Catalyst

Secondary Science Review

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Working with light

Scientific photography

SEP
Science Enhancement Programme

Catalyst

The front cover shows light emerging from a fibre optic cable; this image was taken by Stephen Kill, scientific photographer (see article on pages 13-14).

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Contents

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The image of science

Science changes the world, and it changes how we see the world. CATALYST has published many articles describing how scientific advances have led to new technologies which have benefited people around the world.

But there is more to science than simply making new discoveries and applying them. Every scientific development comes with issues attached – questions about the implications of what we have learned to do.

- On page 18, Michael Reiss opens up the theme of bioethics. When we are confronted with new possibilities in biology, how can we decide whether or not to proceed with them?
- Science has a powerful draw on people's imaginations, so that it is often used to sell products. On page 7, Alice Tuff describes what happened when a group of young scientists set about challenging some of the 'scientific' claims they found in advertisements.
- And on page 13, Stephen Kill describes how his work as a scientific photographer enables him to promote a positive image of science.

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Gary Skinner
Stephen Tomkins

In the pink:
Colour from carotenes

Think of amplification and you probably imagine a band on stage next to huge speakers. But things other than sound can be amplified, and not just by electronics.

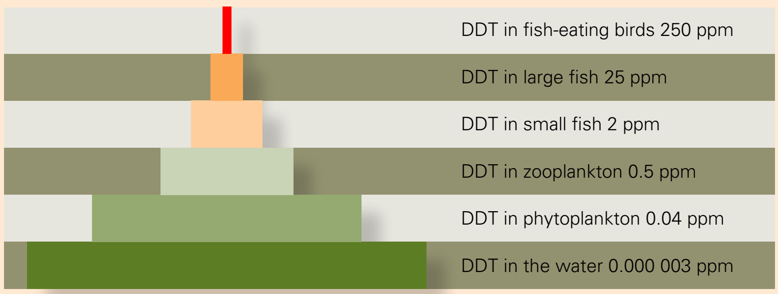
In nature, *bioamplification* causes substances to become more concentrated as they move from eater to eaten along a food chain. You may have heard this story in relation to the concentration of pesticides like DDT along a food chain, and how this causes problems for those animals, like birds of prey, at the top (see Box 1).

However, bioamplification can be more benign than that. It leads to much of the colour in nature. For example, in birds, there are three main sources of their (often striking) colouration: melanin pigmentation, structural colouration and carotenoid pigmentation. Melanin is made in the animal's own body and structural colours come from the way feathers interact with light, but carotene pigments come, in many cases, from the diet and are amplified along a food chain and concentrated in parts such as feathers, beak or skin.

Box 1 Bioamplification

The concentration of DDT, a pesticide still in use in some parts of the world, is amplified up a food chain by a factor of 10 million or more.

Bioamplification also gave rise to Minamata disease in Japan. Mercury-containing compounds from industrial processes were released into the sea. They accumulated up the food chain until people who ate contaminated tuna became seriously ill. Of the 10 000+ known victims, over 1800 died.



ppm = parts per million

Key words
food chain
food web
photosynthesis
spectrum

Salt lake life

First then to the world's salt lakes, the most famous probably being the Great Salt Lake in Utah, USA. At certain times of year this lake has a green appearance in the water due to vast numbers of a tiny alga called *Dunaliella* (Figure 1).

Figure 1 *The green colour of this lake is caused by the presence of the* Dunaliella *alga whose cells contain chlorophyll..*

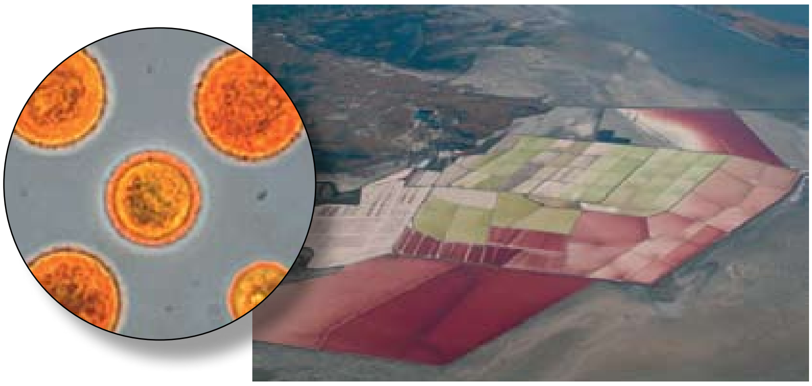


Figure 2 *The red colouring of these salt ponds in San Francisco Bay is due to the presence of* Dunaliella.

