Alternative Fuels and Synchrotron Science

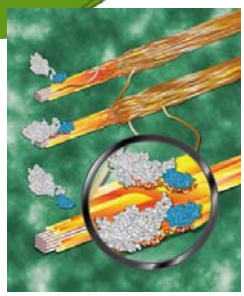
Research into alternative fuel sources is being conducted around the world in an effort to reduce human reliance on fossil fuels. Biofuels like biodiesel, biobutanol, and biohydrogen are being developed by scientists, often with the help of a synchrotron facility. Synchrotrons allow researchers the opportunity to study these fuels at the molecular level and determine the properties of the fuel. Important data on fuel efficiency, compatibility with current engine technology, and emissions output can be discovered. When an alternative to oil is introduced into the mainstream, there is a great chance that a synchrotron facility had a part in the development.

Biodiesel is produced from oils such as canola, rapeseed, soybean, and even animal fat. This product contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It is less toxic than table salt and biodegrades as fast as sugar. Infra red spectroscopy can be used to determine the oil content of the seeds. This information can lead to the development of seed varieties with higher oil content. Other synchrotron possibilities include the study of a genetically engineered bacterium to improve biodiesel production. This bacterium could lay the foundation for new types of liquid fuel

www.agwest.sk.ca/publications/documents/BPnov04.rtf
www.biodiesel.org/resources/biodiesel_basics/default.shtm

Cellulose is the primary structural component in the cell walls of green plants. A critical step in producing **cellulosic ethanol** involves breaking down a plant's cell wall material and fermenting the sugars that are released. Microbial enzymes are efficient at breaking down the plant's cell wall by binding to and digesting plant cell wall material. Once attached, a catalyst then breaks the cell wall material into small units, which can then be turned into ethanol. Synchrotron techniques can be used to analyse cellulose-binding enzymes that will break down the cell wall in a more efficient manner. Additionally, these techniques can be used to further understand lignin cellulose structures of plant material.

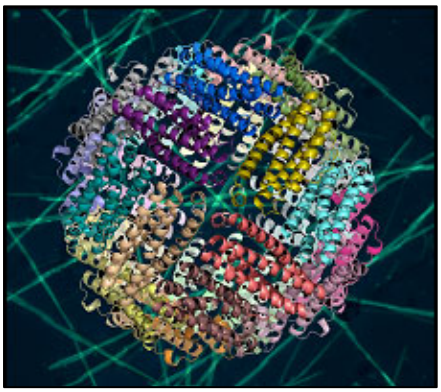
www.sciencedaily.com/releases/2007/04/070427125709.htm



http://www.sciencedaily.com/releases/2007/04/070427125709.htm

Synchrotron Science & the Environment

In today's world, it has become essential to understand the fate and transport of environmental contaminants in the soil, air, and water. To be effective, scientists need to understand exactly what toxin they are dealing with, in what kind of surroundings. Synchrotrons are one of the tools that researchers use to gather information in all these areas.



Diatoms in the oceans are responsible for half of the world's carbon sequestration. As diatoms grow, they absorb carbon dioxide. The availability of certain nutrients, like iron, determines the diatom's size, and, thus, the amount of carbon dioxide the diatom with absorb in its lifetime. Protein crystallography is helping researchers Michael Murphy and Angele Arrieta to determine the structure of an **iron storage protein, ferritin,** in pinnate diaoms—a group of phytoplankton. These diatoms are unique in their ability to store iron and thus to dominate low iron environments and phytoplankton blooms, which are caused by an excess of nutrients. Understanding the way ferritin enables these diatoms to dominate blooms, grow larger, and absorb carbon could aid in the sequestration of carbon dioxide.
http://www.nature.com/nature/journal/v457/n7228/abs/nature07539.html

