Multiple Uses of Chemicals

Written by Peter Mahaffy, The King's University College, Edmonton Canada

A chemical plant.

For many people, this rightly brings to mind a large building complex in which polymers, pharmaceuticals, or petrochemical products are synthesized from simpler starting materials. But botanical plants are also chemical factories. They utilize simple starting materials such as carbon dioxide molecules from the air to synthesize complex chemical substances that are a crucial part of our ecosystem and economy. We rely every day on the chemicals produced by both kinds of plants for food and medicine. Many pharmaceutical products were originally extracted from plants with a history of medicinal uses, or are closely related to those extracted compounds. An estimated 80% of the world's population relies completely on herbal medicine to treat disease.

So chemical plants, whether created by humans or found in nature, produce chemical substances essential to every day life. Often the same substance can be used to save lives or destroy them, depending on the dose of the substance, the chemical transformations we subject that substance to, and the way it is used in society. Let's consider one example.

Pseudoephedrine and Crystal Methamphetamine

***Ephedra*: An Ancient and Beneficial Medicinal Plant.** Ma-Huang, an evergreen shrub native to Northern China, is one species of the *Ephedra* plant. It's been called the world's oldest medicine, with uses in traditional Chinese medicine for over 5000 years. Traditional practitioners have used it for a wide range of illnesses, from colds, asthma, and hay fever to various kidney ailments. Over time, several pure amphetamine-like compounds called alkaloids have been extracted from *Ephedra*. These include the strongly bioactive isomeric molecules ephedrine and pseudoephedrine, which are remarkably similar to each other, differing only in the three dimensional arrangement in space of atoms attached to two carbon centres.

Ephedrine is reported to be one of the first active constituents from many Chinese herbal preparations to become widely used in Western medicine. Following thousands of years of medicinal use of *Ephedra* as an herbal preparation, ephedrine was admitted as a standard drug by the American Medical Association in 1927, and it was synthesized in the laboratory. However, the demand for ephedrine exploded so rapidly, that not enough of the drug could be synthesized. Thirteen years after the medical association designation, 700,000 kg of the plant *Ephedra sinica* were imported to the United States from China. By the 1940s, the United States began to cultivate the plant and import it from India and Pakistan.

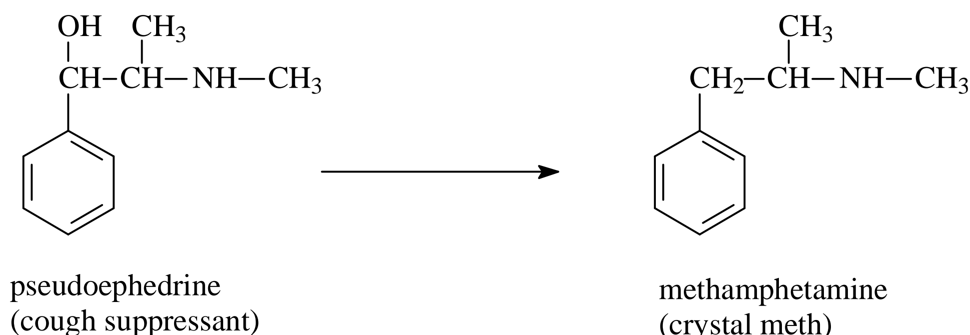
In the second half of the 20th Century, the use of *Ephedra* and its medicinally active extracts continued to grow. Recently *Ephedra* preparations have been marketed as stimulants that heighten sensations and as weight loss agents. One such formulation is

referred to as an "ECA Stack," an acronym for **E**phedra, **C**affeine, and **A**spirin (ASA) with the three advertised as working together to burn fat from your body.

Another *Ephedra* extract, which can also be made synthetically, is pseudoephedrine, which has fewer central stimulant effects than ephedrine. Pseudoephedrine is used in many pharmaceutical decongestants and antiasthmatic formulations as a nasal decongestant and a bronchodilator to relax and open air passages to the lungs.

***Ephedra* Extracts: Misuse of a Beneficial Medicinal Plant.** But the beneficial compounds extracted from this medicinal plant can have severe adverse side-effects when overused. Major concerns have been raised recently around the world about dangerous side effects and drug interactions of *Ephedra* extracts, leading to restrictions such as the 2004 United States Food and Drug Administration (US FDA) ban on the sale of dietary supplements containing *Ephedra* alkaloids (lifted in 2005) and a similar 2004 ban in the Netherlands.

The Dark Crystal: Abuse of the Beneficial Medicinal Plant Ephedra. Pseudoephedrine, which has been put into pharmaceutical decongestants, can readily be taken back out again and chemically transformed. As a result, it is rapidly becoming infamous as a readily available precursor for the production of one of the world's fastest growing drugs of abuse, methamphetamine, or "Crystal Meth." Pseudoephedrine and methamphetamine are very closely related in structure, with reduction, or replacement of an alcohol functional group on the carbon chain with a hydrogen atom, the only transformation required to convert pseudoephedrine into methamphetamine.



pseudoephedrine
(cough suppressant)

methamphetamine
(crystal meth)

Using recipes for this chemical transformation available on the internet, and easily obtained store-bought supplies and equipment, small clandestine laboratories in many neighborhoods around the world turn decongestant tablets into clear, crystal chunks of Meth. Crystal Meth can be smoked, snorted, or injected, and is now the most prevalent synthetic drug manufactured in the United States. The huge demand for the product has also spawned illicit export industries in many countries. Some countries are reported to have increased importation of cold medication by hundreds of tonnes in a few years, far exceeding the legitimate demands for use by cold and asthma suffers.

The effects of methamphetamine abuse are similar to those of cocaine, but last longer. Users can experience erratic and violent behavior, suppressed appetite, interference with sleeping behavior, mood swings and unpredictability, tremors and convulsions, increased blood pressure and irregular heart rate. Coma, stroke, or death are possible long-term effects.

Not only methamphetamine drug addicts feel the effects. Municipalities and other levels of government in many countries need to budget large sums for treating and rehabilitating addicts. Hardcore methamphetamine users often leave a trail of domestic violence and criminal activity. Crystal Meth labs are often simple, small scale operations found in garages or the basements of homes. The create hazards from explosions, fires, and unsafe storage of materials and synthetic apparatus. For each kg of finished methamphetamine, about five kg of toxic environmental waste material is produced. Since proper disposal of this waste might trigger the identification of a clandestine laboratory, this waste material is often dumped illegally and creates environmental damage.

