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Environmental Health Issues Meet Algebra

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Objectives

The last time you grabbed an apple, rinsed it off and took a bite, did you think about pesticide residues on it? What about the banana or green beans or the bread on your sandwich? If your food was not labeled "Organic" it came to you with pesticide(s) added. In this unit, I want my students to learn about potential health risks from common pesticide products in order to make informed decisions about their use and consider "green" alternatives. In the process of learning about health risks from pesticides, I will interject mathematics. Students will use government-published data to consider their level of exposure to pesticides from multiple sources: ingestion (food or water), inhalation (breathing), and dermal (skin contact). A critical math skill necessary for these calculations is converting units; therefore, the overriding mathematic theme of this unit will be Dimensional Analysis, sometimes referred to as the Factor-Label Method.

I teach at a comprehensive vocational-technical high school where students spend up to one-half of each day in their chosen career area and the remainder of their day in academic classes. The school is a "choice" public school and our students are held to the same academic standards as all public school students in the state. Our math classes are generally grouped heterogeneously and we find a wide range of abilities. Students choose our school for a variety of reasons. Some are focused on what they want to do when they finish high school and use the vo-tech school to get a head start; some have been moderately successful students and are looking for a route to success other than a four-year college, and some are avoiding their "feeder" school. All students ask the question, "Why do I need to learn this?"

By demonstrating that we come in contact with pesticides daily, in places we may not have considered, I think the students will quickly understand why they need to learn this. All of the data published in the government documents is given in metric units, but my students do not have a good sense for the magnitude of metric units. The mathematics in Dimensional Analysis will help them convert to units that are more familiar to them. The skills they learn in this unit will also prove useful in their science classes. While I think parts of this unit are general enough to be used for any high school, or even middle school, math class, I am planning to use it for students in Intermediate Algebra. At my school, it is actually the fourth math course our students take, and it fills in a lot of gaps left by the Integrated Math program that we use. The students are primarily juniors or seniors and many of them will continue their schooling at the local community college. They are beyond the Mathematics high-stakes state test, so interjecting this unit into the course will strengthen their number sense and measurement skills without compromising the curriculum. An added benefit is that our 11 th grade students take the Science state test, and Dimensional Analysis may help with the mathematical part of that.

Background Information

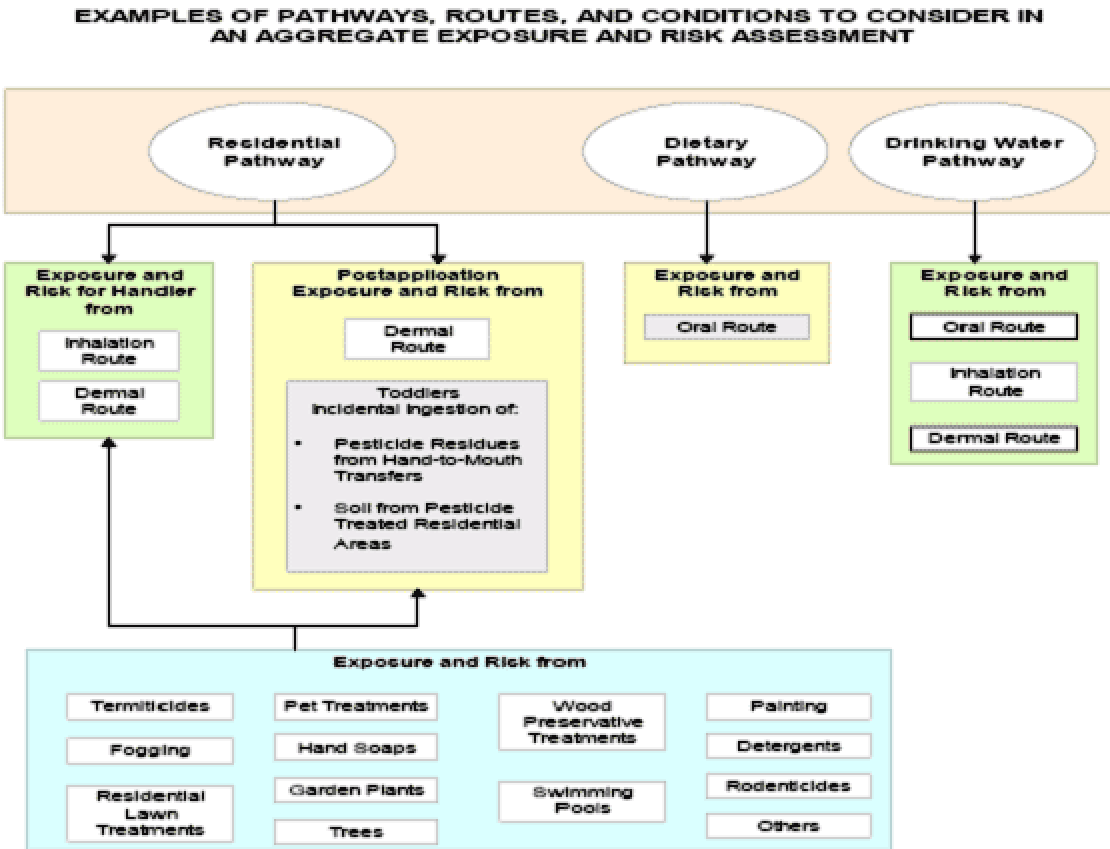
According to the Environmental Protection Agency (EPA) governmental website, the term pesticide covers many categories of substances depending on the type of pest they target, or the method in which they are produced (i.e. chemical pesticides versus biopesticides). Some examples of pesticides that students might recognize (but may not realize fit the category) are algicides (kills algae), defoliants (kills leaves on trees), disinfectants/sanitizers, fungicides (kills fungus), herbicides (kills plants), insecticides, repellents, and rodenticides (kills rodents). [1] Many common household products are pesticides, such as ant and roach killers, bug repellent, flea and tick collars for pets, lawn and garden products, kitchen, bath or laundry cleaning products, and swimming pool chemicals.

Before taking this seminar, "Urban Environmental Quality and Human Health" led by Professor John Wargo, I never thought of all the ways we can be exposed to pesticides. When food crops are sprayed the pesticide settles on the leaves and the "fruit" and also on the ground. That much I knew. But, the application of the pesticide is not really uniform. Depending on the machinery used, the level may be higher at the ends of rows while the tractor/machine is turning, or it may be higher in the center if the pesticide is being applied by airplane. Plus there's overlap of spraying areas, increasing the level applied to some fraction of plants, but sampling methods are not likely to find the differences. Then there's the pesticide that reaches the ground that may be absorbed into the plant, or may eventually seep into the groundwater. Or, the pesticide may get into surface streams or lakes from run-off after heavy rains. All of these exposures could reach humans in one step, but we can also be exposed to some persistent pesticides through the food chain.

