Dioxin Study

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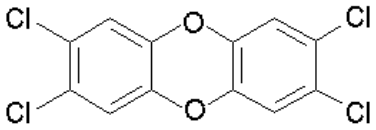
20 August, 2008

Dioxins are molecular compounds with a base structure that is a ringed hydrocarbon (contains hydrogen and carbon) with different numbers of attached chlorines. Dioxins with different numbers of chlorines located at different positions on the hydrocarbon rings are called *congeners*. There are "419 types of dioxin-related compounds" (Dioxins). The most common type has four chlorines attached to the base structure. 2,3,7,8- Tetrachlorodibeno-para-dioxin (TCDD) is the most toxic of the dioxin family. Below is the chemical structure of TCDD (from www.ktf-split.hr/glossary/image/dioxin.gif).



Dioxins have some unifying properties: they are non-flammable, have low aqueous solubility, have oxidation resistance and hydrolysis resistance, and have low electrical conductivity (Connell 132). The most famous use of TCDD was as a part of Agent Orange during the Vietnam War (Wyman 386). Agent Orange is composed of "2, 4-D" and herbicide "2, 4, 5-T," which contains TCDD as an "impurity" (Girard 446). 2, 4-D (2, 4-dichlorophenoxyacetic acid) is a pesticide with small amounts of dioxin. 2, 4, 5-T's full name is 2, 4, 5-trichlorophenoxyacetic acid (Connell 131).

There are two main related compounds, furans and PCBs. A furan is a "cyclic flammable liquid C_4H_4O that is obtained from wood oils of pines or made synthetically" (Furan). PCBs or "polychlorinated biphenyls," are "mixtures of human-made chemicals with similar chemical structures. PCBs can range from oily liquids to waxy solids" (PCBs). PCBs that are coplanar are similar to dioxin chemically and structurally and have higher toxicity, so they act as dioxin does in living systems. The PCBs (which can be flat – planar or coplanar – or not flat, when the

two rings are perpendicular to one another) show higher toxicity when the chlorines are substituted in a way that allows the PCB to be planar.

Dioxins are highly dangerous. In animal systems, dioxins are thought to attach to an "intracellular protein molecule that is soluble and not bound to the cell membrane" (Connell 143). In this way, it mimics a hormone due to its structure. Hormones in the body act in minute amounts as "chemical messengers," which guide essential body functions. TCDD acts as a chemical messenger, which also works in tiny amounts and effects bodily functions, and thus mimics the action of a hormone. Dioxin binds to a receptor, which is a small protein molecule designed to bind to other molecules as a "lock" and "key" (Health Effects). This specific receptor is called the Ah-receptor, since it "causes the organism to become extremely responsive toward the presence of aryl (or aromatic) hydrocarbons" (Connell 143). The dioxin that binds most strongly to this receptor is TCDD. After TCDD locks into the Ah receptor, a so far unexplained "transformation process" occurs, in which the receptor's structure is changed. The dioxin-Ah complex then enters the nucleus of the cell, and binds to the DNA at specific locations; "These sites are just upstream of a cytochrome P_{450} gene" (Connell 144). The latching onto the DNA begins transcription of messenger RNA molecules, "which direct the synthesis of new cytochrome P_{450}" (Connell 144).

Cytochrome P_{450}'s normal function is to "catalyze the biotransformation of many lipophilic substances, including hormones, fatty acids, some drugs, and hydrocarbons such as polyaromatic hydrocarbons (PAHs)." However, the interaction of cytochrome P_{450} and PAHs might create intermediate compounds which are carcinogenic or highly toxic. Currently, it is thought that the "dioxin –receptor complex" distorts DNA by bending it. Thus, this complex effectively allows other proteins to bind to the DNA, leading to "induction of other enzymes" (Connell 144).

Additionally, the dioxin –receptor complex bound to DNA "activates genes which produce substances that regulate the growth and division of cells" (Health effects). In this aspect, they are similar to hormones as well. Where hormones control cell division, dioxins disrupt cell division. They do this by reconfiguring the characteristics of cells, and by causing uncontrolled growth of cells (Health Effects). The mechanism of dioxin toxicity is illustrated in Figures 1 and 2 at the end of the report.

A dioxin's toxicity is generally measured against TCDD, the most toxic dioxin. This process utilizes what are called International Toxic Equivalence Factors (or I-TEFs) in which a toxic measure of a given congener (e.g., EC_{50}, middle effective concentration, with a test organism) is compared with the same toxic measure for TCDD (Connell 146). A toxic equivalent of TCDD has the acronym of TEQ. The TEQ = I-TEF x Concentration of the specific compound. The I-TEF = EC_{50} (TCDD) / EC_{50} (congener of interest).