Multi-use Materials: Beauty of Use and Power for Abuse in the Hand of the Holder. As we've seen in the example above, the *Ephedra* plant and the chemicals extracted from it can be used by humans for thousands of years for beneficial medicinal purposes, and in a very short period of time, turned by other humans to harmful and destructive purposes. This is true of many of the chemicals we synthesize and extract from nature. We call these chemical substances **multi-use materials**. Choices about the beneficial use, misuse, and abuse of these multi-use chemicals lie in our hands.

The Role for Science Education. What is the role for formal and public education in raising awareness of the need for responsible uses of substances such as the extracts of the *Ephedra* plant? One can envision several different levels at which educators might meaningfully engage students and the general public about their ethical responsibility toward multi-use chemicals such as pseudoephedrine. But many of the questions are difficult, including the following:

- **Access to Information**. If teachers introduce examples of multi-use materials like pseudoephedrine and Crystal Meth to young students, is there a danger that people who didn't know about this drug of abuse will not only find out about a new drug of abuse, but easily obtain formulas for making it?

- **Diversion of Readily Available Materials.** On the other hand, if students and the general public become aware of the combination of store-bought materials that are needed to produce a drug of abuse like Crystal Meth, can that information empower them to play a meaningful role in preventing misuse by others? It is interesting to note that police and other protectors of public safety in North America now sometimes publish on the Internet a great deal of information about how Crystal Meth is made, including pictures of equipment, so parents and others can recognize clandestine labs when they see them.

- **Whose Responsibility**? Where does the responsibility lie to monitor the diversion of supplies and materials for clandestine purposes such as making drugs of abuse? Governments at the national or local level? Medical and social services systems? Pharmacies that sell decongestants and supermarket stores that sell scissors, tubing, canning jars, iodine tincture, and rubbing alcohol?

- **Understanding and Owning Ethical Responsibility.** Do students and teachers have ethical responsibilities that result from the scientific knowledge they possess about the potential for use and misuse of everyday chemical substances? If you don't know anyone who abuses Crystal Meth, does this lessen your ethical responsibilities?

2. Other Examples.

Talk with others in your group, and identify other examples of multi-use substances in your communities that are beneficial, but have the potential to be used or misused. What are the best ways to introduce these examples into classrooms or public education?

3. Chemical and Biological Weapons

The pseudoephedrine/Crystal Meth example has some intriguing parallels with other multi-use substances that have many beneficial applications, but have also been abused in the past century by conversion into weapons of destruction. We would hardly recognize many of these substances as they are so commonly used to enrich our lives. A solvent like isopropanol or rubbing alcohol, for example, is a clear and flammable liquid that is used as a disinfectant in hospitals and homes, and a low cost solvent for many applications. Some examples of its uses include:

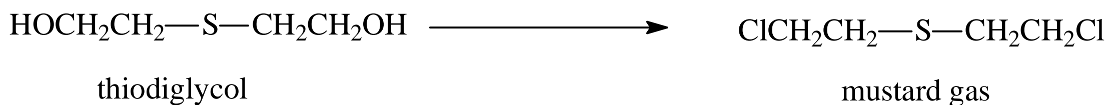
- Extracting active ingredients (natural products) from plants
- The manufacture of food products
- Dissolving and apply coatings and dyes
- Cleaning and drying agent in the manufacture of electronic components and metals
- Distributing pharmaceutical products and cosmetics that are applied to the skin
- An aerosol solvent for cleaners, waxes, pharmaceutical products, deodorants, and pesticides.

Yet those same properties that make isopropanol an excellent solvent for beneficial applications have been exploited in the synthesis of some of the most toxic nerve agents that have been produced by humans. One such nerve agent is Sarin, used effectively in an attack on the subway system in Tokyo during the peak of morning rush hour on March 20, 1995. Nerve agents like Sarin, Soman, and VX attack the nervous system of the human body, with devastating effects. In the Tokyo incident, 12 people were killed and five thousand others injured. The final step in the production of Sarin involved using mixing isopropanol with two precursors to produce the nerve agent, which was carried on to the subways in 11 plastic bags and released by poking umbrella points through the bags.

Thiodiglycol is another chemical that is widely used for water based dyes in the cloth manufacturing industry in developing countries and elsewhere. It is a key component in

water based inks used in the manufacture of felt tip pens and some printing inks. It is also a used in the production of specialty resins and adhesives, and as a lubricant additive.

Yet a chemical transformation turns thiodiglycol into mustard gas, the chemical weapon that gave shape to a new way of killing in World War I.



> **The Role for Science Education.** What is the role for formal and public science education in raising awareness about the production of chemical weapons such as Sarin, and the multiple uses of chemicals such as isopropyl alcohol used in their manufacture? Should information flow about the precursors and reactions and materials needed for synthesis be restricted, so the public won't learn how to produce chemical weapons? Whose responsibility should it be to monitor precursors and materials needed to make chemical or biological weapons? If you don't know anyone who produces chemical weapons, does this change your ethical responsibilities?

References:

Many of the details above come from sources on the internet. Key references include:

1. http://www.opcw.org – Web site of the Organisation for the Prohibition of Chemical Weapons
2. http://www.deadiversion.usdoj.gov/pubs/brochures/pseudo/pseudo_trifold.htm US Department of Justice, resources on preventing the diversion of pseudoephedrine to the production of Crystal Meth.
3. http://www.newhousenews.com/archive/suo060605.html News story on the production of Crystal Meth in Mexico to feed the American market.
4. http://www.chemicalland21.com/ A Korean company that buys and sells chemicals, including pseudoephedrine.
5. http://nccam.nih.gov/health/alerts/ephedra/consumeradvisory.htm Advisory by the US Food and Drug Administration banning the sale of dietary supplements containing ephedrine alkaloids.
6. http://www.botgard.ucla.edu/html/botanytextbooks/economicbotany/Ephedra/ Botanical information on *Ephedra* from the Mildred Mathias Botanical Garden at UCLA in the US.
7. http://www.ephedra.nu. A comprehensive guide by *Ephedra* "stakeholders."
8. http://www.drugfree.org/Portal/drug_guide/Crystal_Meth# Information on Crystal Meth from a "nonprofit coalition of communication, health, medical and educational professionals working to reduce illicit drug use and help people live healthy, drug-free lives."
9. http://www.healthyplace.com/Communities/Thought_Disorders/schizo/articles/crystal_meth.htm. Information on Crystal Meth from a large consumer mental health site, whose mandate is to provide comprehensive information on psychological disorders and psychiatric medications from both a consumer and expert point of view.
10. http://www.isp.state.il.us/crime/whatismeth.cfm. Information from the US Illinois state police on Crystal Meth, including pictures of devices used to produce it.
11. http://www.totse.com/en/drugs/speedy_drugs/howtomanufactu172921.html - A recipe for making Crystal Meth.