We also talked about breathing contaminated air. For example, EPA has limits, called re-entry times (RET), for how quickly farm workers are allowed to return to an area after pesticides have been applied. Not that we know the exact process, but the pesticide would be in the air for some length of time before reaching the ground, plus there could be ongoing evaporation or volatility of some of the pesticide, and all of it can be affected by weather conditions. For a person in the area when a pesticide is applied, there could also be dermal exposure. The pesticide can touch the skin directly, or soak through clothing. And, other people can be exposed by touching someone else's contaminated clothing. [2]

In addition to pesticides applied to farmland, or, on a smaller scale, our lawns and gardens, we use pesticides inside our homes. Again, I had never considered some of the risks we face at home. Our indoor air can be contaminated with the obvious pesticides for killing ants or roaches, or with sanitizers or additives to paint and carpet. If our windows are closed, the contaminants remain and can build up. Children are at a greater risk indoors for several reasons. First, they spend more time indoors than adults. Second, they are closer to the ground where pesticide residues will settle, and they have a natural habit of putting things, including fingers that have potentially touched the residue, in their mouths. Think about a child crawling on a floor after someone walked through after applying weed killer outside. (Fortunately, this kind of exposure can be eliminated easily by leaving work shoes outside!) [3]

As I just described, we can be exposed to pesticides through multiple routes: ingestion (oral), inhalation, or dermal. The EPA sets limits for each of the possible exposure routes for each pesticide it registers. The figure below summarizes the possible routes and sources of pesticide exposure that I descrived. [4] In the figure, "Residential Pathway" refers to pesticides used for lawns, gardens, golf courses, schools, pets, and as common household items.



EPA tolerances (maximum allowable level) for pesticides are set based on a No Observable Adverse Effect Level (NOAEL, or sometimes NOEL). The testing process for determining NOAEL is done with animals, so the scientists must do some extrapolation. First they produce a dose response curve (some measure of response in the animal versus dose of pesticide) and find the benchmark dose that produces a response in 10% of the subjects, called BMD_{10}. The pesticide level (dose) at that point is known as the Point of Departure (PoD), and is used to extrapolate to the human risk. Since extrapolation is merely a prediction of behavior, the PoD is then divided by a safety factor of at least 100, and up to 1000 in an effort to provide a safety margin of exposure (MOE), even a margin great enough for children. [5] As I mentioned earlier, children's exposure to pesticides represents an even greater risk than adults' because of their behavior (crawling, hand-to-mouth). But, children's exposure is also greater because of their size and metabolism. For example, children consume more food, and more of a smaller variety of foods per pound of body weight than adults. In addition, children's respiration rates are higher than adults' accounting for their relative body size. [6]

In 1996 the Food Quality Protection Act (FQPA) tightened some of the regulations for registering pesticides. The law requires a manufacturer to demonstrate General Safety Standards (tighter tolerances for residues on food). It shifted the burden of proof to the manufacturer to demonstrate the safety of registered pesticides. The new law also considered aggregate risk (multiple sources of one chemical) and cumulative risk (multiple chemicals with similar mechanisms), and required review of all pesticide tolerances to ensure they met the new standards by 2006, beginning with the pesticides posing the greatest risk. Probably the most important and far-reaching part of the Act was increasing protection for children. It is because of the FQPA that the safety factor I referred to earlier was increased by another factor of ten, becoming 1000. [7]

In our seminar, "Urban Environmental Quality and Human Health," we discussed several reasons to be wary of tolerances and reported exposures for pesticides. One reason is how sampling is done to test for pesticide residues. For example, only small quantities of food might be tested and found to be pesticide-free while a small (but dangerous) quantity exists that has a high level of toxicity. Or, pieces of food are blended together to determine an average residue level. The average level may be low, but an individual food item could contain pesticide levels with MOE values below 100 for adults, or below 1000 (or an accepted lower value) for children. The percentage of these cases may be low, but even if 0.1% of the US population eats an apple a day, it is still 300,000 potentially poisonous apples! There is even more uncertainty because pesticides are typically mixtures of several chemicals, and, currently, there isn't any testing done to learn about interactive or cumulative effects of multiple chemicals; EPA tolerances are only for individual chemicals. Not only that, but the inert ingredients in a pesticide may also be harmful chemicals, but are not considered in pesticide residue data. [8]

One common class of pesticides, called organophosphates, affects the nervous system of pests, and humans if the exposure level is high enough. While it may not be the best way to determine their toxicity, measuring the cholinesterase enzyme level in blood is the accepted method for measuring exposure to organophosphate pesticides. In the human body, stimulating signals for muscles are carried across synapses in the nervous system by acetylcholine. These stimulating signals are turned off by the enzyme acetylcholinesterase, and this reaction occurs very quickly and often. However, if a person is exposed to a high enough level of an organophosphate pesticide, there will not be enough of the cholinesterase in the synapses and acetylcholine can build up. That means the muscles will remain in a stimulated state, moving uncontrollably, twitching, possibly causing convulsions or paralyzed breathing, and even death. [9] Sometimes the symptoms of organophosphate poisoning are misdiagnosed because they appear similar to flu symptoms.

One of the most commonly used organophosphate pesticides, chlorpyrifos, is a broad-spectrum pesticide. Prior to 2002 it was widely used on many crops, by professional exterminators for indoor and outdoor applications in commercial buildings, schools, daycare centers, hotels, restaurants, hospitals, stores, warehouses, food manufacturing plants and vehicles (cars, trains, airplanes, etc.). It was also used by homeowners to spray for bugs around the house. It is effective at killing many species of bugs, including termites, mosquitoes, ants, ticks, fleas, grubs, and termites. [10] Late in 2001 it was banned for indoor uses and no longer sold to nonprofessional users primarily because of potential harm to young children. It was also banned for use on tomatoes and limited for use on grapes and apples because they are a large percentage of children's diet. [11]

Strategies

I plan to use this unit at the very beginning of the school year/semester. It is a relatively short unit, probably only 3-4 days on a block schedule. I hope it will spark some interest, make my students aware of their environment and some social issues affecting it. I want them to think about alternatives with respect to things they do and things they eat. I also want them to recognize that math applies to other aspects of their lives, not just the math classroom. Dimensional Analysis is not typically taught formally in math classes, but it is a skill that got me through my engineering courses in college! I think that teaching it at the beginning of the course will serve as a good review of previously learned skills and get them thinking mathematically again.

With respect to Delaware state standards, it addresses the content standards of Numeric Reasoning and Quantitative Reasoning, and the process standards of Communication and Connections.

My high school, in accordance with the school district, has instituted a Literacy Initiative for the upcoming school year for all grade levels and all departments in an effort to improve scores on the high-stakes DSTP (Delaware State Testing Program). As the initial part of my unit, I will develop "Before, During, and After" reading activities for daily articles that provide background information about pesticide use. These activities will not only satisfy the district and school Initiative, but also provide connections between mathematics and other disciplines. Also, by starting the school year with a reading assignment, my students will learn right from the start that they will have to read and process their reading, even in math class.

