at National University Hospital in Copenhagen, Denmark, found a third, much less common mutation in which an arginine (at position 52) is replaced with cysteine.

What apparently happens, Turner says, is that the mutations disrupt MBP's structure, thus preventing it from performing its functions. The protein has two parts: a head that binds sugars plus a tail consisting of the structural protein collagen in which three chains wind together in a triple helix. And as Turner notes, the mutations should prevent formation of the helical structure, which is needed for complement activation, because glycine is the only amino acid that can fit in the turn of the helix. "If you introduce a dicarboxylic acid, such as aspartic acid or glutamic acid, which is what we see with the major mutations, the protein can't polymerize," says Turner. In work in press in *Immunology*, his team has evidence in support of that hypothesis. The researchers found that in patients with the defective MBP gene the protein is not polymerized.

What's more, MBP problems may not be limited to children as previously thought. In the 8 April issue of *The Lancet*, Summerfield and his colleagues report that they've found mutations in one or both copies of the MBP gene in five adult patients with severe bacterial infections, and in three of these individuals extensive testing had ruled out HIV infections and other immunodeficiencies as the cause of the problem. How extensive a problem MBP deficiency is in adults remains to be established, however.

Also unclear, given the apparent importance of MBP in immune defenses, at least in children, is the question of why so many people seem to carry mutations in the gene. One possibility is that the mutated gene might confer a selective advantage that outweighs its deleterious effects. Ezekowitz suggests, for example, that people with reduced levels of MBP might be protected against the complement-mediated damage often seen in inflammatory conditions, such as rheumatoid arthritis or the septicemia caused by meningococcal bacteria.

Despite these uncertainties, researchers are looking to explore the clinical implications of the MBP work. At the very least, identification of the gene defects should help clinicians diagnose children with unexplained immunodeficiencies. And eventually, it might be possible to produce recombinant MBP and use it to treat patients with active infections. As Super points out, however, because the protein is very large and complex, "it's going to be a major headache to manufacture." Even so, during the past few years MBP has risen from obscurity to prime suspect as a cause of immunodeficiency disease.

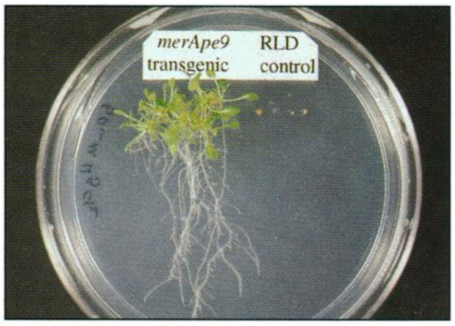
–Clare Thompson

Clare Thompson is a medical writer based in London.

ENVIRONMENTAL BIOLOGY

Plants Proving Their Worth in Toxic Metal Cleanup

Delbert Hershbach, a grower of ornamental plants in California's San Joaquin Valley, probably doesn't think of himself as a scientific pioneer. But he is. About 5 years ago, his farming operation ran into trouble. The irrigation water he was using was leaching toxic selenium salts from the soil, allowing them to escape into the drainage water, polluting local evaporation ponds and endangering aquatic wildlife. To solve the problem, Hershbach began growing plants, such as mustard, that remove the toxic compounds, concentrating them in their own tissues and keeping the toxic compounds from entering drainage ponds. Soon, he expects to return to growing his regular, profitable crops. "This strategy of cleansing soils makes a lot of sense," says Hershbach. "Without it, I would have to abandon the field or grow something I'm not happy about."



RICHARD MEAGHER

Mercury lover. The *Arabidopsis* plants *(left)* carry a bacterial gene that enables them to grow on a mercuric chloride solution.

Indeed, the strategy Hershbach used, known as phytoremediation, is making sense to many other people. Faced with a growing list of sites contaminated with toxic materials, researchers are increasingly turning to plants as a possible means of cleansing the soils. "Interest in phytoremediation has exploded in the last few years," says Norman Terry, a plant biologist at the University of California, Berkeley. One indication of the growing enthusiasm: The first international conference devoted to the subject, held in April at the University of Missouri, Columbia, was oversubscribed, attracting a multidisciplinary crowd of 250 biochemists, plant physiologists, ecologists, and soil scientists, among others.