There are multiple sources of dioxin. Some include volcanic eruptions, forest fires, and smelting. Dioxin content is also very high in "soil, sediments and food, especially dairy products, meat, fish and shellfish" (Dioxins). The most toxic dioxin, TCDD, is also "formed as a byproduct of the manufacture of trichlorophenol, a chemical that is used in the manufacture of a variety of herbicides" (Girard 446). In general, there are two main sources of dioxin, chemical processes and combustion programs. The chemical processes involve chlorine and generally occur at paper mills and other industries. Combustion occurs at municipal solid waste incinerators, power plants which are coal-burning, fires caused by organochlorine compounds (including PCBs) or burning of vegetation treated with phenoxyacetic acid herbicides. In combustion emissions, there are three proposed reasons for dioxin presence. 1. They are already present in the combusted material and are not destroyed by the combustion process. 2. They may

be formed from organochlorine precursors (e.g. …PCBs) present in the combusted material, during the combustion process. 3. They are created from high-temperature reactions between nonchlorinated organic molecules and chloride ions (Connell 130-132). Humans are primarily exposed to dioxins through consuming fish.

Dioxins affect a wide range of organisms - animals, wildlife, and humans. Even worse, TCDD has a very high toxicity, and has "delayed lethality," meaning the poison seeps through the body for days until death (Connell 143). "A millionth of a gram will kill a guinea pig" (Health Effects). The affect on humans is equally harmful (although people have survived poisonings – like President Viktor Yushchenko of the Ukraine). It can cause brain damage, neurological injury, skin lesions, poisoning of the liver and kidney, and immune system dissolution (WHO). Dioxin is also known to induce reproductive deficiencies (miscarriage, sterility), and chloracne, a skin disease (Health effects). To make matters worse, it has been known to be carcinogenic, or tumor- producing.

A pertinent question is - how to eliminate dioxin? Two ways have been used. First, waste incineration has been used. However, incineration must be at high temperatures, over 850 °C, due to dioxins inflammability. To eliminate larger amounts of contaminated material, even higher temperatures - 1000°C or more – are required. Secondly, strict industrial procedures have been set, which place regulations on paper mills and other industrial emissions. Another prevention technique is the implementation of food contamination monitoring systems. Despite the progress, testing for dioxin is very limited due to the high cost, approximately $1000 for each test.

Both Maine and New Hampshire have taken steps to deal with dioxins. In Maine, my contact was Mr. Barry Mower at the Maine Department of Environmental Protection (MDEP).

According to Mr. Mower, dioxin interest was sparked by EPA's *National Dioxin Study*, which began in 1984 in Michigan because of "dioxin contamination from a Dow Chemical Co. plant in Midland, Mi. making pesticides." The EPA passed, furthermore, a series of "cluster rules," which limited dioxin emissions to 10 parts per quadrillion. In Maine, the EPA selected the Androscoggin River in Gulf Island Pond as a "Tier 7 or clean background site." Further investigations revealed that the Pond had contaminated fish. The sources of dioxin include run-off from erosion and the bleaching process used by paper mills. New guidelines have been written for paper mills to follow to limit dioxin emission.

In Maine, the MDEP employs fish sampling (bio-accumulation factor) of wild fish (e.g. suckers and bass), to test for dioxin levels. This is done because dioxin concentrations build up in fatty tissues of animals, especially fish. An alternate sampling technique used is the SPMD or the Semi-permeable membrane device, which is a gelatinous fish model. The SPMD absorbs non-polar organics, and is used to absorb dioxin from river water. The dioxin measuring technique in Maine is that the caught wild fish are analyzed "for all 17 2378-substituted dioxins and furans within the DMP and for all 12 coplanar PCBs within the SWAT program." DMP stands for the Dioxin Monitoring Program and SWAT represents Surface Water Ambient Toxics Monitoring Program. For a sample to be safe in regards to dioxin, it must meet a Fish Tissue Action Level. The Maine Center for Disease Control's (MCDC) Fish Tissue Action Level (FTAL) for dioxins and coplanar PCBs is 0.4 parts per trillion in fish tissue. FTALs are the "fish tissue concentration that allow a consumption rate of one 8 ounce meal per week for an adult" (Bureau of Health).

For data analysis, means and standard deviations are calculated. Furthermore, an upper 95^{th} confidence limit for TEQs (Dioxin Toxicity equivalents (DTEs) and Coplanar Toxicity

Equivalents (CTEs)) is taken with non-detects (ND) at ½ the detection limit (DL). TEQs with ND = 0 and DL are also calculated. TEQs, described above, stand for the toxic equivalent of TCDD, a dioxin's toxicity measure. The upper 95th confidence limit is "the upper bound below which would be 95% of means of n samples. It is the statistic that the Maine Center for Disease Control and Prevention uses to compare against the Fish Tissue Action Level in setting the Fish Consumption Advisories." The detection limit is the limit of detection of the chemical analysis. Non-detects means that "the value of the chemical analysis was below the detection limit, which does not necessarily mean the value is zero." After the fish is analyzed, the data are collected and entered in a spreadsheet. The spreadsheets usually have file names similar to 07DFC, which stands for dioxins, furans, and coplanar's for 2007 data.