As plants, these algae make food in the process of photosynthesis and are at the base of a short food chain in this and other similar lakes. From the glucose they make in photosynthesis, with the addition of a few minerals, they can make everything else they need. Included in what they make is a pigment called carotene, found in abundance in nature, famously in carrots. This carotene is most obvious in the older algal cysts, which are reddish and, in huge numbers, give the lake water a red colour too (Figure 2).

Up the food chain

The main consumer of the algae is a small crustacean called the brine shrimp (*Artemia salina*). These are one of the few animal species which can live in the very salty water, and they therefore get most of the available algal food. Their numbers are, as a consequence, vast. At a point in their life cycle, the *Artemia* also form cysts containing concentrated carotene which gives the egg-like cysts an orange colour.

Brine shrimps, Artemia, *one male and one female (with eggs). Brine shrimps live in inland salt lakes but not in the sea.*

This carotene helps to protect the embryos inside the cysts, which can stay viable for many years.

Box 2 Carotene as a protective antioxidant

Most molecules from which living things are made are subject to oxidation, and this can produce free radicals which, in turn, can damage cells, leading to such diseases as cancer. The cysts of brine shrimps, being highly desiccated, are very susceptible to oxidation and free radical damage, but this is avoided by high levels of carotenoid pigments.

In one short food chain the brine shrimps are fed on by flamingos (although not in the Great Salt Lake). These birds have a highly specialised beak to be able to take advantage of this abundant, but tiny, food. The beak acts as a sieve allowing the bird to process large volumes of water and extract a lot of food in a short time (Figure 3). The carotene ends up in the flamingos and, yes, is the source of their pinky-orange colour.

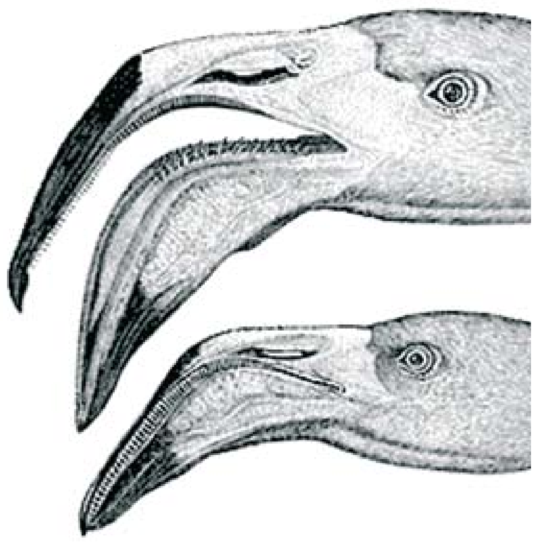


Figure 3

Flamingos are born white and gain their pink colour from the carotenes in their food which they take in through their filter-feeding beak.

When flamingos are kept in captivity, as they often are, this specialised diet is difficult to provide, and they will feed on other things. They would not be pink if they were not given a dye in their artificial food. Zoos usually add something called Roxanthin Red to the food, and indeed there are companies who supply Flamingo Food (e.g. Flamingo Fare) which contains this and other carotene-related compounds.

But the role of carotenoids in making nature beautiful does not end with flamingos. The red bill of the zebra finch, the yellow one of the blackbird, the yellow of canary feathers and many of the colours we find in fruits and vegetables are, at least in part, due to carotene and related compounds. The role of carotene and its relatives in birds was first proved in 1934. Canaries were fed on an artificial diet free of carotenes and ended up with white feathers!

Plants and carotenes

So plants make carotenes, which animals cannot do, and then animals acquire these and use them to protect themselves against free radicals (Box 2) and to produce mate attracting colours, warning colours and so on. But why do the plants make them in the first place? The simple, and not surprising, answer is photosynthesis. The carotenes are, of course, pigments and as such they absorb light, the very thing plants need to do to make sugar from carbon dioxide and water. Chlorophyll is the main light absorbing pigment, but it only absorbs red and blue light, hence its green colour – see Figure 4.

Figure 4 *Plants look green because they reflect the green part of the visible light spectrum.*

An absorption spectrum shows more clearly the extent to which different wavelengths of light are absorbed by a pigment. The absorption spectrum of chlorophyll is shown in Figure 5a; the two 'bumps' show that chlorophyll absorbs strongly at the low and high wavelength ends of the spectrum.

