Q&A with an ENVIRONMENTAL RESEARCH SCIENTIST

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NANOOZE

THE ENVIRONMENT ISSUE

Scientists are developing tiny sensors that can be embedded into trees and plants.

NANO ALL AROUND US

TINY SENSORS

NANO AND SAFETY

VERY CLEAN CLEANROOMS

nanooze.org

Emily Maletz / Nanooze

Nanooze

ALL ABOUT THE THINGS TOO SMALL TO SEE

Welcome to Nanooze!

What is a Nanooze? (Sounds like nah-news.) Nanooze is not a thing, Nanooze is a place to hear about the latest exciting stuff in science and technology. What kind of stuff? Mostly discoveries about the part of our world that is too small to see and making tiny things using nanotechnology. Things like computer chips, the latest trends in fashion, and even important stuff like bicycles and tennis rackets. Nanooze was created for kids, so inside you'll find interesting articles about what nanotechnology is and what it might mean to your future. Nanooze is online at www.nanooze.org, or just Google "Nanooze"—you'll find interviews with real scientists, the latest in science news, games and more!

How can I get Nanooze in my classroom?

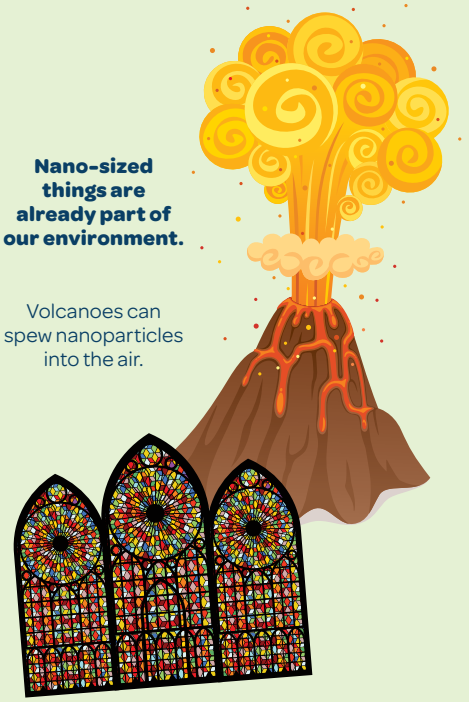
Copies of Nanooze are **FREE** for classroom teachers. Please visit www.nanooze.org for more information or email a request for copies to: info@nanooze.org.

THE ENVIRONMENT ISSUE

Nanotechnology is a new field of science that lets us do things at the atomic scale.

We can build stuff from the ground up, one atom at a time. It isn't really a "new" science, just new to us—there has been nanometer-sized stuff around since the beginning. Our environment is full of nanometer-sized things, from tiny dust particles to stained glass to nanoparticles of rare materials thrown up into the atmosphere by volcanoes. There is new concern about nanomaterials in the environment and how they might impact our health and the health of the planet. How nanomaterials impact the environment is a complicated question, because some materials are man-made, while others occur naturally. Things like asbestos, which was once an important insulator used on things like steam pipes, are now known to cause serious diseases. This issue is all about nanomaterials in the environment, where they are found and how we can also use nanotechnology to find them.

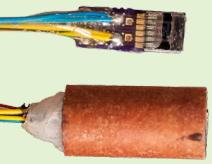
Nano-sized things are already part of our environment.



Volcanoes can spew nanoparticles into the air.

Some colors of stained glass are created using particles of gold that are nano-sized.

iStock



ON THE COVER

Scientists are working on tiny sensors that can be embedded directly into the trunk of a tree or the stem of a plant. These sensors can help monitor the plant's health and detect whether it is stressed due to lack of water. In the future these types of sensors could help farmers monitor crops remotely and work their fields more efficiently.

This sensor was built by Siyu Zhu, a PhD student in the Robert Frederick Smith School of Chemical and Biomolecular Engineering at Cornell University. Learn more at: ***www.stroockgroup.org***

NANO KNOW-HOW

Learning about nano stuff is fun but it can be complex, so it helps to keep these four important facts in mind:

1. All things are made of atoms.

It's true! Most stuff, like you, your dog, your toothbrush, your computer, is made entirely of atoms. Things like light, sound and electricity are not made of atoms, but the sun, the earth and the moon are all made of atoms. That's a lot of atoms! And they're incredibly small. In fact, you could lay one million atoms across the head of a pin.

2. At the nanometer scale, atoms are in constant motion.

Even when water is frozen into ice, the water molecules are still moving. So how come we can't see them move? It's hard to imagine that each atom vibrates, but they are so tiny that it's impossible to see them move with our eyes.

