicating little difference in environmental impacts associated with the use of either fuel.

These data agree with USEPA's conclusions (1997) that, "with the exception of zinc emissions, potential emissions from TDF are not expected to be very much different from other conventional fossil fuels, as long as combustion occurs in a well-designed, well-operated, and well-maintained combustion device," like a rotary cement kiln. Test data from cement kilns cited in this study indicate that supplemental use of

TDF in various combinations up to 20% TDF did not affect the ability of the facilities to meet air emission environmental compliance limits.

Available data published in peer-reviewed literature do not support the MEIC assertion of a significant increase in dioxin emissions associated with TDF use at the Trident facility. MEIC cites a report Schwartz et al, which was prepared for (but not accepted by) the California Integrated Waste Management Board, in which PCDD/PCDF compounds are reported to increase between 50 and 100% at four studied plants, with PAH, lead, and hexavalent chromium increasing significantly at some sites when TDF was burned but decreasing at others. This report, which was not peer reviewed, does not present the actual data upon which the calculated percentages were based, so it was not possible to include them in the calculations presented in this study. Attempts to obtain these data from the authors directly were unsuccessful. The Schwartz study also does not make clear how the reported increases correspond to air emissions standards, or what explains the observed variation. At the very low dioxin concentrations reported for several TDF facilities in Table 1, however, it is likely that a 50 to 100% increase in PCDD/PCDF concentrations reflects a very small difference in actual concentration, which may be well below compliance levels. These relative differences compare reasonably well with the values reported by Dames and Moore (1997) in Table 1, which shows a 50% increase in maximum mean total PCDD/PCDF value and a 100% decrease in minimum mean total PCDD/PCDF value concentration. It is interesting that the MEIC considers this persuasive evidence of significant environmental impact, when similar data are interpreted very differently by government and industry scientists.

4.0 Pathways for Transport of Dioxin Away from the Kiln

Environmental mobility and bioavailability are controlled by the very stable nature of polychlorinated dibenzo-p-dioxins (PCDDs) and related polychlorinated dibenzofuran (PCDF) compounds. The physical and chemical nature of the cogeners varies with the degree and position of chlorine substitution, but as a group these compounds have low vapor pressure and solubility and are resistant to abiotic and biotic transformation. The primary source is release to air, and they can be transported over large distances before they are deposited through dry and wet deposition onto soils, water, and plants. Their physical chemistry characteristics are summarized in Table 3. PCDD/PCDF compounds are strongly bioavailable due to their lipophilic nature.

As a result of the persistent, bioaccumulative nature of PCDD/PCDF compounds, they are found throughout the world, in part due to production by natural sources and more significantly, due to historic and active anthropogenic production. It is important to recognize this background presence of dioxin world wide, which reflects dioxin exposures in the Gallatin Valley unrelated to actions at the Holnam Trident plant.

Whatever incremental additional dioxin release results from TDF combustion, atmospheric deposition (as gas and particulate) onto soil, water, and vegetation will be the primary environmental pathway of exposure for terrestrial/agricultural and aquatic biota (USEPA, 2000b). The lipophilic nature and low solubility of PCDD/PCDF compounds causes them to remain associated with particulate and organic matter in soil and water. Soil erosion into surface water will remobilize PCDD/PCDF to some extent. Minor volatilization from soil and water will occur, but whatever limited abiotic transformation occurs will be by photolysis (USEPA 2000b). Biodegradation is also limited. Once sorbed to soils, potential for volatilization or leaching is very low (USEPA, USEPA 200b). This is particularly true for OCDD/OCDF, which represent a significant fraction of the potential cogener release from TDF combustion (Table 1). As shown in Table 2, OCDD has a smaller solubility, lower vapor pressure, and higher Kow than other cogeners, and would therefore not be strongly mobile. PcCDF and HxCDD compounds would more readily undergo photolytic transformation than OCDD, while furans would have higher solubility.