Toxicology of Chemical Warfare Agents

Written by Alastair Hay – University of Leeds, UK

Large scale use of toxic chemicals as weapons occurred during the First World War (1914-18). Over one hundred thousand tonnes of chemicals were used on the battlefields. Initial chemicals were used to harass rather than seriously injure or kill. In the region of ten per cent of the total tonnage of chemical warfare agents used during the First World War (WW1) were chemicals of this type, namely tear gases, lung irritants and vomiting agents. Use of more lethal chemicals followed the use of the disabling chemicals resulting in some 1.3 million casualties during the war, of whom some 90,000 are estimated to have died.

In the Second World War (1939-45) substantial stocks of chemical weapons were accumulated with Japanese use in China being the only significant occurrence during the war of chemicals being used as weapons. Following the end of the Second World War , systematic surveys which had been conducted during the war and before this to find ideal chemical warfare agents continued.

Despite the screening of thousands of chemicals only some 60 or so satisfied the appropriate physical, chemical and toxicological properties to enable their use as chemical warfare agents. Some two thirds of these were used during the First World War when battlefields acted as testing grounds. Analysis of the casualties caused whittled the number of effective chemicals as weapons down to about a dozen. More agents have been added since and some of the early agents supplemented by newer developed chemicals.

Classification of chemical warfare agents
Chemical warfare agents can be classified into lethal agents which are intended either to kill or injure the enemy so severely as to necessitate evacuation and medical treatment, or as disabling chemicals which would incapacitate and cause a disability from which recovery may be possible without medical aid. In addition to the known chemical warfare agents there are many toxic industrial chemicals which although less toxic than the known chemical warfare agents, could cause great harm. Take the release of the chemical methyl isocyanate in Bhopal, India, which caused thousands of deaths and even greater number of individuals with reported chronic injuries. When considering chemicals as weapons it is important, therefore, to consider not just the standard chemical warfare agents, but other toxic industrial chemicals.

Lethal chemicals
Lethal chemicals which have been developed into chemical warfare agents (toxic and industrial chemicals) may be divided into two further categories which are tissue irritants and systemic poisons. The first category would contain the choking gases (such as chlorine and phosgene) and blister gases (such as mustard gas). Systemic poisons would include what was previously classed as blood gases, such as hydrogen cyanide and the nerve gases (such as sarin and VX).

Chlorine, which is an asphyxiant was the first lethal chemical used in World War One. In April 1915 large scale surprise attacks were launched by the German army causing thousands of casualties among Franco-Algerian troops who had no protection against air-borne chemicals. Although interrogation of German prisoners had indicated cylinders of chemicals were being placed in trenches, it would appear that these warnings were not taken seriously enough by all sectors. Evidence suggests that the British and Canadian high commands treated the reports more seriously enabling a more rapid British retaliatory response to the initial attacks. Respirators used initially to protect the troops were crude at first but became increasingly more sophisticated. At the same time efforts were made to find agents more aggressive than chlorine leading to the wide spread use of phosgene, another lung irritant. Hydrogen cyanide which was available was not used much because the small munitions available at the time did not deliver sufficient casualty inducing concentrations of this gas which is lighter than air. The most significant development during the First World War was the use of what are known as vesicant agents which will damage tissue that the agent comes into contact with. Mustard gas is in this category and it will poison both through inhalation and skin penetration.

Without doubt the most significant development in the lethal agents occurred when organophosphate nerve agents were synthesised. The search in Germany for an organophosphate compound to find suitable insecticides resulted in the first nerve agent being identified. Known as Tabun some 12,000 tonnes of the agent had been produced by 1945 and much of it filled into munitions. None of the agent was used by Germany during World War Two. Tabun is what is classed as a ‘non-persistent’ nerve agent. After 1945 work continued in a number of countries on nerve agents and a further class of more persistent organophosphate nerve agents (one of which was known as VX) was identified, many tonnes of which subsequently were filled into munitions.

Individual chemicals

Phosgene

Phosgene does not occur naturally but since its initial preparation in the early 1800s it has become widely available in the chemical industry where it is used as an intermediate in the manufacture of a wide range of other substances including dye stuffs, pesticides and polymers. Annual production worldwide is in the millions of tonnes. Exposure to phosgene is primarily through inhalation. The lung is the main target organ with damage to it following acute exposure being proportional to the product of the concentration and duration of exposure. At high concentrations skin and eye irritation also occur. Descriptions of its smell range from decaying fruit, fresh cut grass or mouldy hay. Irritation of eyes, nose and throat together with chest tightness will occur rapidly when concentrations are greater than 3 parts per million (3 ppm), and these symptoms will be followed by shortness of breath and a cough. If these are the only symptoms they will disappear rapidly after exposure ceases. If the dose is greater than (30 ppm) every minute more serious respiratory and lung damage occurs. This presents itself as water on the lung which is occasionally fatal. Although individuals can be trained to detect phosgene at low concentrations, the sense of smell is a poor guide to interpreting might be in the air. At high concentrations individuals lose their sense of smell and their ability to assess danger.

Hydrogen cyanide

A rapid-acting lethal agent hydrogen cyanide poisons by preventing individual cells utilising oxygen. At atmospheric pressure liquid hydrogen cyanide is colourless to yellowish brown in appearance. Not everyone can detect hydrogen cyanide at low concentrations but those who do describe a smell of bitter almonds or marzipan.

Hydrogen cyanide is widely available in the chemical industry as an intermediate and it is also used as a pesticide, rodenticide and a fumigant. In some countries where capital punishment is still permitted hydrogen cyanide is used to kill. More general exposure to hydrogen cyanide occurs through tobacco smoke and smoke inhalation from fires. The most likely route of entry is inhalation. Although hydrogen cyanide vapour will not cross the skin, liquid hydrogen cyanide will penetrate as will many aerosols. An exposure to 60milligrams (mg)/metre(m)^3 may not cause any serious symptoms but at concentrations above 200mg/m^3 death occurs after ten minutes. Above 2,500mg/ m^3 death is likely within one minute.

As the gas is rapidly absorbed from the lungs symptoms of poisoning are equally rapid. Hyperventilation occurs initially and increases with the dose inhaled leading to rapid loss of consciousness. Death occurs either through heart failure or failure to breathe. No long term health implications are likely for those exposed to low concentrations but at near lethal concentrations the effects of hydrogen cyanide on the cell's ability to utilise oxygen is likely to affect brain function.