3. Molecules have size and shape.

Atoms bond together to form molecules that have different sizes and shapes. For instance, water is a small molecule made up of two hydrogen atoms and one oxygen atom, so it is called H_2O. All water molecules have the same shape because the bonds between the hydrogen atoms and the oxygen atom are more or less the same angle.

Single molecules can be made up of thousands and thousands of atoms. Insulin is a molecule in our bodies that helps to control the amount of sugar in our blood. It is made up of more than one thousand atoms! Scientists can map out the shapes of different molecules and can even build most types of molecules in the lab.

4. Molecules in their nanometer-scale environment have unexpected properties.

The rules at the nanometer scale are different than what we usually encounter in our human-sized environment. For instance, gravity doesn't count because other forces are more powerful at the molecular level. Static and surface tension become really important. What is cool about nanotechnology is that we can make things that don't behave like we expect. **Things are really different down there!!**

Q&A

with Environmental Research Scientist Katrina Varner

What is your current job and what do you do during a typical day at work? I am an investigative research scientist with the U.S. Environmental Protection Agency (EPA), focusing on chemistry. Every day is a little different. My routine each day depends on where I'm at with my research project. Some days I start in the sample prep lab. It's there where standards or different concentrations of my samples are prepared.

The cool thing about working for the EPA is that I have the opportunity to use newly developed instruments and technologies. Usually, federal government scientists are the first group of people to use and test out new equipment! So in preparing the standards and samples, I use either an Accelerated Solvent Extraction system for soil samples or an AutoTrace Extraction system for water samples. These are automated systems that save me hours of old-fashioned extraction work and time. Not to mention using fewer chemicals. If I'm just starting with a new sample, I will put it in our weathering machine, which will mimic being exposed out in the environmental elements. Then I will take that sample and run it through the liquid chromatograph/mass spectrometer to see if the main chemical has broken apart. I will also take a look at that chemical under a scanning electron microscope to see if there are other changes to its shape or structure.

What kind of education did you need to take on your current job? I have a bachelor's degree in biology! My first job, I worked with the local municipality, the Las Vegas Valley Water District, as a chemist. Next I worked at a private company using my chemistry knowledge to develop sensors to detect leaks from underground gasoline and dry-cleaning tanks. So I gained a lot of experience in chemistry from on-the-job training.

Is working for the federal government a lot different than you expected? Yes. I never, ever thought of working for the government! I was working for the private sensor development company and realized I was working all the time. Well, six days a week, when I was only supposed to work five days a week, Monday through Friday. I was a Big Sister with Big Brothers Big Sisters. My boss would walk into the lab Friday afternoons and say, "See ya tomorrow. Be here by 8:30." Nearly every Friday for several months. I didn't like that at all. I felt terrible because I would have to cancel on my Little Sister and not do our Saturday activities. I accepted the job with the EPA after those occurrences.

What kind of problems do you investigate in the area of nanotechnology and the environment? My current project is investigating how to measure the amount and type of super small, carbon-based, man-made or engineered nanochemicals/nanomaterials in soil and water. The nanochemical compounds I am looking at are C60—known by several names including bucky balls or fullerenes. And carbon nanotubes, which are very cool-looking coiled cylindrical wires. I learn about how these chemicals may react in the environment.

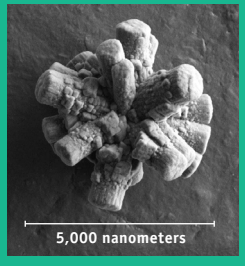
I am trying to solve the question: Does it cause harm to the environment or people if man-made fullerenes and nanotubes get into the water and/or soil? You might be asking how that can happen. Well, many of the things we use every day—consumer products—are being made with these nanochemicals or nanomaterials. Things like hair care and skin care (products) as well as toiletries. And scientists are not sure what happens to them when we are done using the product. For instance, what happens to the plants and/or animals, like fish, if they are exposed to these nanochemicals? In other words, what is the environmental impact?

EPA

Katrina in the lab with a mass spectrometer.

When you were growing up, did you imagine that you would be working as a scientist in the government? No, not at all! I wanted to be a lawyer or forensic doctor. But I did not take that path. So a lesson I've heard time and time again as an adult is believe in yourself. Believe in your dreams. And if you want to do something, well, pursue that something. Then if it doesn't work out, you can try something else. I really like mysteries and solving them. So being a research scientist is like being a super sleuth. And I get to work with lawyers and doctors to help them solve their cases!