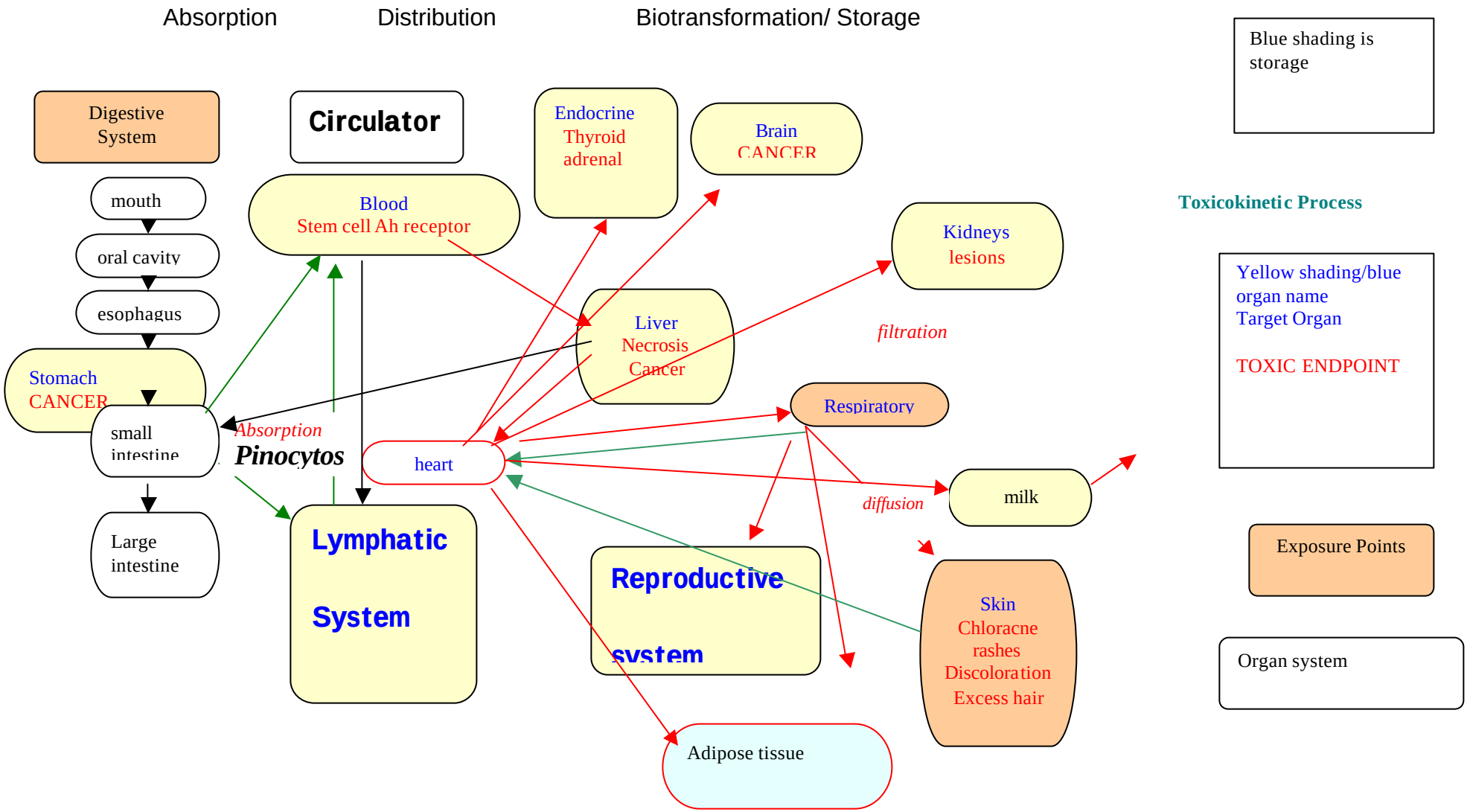
5.0 Receptors Potentially Affected by Dioxin

As defined in equation 1, potential receptors include humans, fisheries, wildlife, livestock, and vegetation. Bioaccumulation, beginning low in the food chain with aquatic microorganisms and plants, is evident in higher trophic organisms, particularly fish (USEPA, 1999) and livestock (Belgium Federal Ministry of Agriculture, 1999). Human exposure would primarily be through ingestion of fish and other food sources, including agricultural products and livestock. As of 1998, 19 states had issued 59 fish advisories due to dioxin accumulation in fish (USEPA. 1999b); USEPA has also documented dioxin concentrations in most food sources (USEPA, 2000a).