I've referred to Dimensional Analysis, also known as the Factor-Label Method [12] , several times already. It is a method for keeping track of units in calculations, and is particularly useful when working with complicated formulas. If the units come out "right," then the answer is probably right, too. If data is provided in units other than those needed in a formula, it can be converted to appropriate units by Dimensional Analysis. The underlying mathematic principle is the Identity Property of Multiplication, namely that the value of a number does not change if it is multiplied by the number one. From our knowledge of fractions (said with tongue in cheek, since many students are terrified of fractions), if the numerator and denominator of a fraction are equal, then the fraction is equal to the number one (i.e. 5/5=1). So, if we want to convert units, and we know the conversion factor, we make a fraction equal to one by strategically putting one part of the conversion factor on the top of the fraction (units and all) and the other part in the bottom. We multiply or divide units as we would multiply or divide numbers or variables, and look for and "cancel" values of one. For example, to convert 6 inches to centimeters, we need to know a conversion factor such as 1 *in*. = 2.54 *cm*. The calculation, using Dimensional Analysis, is 6*in*x2.54*cm*/1*in*=15.24*cm*. What I meant, above, by "strategically" arranging the conversion factor is that since 2.54*cm*/1*in*=1*in*/2.54*cm*=1 , I chose the fraction so that the units I started with (*in*.) would cancel with the same units in the denominator (*in*./*in*.=1), leaving the desired units *cm* in the numerator. Once we check that the units will work out the way we want, we perform the mathematical operation 6 Â´ 2.54 = 15.24 and attach the remaining units to our result. If the problem were to convert from 10*cm* to inches, we would use the fraction with 1*in.* in the numerator and 2.54*cm* in the denominator (10*cm*x1*in*./2.54*cm*) so that *cm* would cancel and leave only inches as the final units. Then we would compute 6/2.54 = 2.4 because the value 2.54 was in the denominator. This process is also called the Factor-Label Method because you are multiplying (factors) labels and looking at how to set up the equations to cancel the unit labels. It is also possible to do multiple conversions in one calculation. For example, to convert 500*cm* to yards, I would set it up as 500*cm*x1*in*./2.54*cm*x1*ft*./12*in*.x1*yd*./3*ft*. Notice that each fraction is equal to one. (Of course, I could have used 1 *yd.* = 36 *in.* in place of the 2 nd and 3 rd factors in the expression above.) First the *cm* cancel, leaving you with *in.* Then *in.* cancel, leaving you with *ft.*, and finally *ft.* cancel, leaving you with *yd.*, the desired units. When the conversions are set up this way, students can easily see that they need to start with the number 500 and divide it by each of the other numbers. *Warning*: I have seen students try to type the division steps in all at once and do it incorrectly. For example, if they type 500/2.54x12x3, their product will be incorrect because they would be multiplying by the 12 and 3 rather than dividing. Hopefully, writing out the 3 conversion factors as fractions they will recognize that they must divide three times to convert from *cm* to *yd*.

In this unit, pesticide exposures are often given in mg (micrograms, or one-millionth of a gram). Since most students won't have a good feel for metric measurements, I will have them convert to something more familiar: ounces. The most commonly known conversion factor for converting metric mass to English weight units is 1*kg* = 2.2*lb.*, and then 1*lb.* = 16oz. It's also helpful to know the metric prefixes, and 1g = 10 ^{6}*mg.* So, if the maximum residue level is 2.3*mg*, we could set up the calculation with multiple factors, as $2.3\mu g \times \frac{1g}{10^6 \mu g} \times \frac{1kg}{1000g} \times \frac{2.2lb}{1kg} \times \frac{16oz.}{1lb.}$. The *mg*, *g*, *kg*, and *lb.* units will all cancel, leaving *oz.*, as desired. The mathematical calculation is then 2.3/10^6/1000x2.2x16 = 8.1Â´10^-9. I know that this calculation will trigger the additional discussion with my students of what the "E - 9" means on their calculator screens. They have all been exposed to Scientific Notation in previous math and science classes, but it never hurts to reinforce its meaning and purpose.

At this point, another follow-up to the conversion of mg to ounces will be the concept of ppm (parts per million) or ppb (parts per billion). It's another example of Numeric Reasoning. The result above, 8.1Â´10^-9, represents the very small number 0.0000000081, which can be written as the fraction 8.1/1,000,000,000. Since the denominator is the number 1 billion, 8.1Â´10^-9 is equal to 8.1 ppb. When I have students working with very large or very small numbers like these, I like to help them put them into perspective. So, once again, I will integrate a Literacy strategy of reading aloud to students, interjecting comments as I read. One children's book that I like, *How Much is a Million*, by David Schwartz, actually states the assumptions used make the analogies for millions and billions of items, so my students can practice Dimensional Analysis computations to confirm the calculations in the book.

Now that the students have regained their math skills, it's time to return to the topic of pesticides. I want students to consider how they are exposed to pesticides, and at what level. I want them to consider their diet, as well as their actions (indoor/outdoor activities, use of pesticides indoors/outdoors, etc.) There are several documents published by the U.S. Government that I will make available on the school computer network's public drive to have students calculate exposure levels to pesticides. First is the EPA's *Child-Specific Exposure Factors Handbook (Interim Report)*, and second is the USDA's *Pesticide Data Program Annual Summary, Calendar Year 2006*. I will also upload several files with chlorpyrifos exposure data that was submitted to EPA for reregistration of the pesticide.

The 1996 FQPA forced more government groups to focus on potential risks to children. The *Child-Specific Exposure Factors Handbook* has data extracted from the full EPA *Exposure Factors Handbook* for adults and children. The child-specific factors include factors that affect children from birth through age 19 years, just perfect for high school students. All routes of pesticide exposure are considered, beginning with ingestion of food and water. There are separate chapters devoted to Breast Milk Intake, Food Intake broken down into categories such as vegetables, grains, fruits, milk, and meat/fish. The chapter on Drinking Water Intake includes direct and indirect (added during food preparation) water use. The handbook even provides data for amounts of Soil Ingestion and Nondietary Ingestion (primarily from hand-to-mouth action by young children). The second type of exposure considered is Inhalation Routes (varies with activity level), and finally Dermal Routes, taking into account the surface area of young children versus older ones. The chapter entitled Activity Factors may apply to any of the three exposure routes. Each chapter describes the studies that produced the data and even states a low, medium or high confidence level for the data provided. Fortunately, the data is presented in a multitude of tables, and you can find a list of tables early in the document.

The *Pesticide Data Program Annual Summary, Calendar Year 2006* gives numerical values for pesticide residues on foods and in water. The data covers fruits and vegetables, peanut butter, wheat, poultry, and bottled and municipal drinking water. It also gives information about foods that have multiple pesticides and/or residues. I learned that there can be more than one residue for a single pesticide if it metabolizes or degrades into a different chemical compound. The narrative of the report explains the sampling and laboratory methods used. But, the most useful data in the summary report for this unit is the levels of specific pesticides on specific foods, which is compared directly to the EPA tolerance levels in the same table. I want my students to spend some time with some of the data tables and the narrative that explains how the numbers were derived. This kind of activity is another one of those skills that we don't typically teach directly. But, here is a perfect opportunity for students to experience some real data that applies to them. In addition, interpreting tables and graphs is part of the state standards in all content areas. By preparing a set of questions, I will again satisfy our literacy Initiative and ensure that my students understand the data. I also hope it will generate some excited and constructive discussion in the classroom.