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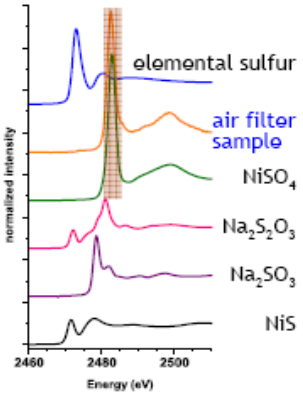
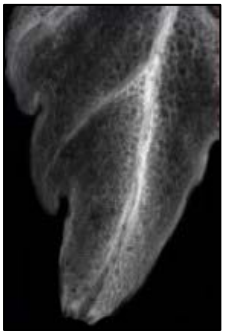
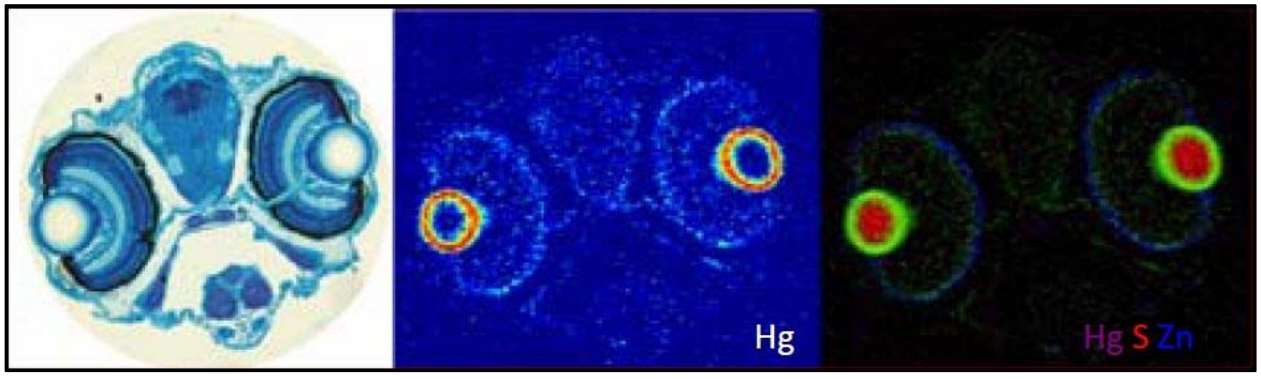


Synchrotron research allows scientists to examine the resulting emissions from fossil fuel burning plants. These harmful emissions often contain carbon, sulphur and nitrogen oxide components. Examine the resulting emissions from nickel smelters (to the right) to identify and measure the gases released. The air filter sample matches Nickel Sulphate, which is not a toxic substance. Synchrotron-based X-ray Absorption Near-Edge Structure (XANES) spectroscopy is increasingly being used to analyze and quantify the relative amounts of chemical species and oxidation states in natural environments and complex industrial process streams. Testing done at synchrotrons can measure the amount of gases being released and determine whether the amount is within environmental regulations.
http://www.lightsource.ca/brochures/report2006/CLS_actrep05-06_all.pdf - page 93
-Also refer to Environmental Issues Lesson Plan



Arsenic is famous for being a deadly poison, but it is also an environmental problem. In some soils around the world, arsenic levels are too high to grow plants. However, a fern from Florida accumulates arsenic from the soil at a very high rate. Its hyper accumulation of arsenic might help to clean polluted land. Hard X-Ray Absorption Spectroscopy is helping researcher Ingrid Pickering to determine how and why the fern—*Pteris Vittata*—accumulates, transports, uses, and stores arsenic. More research may lead to the fern being used for phytoremedication—a process which uses plants to clean soils.