In animals, acute toxicity occurs as a pronounced wasting syndrome, characterized by weight loss and depletion of body fat in laboratory animals. Laboratory animals have survived acute doses of OCDD, however. Exposure to dioxin also affects heart, liver, kidneys, blood, stomach and endocrine systems of laboratory animals. (USEPA, 1999b) Dioxin related mortality in chick populations was observed in Belgium (Belgium Federal Ministry of Agriculture, 1999) . Carcinogenic affects are well documented in animals.

Human health affects are summarized in Figure 2. Human dioxin exposure is primarily through ingestion of fatty foods, although inhalation and transdermal absorption also occur. The specific mechanisms of biotransformation and cell changes are the focus on active research, primarily focused on changes in Ah-receptors in stem cells. Short term clinical manifestations include chloracne, eye irritation, allergic dermatitis, porphyria, and gastrointestinal disturbances. Possible long term affects, which have been documented in animals and are hypothesized in humans, include teratogenesis, reproductive affects, liver and kidney damage, carcinogenesis in various exposed tissues, and low level hormonal influences on development and fertility. (US EPA, 2000c; 2000d; 2000e). Virtually all humans store some amount of dioxin in their adipose tissue, and excrete it in milk.

Figure 2. Conceptual Model of PCDD/PCDF absorption, distribution, biotransformation, and target organ effects.



Red arrows are transport/biotransformation vectors to various organs

Green arrows are absorption exposure vectors

6.0 Potential PCDD/PCDF Release and Options for Control during Kiln Combustion of TDF

In the absence of site test burn data, it is necessary to consider the range of published values for dioxin release from TDF facilities to predict how much additional dioxin could be released into the environment of the Gallatin Valley due to TDF combustion at the Trident plant. Reference to Table 1 will show a calculation of annual release in grams of PCDD/PCDF compounds, for the minimum and maximum total release values (I-TEQ) reported by Dames and Moore (1997) in its study of 11 TDF burning facilities. These values encompass the range of emissions for all studied facilities, so that maximum and minimum values reported for baseline and TDF combustion conditions do not necessarily represent the same facility. Nevertheless, comparison of the total annual release indicates a potential increase ranging from 0.00385 g to 1.07 g per year PCDD/PCDF in I-TEQ units, depending upon TDF combustion conditions. As the Trident plant will use midpoint TDF introduction, and has a temperature of less than 450^{o}f at the inlet to the electrostatic precipitator, it is likely that any incremental dioxin emission will be on the lower end of this range. This is supported by the USEPA (2000a), which indicated an increase from 0.27 ng/kg clinker produced at a cement kiln to 0.282 ng/kg clinker produced for a TDF-fired facility. Using these numbers, Holnam dioxin discharge would increase relative to existing background releases in the Gallatin Valley by less than 0.6%, as shown in Table 2.

If a significant increase were observed, Holnam would have options available to reduce emissions. The observed range in PCDD/PCDF emissions at TDF-burning facilities (see Section 3.0) indicates that options exist for minimizing the generation of these persistent and bioaccumulative toxins. Options include control of combustion temperature, by introducing wastes into portions of the kiln where temperatures are higher than 450^{o}C, and increasing the cooling rate of wastes and waste gases to limit the time spent in the temperature range 200-450^{o}C that is optimal for PCDD/PCDF formation. Similar consideration should be given to restricted use of TDF during maintenance cycles when temperatures may vary from optimum operating conditions. As the limestone present in a kiln will neutralize sulfur dioxide gas, it is unlikely that sulfur dioxide would be of use in reducing chlorine activity although the presence of SO_2 gas has been shown to reduce hydrogen chloride emissions (USEPA, 2000). Air pollution control devices, such as fabric filters in addition to electrostatic precipitators, have been shown to reduce particulate release and in doing so, reduce dioxin emissions (USEPA, 2000). Holnam will be required to use Maximum Available Control Technology under new MACT guidelines, and will monitor periodically for PCDD/PCDF emissions. If standards are exceeded, Holnam can cease burning TDF. This potential underscores the importance of appropriate monitoring and regulatory enforcement.