Another significant document in the study of pesticides is the 2006 Update of the *Organophosphate Cumulative Risk Assessment* published by the EPA. It combines pesticide exposures from a variety of sources and exposure routes for varying age groups (young children, again, being of primary concern because of the FQPA) to make sure overall exposure levels for each pesticide meet the EPA tolerances. This Cumulative Risk Assessment relied on the data from the USDA Pesticide Data Project described above. It is an enormous document full of a lot of statistical justification for the pesticide levels that are stated. However, by plodding through it, I found some items that I would want to share with my students. For example, pest strips and flea collars contribute a large piece of the inhalation exposure route for pesticides in residential scenarios because they continually release the pesticide until it's gone after several months. [13] The document also lists the foods consumed by different age groups in decreasing order of consumption. It also states the foods in the top 0.2% for organophosphate residue. In other words, these foods (snap beans, watermelon, and tomatoes are the top three) have more residue than 99.8% of all foods. [14] Something else that I learned from this document is a long list of acronyms (I suggest you keep a running list if you decide to attack the document), which I have included in Appendix B. And, my big "Ah-hah" after several days at it was that in order to add all types of pesticide exposures together (multiple chemicals with different toxicity levels plus multiple exposure routes), you have to make the data compatible. It's kind of like finding a common denominator before adding fractions. In the pesticide world, you need to find relative toxicity. EPA has a way to do this: they find a Relative Potency Factor (RPF) based on one pesticide that they have a sufficient amount of data for. Then, all other pesticides are compared by ratio to the reference one. Doing the comparisons and interpreting the data is another potential mathematics exercise for students. Also, there are some exponential equations that appear for modeling the effect of different organophosphates on cholinesterase activity. These equations, along with half-life information, could be used in upper level math courses in the study of logarithms.

Now it's time to blend pesticide data with Dimensional Analysis. To keep things relatively simple for this unit, I will focus on EPA data and tolerances for chlorpyrifos, although, I will encourage my students to research EPA data for some other pesticides that they may be familiar with and for alternatives that pose less risk. Going back to the question about the pesticide residue on an apple from the opening of this unit, I will demonstrate how to calculate the amount of residue on an apple as if it had the maximum ("worst-case") reported level of chlorpyrifos and compare it to the corresponding EPA tolerance level. The maximum reported chlorpyrifos residue on an apple was 0.4 ppm. [15] Hopefully I will be able to procure a balance from the science department so we can find the mass of the apple in front of them. If not, we'll estimate that a medium-sized apple has a mass of approximately 150g. Then the mass of chlorpyrifos of 0.4 ppm by weight would be 0.4/1,000,000x150*g*=60*g*/1,000,000, or 6Â´10^-5g. This small number could be converted to milligrams by 6x10^-5*g*x1000*mg*/1*g*=0.06*mg*, and could have been done all in one equation. The EPA tolerance for acute exposure to chlorpyrifos is 0.0017 mg/kg-day. [16] The units mg/kg-day means milligrams of chlorpyrifos per kilogram of body weight per day. Therefore, students need to determine their own body weight in kilograms, using the conversion factor for pounds to kg given above. A petite student that weighs 110*lb.* would have a mass of 110*lb*.x1*kg*/2.2*lb*.=50*kg*. This student's tolerance level for chlorpyrifos exposure for one day would then be 0.0017*mg*/*kg*/*day*x50*kg*x1*day*=0.085*mg*. Since the residue level on the apple (0.06mg) is less than the tolerance level (0.085mg) for this person, the apple should not pose a risk. I would have all students calculate their own exposure tolerance for chlorpyrifos and compare their results to others'. This comparison should help them understand why young children are at a greater risk of pesticide exposure than adults, especially if I have the largest and smallest student in the class stand side by side and report their exposure limits!

Sample inhalation and dermal exposure calculations for dog collars containing chlorpyrifos, based on EPA data from the "Residential" file are next. Adults' inhalation and dermal exposures are reported as 0.74 mg/kg body wt./day and 0.045 mg/kg body wt./day, respectively. [17] For a male high school student (we're assuming he fits the adult category) that weighs 145 pounds and spends 3 hours a day in the same room with his dog, his inhalation exposure would be calculated as $\frac{0.74\mu g}{kg-day}\times 145lb.\times\frac{1kg}{2.2lb.}\times 3hr\times\frac{1day}{24hr}=6.1\mu g$. If the same student spent 20 minutes a day petting his dog, his dermal exposure would be $\frac{0.045\mu g}{kg-day}\times 145lb.\times\frac{1kg}{2.2lb.}\times 20\min\times\frac{1hr}{60\min}\times\frac{1day}{24hr}=0.041\mu g$. The maximum exposure limit for a 145 *lb.* student would be $\frac{0.0017mg}{kg-day}\times 145lb.\times\frac{1kg}{2.2lb.}=\frac{0.11mg}{day}\times\frac{1000\mu g}{mg}=\frac{110\mu g}{day}$. Combining the inhalation and dermal exposure to the student's dog in one day (6.1*mg* + 0.041*mg* = 6.1041*mg*), he is well below the limit for chlorpyrifos exposure (110*mg*). And again, I would reinforce the differences in the exposure numbers for the largest and smallest student in the classroom.

These are basic examples of using ingestion, inhalation and dermal exposure data to estimate the risk of exposure to chlorpyrifos. There are a multitude of computations that can be done with the information provided in governmental publications and other online resources. For example, Geometry topics, such as surface area and volume, can be embedded in the calculations. Science topics, such as density and concentration, can be included. In addition to the Mathematics topic of logarithms I mentioned earlier, this data could also be used in Statistics units. Refer to the lesson plans in the Classroom Activities section, and Problem Sets in the Appendix for additional resources for mathematical calculations relating to pesticide exposure.

Classroom Activities

Lesson 1 - Introduction to Pesticide Residue on Common Foods

The "hook" into this unit will be the question I posed at the beginning of the narrative about pesticide residues on apples, bananas, green beans, and bread. I will lead the class through the calculation for the "worst-case" chlorpyrifos residue on an apple. Following that example, I will give a more formal lesson on converting units by Dimensional Analysis. Students will then calculate their own weights in *oz*, *kg*, *g*, *mg*, and heights in *cm*, *m*, *km* and *yd*. If time permits, I will have them estimate and then calculate how many seconds they have been alive (it's always interesting to see their reactions to their misperceptions!). Next, to reinforce the concepts of pesticide residues and converting units, I will have the students work in groups to estimate the "worst-case" pesticide levels on a variety of foods that I supply. (Note: If it were not the first day of a new semester, I would ask students to bring in fruits and/or vegetables themselves.) I will either display or hand out printed copies of data from Appendix J of the *USDA Pesticide Data Program*, which gives a list of commodities and the pesticide residues (in ppm) that have been found on them. Each group will be assigned a different food commodity. They will determine the mass of the food supplied, and each student in the group will calculate the residue from a different pesticide in milligrams and also in ounces using the maximum level reported. To extend this lesson, I would have students go to the EPA website to find tolerances for the different pesticides they just used in their calculations, and do the calculation that I demonstrated for daily maximum allowable residue levels based on body weight, and compare the results.