Mustard gas

Mustard gas (sometimes known as sulphur mustard) is a vesicant or blister agent. It causes general tissue irritation as well as affecting internal body functions. Of the vesicant agents investigated for chemical warfare purposes, mustard gas was a favourite. First synthesised in 1860 it was developed as a chemical warfare agent during the First World War and it has practically no other application. At high concentrations the gas has a pungent odour variously described as being like that horse radish, onions or garlic. Only slightly soluble in water it will dissolve in organic solvents and fats. Exposure to both liquid and vapour occurs mainly by inhalation and skin contact. Eye injuries sufficient to incapacitate will occur at concentrations of 100mg/m^3 if the exposure occurs for one minute. [This is often written as 100 mg.min/m^3]. Significant skin burns occur at concentrations twice this. The estimated lethal dose by inhalation is 1500 mg.min /m$^{3.}$

Mustard gas vapour can be carried long distances by the wind. Significant casualties from mustard gas occurred in the First World War, in the Iraq –Iran war between 1980-1988 and amongst the Iraqi Kurds in 1988. In those with no protection signs and symptoms of exposure to mustard gas develop gradually after an interval of several hours. This interval will vary between individuals and is affected by the route of exposure and environmental temperature.

The eyes are usually the first affected and develop a gritty feeling and appear bloodshot. This is followed by acute pain in the eyes which begin to water extensively and vision is affected. Other symptoms follow with runny nose, sneezing, sore throat, coughing and hoarseness.

Breathing problems may also develop. People are likely to complain of nausea and may vomit. Within 16-24 hours the skin begins to itch and darken in exposed areas. The armpits and genitals are vulnerable to blistering. Where there is moderate to severe exposure large blisters developwhich are filled with a clear yellow fluid. When these break the skin is eroded and ulcers may occur. These may heal in 2-3 weeks but if the erosion of the skin is severe healing may take 6-12 weeks and there may be significant scarring.. In the area of the damaged skin severe pigmentation may occur. The actual site of the mustard burn is also very sensitive to any kind of physical trauma. Individuals with significant scarring complain of persistent itching.

The airways can be severely damaged as a result of mustard gas exposure and the damaged tissue allows infection to set in. This may result in pneumonia which in turn could be fatal. Recovery from lung injury is slow. Sulphur mustard is absorbed and distributed through the bloodstream and it will affect an individual's immunity leaving them vulnerable to infections; pneumonia and septicaemia may result.

The long term effects of exposure have become evident in Iranian victims of mustard gas exposure. There are persistent skin problems and severe lung diseases such as bronchitis and emphysema. Eye damage is also evident in some individuals and the effect has both been delayed and led to blindness. Mustard gas also has the ability to damage DNA and is a potential cancer causing agent. Individuals involved in the manufacture of mustard gas have a high incidence of cancer of the respiratory tract.

A related type of mustard agent called nitrogen mustard is actually used to prevent cancer. Mustard agents have at least two 2-chloroethyl groups attached either to thioether residues (the sulphur mustards) or to amine residues as in nitrogen mustards. The N ($CH_2)_2$ Cl grouping of nitrogen mustard is an essential component of 3 common anticancer drugs used to treat cancers such as myeloma, Non-Hodgkin's lymphoma, Hodgkin's disease and certain leukaemias.

Nerve gases

Nerve gases or nerve agents are organophosphate compounds that inhibit the enzymes known as cholinesterases. This inhibition will disrupt nerve function. Nerve gases are in two families: those known as G agents which act primarily through inhalation and the so-called V agents which act primarily through skin penetration and inhalation of an aerosol. The nerve gases are similar both chemically and in their toxic properties to many of the commercial organophosphate pesticides. The nerve agents are mostly odourless and colourless and at ambient temperature appear as either colourless or yellow-brown liquids.

Nerve gases may be absorbed through any body surface and when dispersed as a vapour, aerosol or adsorbed to dust, they are rapidly absorbed through the lungs. Exposures to concentrations above 3 $mg.min/m^3$ will affect vision. At higher exposures the inhibitory effects of the gases on the cholinesterase enzymes causes a wide range of symptoms including severe headache, eye pain, runny nose, tightness in the chest, wheezing, increased sweating, pronounced tiredness and weakness, rapid changes in mood and nightmares. Individuals are invariably very confused.

Lethal doses of nerve agent are estimated to be about 150 mg/m^3 per minute for Tabun. Doses of chemical warfare agents are given as the product of concentration and time. Thus for Tabun a lethal dose would also be 15 mg/m^3 over ten minutes. To cover both time intervals the dose is usually written as 150mg.min/m^3. With the nerve agent Sarin, lethal doses are 70-100 mg.min/m^3. For VX the lethal dose is about half that for Sarin. If the concentration of the nerve agent is high effects are likely to occur within several minutes and if exposure is to several lethal doses death will occur in a matter of minutes.

After a single mild to moderate exposure a full recovery is likely. With more severe poisoning specific treatment with antidotes is necessary to save lives. Nerve agents are the only chemical warfare agents for which there are specific antidotes. Following severe poisoning there is no guarantee of full recovery.

Agent CS

2-chlorobenzalmalononitrile, or CS as it is more commonly known, is a white crystalline solid at ambient temperatures. Classed as a harassing agent, CS acts rapidly to intensely irritate the eyes and mucous membranes in the nose and throat. It can be spread as a dust cloud or in solution in an organic solvent. CS is widely available commercially as a riot control agent.

The eye and respiratory tract irritation occur within a minute in some individuals at exposures as low as 0.004 mg/m^3. Very marked harassment of individuals occurs at concentrations of 4mg/m^3. These agents are in favour as riot control agents because the lethal dose is extremely high and many, many times greater than the concentration required to cause irritation. Estimates of the lethal dose, and they are only estimates, range from 25,000 to 150,000 mg.min/m^3 .

Recovery from harassing exposures usually occurs within about 30 minutes of exposure ending but may persist for longer. The major reason for signs and symptoms persisting is the ineffective removal of CS agents from affected body surfaces. Solutions of CS cause severe skin irritation, the reddening of the skin occurring within a few minutes and persisting for about one hour. A delayed marked reddening (erythema) of the skin may persist for 24 to 72 hours and the skin may also blister and have a crusty look. Recovery of the skin from this more severe damage may take weeks.

In those exposed to CS the chest will feel sore and tight and some people try to hold their breath. Exposed skin, particularly in the nose and throat, will sting and burn after a few minutes. Some people may also feel nauseous and vomit. The highly irritant effects of CS make people anxious and lead to a temporary increase in both blood pressure and heart rate. Those with asthma are at risk of asthmatic symptoms because of irritation of the lungs. There is no evidence that CS will cause cancer.

