The Road to Toxicity

The rules

The goal of the game is to become TOXIC – to be converted from inorganic mercury to methylmercury, the form that bioaccumulates in organisms. You can become toxic in soils, lakes, streams, or wetlands – depending where you land.

- Each player picks a game piece (thermometer, power plant, volcano, hazardous waste).
- Shuffle each stack of cards (FACT and FACTOR) and place in a central location.
- Take turns rolling 1 die and move the number of spaces indicated.
- If you land on a silver space, pick up a FACT card. Read the card aloud to the other players – the information will be important later. Keep the card.
- If you land on a green space, pick up a FACTOR card. Read it aloud to the other players. Keep this card – you need to collect all three factors to become toxic. The three factors are:
    - Chemistry
    - Anaerobic conditions
    - Microbes
- If you land on a SEQUESTERED space, slide to the soil, lake, wetland, or stream nearby. You're now sequestered – stored in the environment, waiting for the right conditions for methylation so you can become toxic. You need to collect all 3 FACTOR cards before becoming toxic.
- If you're missing one or more FACTOR cards, you can steal them from another player when they land on a POP QUIZ space. Ask them a question about one of the FACT cards you're holding. If they get it right, nothing happens. If they get it wrong, you can take one of their FACTOR cards. If no one has a FACTOR card and a POP QUIZ happens, the penalty for an incorrect response is a lost turn.

Once one player becomes toxic, s/he wins. If time allows, keep playing until everyone is toxic.

FACTOR CARDS (print 2-3 copies of the following pages, cut out cards, and write "FACTOR" on the back of each.)

Methylation overview (for teachers)

Methylation is a product of complex processes that move and transform mercury. Atmospheric deposition contains the three principal forms of mercury, although inorganic divalent mercury (Hg^{2+}, often called just HgII) is the dominant form. Once in surface water, mercury enters a complex cycle in which one form can be converted to another. Mercury attached to particles can settle onto the sediments where it can diffuse into the water column, be resuspended, be buried by other sediments, or be methylated. Methylmercury can enter the food chain, or it can be released back to the atmosphere by volatilization.

http://www.usgs.gov/themes/factsheet/146-00/

CHEMISTRY

Besides having mercury present to make methylmercury, scientists are finding out that there needs to be organic carbon - organic material from plants and animals like decomposing leaves, fats, proteins, or carbohydrates from animals or plants breaking down. Also, some scientists think that having the right amount of sulfur for the microbes to feast on and the right pH (acidity) in their environment helps increase methylation.

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MICROBES

Bacteria that process sulfate in the environment take up mercury in its inorganic form and convert it to methylmercury through metabolic processes (for humans, a metabolic process is eating & digesting food). Making methylmercury from inorganic mercury is important because it is more toxic and takes longer to eliminate than inorganic mercury. Methylmercury-containing bacteria may be consumed by the next higher level in the food chain, or the bacteria may excrete the methylmercury to the water where it can stick to plankton, which are also eaten by the next level in the food chain.

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ANAEROBIC CONDITIONS

Anaerobic means "without air". The microbes (bacteria) that convert mercury to its toxic form, methylmercury, live in anaerobic environments like lake sediments (muck at the bottom of lakes), stream bottoms, wetlands, or even in pockets of wet soil in forested places.

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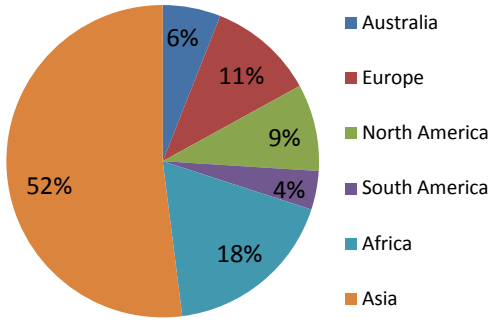
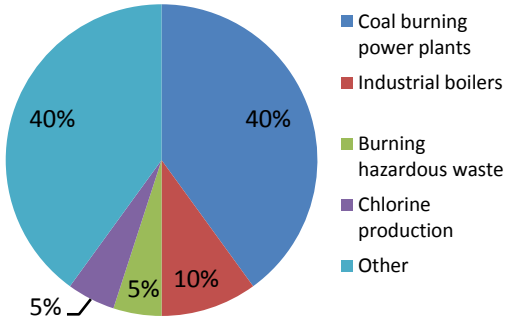
FACT cards (print one copy of the following pages, cut out cards, and write "FACT" on the back of each)

According to a 1999 study, North America accounts for 9% of global emissions of mercury, whereas Asia accounts for over half.