To conclude this first lesson, I will give a brief history of pesticides, especially the use of DDT during WWII, so students can consider the benefits versus the risks of pesticide use. I found an article in a 1971 issue of *American Heritage Magazine* for this purpose. (Refer to the Teacher Resources section at the end of this unit.)

Lesson 2 - Routes of Pesticide Exposure

The "Warm-up" Activity for this lesson will be an extended Reading Activity. I selected an excerpt from John Wargo's book, *Our Children's Toxic Legacy*. As a pre-reading activity, I will ask the class to list all of the pesticides they can think of, and compile the list on the board. Next, I will ask them how they come in contact with each of these pesticides, and write their responses on the board, as well. Finally, before they read the excerpt, I will ask them to (silently) consider their own definition of the word pesticide and whether or not it changes as they read. I prepared a graphic organizer to accompany the reading with some headings already filled in and spaces for students to fill in as they read. The graphic organizer is in Appendix D. After students finish the reading, I will review the information they filled in and elaborate as needed. I want to be sure that they recognize that the word pesticide covers a broad span of products from herbicides to insecticides to disinfectants. Finally, before moving on to "Math," I will ask students to write two or three sentences on the back of the graphic organizer about what they learned from the reading, and if there are any changes they plan to make at home or at school because of what they read.

The Math for this lesson will cover all three pesticide exposure routes. I showed the oral/ingestion route in Lesson 1, so my examples for this lesson will only illustrate inhalation and dermal routes of exposure. I will use the pet collar example given in the narrative above. The problem set I developed is in Appendix E. Problems cover the topics of drinking water, aerosol bug killer, turf weed killer, and food residues. Questions ask for concentration, maximum mass of pesticide allowed, or mass of pesticide detected. All problems require students to consider the units associated with the data provided and figure out how to answer the question, in terms of the units specified. Hopefully they will see how Dimensional Analysis helps them in the process.

Lesson 3 - Interpreting Tables and Graphs

I have another Reading Activity as a Warm-up for this lesson. It's a local newspaper article about families using natural cleaning products in their homes. My introductory questions would be about what products students use to clean their homes, and whether anyone uses common household products like vinegar or baking soda. This article is simpler than the previous one, so I will just ask students to split their paper into three columns. The three headings are "Green Cleaning Examples," "Pros," and "Cons" and students will fill in the columns as they read. Again, I will ask students to write a sentence or two on the back about what they learned and any changes they might make because of what they read.

I selected pieces from governmental documents for students to get a glimpse of the type of reports that are generated by the EPA, and to practice interpreting graphs and tables. The first table, in Appendix F, compares residue levels for three foods, both fresh and dried. I ask students to compare the residue levels and make some generalizations.

Appendix G has a table of Relative Potency Factors for a list of chemicals for all three exposure routes, where applicable. All factors are ratios relative to the chemical Methamidophos, but I want my students to figure that out for themselves; the factor for Methamidophos equals one for each exposure route because the numerator and denominator are the same value (it's being compared to itself). Questions based on the table are also available in the Appendix. The third piece, in Appendix H, is a written explanation plus two graphs that show data for three exposure routes for pest strips and flea collars. Again, I wrote some questions to go with the reading and graphs to check for understanding.

There is certainly a lot more that can be done to teach students about pesticides in their environment, but my goal here is to use the topic as a means to get my students thinking about math at the start of the semester. To conclude this brief unit with an assessment, I will ask the students to keep a food diary for several days. Then, I will provide a table of Chlorpyrifos residue values for them to estimate their total ingestion during that period, and scale it up to estimate the amount they would ingest in a year.

Appendix A - Implementing District Standards

Our district standards align with state standards, so the following is a list of State of Delaware Mathematics Standards that are addressed by this unit.

Content Standard 1 - Numeric Reasoning: Students will develop Numeric Reasoning and an understanding of *Number and Operations* by solving problems in which there is a need to represent and model real numbers verbally, physically, and symbolically; to explain the relationship between numbers; to determine the relative magnitude of real numbers; to use operations with understanding; and to select appropriate methods of calculations from among mental math, paper-and-pencil, calculators, or computers.

Content Standard 4 - Quantitative Reasoning: Students will develop Quantitative Reasoning and an understanding of Data Analysis and Probability by solving problems in which there is a need to collect, appropriately represent, and interpret data; to make inferences or predictions and to present convincing arguments; and to model mathematical situations to determine the probability.

Process Standard 7 - Communication: Students will develop their mathematical Communication ability by solving problems in which there is a need to obtain information from the real world through reading, listening and observing; to translate this information into mathematical language and symbols; to process this information mathematically; and to present results in written, oral, and visual formats. All students in grades K-12 will be able to:

- Organize and consolidate their mathematical thinking through communication
- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others
- Analyze and evaluate the mathematical thinking and strategies of others
- Use the language of mathematics to express mathematical ideas precisely.

Process Standard 8 - Connections: Students will develop mathematical Connections by solving problems in which there is a need to view mathematics as an integrated whole and to integrate mathematics with other disciplines, while allowing the flexibility to approach problems, from within and outside mathematics, in a variety of ways. All students in grades K-12 will be able to:

- Recognize and use connections among mathematical ideas
- Understand how mathematical ideas interconnect and build on one another to produce a coherent whole
- Recognize and apply mathematics in contexts outside of mathematics.

Appendix B - Glossary of Acronyms

ADD - Average Daily Dose

BMD_{10} - Benchmark Dose that produced a response in 10% of the subjects

EPA - Environmental Protection Agency

FDA - Food and Drug Administration

FQPA - Food Quality and Protection Act (1996)

LOAEL - Lowest Observed Adverse Effect Level

LOD - Limit of Detection

MCL - Maximum Contaminant Level

MOE - Margin of Exposure (safety factor between human total exposure and the BMD_{10} from animal studies; accepted MOE is greater than 100 for adults, and generally greater than 1000 for children)

MRL - Maximum Residue Level

NOAEL - No Observed Adverse Effect Level

PDP - Pesticide Data Program (USDA)

PoD - Point of Departure (used to extrapolate for estimate of human risk)

ppb - parts per billion

ppm - parts per million

RET - Re-entry Time (minimum amount of time after pesticide application before re-entry without protective equipment)

RPF - Relative Potency Factor

USDA - United States Department of Agriculture

Appendix C - Useful Conversion Factors

1 kilogram (kg) = 1000 grams (g)

1 g = 1000 milligrams (mg) = 1,000,000 micrograms (mg)

1 fluid ounce = 30 milliliters (mL)