In highly polluted waters, fish accumulate **mercury** which is passed up the food chain when the fish is eaten. Researchers are using synchrotron research to determine how mercury affects fish. Researcher Ingrid Pickering, using Hard X-Ray Fluorescence Imaging, looked at the accumulation of mercury in zebra fish as a way to help determine what happens when fish are exposed. The larvae were raised in water containing methyl-mercury before researchers mapped the locations of the mercury and other elements. The researchers found hotspots of mercury in the fishes' eyes—in rapidly dividing cells on the lens surface layer. This may explain the connection between mercury exposure and blindness in people. Pickering also mapped sulphur and zinc in the fish, trying to understand how elements are absorbed and used during the fishes' development. This research may help to further our understanding of developmental biology and mercury toxicity.
http://www.pnas.org/content/105/34/12108



The Petroleum Industry, Mining, & Synchrotron Science

The development of natural resources is an integral part of the Canadian economy. However, companies must be responsible when mining, drilling, and refining our resources. The Canadian Light Source, and other synchrotron facilities, is one tool used by companies to solve unknown problems as well as to verify that their industrial projects are maintaining appropriate environmental standards.

Synchrotron science allows researchers to understand the **chemistry of heavy metal elements within mine tailing** thereby better managing risks to the environment. Using techniques such as X-ray absorption spectroscopy scientists can determine if those metals are stable or bio-available. Scientists from the Canadian Light Source conducted research on the mine tailings from AREVA's McClean Lake uranium mine in northern Saskatchewan. Information gathered by the scientists about the arsenic in mine assisted the McClean Lake mine to maintain ISO 14001 Environmental Accreditation status.

www.lightsource.ca/brochures/pdf/CLSI_Arsenic_ISO14001.pdf
gsa.confex.com/gsa/2001AM/finalprogram/abstract_28827.htm

Injecting CO2 into oil wells extends the life of oil fields, enhances the economy, and benefits the environment. Scientists are developing ways to improve existing oil recovery technology by better understanding the interaction between CO2 and different types of soil and minerals underground. To do so, researchers are conducting experiments 'in situ'. This term literally means 'in place'. A microreactor system has been developed that simulates the temperature and pressure that these reactions take place under in oil wells. Though experiments are done at a synchrotron, they are under the same conditions reactions would normally take place under. In situ process observations are central to developing the mechanistic understanding needed to effectively evaluate and engineer improved technologies.

www.ir.gov.sk.ca/adx/asp/adxGetMedia.asp?DocID=4829,3442,3440,3385,2936,Documents&MediaID=12063&Filename=durocher.pdf
www.ncbi.nlm.nih.gov/sites/entrez?cmd=Retrieve&db=PubMed&list_uids=14968885&dopt=Abstract

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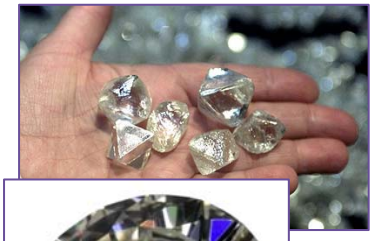
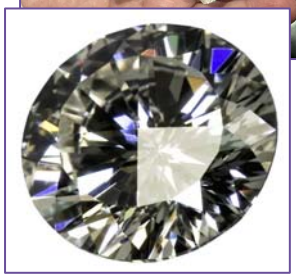
Blood Diamonds have been a popular media topic recently. Synchrotron science offers another tool enabling researchers to determine exactly where on earth a given diamond was mined. Scientists used the Canadian Light Source to shine X-ray light on a microdiamond which allowed them to take a non-destructive look at the chemical composition of the stone. X-ray florescence identifies trace minerals within the diamond. This technique helps scientists determine if diamonds from different regions have unique chemical compositions. With this technology companies and authorities can determine where certain diamonds originated: Canada, Russia or Sierra Leone?