Burning hazardous wastes, producing chlorine, breaking mercury products, and spilling mercury, as well as the improper treatment and disposal of products or wastes containing mercury, can also release it into the environment. Current estimates are that less than half of all mercury deposition within the U.S. comes from U.S. sources.

Mercury is found in many rocks including coal. When coal is burned, mercury is released into the environment. Coal-burning power plants are the largest human-caused source of mercury emissions to the air in the United States.



EPA has estimated that about one quarter of U.S. emissions from coal-burning power plants are deposited within the contiguous U.S. and the remainder enters the global cycle.

Where does mercury come from? Mercury is an element in the earth's crust. Humans cannot create or destroy mercury. Pure mercury is a liquid metal, sometimes referred to as quicksilver that volatizes (turns into a gas) readily. It has traditionally been used to make products like thermometers, switches, and some light bulbs.

Once in the atmosphere, mercury can stay in the air for anywhere from 6 months to 2 years. This gives it enough time to circle the globe! Scientists think they're seeing mercury from China and other Asian countries landing on mountaintops in Washington State.

Most of the mercury in soils is in the organic layer – the top part of soil that looks like partially broken down leaves and needles. It is kind of like compost – very nutrient-rich and full of organic carbon from plant parts breaking down.

Soils usually have a lot more mercury in them than water – like streamwater or rainwater – does. While streams and lakes might have a few parts per trillion, soils usually have about 100 parts per billion – that's almost 10,000 times more in soils than lakes for the same mass of material.

When mercury (or other chemicals) fall from the sky in rain, snow, or with dust particles, scientists call this "Atmospheric Deposition". About half of the atmospheric deposition of mercury falling in Maine is dissolved in rain or snow – which scientists call wet deposition, and the other half is associated with dust particles – which scientists call dry deposition.

Leaves and needles that fall from trees and shrubs are called "litterfall". Because some mercury in rain and dust can stick on to leaves and might get incorporated into the leaf or needle if the stomata are open. Stomata are tiny holes in leaves where they take in gas for respiration and control moisture loss by closing when it's dry or cold.

When mercury falls from the sky in rain, snow, or with dust particles (atmospheric deposition), it can land on trees, grass, houses, lakes - anything in its way on its fall!

Scientists think that trees – especially softwoods like spruce and fir – are very efficient at collecting the dry dust particles of mercury. The needles have a lot of surface area, which makes them good at 'combing' mercury out of the air then letting it wash down to the forest floor the next time it rains.

Once they have fallen to the ground as litterfall, leaves and needles begin to decompose, turning into organic soils. Therefore, some of the mercury in the organic soil layer is probably the mercury that was stuck in or on leaves, and some is the mercury that has been raining down as dust, rain, or snow all year.

The amount of methylmercury in fish in different waterbodies is a function of a number of factors, including the amount of mercury deposited from the atmosphere, local non-air releases of mercury, naturally occurring mercury in soils, the physical, biological, and chemical properties of different waterbodies and the age, size and types of food the fish eats. This explains why fish from lakes with similar local sources of methylmercury can have significantly different methylmercury concentrations.

www.epa.gov/mercury

Birds and mammals that eat fish are more exposed to methylmercury than any other animals in water ecosystems. Similarly, predators that eat fish-eating animals are at risk. Methylmercury has been found in eagles, otters, and endangered Florida panthers.

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Effects of methylmercury exposure on wildlife can include mortality (death), reduced fertility, slower growth and development and abnormal behavior that affects survival, depending on the level of exposure. In addition, research indicates that the endocrine system of fish, which plays an important role in fish development and reproduction, may be altered by the levels of methylmercury found in the environment.

www.epa.gov/mercury

In Maine, mercury has been found in loons, fish, and amphibians at levels high enough to cause concern. Across the whole state, there is a fish consumption advisory, meaning that you should limit the amount of fish you eat – especially those that are higher on the food chain.

Soil erosion – soil washing into streams – is a pollution problem in itself. However, mercury scientists think that not only is the soil 'muddying' the stream waters, but it also seems to be carrying mercury with it into streams. Mercury likes to cling to dissolved organic carbon (DOC) – the stuff that makes some water look like iced tea. This DOC is just all the tannins and other carbon-based chemicals that soak out of leaves when they decompose or sit in the water. In fact, this is just like making tea – the leaves steep in water and the organic carbon comes out and colors the water brown.

What type of mercury is in water? Most of the mercury in streams and lakes is the inorganic form, like that which falls from the sky. Usually only a very small percent – usually about 5% or less – of the mercury in a lake or stream is methylated.