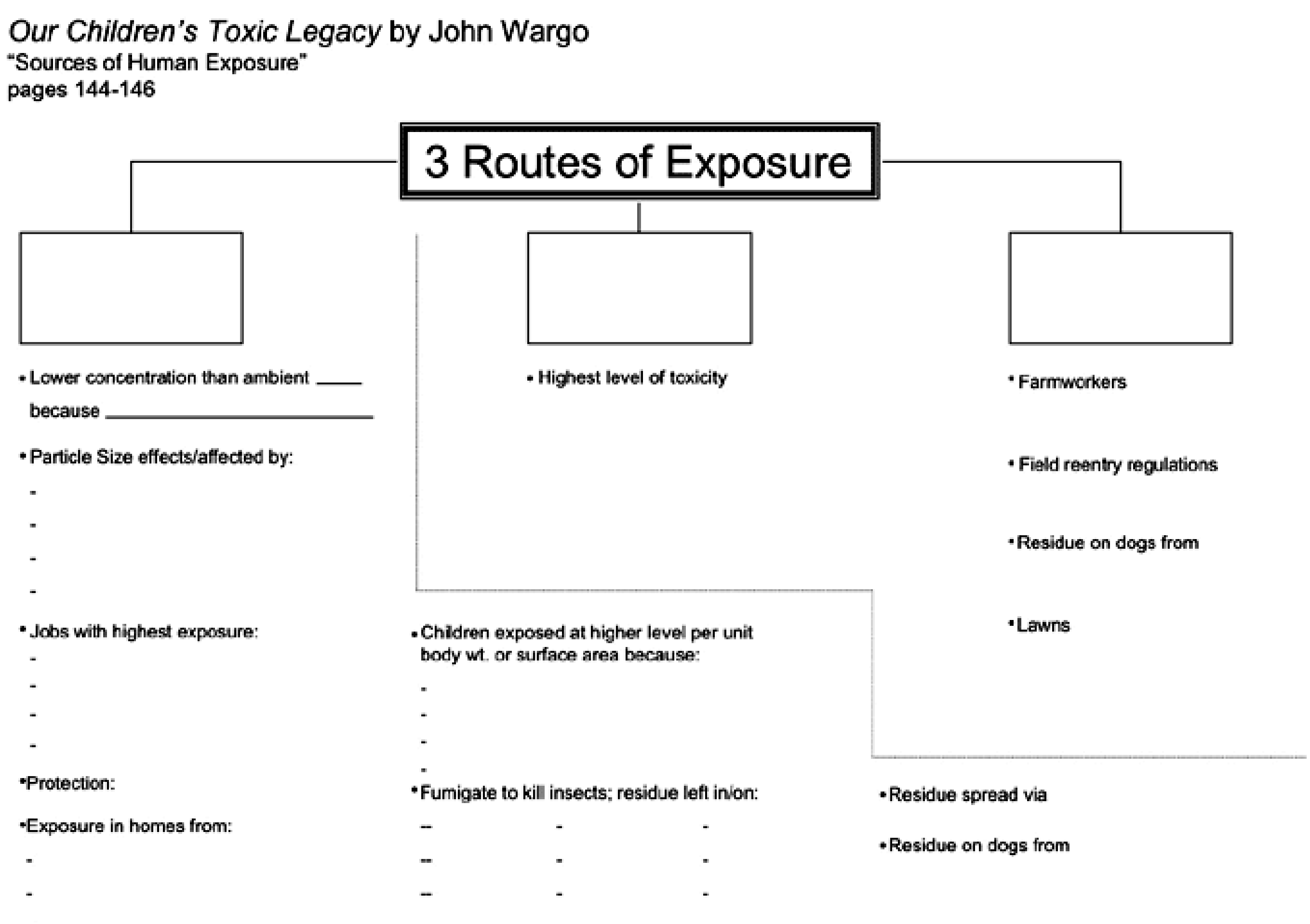
1 pound (lb.) = 16 ounces (oz.)

1 kg = 2.2 lb

1 inch (in.) = 2.54 centimeters (cm)

1 meter (m) = 100 cm

Appendix D - Graphic Organizer for Sources of Human Exposure



Appendix E - Pesticides Problem Set

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1. Complete the table. Show your work in the last column.

FOOD	Weight of sample	Mass of residue (mg or Âµg)	Concentration of residue (ppm or ppb)	Calculation set-up (show your work)
Cherries	2.25 lb.	0.26mg		
Orange Juice	8.1 oz.	0.575Âµg		
Potato	10 oz.	6.81Âµg		
Peanuts	0.75 lb.	0.051Âµg		
Grapes	1.75 lb.		0.44 ppm	
Tomatoes	14 oz.		0.31 ppm	

2. On average, 15-19 year olds consume tap water at a rate of 12mL/kg of body weight per day. This includes water that you drink and water that you add when preparing food.

Estimate how much you consume in a typical day:

a. How many ounces of water do you consume in a day?
b. If 1 liquid ounce = 30 mL, how many mL do you consume in a day?
c. What is your mass in kg?
d. For your body weight, do you consume more or less water than the mean/average? *Show your work.*
e. Water Intake for 15-19 year olds

percentile	25^{th}	50^{th}	75^{th}	90^{th}	95^{th}	99^{th}
mL/kg-day	3	9	16	25	32	61

e. Which (approximate) percentile does your water intake fit into?

3. According to EPA, the maximum contaminant level for the pesticide Atrazine in water is 3 ppb. Using your water consumption from #2, and the fact that the density of water is 1.0 g/mL, what is the maximum number of grams of Atrazine allowable in your water? (FYI: The maximum level reported is 1838 ppt.) S*how your work.*

4. Assume the concentration from a spray aerosol bug killer used in your basement is 0.61mg/m ^{3} . If you were sitting on the couch watching TV, you would inhale at a rate of 0.4m ^{3} /hr. If you moved a little, playing Wii, you might inhale at a rate of 1.2m ^{3} /hr. If you ran on the treadmill, you might inhale at a rate of 1.9m ^{3} /hr. How much bug killer would you inhale for each of the following activities?

a. watching TV for 3 hours
b. playing Wii games for 1.5 hours
c. running on the treadmill for 40 minutes

5. Assume the bug killer in #5 contains 0.5% active ingredient. If the inhalation limit for the active ingredient is 0.1mg/m ^{3} , what is the maximum amount of bug killer that can be sprayed for the following activities? *Show your work.*

a. watching TV for 2.5 hours
b. playing Wii games for 45 minutes
c. running on the treadmill for 15 minutes

6. Suppose the school athletic fields were sprayed with pesticide containing Chlorpyrifos just before practice. Athletes inhale approximately 1.9m^3/hr, and the maximum allowable concentration for Chlorpyrifos inhalation is 0.1mg/m^3. What is the maximum level of Chlorpyrifos that should be inhaled by the athletes during a 1.5 hour practice on the fields? *Show your work.*

7. Suppose the same fields were sprayed at a rate of 23 mg/cm^2. Estimate the surface area of your hands, arms, or other exposed area, in cm^2, to determine your dermal exposure to the pesticide if you fell on the grass. *Show your work.*

Appendix F - Interpreting Tables and Graphs, 1 [18]