http://www.eos.ubc.ca/research/diamonds/kopylova/AmMin2005.pdf

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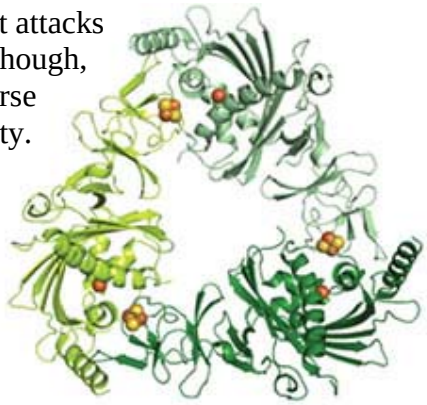
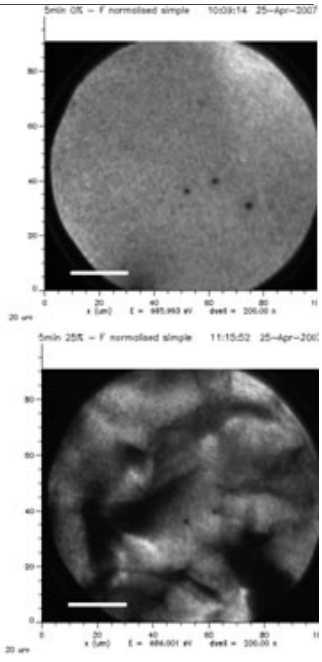
Helping Health with Synchrotron Science

Synchrotrons have several medical applications. Different techniques can help researchers develop new drugs to treat viruses and bacteria, look at the surface of bones and tendons, and make safer medical devices.



Tuberculosis (TB) has affected people for centuries. It attacks the lungs, and several other systems. For forty years, though, it has been treated with a six month to a year long course of antibiotics, causing a decrease in the disease's fatality. Although people thought that this would cause an end to the disease, the emergence of antibiotic-resistant bacteria in the 1980s has caused a re-emergence of the disease. Tuberculosis currently costs Africa 100 billion dollars in lost GDP every decade. Two billion people around the world carry strains of TB. It attacks people with weakened immune systems. Tuberculosis hides in the white blood cells that fight bacterial infection and feeds off the cells' cholesterol.

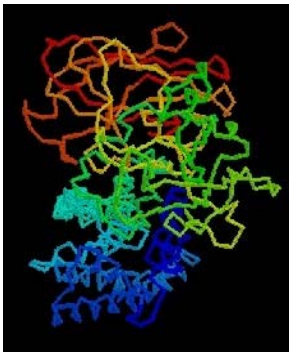
Using crystallography, researchers have created a model of the protein that allows TB to use the cholesterol for energy. They found that not one, but three proteins joined together allowed the bacteria to consume the cells' energy. By knowing this information, researchers are designing a drug that will be able to break this protein cycle and effectively treat TB without antibiotics.
http://www.jbc.org/cgi/content/abstract/284/15/9937



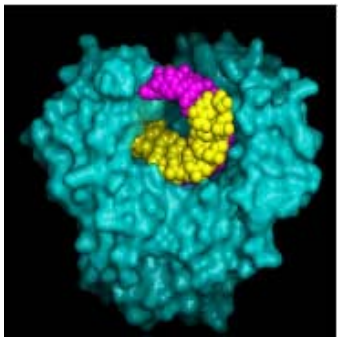
Heart stents are stainless steel tubes that are used to open blocked arteries in the heart. To avoid problems with the stent becoming blocked with star tissue, which happens in 33-40% of cases, the stent is coated with drugs. However, the drugs often crack. Synchrotron techniques have helped researchers to realize that the drugs were not bonded directly to the stainless steel, but to a layer of chromium-rich oxide on the surface of the stent. With this information, researchers can now begin to develop new ways to manufacture stents with a coating that resists cracking. This research can also aid in the development of new coatings in many different applications.

X-ray Photoemission Electron Microscope images of a 35 nanometer-thick stent coating, before (top) and after (bottom) mechanical deformation. Source: Paula Horny and Stephane Turgeon, Laval University.