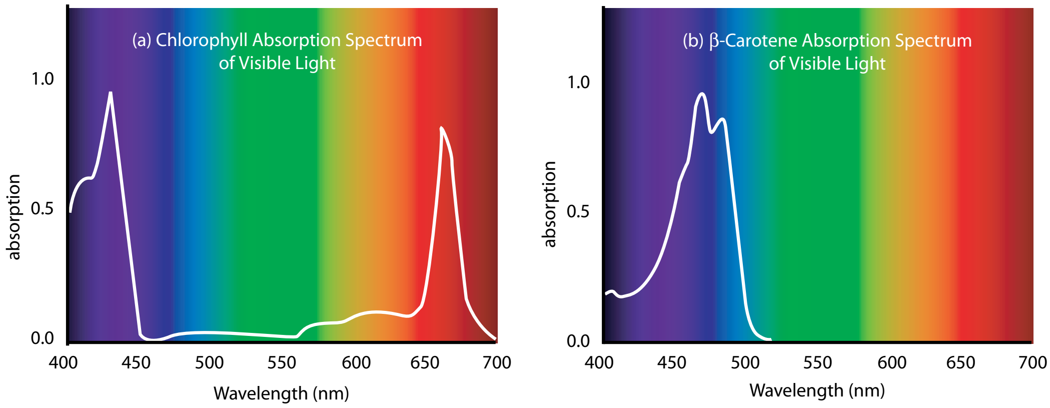


Figure 5 *Absorption spectra of* ***(a)*** *chlorophyll, and* ***(b)*** *β-carotene.*

All the green and yellow light is reflected and thus wasted. It is not surprising to realise that carotenes absorb different coloured light from chlorophyll; they are after all a different colour. The carotene absorption spectrum is shown in Figure 5b. This shows that the carotene is filling in some of the wavelengths that the chlorophyll does not absorb. Plants have many such accessory pigments which absorb light energy and pass it to chlorophyll for photosynthesis.

Gary Skinner is biology editor of C*ATALYST*. *Stephen Tomkins teaches biology at Cambridge University.*

Tim Adlam

Using shape memory alloys

Key words
alloy
smart materials
solenoid
technology

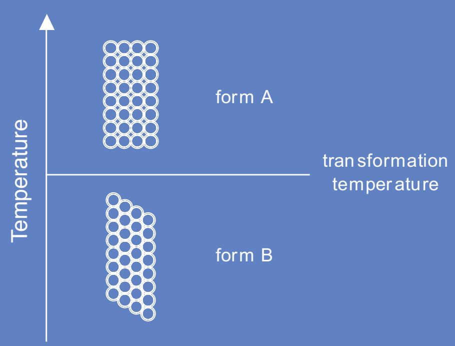
Today, many more people with physical and mental disabilities are leading independent lives at home, thanks in part to recent technological developments. Here, Tim Adlam of the University of Bath describes one project which makes use of smart materials to help people with dementia.

Human muscles can contract and exert large forces with very fine control, but the trouble is they need warmth, blood, nerves and a skeleton made of bone if they are to function consistently and usefully. At the moment engineers can't use biological muscles in their creations except in very unusual circumstances. It would be useful though, if we could employ actuators that work like a muscle – actuators that are compact, powerful and very reliable.

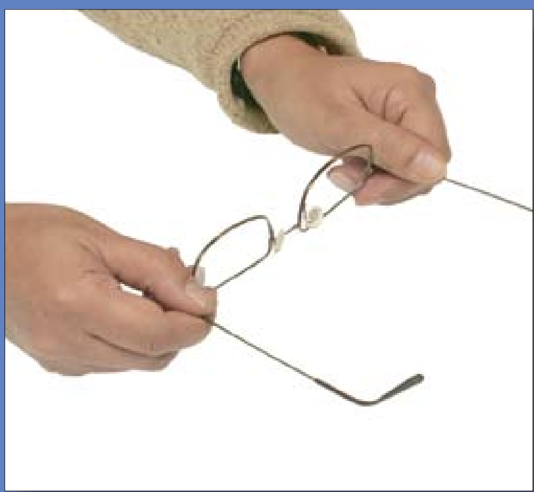
Fortunately there are such actuators – shape memory alloys (SMAs). These are metals that can radically change and recover their shape. They are used in diverse applications from moving the control surfaces of model aircraft to the activation of tiny cages and baskets that are inserted via the arteries deep inside the human body. Box 1 explains how they work.

BOX 1 What is a Shape Memory Alloy?