Conclusion

Much more information about the chemical and toxic properties of the few agents described above is available in the scientific literature. A wealth of information has been published about other types of chemical warfare agents as well. The published literature can be accessed through a range of on-line databases including MEDLINE, EMBASE, PubMed and TOXLINE. Other published sources include the following books:

References

"Public Health Response to Biological and Chemical Weapons": WHO Guidance. World Health Organisation, Geneva, 2004. Also available at http://www.who.int/csr/delibepidemics/informationresources/en/
The text is available in English, French, Spanish and Russian.

Mars, T.C., Maynard, R.L., Sidell, F.R., *Chemical Warfare Agents Toxicology and Treatment*. Chichester. Wiley, 1996.

Vedder, E.B., *The Medical Aspects of Chemical Warfare*. Baltimore, Maryland. Williams and Wilkins, 1925.

Sidell, F.R., Patrick, W.C., Dashiell, T.R., *Jane's Chem-Bio Handbook*. Coulsdon, England. Jane's Information Group, 1998.

Somani, S.M., Romano, J.A. (eds.), *Chemical Warfare Agents: Toxicity at Low Levels*. Boca Raton, Fa. CRC Press, 2001.

Chemicals – Good and Bad

Written by Edwin Becker, National Institutes of Health, USA and Ralf Trapp, Organization for the Prohibition of Chemical Weapons (OPCW)

Everything in the world is made of chemicals – naturally occurring and synthesized by humans. Some naturally occurring chemicals are used in their native form – for example, water, sand on the beach, oxygen in the air we breathe. Some are processed before use, as in petroleum that is refined to extract the chemicals used in gasoline; iron that is extracted from its ore; food that is extracted from plants and processed to make chocolate cake. Some chemicals are totally created by humans from various combinations of naturally occurring raw materials, such as nylon fabrics, computer chips and many pharmaceuticals. Over 200 years, a vast and complex industry has developed to synthesize these chemicals, sometimes in large sophisticated reactors, sometimes by enlisting the aid of microorganisms to carry out part of the work. Our entire way of life depends on the interplay of the chemicals that make up our bodies with the chemicals in the world that surrounds us.

All chemicals pose some degree of hazard, either alone or in various combinations. Chemists have learned how to handle chemicals and to control chemical reactions so as to minimize any risk to humans and to the environment. The chemical industry is continually finding better ways to make synthetic chemicals and their production safer and to eliminate waste products that could damage the environment – the aim of so-called “green chemistry.”

However, some chemicals are deliberately designed to be toxic! For example, the pharmaceutical industry creates many chemicals that, if the dose is right, can kill pathogenic bacteria and viruses without harming the host organism. Other chemicals are designed to poison cancer cells in the human body. The agrochemical industry synthesizes chemicals that kill insects, fungi, rodents and other pests that could destroy our food supply, or that help controlling weeds. So even very toxic chemicals can be beneficial to humans provided they are designed to target only the offending elements and are used in a careful and responsible manner.

Certain toxic chemicals have been created with a completely different purpose – to kill or injure humans. Chemical weapons (in the past often called “poison gas”) have been used through history, beginning with primitive materials, such as noxious fumes from burning sulfur, and moving to synthetic chemicals with extreme toxicity that were largely developed during the first half of the twentieth century. These chemical weapons were used during World War I and subsequently in several regional wars and conflicts. During the second half of the 20th century tens of thousands of tons of chemical warfare agents were produced in forms that could be used as weapons of war and stockpiled in munitions shells, bombs, containers and in other forms. Some agents cause horrible blistering of the skin and suffocation by their attack on the lungs. Others are deadly poisons to the central nervous system and cause rapid paralysis and death. Of all the weapons of war, chemical weapons have long been regarded as particularly repulsive.

Throughout history there have been taboos against the use of chemical weapons. For example, the use in war of "plague and poison" has been stigmatized in diverse cultures, including by the Greeks and Romans, in the Manu Law of War in India, or in the Saracens' rules of conduct of war. In the latter part of the 19th century there were several international attempts to codify the ban on chemical weapons, but those agreements did not prevent their use and their production for possible future use. In 1925, the Geneva Protocol was adopted, banning the use of chemical weapons and of bacteriological (biological) means of warfare. But this did not stop nations from acquiring and in some instances using them. Finally, in 1993 the countries of the world formulated a more sophisticated and far-reaching treaty – the ***Chemical Weapons Convention*** [CWC] – that bans the possession and use of chemical weapons and aims to eliminate chemical weapons, everywhere in the world, forever and under strict international verification. In 1997 it came into force after 65 nations had ratified it in1996, and subsequently that number has risen to 173 *States Parties*. A further 12 States have signed, but not yet ratified the Convention, and although they are not formally a party to the CWC they have made a commitment to adhere to the principle that chemical weapons are banned. Only 9 States have not taken any such action.

Everyone engaged in the use of chemicals and chemical technology should understand the intent of the CWC – to recognize what aspects of chemicals it prohibits and to appreciate the much broader applications of chemistry that it not only allows but encourages. Everybody engaged in the use of chemicals and chemical technology should realize that the CWC might apply to them – chemicals *per se* are not good or bad but even chemicals and technologies intended for the best of purposes could be misused.

The CWC: An Overview

The full text of the Chemical Weapons Convention and its Annexes runs about 140 pages.[#] Like most legal documents, its language is precise and very detailed in order to provide an unambiguous text for regulation, but the basic concepts are really rather straightforward. At the risk of some oversimplification, let's try to look at the meaning behind the technical and legal jargon.

The framers of the CWC recognized the value of chemistry and chemicals to the world, and the CWC is designed to promote the responsible use of chemicals. It has been strongly supported by the international chemical industry, which recognizes the need for a certain amount of regulation of its activities in order to prevent the misuse of chemicals as weapons of war.

The CWC deals with *toxic chemicals*, defined as "any chemical which through its chemical action on life processes can cause death, temporary incapacitation or permanent harm to humans or animals," along with certain *precursors* to toxic chemicals. Because such chemicals may have many peaceful and very valuable uses themselves or in chemical reactions to produce other valuable substances, the CWC distinguishes the *purposes* for which the chemical is prepared, stored, traded or used. This so-called ***general-purpose***

[#] The text of the CWC is available at www.opcw.org

criterion is at the heart of the CWC. It prohibits all toxic chemicals and their precursors "except where intended for purposes not prohibited under this Convention, as long as the types and quantities are consistent with such purposes". This rather tedious phrasing *allows* the use of chemicals for all applications any of us would encounter in normal, legitimate activities. The CWC specifically *includes* among such allowed purposes industrial, agricultural, research, medical, pharmaceutical, or other peaceful purposes, as well as protection against toxic chemicals and chemical weapons, and law enforcement. It even allows (or rather, it does not prohibit) the use of chemicals for military purposes [for example, as explosives] provided they are not dependent on the use of the toxic properties of chemicals as a method of warfare.