http://www3.interscience.wiley.com/journal/121528394/abstract?CRETRY=1&SRETRY=0

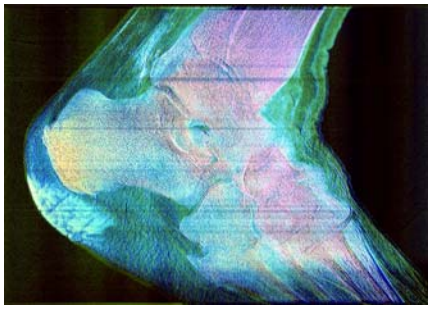


The most important spruce defoliator in Canada and Northern US can be killed with the **Cry1Aa toxin**! Activated toxins bind to the cell surface while in a water-soluble form and convert into the form capable of inserting into the membrane. They create pores that are permeable to other contaminates that result ultimately in insect death. This research was undertaken by Dr. Pawel Grochulski, a beamline scientist at CLS.
www.agwest.sk.ca/publications/infosource/abifeb04.pdf
www.na.fs.fed.us/spfo/pubs/fidls/sbw/budworm.htm



Norwalk causes "stomach flu" or "food-poisoning" in an estimated 300 to 400 people in Canada a year. It is highly contagious, especially among people in close quarters. Although it is relatively minor in healthy adults, it can be fatal in people with compromised immune systems. Currently, doctors are only able to treat symptoms of the virus. Scientists are looking for a way to treat the virus, before it is able to spread. The first step in this process is to determine the protein that allows it to reduplicate its DNA. By finding that structure, scientists can develop a drug to stop its reproduction and, thus, stop outbreaks of the disease. The research does not only have implications in stopping the spread of Norwalk; treatments using this research could also stop members of the same viral family, such as Polio, Hepatitis C, Foot-And-Mouth Disease, and SARS.
http://www.jbc.org/cgi/content/full/283/12/7705

Cartilage specimens can be imaged in different stages of degeneration using this DEI technique. The information obtained from this is important to help understand diseases such as

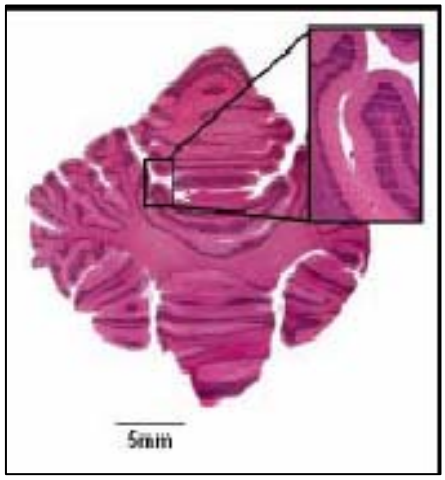


osteoarthritis. These images help researchers understand and diagnose the earliest stages of cartilage breakdown associated with the disease, before the damage can be seen using a conventional x-ray machine. DEI promises earlier detection of osteoarthritis and hopefully will lead to the prevention and treatment of the disease.
www.nsls.bnl.gov/about/everyday/osteoarthritis.html

Shedding Light on Cancer Treatments

Canadians are very interested in developing new and better medical treatments with cancer at the forefront. The CLS is contributing to the development of new and unique treatments.

Microbeam Radiation Therapy (MRT)



Synchrotrons offer a hope of treating deadly, difficult to treat brain tumours. Microbeam Radiation Therapy (MRT) uses superfine beams of high energy x-rays to destroy tumour cells while minimizing the damage to surrounding healthy tissue. The image to the right is of a stained section of piglet cerebellum. The lighter pink lines in the tissue indicate the path of the microbeams. Note that the surrounding tissue appears to be normal. While doing this trial researchers purposely treated through parts of the brain needed to function. The pigs that were treated were developmentally, behaviourally, neurologically and radiologically normal as observed and tested by experienced farmers and veterinary scientists unaware of which piglets had received treatment. This research, while still in the very early stages, provides hope for the potential treatment for currently inoperable tumours in infants.

http://www.lightsource.ca/bioimaging/microbeam.htm
http://www.esrf.eu/UsersAndScience/Publications/Highlights/2001/life-sciences/LS14.html