SMAs are used either where a device needs to change shape, or where a force needs to be applied. They do this when they are heated above a specific transition temperature that varies from alloy to alloy. When they reach this temperature, the internal crystal structure of the metal changes suddenly and the metal shrinks by as much as 5%, at least ten times as much change in length as would normally be expected from a metal that is being heated. As the metal contracts, it exerts a large force. The SMA changes from its ductile annealed state or phase, to a super-elastic phase that is smaller and can tolerate huge amounts of bending and stretching.



Have you seen the glasses frames that you can tie in a knot without damaging them? They are made from an SMA in its super-elastic phase. While the alloy is maintained above its transition temperature, it stays super-elastic and contracted, but if it is allowed to cool below its transition temperature, it becomes possible to stretch it out to its original length with very little force. The problem here is that if it is stretched too much, it loses some of its shape memory and does not contract as well next time it is heated. The alloy can be over-extended. This means that whatever mechanism it is built into must protect it from being over-extended and damaged.



Putting SMAs to work

My own experience of using shape memory alloys has been while designing smart household equipment for people with dementia. At the Bath Institute of Medical Engineering, we have been working with people with dementia since 1999, and the focus of our work has been to develop technology that will support people with dementia in their own homes, enabling them to be more independent, and hopefully postponing the day when they must be admitted to residential care.

One of the problems we set out to solve was how to enable a person with dementia to cook safely when they might often forget to light the gas or to turn it off after use. With my electronics engineer colleague, I designed a cooker monitor that could detect gas or smoke, and then turn off the cooker knobs. If the problem didn't go away, the monitor would then call for help using a GSM mobile phone module to send a text message to a nearby carer. The clever thing about the cooker monitor was the knobs. They could be fitted to just about any cooker in place of the normal knobs and were able to turn off automatically without preventing the person with dementia from using the cooker after the problem had been sorted out.

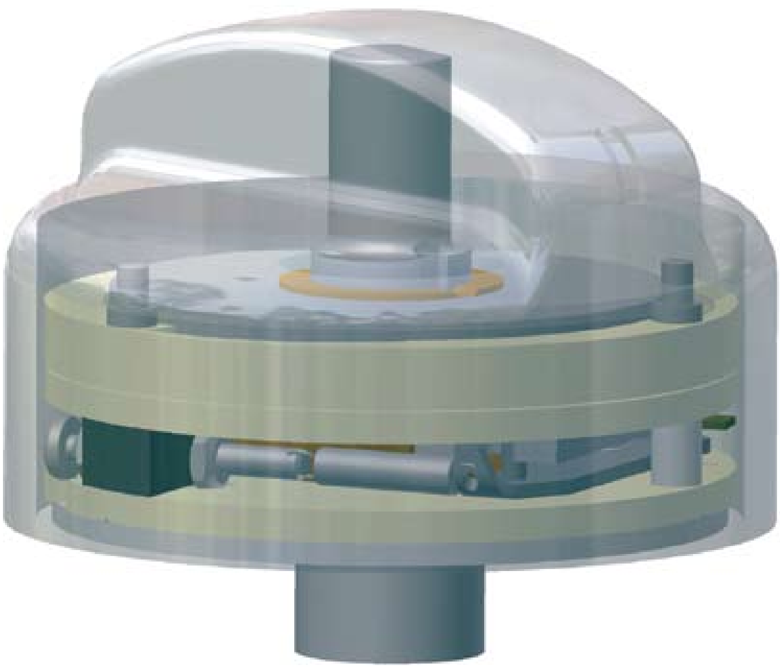
The knobs needed to look just like normal cooker knobs so that they would be recognisable by a person with dementia, but they had to be powerful enough to turn off the gas valve that the normal knobs were attached to. Fitting a mechanism inside each knob that could be relied on to turn off the cooker when needed was a challenge. First we decided to use the user's own strength to turn off the valve by storing the energy they used to turn the valve on in a spring. All we had to do then to turn off the valve was release the energy stored in the spring, and for this we needed to release a ratchet that prevented the spring from unwinding.

Two methods of releasing the ratchet were tried. The first, a compact solenoid could not be built small enough to fit inside a knob and still remain powerful enough to disengage the ratchet; so shape memory alloys were investigated. For this application, it was decided to use a simple wire that could pull the pawl out of the ratchet and release the energy stored in the spring, turning off the knob. The wire had to pull with about 9 N of force and give 1.23 mm of pull.