Although the general purpose criterion covers all chemicals that exist and any that might be synthesized in the future, the framers of the CWC also included three lists or *schedules* of about 50 chemicals and classes of chemicals that have already been developed as chemical weapons or could readily be converted to such weapons. Annual reports are required on the production or transfer of these *scheduled chemicals*, which range from known weapons such as sarin, lewisite, mustard gas and ricin to such common substances as phosgene, hydrogen cyanide, trimethyl phosphite and triethanolamine. The CWC does not prohibit the use of any of these chemicals. Many are needed in chemical synthesis, others are ingredients in formulations and products used in such diverse areas of human activity as dying textiles or mining. Even powerful chemical weapons, such as nitrogen mustard and saxitoxin, have valid uses in research and in medical treatment. The CWC merely keeps track of their production and use, and it provides for the inspection of government and private institutions that manufacture or use them above certain amounts.

Destruction of Chemical Weapons

An important aspect of the CWC is the requirement that States Parties declare their existing stockpiles of chemical weapons and agree to destroy them completely within specified timeframes. Altogether, more than *71,000 metric tons* of chemical weapons were declared by six States, the bulk located in Russia and the United States as a legacy of the cold war. To date, about 12,000 metric tons have been destroyed. The destruction processes are technically challenging and very expensive because of the variety of weapons and chemicals and the need to assure a high level of safety and protection of health and the environment. In addition, 64 chemical weapons production facilities have been declared, and most have already been destroyed or converted to permitted uses.

The OPCW

The CWC provides a framework for administering and enforcing its provisions via the *Organization for the Prohibition of Chemical Weapons* (OPCW). The OPCW consists of the States Parties (which collectively make up the Conference of the States Parties of the CWC), the OPCW Executive Council and a Technical Secretariat, located in The Hague, Netherlands, headed by the Director-General. The OPCW handles a wide variety of tasks,

including the collection, verification, analysis and publication of data from States Parties. Inspectors from the OPCW verify the declarations of chemical weapons as well as their destruction through on-site inspection of the stockpile locations and destruction processes. They also carry out routine inspections of chemical production facilities to verify the accuracy of the declared data and to ensure that activities are in line with the requirements of the Convention not to develop, manufacture or trade any chemicals for chemical weapons purposes. Furthermore, the OPCW has the capability to carry out "challenge inspections" into allegations that a State has violated the CWC – a process that has so far not been used. A challenge inspection can be used to inspect locations or facilities in a State Party "anywhere, any time, at short notice, and without a right of refusal". Routine inspections have been aimed at building confidence among States Parties that there is uniform compliance with the provisions of the CWC. In addition, the OPCW provides technical assistance on chemical weapons disarmament issues to States Parties, helps them improve their protection against chemical weapons, and carries out programs to foster international cooperation in such areas as chemistry education, the exchange of scientific and technical information and equipment for peaceful purposes, the promotion of peaceful chemical research and the adoption of sound practices in chemical manufacturing. The OPCW web site www.opcw.org provides comprehensive information on current activities and programs.

The CWC prohibits *all* use of chemical weapons. However, it is a treaty among nations, and the international enforcement mechanism through the OPCW primarily concerns the activity of States. Implementation within each country is the responsibility of the State Party and the *National Authority* that it creates. Most States Parties have passed implementing legislation that provides civil and criminal penalties for non-compliance, and that requires individuals as well as chemical companies to respect the non-proliferation provisions of the CWC and to report certain data to the National Authority. Today, there is great concern that terrorists will obtain access to chemical weapons or related materials (for example, precursor chemicals or toxic industrial chemicals) in one way or another. The basic responsibility rests on national governments to curb terrorism within its borders, but the OPCW provides advice and technical assistance with the development of legislative, regulatory and enforcement measures that States Parties use to prevent access to chemical weapons and related materials by criminals and terrorists.

The Australia Group

Complementary to the framework of the CWC, but working toward similar objectives, is the *Australia Group*, an informal group of 39 nations and the European Commission, mostly highly industrialized, that are all States Parties to the CWC and the BWC. This Group harmonizes national export licensing measures of the participating nations to *prevent* the distribution of certain facilities, equipment and materials that could be used for chemical and biological weapons programs. . Some States Parties of the CWC criticize the Australia Group because its members also apply these licensing procedures to States Parties of the CWC and they feel that this conflicts with the objective of the CWC to promote exchanges of scientific and technical information and chemicals and equipment between States Parties for peaceful purposes. The members of the Australia Group, on the other hand, see their

measures as fully consistent with the CWC and in harmony with their obligation not to assist in the proliferation of chemical weapons.

The BTWC

The *Biological and Toxin Weapons Convention* (BTWC), which went into effect in 1975, has aims similar to those of the CWC but is directed toward biological weapons. It, too, is built around a general purpose criterion. Although established long before the CWC, the parties to the BTWC have thus far not been able to agree on verification and inspection mechanisms, and there is no multilateral (international) administrative structure comparable with the OPCW. The two conventions overlap in that toxins produced by microorganisms are also chemicals within the meaning of the CWC.

The Future

Incrementally the OPCW is approaching its goal of "universality" in having every nation adhere to the CWC. The OPCW provides international assurances through on-site inspections that these States comply with their treaty obligations and destroy any chemical weapons and related production capabilities they have, and that they will not resume manufacture of chemical weapons in the future. The States Parties themselves are putting legal and other measures in place that extend the ban on chemical weapons beyond the State itself, covering individuals as well as companies. But ultimately, it is also the responsible behavior of the individuals that deal with chemicals and chemical equipment and technologies that is needed if the abolition of chemical weapons is to be lasting. The quotation featured on the OPCW web site – "Determined for the sake of all mankind, to exclude completely the possibility of the use of chemical weapons..." – makes a powerful statement to end this blot on the impressive record of chemistry's contributions to mankind. The work of OPCW, together with individual national efforts, has minimized the spread of potential chemical weapons, but there will always remain the possibility of new discoveries that might create an inadvertent chance for the emergence of what could become new generations of chemical weapons, and there will always remain the possibility of small amounts of chemicals being diverted by terrorists to unsavory uses.