7.0 Conclusions

The likely health risk associated with dioxin release due to TDF combustion at the Holnam plant is very low, based on comparison of peer reviewed, published release rates associated with TDF combustion in cement kilns with probable background dioxin emissions in the Gallatin Valley. In legal terms, questions about Holnam's use of TDF are focused on whether the facility will exceed pertinent dioxin emission standards by combusting TDF fuels at its facility. In public terms, the question will more likely be, should we allow deliberate emission of any dioxins at all in the Gallatin Valley? It is obvious from the data provided on the MEIC website, and from the discussion applied to data that have been interpreted fairly (and very differently) elsewhere, that this will be a highly politicized issue. Unfortunately, it is also a highly technical issue that will be difficult for local residents to understand. It will be important to provide site-specific data as they become available, and to present them in context of background releases.

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Table 1. Cement Kiln Emissions Data

PCDD/PCDF cogeners and values showing significant change are highlighted.

Location		**Holnam Trident** pre-TDF operations		**Florida Crushed Stone**[1]		**CA IWMB Studv**[2]			
normal fuel		coal, wet process		coal, wet process		coal, wet process			
APCD						ESP			
		baseline		*baseline*					
% TDF		0%		0%	14%	0%		varied up to total TDF	
		avg 3 runs				max	min	max	min
particulate	lbs/hr	11.78		56.8	52.21	2.1	0.4	1.9	1
Cadmium		nd		<0.005	0.01	9.13E-03	2.90E-05	1.67E-02	4.00E-06
Zinc	lbs/hr	nd		3.12	1.68				
Chromium	lbs/hr	nd		nd	nd	1.29E-02	4.06E-05	3.58E-02	1.83E-05
Copper	lbs/hr	nd		0.03	0.03	nd	nd	nd	nd
Chloride	nd	nd							
PAH	lbs/hr			0.15	0.44	6.97E-03	3.23E-07	2.62E-03	3.56E-07
THC	lbs/hr	1.57							
Dioxins	lbs/hr								
2378-TCDD	lbs/hr			0.004	ND	1.30E-08	1.30E-10	1.96E-08	1.25E-10
12378PeCDD	lbs/hr			0.017	ND	3.50E-08	7.60E-11	3.31E-08	8.50E-11
123478HxCDD	lbs/hr			0.002	ND	4.80E-08	8.86E-11	2.24E-08	1.70E-10
123789-HxCDD	lbs/hr			0.003	ND	8.40E-08	1.09E-10	3.49E-08	4.00E-11
123678-HxCDD	lbs/hr			0.005	ND	1.25E-07	8.20E-11	2.43E-08	8.10E-11
1234678-HpCDD	lbs/hr			0.001	<0.001	1.21E-06	1.80E-10	1.07E-07	1.70E-10
OCDD	lbs/hr			0	0	5.22E-06	3.80E-10	1.10E-06	3.90E-10
other tetra	lbs/hr			0.003	0.001	nd	nd	nd	nd
other penta	lbs/hr			0.002	<0.001	nd	nd	nd	nd
other hexa	lbs/hr			<0.001	<0.001	nd	nd	nd	nd
other hepta	lbs/hr			<0.001	<0.001	nd	nd	nd	nd
SUBTOTAL	TEQ lbs/hr	5.00E-12	detection limit	0.037	0.001	8.30E-08	3.15E-12	5.84E-08	2.62E-11
Furans									
2378-TCDF	lbs/hr			0.01	0.006	2.90E-07	3.80E-10	4.61E-07	1.86E-10
12378-PeCDF	lbs/hr			0.002	nd	1.27E-07	1.10E-10	1.81E-07	1.20E-10
23478-PeCDF	lbs/hr			0.004	nd	1.91E-07	1.10E-10	2.40E-07	1.30E-10
123478-HxCDF	lbs/hr			<0.001	nd	8.36E-08	4.60E-11	1.68E-07	4.80E-11
123678-HxCDF	lbs/hr			<0.001	nd	5.63E-08	3.60E-11	5.72E-08	4.90E-11
234678-HxCDF	lbs/hr			<0.001	nd	1.20E-07	2.08E-10	5.48E-08	2.93E-10
123789-HxCDF	lbs/hr			nd	nd	6.19E-09	8.58E-11	9.49E-09	1.34E-10
1234678-HPDF	lbs/hr			<0.001	nd	7.90E-08	5.20E-11	4.38E-08	6.50E-11
1234789 HPDF	lbs/hr			nd	nd	1.79E-08	4.97E-11	1.26E-08	4.40E-11
OCDD	lbs/hr			0	nd	2.90E-07	1.63E-10	3.70E-08	2.68E-10
other tetra	lbs/hr			<0.001	<0.001	nd	nd	nd	nd
other penta	lbs/hr			<0.001	<0.001	nd	nd	nd	nd
other hexa	lbs/hr			<0.001	nd	nd	nd	nd	nd
other hepta	lbs/hr			<0.001	nd	nd	nd	nd	nd
SUBTOTAL	TEQ lbs/hr			0.017	0.006	6.17E-07	9.19E-10	8.92E-07	1.86E-10
TOTAL	TEQ lbs/hr					7.00E-07	9.22E-10	9.50E-07	2.12E-10