Currently most of the interest of this growing crowd is focused on removing metals, mainly because much less is known about how plants handle organic contaminants such as oils and cleaning fluids. But Terry says "lots of sites" need phytoremediation to remove metals, so business is booming, even for this single application. Among the poisoned sites: abandoned mines laced with zinc and lead; military sites fouled with lead and cadmium; municipal waste heaps where copper, mercury, and lead can be hazards; and dump sites for sewage sludge where all these metals are problems.

Although phytoremediation research is in its early stages, the hope is that plants will prove easier and cheaper to use than the current technique for dealing with metal-tainted soils—excavation and reburial. Such cleanup is practical only for small areas, often a half hectare or less, and cleaning one hectare to a depth of one meter costs between $600,000 and $3,000,000, depending on the type and intensity of pollution.

Metal-scavenging plants may be able to improve on this record, because they can be planted over large areas and they are cheap to grow. An added economic benefit may come from the fact that the harvested plants can be burned and metals, such as nickel, recovered. "Contamination of soils is a big-time social issue," says Scott Cunningham of DuPont in Wilmington, Delaware. "Phytoremediation is going to be much better and cost-effective than conventional cleanup strategies," he predicts.

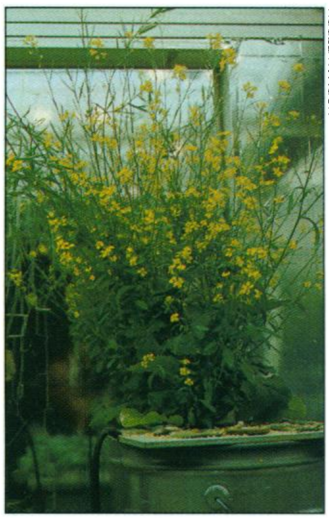
Both amateur and professional botanists have long known that certain plants can concentrate metals to levels that would kill off most species. For example, for hundreds of years, prospectors looking for copper used this knowledge to hunt for precious ores lurking near the surface. "Hyperaccumulating plants are an evolutionary response to soils of a particular geologic origin," says Alan Baker, a plant ecologist at the University of Sheffield, U.K. "They grow on a range of geologic substrates, including nickel-rich serpentine soils, soils containing calamine and other zinc and lead minerals, and those rich in copper and cobalt."

The plants are especially common in the tropics or subtropics, apparently because metal accumulation is a defense against plant-eating insects and microbial pathogens. Because these organisms are most numerous in areas that escaped glaciation, the hyperaccumulating plants are, too. In an August 1994 trip to Cuba, for example, Baker turned up more than 80 species of nickel-accumulating plants in just two families, the Buxaceae, which includes boxwood, and Euphorbiaceae, which includes many cactuslike succulents. This, Baker says, is "the largest number yet found in one country." Some of the euphorbs look promising, as they can accumulate nickel in amounts up to 5% of their dry weight.

The mustard plant used by Hershbach on his farmlands is also a tropical species. He decided to grow it on his selenium-laden fields after reading a publication by soil scientist Gary Banuelos of the U.S. Department of Agriculture's (USDA's) Water Management Lab in Fresno, California. Banuelos had reasoned that plants that take up sulfur in significant amounts, such as the many species of the genus *Brassica*, might also accumulate selenium, as the two elements are chemically similar. To test this idea, Banuelos traveled to Pakistan and India, which have soils high in selenium. There, he spotted *Brassica juncea*, a mustard plant much like oilseed rape but with better resistance to drought, a property that makes it well suited to the salty, arid soils of California's Central Valley.

Banuelos showed under field conditions that when *B. juncea* was planted over several years and managed with minimal irrigation, selenium levels were reduced up to 50% down to a soil depth of 1 meter. The plant may also have potential for cleaning up additional toxic elements. Just last year, Ilya Raskin of Rutgers University found that it can concentrate lead, chromium, cadmium, nickel, zinc, and copper. Exactly how the plant accumulates these metals is unclear, although it may transport them into the cell's waste disposal sites, the vacuoles, where they can be held in complexes with organic acids and prevented from damaging the cell's essential biochemical machinery.