Pesticide	APPLES -- Fresh (2005) % of Samples with Detects	Minimum Value Detected, ppm	Maximum Value Detected, ppm	APPLE SAUCE (2006) % of Samples with Detects	Minimum Value Detected, ppm	Maximum Value Detected, ppm
Acetamiprid	70.0	0.001	0.13	51.5	0.001	0.031
Carbaryl	7.1	0.0005	0.32	22.2	0.0005	0.23
Carbendazim	20.8	0.0002	0.16	82.6	0.0005	0.04
Diphenylamine	82.9	0.0048	2.9	30.2	0.0048	0.16
Imidacloprid	26.6	0.0002	0.015	17.5	0.0002	0.0027
Phosmet	19.4	0.008	0.28	1.7	0.008	0.008
Thiabendazole	88.0	0.0002	7.0	38.8	0.0002	1.2
Thiacloprid	3.0	0.003	0.018	12.8	0.0007	0.0062
	GRAPES -- Fresh (2005)			RAISINS (2006)		
Captan	16.8	0.0125	1.2	0.5	0.040	0.040
Chlorpyrifos	12.4	0.0063	0.19	0.8	0.007	0.022
Cyprodinil	26.8	0.0079	1.4	1.9	0.027	0.41
Fludioxonil	13.7	0.011	0.5	0.3	0.13	0.13
Imidacloprid	18.1	0.01	0.47	0.9	0.066	0.066
Iprodione	16.1	0.025	1.6	0.8	0.025	1.3
Myclobutanil	15.8	0.033	0.35	1.3	0.053	0.067
Propargite	0	0	0	31.5	0.0058	1.2
	PLUMS -- Fresh (2006)			PLUMS -- Dried (2006)		
Chlorpyrifos	17.1	0.005	0.18	0	0	0
Fludioxonil	18.8	0.18	1.8	0	0	0
Iprodione	36.3	0.065	6.9	0.4	0.36	0.36
Phosmet	15.5	0.005	0.18	1.8	0.005	0.16

Table 4. Selected Residue Comparisons for Fresh and Processed Commodities. *The percentage of samples with detections and the range of reported values for selected pesticides recovered from fresh vs. processed apples, grapes, and plums are shown. Commodity/residue pairs were selected based on the following criteria: data availability for fresh and processed product within the same sampling timeframe; greater than 10% detection rate for a residue in either the fresh or processed commodity; and number of samples analyzed sufficient to ensure adequate representation.*

1. In general, which type of food contains more pesticide residue, fresh or processed? What information did you use to answer this question?

2. In general, what happens to the minimum pesticide value detected in grapes and plums when they are dried?

3. In general, what happens to the maximum pesticide value detected in fresh versus processed fruit?

Appendix G - Interpreting Tables and Graphs, 2 [19]

Table I.B-5 Relative Potency Factors for Oral, Dermal, and Inhalation routes.

Relative Potency Factors for Female Brain Cholinesterase Activity			
Chemicals	Oral	Dermal	Inhalation
Acephate	0.08	0.0025	0.208
Azinphos-methyl	0.10		
Bensulide	0.003	0.0015	
Chlorethoxyfos	0.13		
Chlorpyrifos	0.06		
Chlorpyrifos-methyl	0.005		
Diazinon	0.01		
DDVP	0.03		0.677
Dicrotophos	1.91		
Dimethoate	0.32		
Disulfoton	1.26	0.47	6.596
Ethoprop	0.06		
Fenamiphos	0.04	1.5	0.315
Fenthion	0.33	0.015	
Fosthiazate	0.07		
Malathion	0.0003	0.015	0.003
Methamidophos	1.00	1.00	1.00
Methidathion	0.32		
Methyl-parathion	0.12		
Mevinphos	0.76		
Naled	0.08	0.075	0.82
Omethoate	0.93		
Oxydemeton-methyl	0.86		
Phorate	0.39		
Phosalone	0.01		
Phosmet	0.02		
Phostebupirim	0.22		
Pirimiphos-methyl	0.04		
Profenofos	0.004		
Terbufos	0.85		
Tetrachlorvinphos	0.001	0.00075	
Tribufos	0.02		
Trichlorfon	0.003	0.0075	0.087

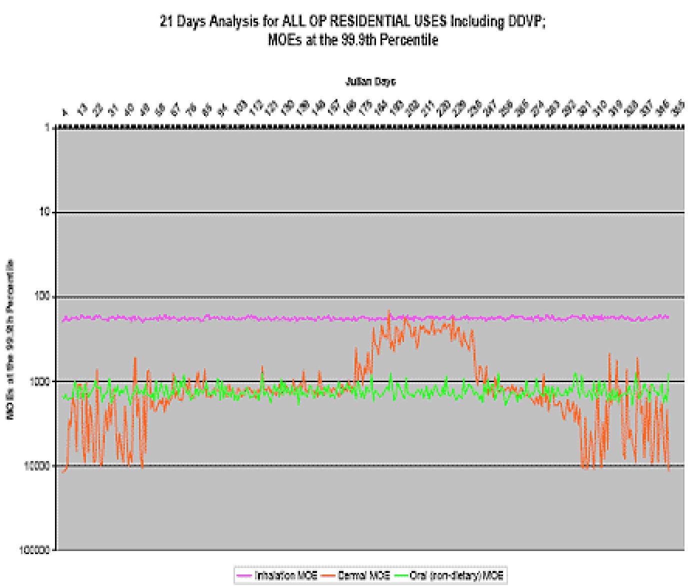
A Relative Potency Factor (RPF) is the ratio of a measurable effect for two pesticides. For organophosphates, the measurable effect is the amount (dose) needed to see an adverse neurological effect (BMD, benchmark dose). All pesticides in the table are compared to the same pesticide (i.e. the dose used in the denominator of each ratio is always the same).

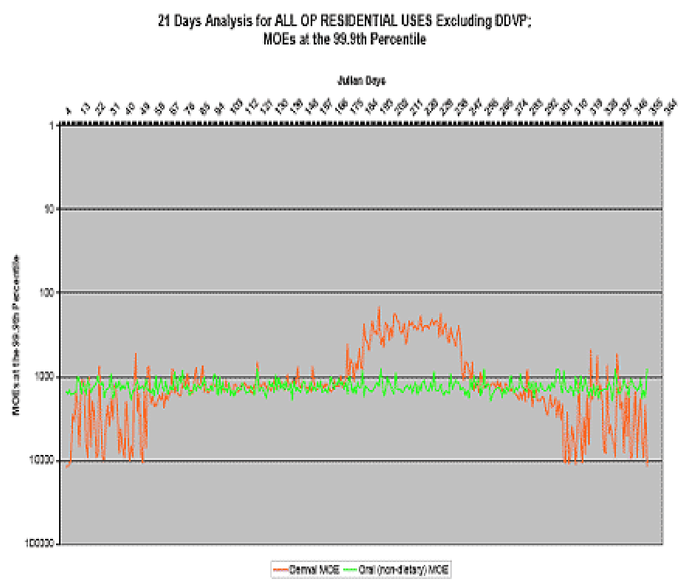
1. Which pesticide in the table is the Reference chemical (all other chemicals are compared to it)? *How do you know?*
2. Which pesticide in the table shows the greatest risk for oral exposure? *How do you know?*
3. Which pesticide in the table shows the least risk for dermal exposure? *How do you know?*
4. Which pesticide in the table shows the greatest risk for inhalation? *How do you know?*
5. Which pesticide in the table shows the greatest risk for dermal exposure? *How do you know?*
6. Which pesticide in the table shows the least risk for oral exposure? *How do you know?*
7. Compare Chlorpyrifos to Trichlorfon. Which one is more potent? How much more? *Show your work.*

Appendix H - Interpreting Tables and Graphs, 3

Excerpt (with clarification added) from EPA's "*Organophosphorus Cumulative Risk Assessment - 2006 Update,* p. 98-100.