When you are not being a scientist, what do you do for fun? I love music, hiking and reading. I really enjoy listening to all kinds of music. Since my singing ability is really limited, I like going to music festivals and concerts and dancing to the beats! I try to hike every weekend. Many people don't realize the beauty hidden on off-road trails. I live in the desert and you wouldn't think that there is much to see, but you would be wrong. There are waterfalls and ponds that you would never know were out there unless you took a hike to see them! I am also an enthusiastic reader. I've always liked to read. It's a great way to escape into a new and exciting journey.



Katrina Varner / Jeremy Hilgar

A scanning electron microscope (SEM) image of a cluster of fullerenes, a nanomaterial that Katrina studies.

Nano all around us

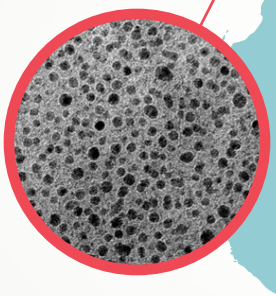
Nanoparticles and nanomaterials aren't only found in high-tech science labs. Tiny particles that we can't see are everywhere, and some of them are nano-sized.

Eyjafjallajökull
ICELAND
Volcanic Ash

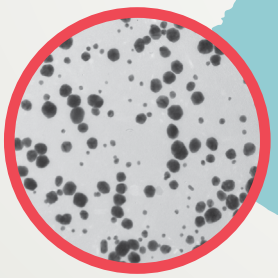
Everywhere
AROUND THE WORLD
Pollen

Kansas City
MISSOURI
Lots and lots of pollen in the air

Poole's Cavern
UNITED KINGDOM
Stalactites



Everywhere
AROUND THE WORLD
Silver household products



Grains of pollen

6,000–100,000 nanometers

You can't usually see grains of pollen floating in the air. But pollen grains aren't even nano-sized. Even the smallest type of pollen is still about 6,000 nanometers wide. Nano is smaller!

Pollen particles in the air cause allergy sufferers to sneeze. As few as 15 pollen particles per cubic meter of air is enough to make you sniffle. Pollen counts are monitored at different centers across the country.

In places like Kansas City, MO, pollen counts above 5,000 per cubic meter of air have been reported. The highest count to date in Kansas City was 7,384 grains per cubic meter on April 18, 2015.

Kansas City pollen count data provided by Charlie Barnes, Children's Mercy Kansas City

Silver nanoparticles

10–100 nanometers

Silver has antibacterial properties. Some products, such as clothing and bandages, are coated with tiny silver nanoparticles to help keep them germ-free.

But silver nanoparticles aren't new. Silver objects, such as jewelry and silverware, can give off silver nanoparticles and people have been using silver objects since ancient times.

Mineral nanoparticles in cave dripwater

2–5 nanometers

Nanoparticles are formed in nature through a variety of different processes and produce lots of different structures.

In some caves, stalactites, those sharp rock formations that hang down from the cave ceiling, are formed through a very slow chemical process. Bits of minerals are dissolved by water and then as they flow to the tip of the stalactite, the water evaporates, depositing nanometer-sized mineral particles.

Pollen: Wikipedia, Silver nanoparticles: Nanocomposix / NISE Network, Mineral nanoparticles: Nature Education / Hartland, Volcano: Wikipedia / Boaworm

Volcanic particles

as small as 500 nanometers

Volcanoes can create nanoparticles! Some volcanic ash contains traces of rare earth elements (zirconium, hafnium, niobium and thorium) that are around 500 nanometers in size.

In April 2010, the eruption of Eyjafjallajökull in Iceland spewed volcanic particles into the air, causing flights across Europe to be grounded for days.

Everywhere
AROUND THE WORLD
Dust

Dust particles

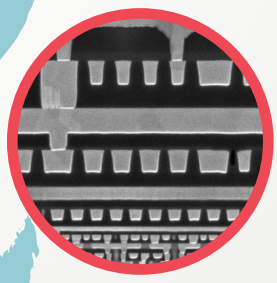
all different sizes

Tons of different materials, both man-made and natural, end up as dust particles in our homes and in the air. Dust particles that are 15-50 nanometers in size can be carried by the wind for thousands of miles. Dust that starts in Asia winds up all over the world. The dust starts off in the deserts of Mongolia and sometimes makes it as far as the United States.

MONGOLIA
Dust

Damascus
SYRIA
Damascus steel

Everywhere
AROUND THE WORLD
Computers, smartphones, devices



Transistors

<10 nanometers

All of your computers and devices contain nano-sized parts. Computer chips have transistors that are less than 10 nanometers in size. A single computer chip can contain billions of transistors.