My contact in New Hampshire was Ms. Pamela Schnepper at the Department of Environmental Services (DES). It is possible that, since dioxins are not water soluble, they could settle in the sediment on the bottom of the river. However, this is not easy to prove. An easier way to measure dioxin is to use fish, since they "bio-accumulate in the food chain," according to Ms. Schnepper in an email with me. Currently, the DES laboratories run no tests for dioxin in the Androscoggin. The DES laboratories, in the past, would send their samples to a "contract lab for dioxin analysis." The cost of dioxin fish tissue analysis is approximately $1000 per sample. Nowadays, there is no money for a further dioxin evaluation, although it is greatly needed.

Ms. Schnepper maintains that the DES laboratories work in coordination with the Maine Department of Health and Human Services to develop fish advisories for both general and shared water bodies. Ms. Schnepper has noted that, "The Maine Dioxin Monitoring Program has been measuring dioxin levels in Androscoggin fish for many years." Further Maine information

concerning dioxin can be found at:

http://www.state.me.us/dep/blwq/docmonitoring/dioxin/index.htm

Ms. Schnepper states that today "there is no data to assess the current situation dioxin contamination in the NH Androscoggin fish." In New Hampshire's previous dioxin testing, Fraser Paper was employed. However, "the monitoring conducted in the past by Fraser Paper was not designed for fish consumption health risk evaluation due to sample compositing and inclusion of stocked fish." If future tests would occur, the DES laboratories would follow fish tissue sampling under EPA guidance (EPA rules listed at end of report). What this means is that there is no recently generated data from New Hampshire. Any data reported by them would have had to come from another source. In addition, any old data would have included that obtained from stocked fish whose dioxin levels most likely would be different than wild fish.

Shown below is a Sample Dioxin Advisory: It was sent from Ms. Pamela Schnepper at DES, and is from the 2008 New Hampshire EPA 305b Water Quality Report.

Androscoggin River Advisory due to Dioxin

"Downstream of the paper mill in Berlin, an advisory has been in effect on the Androscoggin River since 1989 due to elevated levels of dioxin found in fish tissue samples taken in 1988. The primary source of dioxin is believed to be the paper mills in Berlin. The advisory recommends that pregnant and nursing women avoid consumption of all fish species. All other consumers are advised to limit consumption of all fish species to one to two, eight ounce meals per year, prepared according to guidelines (DHHS, 1989). In 1994, the paper mill converted its bleaching process to a much cleaner, elemental chlorine free process or ECF. As a result, dioxin measurements in mill discharge have dropped below the minimum detection level.

In accordance with conditions in their federal (NPDES) and state discharge permits, the PPA has conducted numerous fish sampling efforts since 1994. The latest

sampling occurred in 2004. Unfortunately the limited number of composite samples analyzed and the inclusion of stocked fish has resulted in information that is of limited usefulness. Consequently, more fish tissue testing will need to be conducted in the future to determine if the fish advisory can be rescinded."

Shown here is a comparison of fish advisories in the states of Maine and New Hampshire.

A Comparison of Maine and New Hampshire Fish Advisories

Maine		New Hampshire	
Saltwater Fish	Freshwater Fish	Saltwater Fish	Freshwater Fish
Striped Bass and Bluefish – No more than 2 meals per month	Pregnant and nursing women, women who may get pregnant, and children ages 8 and under "should not eat any freshwater fish from Maine's inland waters." The only exception is brook trout and landlocked salmon, of which 1 meal per month is innocuous.	Excellent Choices: catfish, cod, flounder, haddock, herring, salmon, shellfish (lobster) Full list given at - http://www.des.state.nh.us/factsheets/ehp/ard-ehp-25.htm Rules - Pregnant and nursing women, women who may get pregnant and young children can eat two meals per week. For others, there is no limit.	Pregnant and nursing women, and women who might become pregnant, can eat one 8-ounce meal of freshwater fish per month.
Shark, Swordfish, King Mackerel, and Tilefish – pregnant and nursing women, women who might become pregnant, and children below 8 years, should not eat any swordfish or shark. For everyone else, no more than 2 meals per month are allowed.	All other adults and children over 8 years old can eat 2 freshwater fish meals per month. For brook trout and landlocked salmon, 1 meal per week is the limit.	Moderate choices – Halibut, red snapper, tuna steak, and canned white tuna Rules- Pregnant and nursing women, women who may get pregnant and young children may eat one meal per week. For others, there is no limit.	Children under 7 can eat one 4 ounce meal of freshwater fish per month. All other adults and children over 7 can eat four 8-ounce freshwater fish meals per month.
Canned Tuna - pregnant and	Androscoggin River – Gilead to		"No fish should be consumed from the