annual grams calculated assuming 7056 annual operating hours

Annual grams		1.97	2.94E-03	3.03	6.79E-03
TDF diffce				1.07	3.85E-03

1 USEPA, 1991

2 California Integrated Waste Mgmt Board, 1997

Table 2. Estimated Relative PCDD/PCDF contributions to Gallatin Valley

				PCDD/PCDF emission factor	PCDD/PCDF total release	I-TEQ
Cement Kilns burning TDF			Stack Gas	*2.70E-10*	no tires	g/kg clinker
			Stack Gas with TDF	*2.82E-10*		
			Cement Kiln Dust	3.00E-11		g/kg CKD
Holnam Trident		330 million kg	kg clinker		0.089100	g annual
		27.5 million kg	kg CKD		0.000819	g annual
Holnam Total (includes					0.089919	g annual from Holnam
Holnam Incremental Additional due to TDF					0.003960	0.61%
Fire	forest	500,000 acres	9.43 metric tons/acre	2.00E-09	g/kg biomass	0.00943 g annual
	woodstoves	2,000 kg		2.00E-09	g/kg wood	0.020000 g annual
	barrel burning		30%	7.28E-08	g/kg waste	0.530111 g annual
Fossil fuels	motor vehicles			2.60E-12	g/km	1.72E-03 g annual
Background Total						0.65035 g annual

Air		7
Estimate incremental contribution due to TDF use	min	0.00385 g annual
	max	1.07 g annual

20% 62545

Table 3. Physical Properties PCDD/PCDF Cogeners in TDF Fired Cement Kiln Emissions (after USEPA, 2000_)

	MW	Melting Point	Water solubility	T	Vapor Pressure	T	Henry's constant	Log Kow	Log Koc	PQYield
	g	°C	mg/L	°C	mm Hg	°C	atm-m3/mol			H2O-Ac 313 nm
Dioxins										avg reported
2378-TCDD 12378PeCDD 123478HxCDD 123789-HxCDD	321.98	305-306	1.93E-05	25	1.50E-09	25	3.29E-05	6.8	7.25-7.59	3.52E-02
123678-HxCDD	390.87	285-286	4.4E-06 *		3.60E-11	25	1.07E-5 *	7.8	nd	1.10E-04
1234678-HpCDD	425.31	264-265	2.40E-06	20	5.60E-12	25	1.26E-05	8	nd	1.53E-05
OCDD	460.76	325-326	7.40E-08	25	8.25E-13	25	6.75E-06	8.2	nd	2.26E-05
other tetra other penta other hexa other hepta										
Furans										
2378-TCDF	305.98	227-228	4.19E-04	22.7	1.50E-08	25	1.44E-05	6.1	nd	nd
12378-PeCDF	340.42	225-227	2.4E-4*	22.7	2.70E-09	25	5.00E-06	6.4	nd	nd
23478-PeCDF	340.42	196-196.5	2.36E-04	22.7	2.60E-09	25	4.98E-06	6.5	nd	6.96E-04

123478-HxCDF 123678-HxCDF 1234678-HxCDF 123789-HxCDF 1234678-HPDF 1234789 HPDF	374.87	239-240		1.30E-05	22.7	2.80E-10	25	1.10E-05		7	nd	nd
OCDF other tetra other penta other hexa other hepta	444.76	258-260		1.16E-06	25	3.75E-12	25	1.88E-06		8	nd	nd