Genetically Enhanced Plants Could Clean Up Toxic Waste Sites

June 24, 1999 Philadelphia, Pennsylvania The United States is currently the world's largest producer of hazardous waste, approximately 275 million tons annually. The Environmental Protection Agency maintains an inventory of more than 38,000 uncontrolled waste sites. Those include 1,400 on the National Priorities List (NPL) **-** which are abandoned waste storage or treatment plants and mining and weapons manufacturing facilities. Those 1400 sites pose the greatest threat to public health and the environment. The projected cleanup costs for these NPL sites using existing physical and chemical methods will be approximately $750 billion. That's nearly one trillion dollars.

A University of Pennsylvania plant biochemist, Philip Rea, Ph.D., recently made a breakthrough discovery that isolated the plant gene in a particular plant (*Arabiodopsis thaliana* shown below) that encourages the plant to soak up toxins. He and his research team at the University's Plant Science Institute hope to make this gene work for them in genetically enhanced plants such as sugar beets and potatoes to try out at one or more toxic waste sites to see how efficiently soil can be cleaned up. If the plants are successful, the cost of detoxifying soils could be lowered from nearly a trillion dollars to the millions. Instead of literally digging up tons of soil to be chemically scrubbed and buried somewhere else, the plants could take up most soil contaminants, neutralize the poisons internally, and then be harvested for safe disposal. This new approach to toxic waste clean up is called "phytoremediation."

Photo Credit: *Arabidopsis thaliana* by Philip Rea, Ph.D., Univ. of Pennsylvania.

I asked Dr. Rea how plants can take in lethal poisons such as cadmium, arsenic, lead and mercury and not be poisoned themselves.

Interview:

Philip Rea, Ph.D., Prof. of Biology, University of Pennsylvania, Plant Science Institute, Philadelphia, Pennsylvania: "Actually that's the thing that got us interested in these various processes. The one thing you have to appreciate when you think about a plant is that plant cells have a very large internal reservoir and that reservoir is what is called the vacuole. And that's a compartment that is surrounded by a filtration device, if you will, which is the vacuole membrane. And plants can have a massive capacity for accumulating high levels of toxic materials, providing those toxic materials are dumped into the vacuole. So, you can think of the vacuole as an intracellular, internal landfill within the plant cell. And providing those bad materials are kept within that compartment, kept away from the bulk of the machinery that does metabolism in plant cells, the plant cells are able to accumulate those materials, but not suffer the toxic action of those materials themselves.

And the important thing about what we've been working on is that the heavy metals when they get into the plant cell - there are two things that happen to them - one is that the heavy metals are immobilized, they are bound, soaked up by sponge-like materials, these phytochelatins, and then the phytochelatins plus the heavy metals that are bound to them - those phytochelatins are then dumped into this intracellular landfill, they are dumped into the vacuole. So, the plant cell has at least two levels of protection - one is the binding of the heavy metal to the phytochelatin which in itself makes a major contribution to detoxification.

Then the second step is the dumping of the heavy metals plus the phytochelatin into the vacuole. And the vacuole - this intracellular landfill in many mature plant cells - represents between 40% and 70% of the total volume of that cell. So, that's a massive capacity. If you are looking at an herbaceous plant sitting on your window sill, some 40% to 70% of the volume of that plant is represented by vacuola material. Or another way of looking at it is that every time you bite into an apple or you squeeze the juice of an orange, more than 90% of the volume that you are consuming when you do that is material that has been kept in the vacuole.

WHAT YOU WOULD TRY TO DO IN YOUR WORK IS TO ENHANCE THE GENETIC ABILITY TO EXPAND THAT VACUOLE ABSORPTION EVEN FURTHER?

Precisely. To enhance the chemistry that enables things to be transported into that vacuole. Yes, that's it exactly.

IF YOU ARE SUCCESSFUL, THEN YOU WOULD ENVISION THAT PLANTS SUCH AS SUGAR BEETS AND POTATOES COULD BE PLANTED WHEREVER THERE WAS A TOXIC WASTE SITE, ABSORB AS MUCH OF THE TOXIC METALS AND POISONS AS POSSIBLE, AND THEN SIMPLY BE HARVESTED SORT OF THE WAY WE MIGHT MOW GRASS AND CATCH IT IN A CATCHER AND THROW IT AWAY?