nursing women, women who might become pregnant, and children below 8 years, can have no more than 1 can of "white" tuna or 2 cans of "light" tuna per week.	Merrymeeting Bay – 6-12 fish meals a year		Androscoggin River from Berlin to the Maine border due to potential dioxin contamination" (NH Fish Guidelines).
All other fish from the ocean, and shellfish - pregnant and nursing women, women who might become pregnant, and children below 8 years, may eat no more than 2 meals per week.	Additional location guidelines found at http://www.state.me.us/dhhs/eohp/fish/2KFCA.htm	Warning – King Mackerel, Swordfish, Shark, Tilefish Rules - Pregnant and nursing women, women who may get pregnant and young children should not eat at any cost. For others, two meals per month.	For bass, pickerel, white perch, or yellow perch, the limit is fish of 12 inches or less in length with the above rules.
Lobster Tomalley – No Consumption. Note – "tomalley is the soft, green substance found in the body cavity of the lobster."			For rainbow and brown trout, women of childbearing years and children can eat one meal per week. For a list of places where women of childbearing age and children cannot eat, while others may eat two meals per month is found at: http://www.des.state.nh.us/factsheets/ehp/ard-ehp-25.htm

In the future, further measures must be enacted by both Maine and New Hampshire to radically cut the amount of dioxin in the Androscoggin River.

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EPA Links: http://www.epa.gov/waterscience/fish/advice/volume1/index.html

http://www.epa.gov/waterscience/fish/advice/volume2/

Acknowledgements

The author would like to thank Ferg P. Lea, Planning Director of the Androscoggin Valley Council of Governments (AVCOG) for giving me this internship and for providing guidance throughout. In addition, the author would like to thank Professor Elizabeth Stemmler of Bowdoin College for her help in revising this report.

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Diagrams

Figure 1 – A Proposed Mechanism of TCDD Toxicity
(From http://www.dioxins.com/images/dioxinsfig1.jpg)

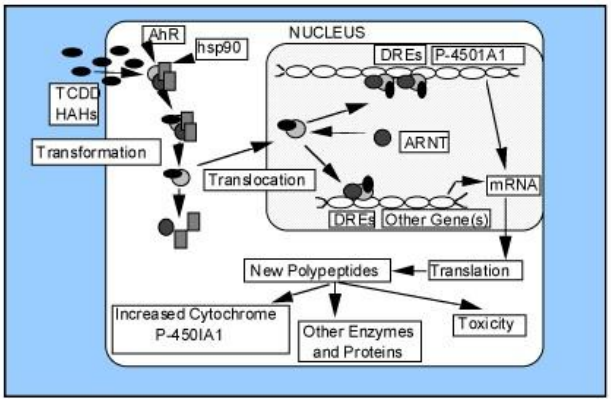

Figure 2 - A heavily illustrated depiction of a TCDD toxicity mechanism
(From Basic Concepts of Environmental Chemistry)

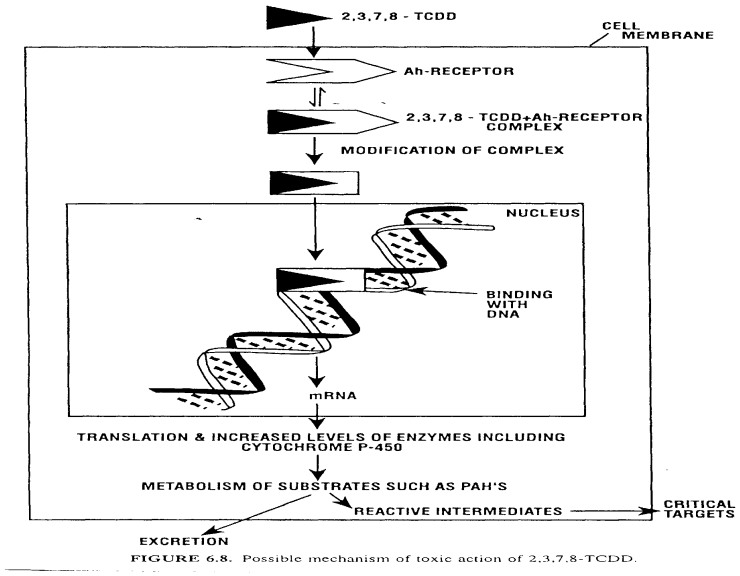

FIGURE 6.8. Possible mechanism of toxic action of 2,3,7,8-TCDD.