Computer chips are made in cleanrooms. The cleanest cleanroom has fewer than 10 particles floating in a cubic foot of air. Regular air has more than 1,000,000 particles per square foot. There are cleanrooms all over the world that are used for manufacturing and research.

Carbon nanotubes in steel

2 nanometers wide

The world's sharpest swords were made from "Damascus steel," named after the capital of Syria. A few hundred years ago, craftsmen made Damascus steel using a secret process. What they didn't know was that the process resulted in the formation of carbon nanotubes with nanometer-sized diameters. Because carbon nanotubes are acid resistant they protected the material and made the swords super sharp.

A nanometer is a billionth of a meter

Transistors: Intel, Dust: Eye of Science / Science Source, Steel: Wikimedia Commons / Ralf Pfeifer

TINY SENSORS
for the Environment

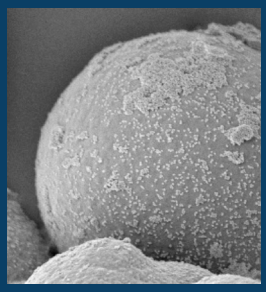
Back about 50 years ago, the simple analysis of mercury in contaminated water required an instrument about the size of a refrigerator and a very specialized scientist to run it. A lot of that size was taken up by the electronics required to analyze the signal. Big electronics also meant big power requirements, so most instruments couldn't be used at the source of the pollution because they needed to be plugged in. These instruments also needed a large sample to detect small amounts of some pollutants at low concentrations.

NANOTECHNOLOGY TO THE RESCUE!

Nanotechnology can be used to make a lot of things smaller. Computers are getting more and more powerful while also getting smaller because electronics in the sensors are being made a lot smaller. Nanotechnology can also be used to make extremely small channels for analyzing samples—fluid channels so small they are called *microfluidic*. Smaller channels allow for much more sensitive detection because it is possible to detect just a few molecules in a very small space.

MEASURING POLLUTANTS

Scientists have built a number of different kinds of sensors for measuring pollutants in the environment. For example, scientists at Cornell University have made tiny sensors that can detect different kinds of molecules including pesticides. They use nanoparticles made out of gold or silver to build these sensors. When the pesticide binds to these nanoparticles the binding can be detected using a powerful laser. The pattern that is made when the laser light bounces off the nanoparticle-bound pesticide is like a fingerprint that can help scientists identify the type of pesticide that is bound.



Paco Barahona

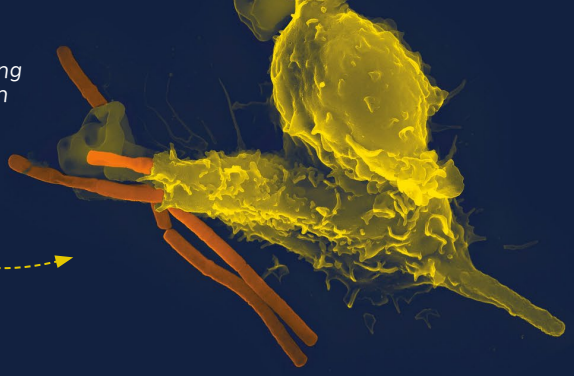
A polymer sphere of about 1,000 nanometers coated with gold nanoparticles. Each gold nanoparticle is about 25 nanometers wide. Scientists at Cornell University created these nanometer-sized sensors that can detect tiny amounts of pollutants in the environment.

THE FUTURE OF SENSORS

What's in the future? Sensors that are smaller, faster, and more accurate for sure. Also sensors that can detect a number of different pollutants at the same time from just one sample.

VS.

A white blood cell engulfing anthrax bacteria through phagocytosis.



PHAGOCYTOSIS
The process by which a cell, such as a white blood cell, ingests microorganisms, other cells and foreign particles.

IS NANO SAFE?

It depends...

Nano (or let's say nanotechnology) might seem like something new or something that is only made by people. In fact, nano, or things that are less than 100 nanometers in size, are all around us already—in the air, in the dirt, even on us. The buzz is about how we can make things that are only nanometers in size, and also control their shape and size.

PHAGO-WHAT?

In some cases, nano-sized particles are not good for your health. Inhaling dust can cause problems depending upon what it is made from. In general, the smaller the particle, the deeper it can go into your lungs if you breathe it in. Most of the problems occur when your cells take up these nanoparticles through a process called *phagocytosis*, which is Greek for the process cells use to devour small things!