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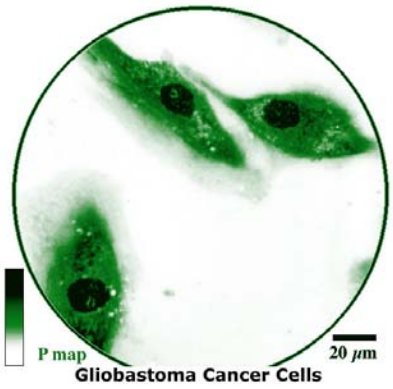
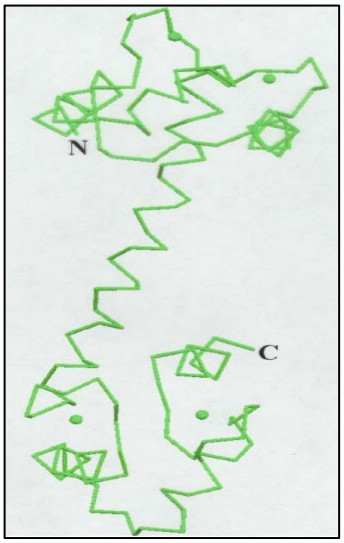


Synchrotron Stereotactic Radiotherapy (SSRT) starts by feeding cancer cells compounds containing a metal, such as gadolinium. Then, precisely-tuned x-rays are used to make the metal atoms emit low energy, very short range electrons, 'cooking' the tumour from the inside out. It changes the DNA of the tumour cells causing them to lose their ability to reproduce and retain fluids. Conventional radiation, which often uses megavoltage beams, is limited by the maximum allowable dose by the surrounding healthy tissue. In contrast SSRT uses kilovoltage x-rays which have low penetration power in tissue unless reacting with high atomic number elements, where they are useful because of the localized energy release.

http://home.physics.wisc.edu/gilbert/radio.htm
http://www.src.wisc.edu/news/Stories/destasio.1.2.06.htm
http://www.iop.org/EJ/article/0031-9155/49/22/008/pmb4_22_008.pdf



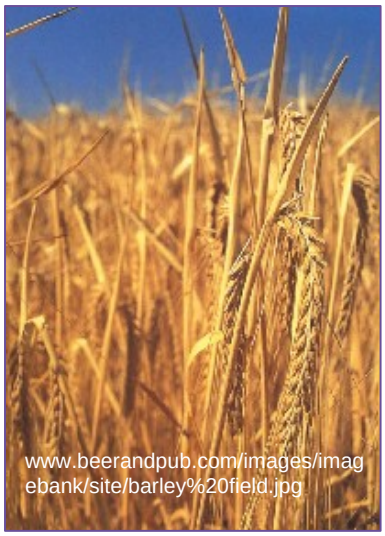
Calmodulin (CaM) is a very important protein that is present in every cell of the body. It is important in the process of cell replication and growth among other things. Trifluoperazine (TFP) is a drug that was developed as an antipsychotic, and often prescribed to treat schizophrenia. A Canadian researcher, Dr. Louis Delbaere at the University of Saskatchewan, resolved the structure of the protein using crystallography and identified a receptor site for TFP on CaM. The receptor site will allow the drug to interact with the protein, and in this case the TFP inhibits the CaM. Calmodulin is particularly abundant in cancerous cells. TFP can be used to starve the cancer by not letting the cancer cells multiply. It is being tested as a drug to treat early phase cancer because there is more calmodulin in the cancer cells, and that is what it targets

http://www.nature.com/nsmb/journal/v1/n11/pdf/nsb1194-795.pdf

Agriculture & Synchrotron Science

Being in the heart of the Prairies, there is a large interest in agricultural applications of the Canadian Light Source. There are many ways synchrotron science can be involved in agricultural research from analyzing soil, contributing to the development of more resistant crops, researching cures for diseases both in crops and animals, researching methods to detoxify the environment, to developing new products. With such a diverse area of research, there are several ways the synchrotron can be utilized.