Yes.

THIS GENETIC DISCOVERY IS QUITE RECENT IN YOUR WORK?

Yes, yes. Only the last few months, yes.

BUT YOU WERE TRYING TO SEE IF YOU COULD ISOLATE SUCH A GENE FOR EXACTLY THIS APPLICATION TO CLEAN UP TOXIC WASTE SITES?

We were not. What we were looking for were genetic regulatory elements that change the level of expression of other genes in response to heavy metals. We weren't actually going after the gene encoding the enzyme that is responsible for the heavy metal detoxification. So, our discovery really was a spin-off of something related, but not something that was directed specifically at cloning the gene for this enzyme.

WHEN YOU REALIZED THAT YOU HAD STUMBLED ON TO THIS POSSIBLE OTHER APPLICATION, WHAT DO YOU DO AS A SCIENTIST TO DEVELOP THIS RESEARCH FURTHER INTO PRACTICAL APPLICATION IN THE WORLD?

OK, the first thing we did, of course, was we patented the discovery. And the next stage is really to look at whether, to determine the best way to engineer the gene into plants such that it has maximum capacity to remove the heavy metal. That actually - there has been a lot of down time in trying to get the gene in the first place. As I said, it's taken a long time in so far as people have not been successful until very recently. The next stage, I think, will be an equally lengthy process and that is finding appropriate plants to use the genes in.

THIS GENE DISCOVERY THAT YOU HAVE - IF YOU CAN ENHANCE ITS ABILITY, IT WOULD NOT ONLY TAKE TOXIC METALS OUT OF THE SOIL SUCH AS CADMIUM AND SOME OF THE MORE TOXIC LIKE MERCURY AND LEAD - NOT ONLY TAKE IT OUT OF THE SOIL, BUT THEN BE ABLE TO NEUTRALIZE THAT TOXICITY WITHIN THE PLANT ITSELF.

Yes. The mode of detoxification is one in which the toxin is bound - there is no chemical modification of the toxin other than its binding to these phytochelatins. And the ability of the plant to withstand the heavy metal and the ability of the plant to hyper-accumulate the heavy metal go hand in hand. In other words, hyper-accumulators have increased resistance to the heavy metal by virtue of their ability to bind the heavy metal.

YOU CAN'T ENVISION THAT THE PLANTS THEMSELVES IN THESE SPECIAL CONDITIONS WOULD DIE FROM THE ABSORPTION OF MERCURY, LEAD OR CADMIUM?

I think provided that they are able to manufacture enough phytochelatin - and there doesn't seem to be an upper limit on that.

HAVE YOU BEEN ABLE TO MEASURE HOW MUCH TOXIC MATERIAL CAN BE TAKEN, LET'S SAY, OUT OF A SQUARE FOOT OR SQUARE YARD OF SOIL BY THESE PLANTS?

That's the next step. We haven't done that.

WHAT DO YOU PROJECT?

My prediction is that we probably can get the levels of the heavy metals down by a factor of approximately 100. If we can push it any lower, I'm not sure.

YOU MEAN 100%?

A hundred fold. A hundred times lower than the prevailing, initial concentration.

WHICH WOULD TAKE IT DOWN NEARLY TO ZERO?

Which would take it down to levels that are far more tolerable.

HOW LONG DO YOU THINK IT WOULD BE BEFORE YOU WILL ACTUALLY HAVE VIABLE APPLICATION OF SOME GENETICALLY ENGINEERED PLANTS TO TRY OUT AT A TOXIC SPILL SITES?

I would say two years.

TWO YEARS.

Yes. The key thing here is to use plants to remove heavy metals is very cheap by comparison to the standard procedure. And the sort of state of the art, the standard procedure, is basically to dig the soil up and take it to a remote site and scrub it with acids and high temperature.

WHICH STILL LEAVES SOME TOXICITY WHERE IT'S BURIED.

Yes.

AND THIS WAY, IF YOU ARE SUCCESSFUL, YOU WILL END UP USING PLANTS TO CLEAN POISONS OUT OF THE SOIL ALMOST 100%.

To a high degree."

More Information:

The funding to continue this work with the gene (phytochelatin synthase protein) that encourages plants to detoxify heavy metals from soil is provided by the National Science Foundation, Department of Energy and the U. S. Department of Agriculture.

Credits