Although tropical plants seem to predominate in this field, not every plant with promise for toxic-metal cleanup comes from the tropics. In 1994, Baker, Steven McGrath of the Rothamstead Experimental Station in the United Kingdom, and their colleagues completed the first controlled field trial of the hyperaccumulator *Thlaspi caerulescens*, a rare Alpine pennycress, on plots treated repeatedly with metal-contaminated sewage sludge. When compared to six other hyperaccumulating plant varieties and three ordinary species (cabbage, radish, and scurvy grass), *Thlaspi* did a "superb job," Baker says, of accumulating zinc and cadmium, to a level of several percent of the dry weight of the plants. Last year, Rufus Chaney of the USDA's Agricultural Research Service in Beltsville, Maryland, and his colleagues also found that *Thlaspi* did a better job of removing zinc and cadmium from soils taken from near an old zinc smelter than did two other species, the hyperaccumulator bladder campion and ordinary tomato.



NORMAN TERRY

Proving its mettle. The mustard relative *B. juncea* can accumulate selenium as well as metals such as lead and chromium.

But even though *Thlaspi* shows promise, the plant also illustrates some of the problems that have hindered the application of hyperaccumulating plants to toxic site clean-ups. It is slow-growing and small, lacking the biomass to remove the kilograms of metals per hectare that are found in most contaminated sites. In recent years, however, work in many labs has given researchers the ability to transfer genes between species. Consequently, researchers are looking to identify the genes that code for the biochemical machinery that enables hyperaccumulators to take up large quantities of metals—and survive—in hopes of transferring the traits to better growing, nonedible plants. "The success of phytoremediation involves coupling the power of native hyperaccumulating species with the desirable agronomic qualities—prolific growth and easy harvest—of common crops," says Baker.

ALAN BAKER

Penny's worth. In field trials, the plant Alpine pennycress (*T. caerulescens*) did well in soil contaminated with zinc and cadmium.

How *T. caerulescens* accumulates metals is still under investigation, but some other plants, including *B. juncea* and also some yeasts, employ molecules called phytochelatins, small peptides that bind metals in forms that are less toxic to the plant. In some cases, the phytochelatins with their bound metals may then be transported into the plant vacuoles for storage.

Following up on the phytochelatins' role, David Ow of the USDA Plant Gene Expression Center in Albany, California, has cloned a yeast gene that produces a peptide that carries a cadmium-binding phytochelatin into the vacuoles. Ow's efforts to put that gene into tobacco and the model plant *Arabidopsis thaliana*, to make them tolerant of cadmium, have not yet worked, however. Although the gene transfer was carried out successfully, the plant cells were not able to express the yeast gene. Ow suspects the problem may lie in certain DNA sequences carried by the gene; he says he hopes it can be overcome by tinkering with the gene and its regulatory sequences.

Other researchers have turned to bacteria to provide genes that might turn plants into hyperaccumulators. Richard Meagher of the University of Georgia, Athens, and his colleagues are working with a bacterial gene that encodes an enzyme known as mercuric reductase that detoxifies mercury by reducing it to a relatively inert form. When the researchers put a modified version of this gene into *Arabidopsis*, the resulting plants were able to grow on a lab solution containing mercuric chloride that was toxic to control plants. The transformed plants survived because the bacterial enzyme they carried converted the mercury in the mercuric salt to elemental mercury and slowly released it into the air. While plants that emit mercury vapors would seem undesirable, Meagher says the amounts released may be low enough to be safe, perhaps as low as the levels released by mercury amalgam fillings. Also, Berkeley's Terry has found that selenium can be volatilized as nontoxic dimethyl selenide by plants, including broccoli and cabbage.

Still, Beltsville's Chaney, one of the earliest supporters of phytoremediation, cautions that these initial experimental successes may not translate into commercial uses of phytoremediation. "I'm not sure the public will accept plumes of vaporized mercury rising from transgenic crops," he says. Also, he says plants laden with metals may pose a hazard to small mammals with a limited range, such as shrews.

And, of course, there's the problem of what to do with the metal-laced plants themselves, although in some cases these might actually prove to be an economic asset. Plants containing the more valuable metals, like copper and nickel, might be burned and the metals recovered from the residue. Plants that concentrate mundane metals, such as lead, could be dried and buried in protected vaults, much as contaminated soils are now. The advantage the plants offer is that they have less mass and therefore would be easier and cheaper to bury than soils. "Phytoremediation's potential for good is much greater than the potential for harm," Chaney says. If he's right, then farmer Hershbach may have even more company on the phytoremediation frontier.

–Anne Simon Moffat