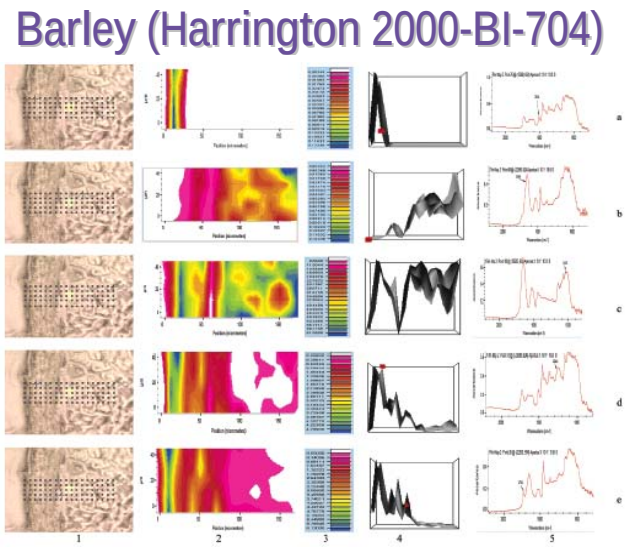
Learning more about plant proteins may allow researchers to develop **crops that are more resistant to environmental stresses** like drought, cold and salt. "It's the proteins in plant membranes that perceive stresses like cold, and then decide how to react to protect the plant," University of Saskatchewan Researcher Michelle Loewen says. Her research involves use of both X-ray Crystallography techniques at the synchrotron and traditional lab techniques. The results of her research could have far reaching implications. Crops with frost and cold resistance could mean longer crop seasons and greater yields. Breeding plants that can resist salt means existing unusable soil may become viable, increasing the available land for agricultural use. These advancements could make changes worldwide.


www.beerandpub.com/images/imagebank/site/barley%20field.jpg

By understanding how the proteins in the plants perceive stresses and how they react they can develop crops with different traits. Analyzing the structure of these proteins with synchrotron crystallography will speed up the results tremendously when compared to traditional methods.

http://www.lightsource.ca/brochures/pdf/michele_final.pdf

Synchrotrons can be used to map where different nutrients are contained in seeds, which could lead to better quality feed. Another use of synchrotron research is a better understanding of substances in seeds such as lignan, which is not useful for feed. Knowing where lignan is in barley seeds could help researchers develop a feed that is easier for animals to digest. University of Saskatchewan researcher Colleen Christensen analyzed barley seeds using



Yu et al. 2003. J. Agric. Food Chem. 51: 6062-6067

InfraRed (IR) light. The spectrum (image to the extreme right) proves the presence of this substance and the maps (colour and 3D intensity) show that lignan is located close to the surface of the seed. If a method of striping the outer edge (a few microns deep) of the seed was developed, a barley feed could be produced that has removed a significant contributor to waste material.

http://pubs.acs.org/cgi-bin/article.cgi/jafcau/2004/52/i06/pdf/jf035065a.pdf

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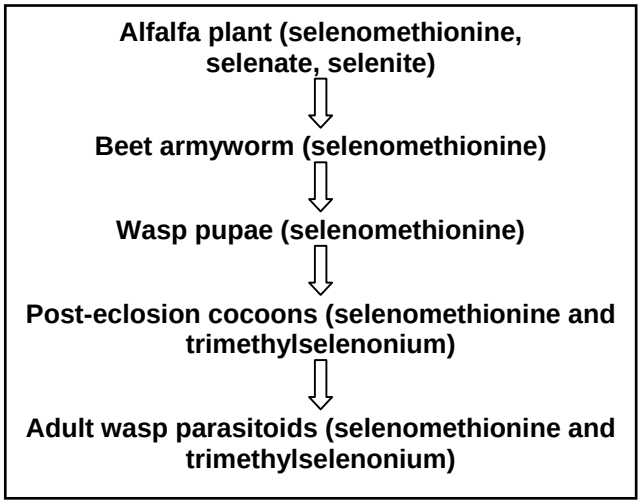
Phytoremediation is an emerging field that uses plants to clean up contaminated soils. Synchrotron light can be used to determine how elements change as they go through the food chain. Selenium poisoning is a global contamination problem release through a variety of industrial and agricultural activities including mining, combustion of fossil fuels, fertilization, and the production of glass. Synchrotron X-ray absorption spectroscopy conducted by University of Saskatchewan researchers Ingrid Pickering, graham George, and Helen Nichol tracked the changes in the speciation of the selenium as alfalfa plants accumulated the toxic selenium from the soil. Each level of the food chain transforms selenium into a less toxic form. Selenium is an essential micronutrient, but at higher levels and in certain states, it can be toxic. Livestock may be poisoned by selenium rich plants.