The results for children 1-2 years old indicate that incidental oral MOEs are not of concern. Additionally, dermal MOEs are well above the level of concern (above 1000) for most of the year. However, a portion of the summer months (days 186 through 243), MOEs go down to approximately 150. Further analysis has determined that these MOEs are the result of trichlorfon lawn exposure. This decrease in MOEs is attributed to the application pattern information for the trichlorfon lawn scenarios. Lawn applications of trichlorfon are expected to occur in the summer months to treat lawn pests, such as grubs, webworms, billbugs, mole crickets and chinch bugs. The inhalation MOEs are consistently the lowest and therefore present the greatest risk. By removing DDVP from the residential assessment, OPP (EPA's Office of Pesticide Programs) determined that the inhalation MOEs result entirely from exposure from the DDVP indoor uses. This is illustrated in the figures below: when all DDVP use is removed from the assessment, no inhalation risks are apparent. Residential inhalation exposure primarily results from indoor post-application exposure to DDVP pest strip and pet collars. Indoor exposure to DDVP pest strips and pet collars is continuous for the effective life of the product (up to 16 weeks). DDVP pest strips and pet collars are constantly emitting sources that dissipate over the duration of use. [20]





1. Why is there no Inhalation line on the second graph?
2. What is the reason that the dermal MOE decreases (look at scales carefully) around day 175?

Resources for teachers

These resources, along with the explanations in the governmental resources listed below, provide background information for understanding exposures to pesticides, including sampling and determination of tolerances.

Davis, Kenneth S. *AmericanHeritage.com* "THE DEADLY DUST: The Unhappy History

of DDT." February 1971, Volume 22, Issue 2.

http://www.americanheritage.com/articles/magazine/ah/1971/2/1971_2_44.shtml

A complete history of DDT to illustrate concurrent benefits and risks of pesticides.

Dow AgroSciences, *Turf & Ornamental*. 2008.

http://www.dowagro.com/turf/prod/dursban.htm (accessed July 11, 2008).

EXTOXNET. *Extension Toxicology Network-Toxicology Information Briefs*.

1993. http://extoxnet.orst.edu/tibs/cholines.htm (accessed July 9, 2008).

U.S. Environmental Protection Agency. 2008. *About Pesticides*.

http://www.epa.gov/opp00001/about/ (accessed July 11, 2008).

—. Office of Inspector General. *Opportunities to Improve Data Quality & Children's*

Health through the Food Quality Protection Act. *Evaluation Report No. 2006-P-*

00009, by Jerri Dorsey, Alice Fong, Montira Pongsiri.

http://www.epa.gov/oig/reports/2006/20060110-2006-P-00009.pdf, (accessed July 15,

2008).

Wargo,John. *Green Intelligence.* New Haven: Yale University Press, 2008.

Great overview of many environmental health issues; includes a chapter on pesticides.

—. *Our Children's Toxic Legacy.* 2 nd ed. New Haven: Yale University Press, 1998.

Excellent resource dealing with pesticide exposure from all sources, and why young children are at a greater risk. Also chapters on changing laws regarding pesticides.

Math Skills Review. *Dimensional Analysis*.

http://www.chem.tamu.edu/class/fyp/mathrev/mr-da.html (accessed July 11, 2008).

Gives a concise definition with examples for Dimensional Analysis.

Schwartz, David M. *How Much Is a Million?* New York: Lee & Shepard Books, 1985.

Children's book that gives visuals for millions, billions and trillions, plus assumptions for their estimates.

Governmental Sources for Pesticide Data

These sources contain data that I plan to make accessible/available to students. They are described in more detail in the Strategies section of this unit.

Code of Federal Regulations (CFR). http://www.gpoaccess.gov/CFR/INDEX.HTML

To find tolerances for pesticides used for foods, click Browse and/or search the CFR: Title 40-Protection of the Environment, then Part 180. Part #180.342 is Chlorpyrifos, but data for comparisons of other pesticides is available, also.

U.S. Department of Agriculture. Agricultural Marketing Service. *Pesticide Data*

Program Annual Summary, Calendar Year 2006.

http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5064786,

(accessed July 14, 2008).

U.S. Environmental Protection Agency. Office of Research and Development, National

Center for Environmental Assessment. *Child-Specific Exposure Factors Handbook*

(Interim Report) 2002. EPA-600-P-00-002B.

http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=55145 (accessed July 25, 2008).

—. Office of Pesticide Programs *US EPA Chlorpyrifos: Occupational/Residential*

Handler & Postapplication Residential Risk Assessment, 2007 on DVD (EPA-HQ-

OPP-2007-0151-0006). For pesticide residue data, request special docket for risk

assessment DVD (EPA-HQ-OPP-2007-0151-0006) from Anthia Peters at

peters.anthiaepa.gov.

—. Office of Pesticide Programs *US EPA Chlorpyrifos: Revised Acute Dietary Risk*

Assessment, 2007 on DVD (EPA-HQ-OPP-2007-0151-0006).

—. Office of Pesticide Programs. *Organophosphorus Cumulative Risk Assessment-2006*

Update.

http://www.epa.gov/pesticides/cumulative/2006-op/op_cra_appendices_part1.pdf,

(accessed July 11, 2008).

Endnotes

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1. U.S. Environmental Protection Agency, *About Pesticides*.

2. Wargo, *Our Children's Toxic Legacy*, 306

3. Ibid., 307.

4. U. S. Environmental Protection Agency. Office of Inspector General. *Opportunities to Improve Data Quality & Children's Health through the Food Quality Protection Act,* 8.

5. Wargo, 263.

6. U. S. Environmental Protection Agency. Office of Inspector General, 16.

7. John Wargo, *Green Intelligence,* Ch. 13.

8. Wargo, *Our Children's Toxic Legacy,* 265.

9. EXTONET. *Extension Toxicology Network-Toxicology Information Briefs*.

10. U. S. Environmental Protection Agency. *US EPA Chlorpyrifos: Occupational/Residential Handler & Postapplication Residential Risk Assessment.*

11. Wargo, *Green Intelligence,* Ch. 13.

12. Math Skills Review. *Dimensional Analysis*.

13. U.S. Environmental Protection Agency. Office of Pesticide Programs. *Organophosphorus Cumulative Risk Assessment-2006 Update*, 98.

14. Ibid., 84.

15. U. S. Environmental Protection Agency. *US EPA Chlorpyrifos: Revised Acute Dietary Risk Assessment.*

16. Ibid.

17. U. S. Environmental Protection Agency. *US EPA Chlorpyrifos: Occupational/Residential Handler & Postapplication Residential Risk Assessment.*

18. U.S. Department of Agriculture, 24.

19. U.S. Environmental Protection Agency. Office of Pesticide Programs. *Organophosphorus Cumulative Risk Assessment-2006*

Update, 51.

20. Ibid., 98.