IUPAC believes that an improved understanding of chemical weapons disarmament, and of the individual ethical responsibilities of everyone using chemicals, can significantly augment these national and international efforts.

The Prevention of Chemical Weapons: What Role for Codes of Conduct?

Written by Brian Rappert (University of Exeter, United Kingdom)

Aims:
* Develop an appreciation of changing place of chemistry and chemical engineering in society.
* Inform about the range, functions of possible merits of professional codes.
* Encourage reflection on professional standards and possible codes.

Defining standards of professional conduct has long been a matter of intense interest for many of those in chemistry. For instance, at the turn of the 20th century, what is today called chemical engineering was just beginning to emerge as a distinct field. ‘Chemical engineers’ of the time had varying levels of knowledge of pure and applied chemistry as well as mechanical engineering. While the use of teams of chemists and mechanical engineers was common in countries such as Germany, in the US the move was made to develop a unique profession. In part, this was motivated out of the relatively low status of industrial chemists there at the time. In 1908 the American Institute of Chemical Engineers was set up to evaluate university programs and standardize training requirements. Defining who could or could not be called a ‘chemical engineer’ this Institute played a vital role in raising both the standards and status of chemical engineers and promoting their unique contribution to industry.

In the decades since, chemistry organizations have followed practices in medicine, accounting, and other engineering professions by using so-called ‘codes of conduct’ as a mechanism for setting standards and encouraging reflection. The general terms ‘codes of conduct’ or ‘codes of ethics’ cover a wide variety of options. One way of distinguishing between codes is by their function; whether their aim is to declare *aspirational* values, propose *educational/advisory* guidelines or stipulate *enforceable* requirements.

Types of Codes

To elaborate, *aspirational codes* set out ideals that practitioners are expected to uphold, such as standards of research integrity or honesty. These may be realistic or idealistic. For instance, in the 1965 the American Chemical Society approved the *Chemist Creed* which stated eight responsibilities for all chemists. For clients, it specified the responsibility ‘to be a faithful and incorruptible agent, respecting confidence, advising honesty, and charging fairly’. For chemistry as a profession, it specified the responsibility ‘to uphold its dignity as a foremost branch of learning and practice, to exchange ideas and information through its societies and publications, to give generous recognition to the work of others, and to refrain from undue advertising.’

Educational/advisory codes go further than merely setting aspirations by providing more detailed guidelines for appropriate action. *Enforceable codes* go further still by embedding standards within wider systems of regulation where they can be made obligatory. The 1963 Code of Ethics of the American Institute of Chemical Engineers provided a variety of rules to its members, such as ‘He will not disclose information concerning the business affairs or

technical processes of any present or former employer or client without his consent.' Failure to comply with this Code could have lead to professional or, in some cases, legal sanction. Thus codes have served various functions including highlighting areas of concern for professionals; providing a basis for inclusion or exclusion in to chemical professions; gaining public trust; and, importantly, establishing expectations for conduct.

In the last few decades the adoption of codes of conduct has become increasingly commonplace, particularly in Western countries were many modern codes originated. As part of this, the content and aims of codes have increasingly reflected widespread concerns about the societal and ethical implications of chemistry. In terms of content, for instance, the *Chemist Creed* was revised in 1994 to include the responsibility that 'Chemists should understand and anticipate the environmental consequences of their work. Chemists have responsibility to avoid pollution and to protect the environment.'

Enforceable codes in the past were far more prevalent in chemical engineering than research-centered areas of chemistry. In chemical engineering, codes were part of systems of accreditation in many countries and they often specified standards for handling commercial relations. But more recently a number of codes have been developed for those in universities engaged in fundamental or applied research. In the US, for instance, the 1980s and 1990s witnessed a number of high profile science scandals regarding academic commercial conflicts of interest, fraud, and other forms of research misconduct. In part as a response to such high profile events, the American Chemical Society issued *Professional Employment Guidelines* (1988) and *Ethical Guidelines to Publication of Chemical Research* (2000) that went well beyond the idealistic aspirations set out in the *Chemist Creed.*

Some Pros and Cons

Despite the increasing prevalence of codes, questions have been raised about their merits. The effectiveness of aspirational or advisory codes not supported by enforcement mechanisms is one frequently identified concern. Another is that codes will almost certainly fail to dissuade those determined to breach them. Similarly, the highly abstract provisions of aspirational codes leaves so much room for interpretation about what should be done. This vagueness together with their limited powers means that they are sometimes perceived as being little more than public relations devices for professions to dissuade those outside the profession influencing its conduct.

Much, of course, depends on the rigour of the mechanisms in place to promote and uphold codes. Those supportive of aspirational codes have argued that they play more varied functions than merely guaranteeing certain forms of behaviour. Raising awareness; suggesting topics to consider; clarifying individual responsibilities; increasing public trust; and establishing minimal ethical expectations are but a few of their advantages. In this way the very process of devising a code can be just as important as the final document.

Enforceable codes do not suffer from the same degree of initial doubt about their effectiveness. However, some have questioned the ability of written codes to adequately determine what counts as appropriate *ethical* conduct. Here it is often argued that ethical

decisions cannot be reduced to merely following 'inert' rules and predetermined algorithms which do not address the complexities of situations. What codes should do is make people think about what they do and encourage them to openly discuss the implications of their work.

Thus codes that consist of highly general aspirations risk criticism for being open to different interpretations while those that are highly rigid risk being seen as irrelevant in fast moving and complex situations.

An example of the difficulty of using codes to make ethical decisions can be given in considering their conflicting obligations. Codes often include responsibilities to give due regard to serving both clients and the public good. Serving clients' interests in the case of the 1993 American Institute of Chemical Engineers *Code of Ethics* means 'never breaching confidentiality'. This Code also requires its members to hold 'paramount the safety, health and welfare of the public'. If a situation arose where a chemist suspects maintaining confidentiality might be at odds with the public good – say in relation to "whistle blowing" about concerns about the long term possible environmental consequences of production activities s/he could find the code quite contradictory. Codes are often ambiguous and not very supportive ethical guides.

The example of a suspected future harm raises further questions about what scientists and engineers should be responsible for. Is it enough that they use their specialist knowledge in accordance with existing regulations and standards? Or should scientists and engineers assume responsibility for ensuring that their work leads to beneficial social outcomes (and for whom)? In short, what questions do they need to ask about the consequences of their work?

Codes of Conduct and the Elimination of Chemical Weapons

As suggested above, codes have often developed in response to changing societal concerns. With the heightened attention in recent years to 'weapons of mass destruction', renewed focus has been given to the role of those in chemistry in preventing the spread and use of chemical weapons. Codes of conduct have been proposed as one means of ensuring their elimination.