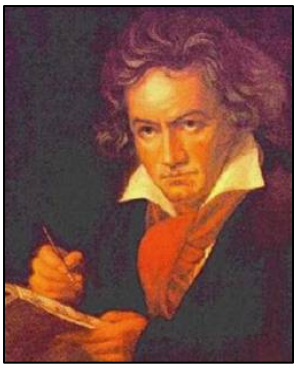


The beet army worm, an insect commonly found with alfalfa plants, consumed the plant and was subsequently consumed by a wasp pupae that continued through its life cycle. The researchers were able to track the changes in speciation of the selenium at each stage showing it to be in an organic state by the end of the life of the wasp. The selenium is in a less toxic form after each step, and this proves that the selenium is being detoxified. While not a solution to selenium contamination (beet army worms are considered an agricultural pest), the synchrotron provided valuable information for the research program. Evidence available from synchrotron research contributes to understanding the role that plants and insects play in the detoxifying process.

http://announcements.usask.ca/news/archive/2004/07/u_of_s_research_18.html
http://pubs.acs.org/cgi-bin/article.cgi/esthag/2004/38/i13/pdf/es049941s.pdf
Picture curtsey of Vicherman, D., Trumble, J., George, G., Pickering, I., and Nichol, H.

Mysteries of the Past & Synchrotron Science

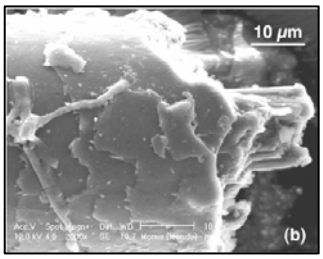
Synchrotron science is playing a role in solving mysteries of the past. Synchrotrons are an attractive tool for researchers because of their ability to analyze a sample without destroying it. It also allows researchers to obtain unique spectroscopic information from a sample that can be combined with complementary information from other scientific tools.



It is well known that composer **Ludwig van Beethoven** suffered from many health problems, but it took a synchrotron to get to the root of his illness. Using a technique called elemental X-ray fluorescence analysis, scientists analyzed Beethoven's hair and a piece of his skull and found levels of lead 100 times higher than normal. Interestingly, Beethoven wrote a letter to a friend describing his wish for researchers to use his body for science in order to determine what it was that ailed him throughout his life.

www.anl.gov/Media_Center/News/2005/news051206.html

Looking at hair with a synchrotron can reveal a lot about a person – such as what they ate and the environment in which they lived – even if the person is a 2,000 year old Peruvian mummy. Using X-ray diffraction, researchers have learned that the inner layers of hair can reveal information about diet, disease and exposure to pollutants.



http://www.unisa.edu.au/news/2003/191103.asp

The Mary Rose served as English King Henry VIII's principal warship for 35 years until she went down outside of Portsmouth in 1545. In 1982 the hull was recovered from the sea and has been undergoing a conservation process since. Unfortunately, wwhen a wooden ship sinks, sulphur accumulates in the timbers. Chemical reactions between the sulphur and iron in the hull and the air form sulphuric acid which literally dissolve the ship from the inside out. Fortunately, X-ray absorption spectroscopy techniques are helping to understand these chemical reactions and contribute to developing ways of halting this destructive process.

www.esrf.fr/NewsAndEvents/PressReleases/MARYROSE
www.esrf.eu/files/press/MARYROSEENGLISH2609.pdf