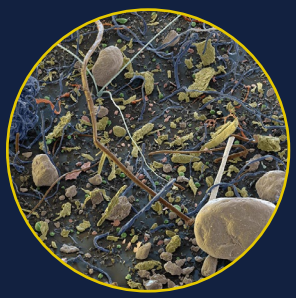
Many cells in our body will take up nano-sized particles by phagocytosis. Most of these cells are involved in our immune defense system and evolved to take up nano-sized particles as part of the protective response. Bacteria and viruses are gobbled up and broken down. Once they are broken down, parts of them are then used to make you immune to that bacteria or virus. The same process can gobble up other nano-sized particles and sometimes cause problems.

THE ASBESTOS EXAMPLE

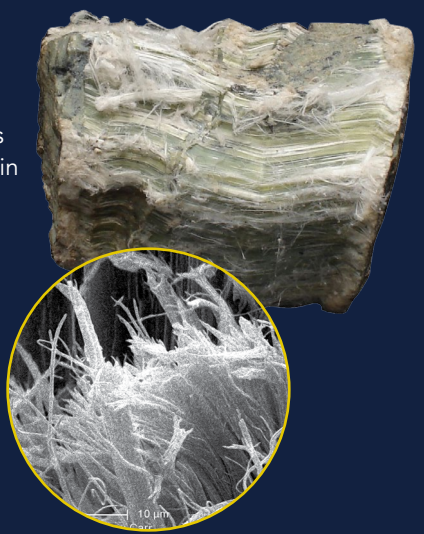
There is concern about nano-sized materials and history has shown that this concern is justified. A long time ago, a material known as asbestos was commonly used to insulate pipes and to make things fireproof. It was widely used until someone discovered that you could breathe in small bits of asbestos and that might cause cancer. Since that discovery, a lot of time and money has gone into carefully removing asbestos from old buildings and other places. In recent years, professionals realized it was better to leave asbestos in place wherever it was certain that tiny pieces wouldn't break off.

Nanotechnology can be used to create incredibly useful materials, but sometimes there are potential hazards. Scientists are studying those hazards in a lot of different systems.

GRAINS OF SAND
When compared with nano-sized particles, grains of sand are actually huge, with the smallest grains being around **5,000 nanometers**.



HOUSEHOLD DUST
Dust can be nano-sized, but the dust we can see is actually almost five times bigger, around **500 nanometers** or more.



ASBESTOS
The tiny filaments that make up asbestos can be less than **100 nanometers** wide.

How *Clean* is Clean?

A lot of nanotechnology happens inside of cleanrooms. There are clean rooms, like your room when you clean it up, and then there are *cleanrooms*. To make computer chips and other nanometer-sized devices it is important to keep the work environment clean. A few particles of dust in the wrong place and suddenly a computer chip gets damaged and won't work. Today's computer chips have super small nanoscale parts that are less than 10 nanometers in size; that is about 1/5,000 the width of an average human hair.

So exactly how clean are cleanrooms?

Different fabrication processes require different levels of cleanliness, or the number of particles that are allowed to float around.The air inside a cleanroom is constantly filtered, and the "cleaner" the cleanroom, the more expensive it is to maintain. Everyday air has millions of particles in each cubic meter and varies a lot depending on many factors including the weather, time of day, time of year, proximity to highways and factories, what is blooming, etc.

In a cleanroom that is classified as "Class 10,000/ ISO 7" there are less than 352,000 particles (bigger than 500 nanometers) per cubic meter. This is about 100 times cleaner than "normal" room air. Today's most modern cleanrooms, such as the ones where the latest computer chips are made, are "Class 10/ISO 4" or lower—less than 352 particles per cubic meter or more than 1,000,000 times cleaner than everyday air.

Everything and everyone that goes into a cleanroom needs to be super clean!

It is also important to make sure that all the crud on our bodies is kept away from the chips. Workers dress up in suits that cover almost every bit of their body. Even the tiniest bit of dead skin or a single hair can cause havoc in the cleanroom. There is even special paper to write notes on because regular paper releases tiny particles and is too "dirty." Making a cleanroom and putting in all the special equipment needed to make computer chips isn't cheap and it isn't cheap to operate. The latest chip fabrication facilities (called "fabs") cost more than five billion dollars to construct. Not only is a cleanroom super clean, but it is also super quiet because even vibrations can mess up the chip manufacturing process.

FOR COMPARISON: EVERYDAY AIR

Regular outside air can have millions of particles floating around in a cubic meter. Dust, pollen, mold, microbes, chemical vapors, exhaust and pollution can all be found in outside air.

1 meter = 1,000,000,000 nanometers
1 meter = 3.28 feet
1 cubic meter = 35.3 cubic feet

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