The appropriateness of the involvement of scientists in military research and development has long been a topic of intense debate across the world. As might be expected, in modern times chemists were intimately associated with the development of chemical weapons. The case of the pioneering and patriotic German chemist Fritz Haber illustrates many of the thorny issues at stake in thinking about the relation between science and ethical conduct. During World War One, Haber actively contributed to the German chemical weapons program and in 1915 personally directed the first use of chlorine gas in warfare at Ypres in Belgium. Such capabilities, he hoped, could offer his nation a distinct military advantage in the trench warfare that had resulted in stalemate. Not everyone was as enthusiastic about this use of chemistry. Faber's wife Clara, a chemist as well, committed suicide, an act, said by

some to have been influenced by her husband's involvement in the development of poisonous weapons.

In 1919, Haber was awarded the Nobel Prize for learning how to fix atmospheric nitrogen to synthesise ammonia. This pre-war work lead to the development of techniques for producing artificial fertilizers, products which have increased food production and helped feed many people around the globe. Haber's discovery also helped Germany remain supplied with high explosives throughout World War 1. And the man is often remembered for stating during his Nobel Prize acceptance speech that 'In no future war will the military be able to ignore poison gas. It is a higher form of killing'. The latter referring to the ways chemical weapons could take soldiers out of combat without necessarily resulting in their death.

Since the early 20th century, numerous international efforts have been made to establish an international agreement of the unacceptability of chemical weapons. These eventually resulted in the 1993 *Chemical Weapons Convention* that bans the possession and use of chemical weapons.

Individual scientists and engineers as well as the chemistry professions have an important role to play in ensuring this prohibition remains intact. A number of developments pose key challenges for the future. While the continuing advancements in synthetic chemistry, the establishment of large databases of compounds in pharmaceutical and agrichemical industries, the refinement of micro-reactor technology, and the proliferation of batch production capabilities undoubtedly assists the production of useful civilian chemical products these advances could also facilitate the development of chemical weapons.

In addition, under the exemption provided in the *Chemical Weapons Convention* for the use of chemicals in "law enforcement", some armed forces are actively pursuing so-called incapacitating chemical agents for riot control, which others believe could well undermine attempts to stigmatize and eliminate all chemical weapons.

The adoption and promulgation of codes of conduct has been identified as one means of raising awareness of the prohibition on chemical weapons. It also encourages states and individuals to adhere to their obligations under the *Chemical Weapons Convention.* Currently, few chemistry codes deal directly with chemical weapons. Nor do they consider contentious wider issues associated with the involvement of scientists and engineers in weapon's development.

In an exception to general practice, the International Network of Engineers and Scientists for Global Responsibility launched an appeal to engineers and scientists encouraging them to sign a document in which they stated that:

> I pledge not to take part in the development and production of weapons of mass destruction and of weapons that are banned by international conventions …
>
> Since the results of science ultimately belong to humankind, I will conscientiously consider my participation in secret research projects that serve military or economic

> interests. I will not participate in secret research projects if I conclude that society will be injured thereby. Should I decide to participate in any secret research, I will continuously reflect upon its implications for society and the environment.

This is an example of an aspirational code but one with very clear aims.

Since 1957 Pugwash has promoted social responsibility in science and technology, with particular regard to issues of arms and warfare. In the 1990s, Student Pugwash developed a pledge for young scientists (analogous to the Hippocratic Oath in medicine) to promote ethical reflection. It states:

> I promise to work for a better world, where science and technology are used in socially responsible ways. I will not use my education for any purpose intended to harm human beings or the environment. Throughout my career, I will consider the ethical implications of my work before I take action. While the demands placed upon me may be great, I sign this declaration because I recognize that individual responsibility is the first step on the path to peace.

The Future of Codes: An Exercise

Much has been written about codes of conduct in science and engineering. In this, many questions have been raised, only some of which were mentioned above. If you were asked to develop a code what questions would you ask besides the following: Are explicit codes really needed? If so, what types of codes? Are they effective and at what? Is a code the most appropriate way to secure high standards of behaviour? How can they be made relevant and alive? Could one ethical code be expected to be universally valid? Do codes have a widespread appeal outside of the countries where they have been developed? Who should be involved in devising them? Answers given to the questions above have varied over time.

In the past codes for professions reflected the social mores and economic needs of the time. Given the rapid pace of developments in chemistry,chemical engineering, and related fields, it is vital that any new codes reflect current situations but that they be flexible enough to deal with issues in the future.

The 'Further Readings' box below provides a number of web sources about codes. After reading some of those listed documents and surveying different existing codes, consider what you would want out of a code of conduct. What would it have in terms of its content? What responsibilities would it include for scientists and engineers regarding the implication of their work? Would it aim simply to inspire or should it provide clear guidelines for appropriate conduct? What would it say about the need to prevent the spread of chemical weapons? Who would be its primary audience? In an ideal world, who would be involved in its development? How could it be disseminated and made relevant to those in science and engineering and possibly beyond?

Further Readings

Examples of Codes
- American Chemical Society's *Chemist Creed*, *Professional Employment Guidelines*, and *Ethical Guidelines to Publication of Chemical Research* see http://www.chemistry.org/
- The American Institute of Chemists (1983) *Code of Ethics* http://onlineethics.org/codes/AIC.html
- American Institute of Chemical Engineers (2003) *Code of Ethics* http://www.aiche.org/about/ethicscode.htm

For a databases of scientific and engineering codes see:
http://onlineethics.org/ and
http://www.iit.edu/departments/csep/PublicWWW/codes/

Selected Analyses of Scientific and Engineering Codes
- A survey of the various scientific codes is given in ICSU (2001) Standards for Ethics and Responsibility in Science 27GA/02/12.4.1 http://www.icsu.org/Gestion/img/ICSU_DOC_DOWNLOAD/217_DD_FILE_SCRES-Standards_Report%20.pdf
- For an examination of various ethical dilemmas and the utility of codes in helping resolve them see http://www.pitt.edu/~bmclaren/ethics/caseframes/index.html
- An examination of codes and biological weapons is given at http://www.projects.ex.ac.uk/codesofconduct/
- For a discussion of the responsibility of scientists see Rotblat J. *Science and Humanity in the Twenty-First Century* http://www.nobel.se/medicine/articles/rotblat/

For further information, please contact

Alastair Hay (A.W.M.Hay@leeds.ac.uk)
Or
Peter Mahaffy (peter.mahaffy@kingsu.ca)