We chose a straight length of Flexinol alloy. We decided to heat the wire using electricity and its own resistance. The wire has a resistance of a few ohms per metre, and is well suited to electrical heating. We found that a 0.5 mm diameter wire, 25 mm long, gave us 10 N of force and a pull of 1.25 mm.

People with dementia often have problems with memory, attention, judgement and problem-solving.

Two modified cooker knobs; to the user, they look normal.



This view of a modified cooker knob reveals the inner mechanism.

Test rig

We wanted to test the wire and find out exactly what it was capable of. How long would it carry on pulling with 10 N? How reliable was it? How well would it tolerate over-extension, would it be overheated?

To answer these questions, we built a testing rig and set it in the lab to run over a weekend, heating it every few seconds so that it contracted, and then allowing it to cool and be extended again. We didn't protect the wire from over-extension for this experiment as we wanted to see how this would affect it. The results of our experiment are shown in Figure 1. You can clearly see the change in the pull length of the wire as time goes by and it is progressively damaged by the over-extension. It was important for us to protect the wire in the mechanism we designed.

The SMA wire test rig.

Another big problem with using SMAs is that they are very difficult to join to anything. They can't be welded; they are very difficult to machine; they can't be bonded with adhesives; and they can't be soldered or brazed. The only secure way of joining them is mechanically with a crimp, a clamp or a pinned joint. In the end, we bought ready-crimped wires from the manufacturer of the SMA alloy, complete with added steel terminal wires for soldering.

The shape memory properties of SMAs can be destroyed by overheating. This meant that we had to design our electronics carefully so that the current through the wire was limited and so that the time it was applied for was also limited.

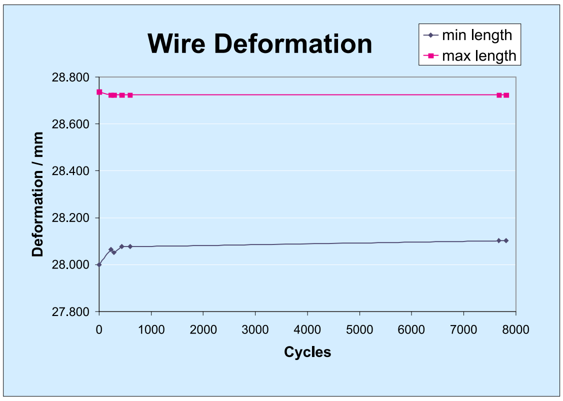


Figure 1

Medical designs

Shape memory alloys have been used in many ingenious and novel medical applications, but this simple use of a straight piece of SMA wire as an actuator illustrates many of the issues that a designer will have to consider when using these amazing materials. There is no other actuator available as powerful and compact as an SMA at present, making them a powerful part of the designer's library of solutions.

Satisfied customer: a carer with an adapted cooker.

Look here!

More clever designs from the Bath Institute of Medical Engineering: *www.bime.org.uk*

Tim Adlam is a chartered mechanical engineer, a registered clinical scientist and a design and development engineer at Bath Institute of Medical Engineering.

Nikolay Suslov/Bigstockphoto

Alice Tuff

Selling science short

"Stabilised oxygen" that has no formula, "Detox patches that draw harmful toxins out of your body", a yoghurt that "optimises the release of energy from our diet". Every time you watch TV you are bombarded with adverts for products with miraculous claims like these and slogans such as "scientifically proven", "biofields" "chemical free". But how true are these claims?

Implausible products

I am part of a group of young scientists who thought these claims sounded implausible. We decided to hunt for the scientific evidence behind them and challenge the manufacturers to explain how these products work. To our surprise, we discovered that although company representatives were happy to try to answer our questions, not one was able to give us any scientific evidence to support their claims or put us in touch with anyone who could. The companies didn't seem to have ever expected to be questioned.

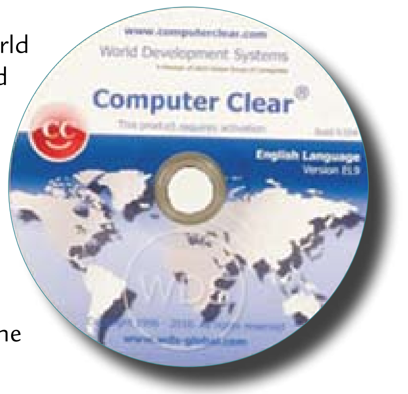
A hunt for evidence

Some of the products we investigated made miraculous claims, but had no plausible science to back them up. Tom Sheldon, a computer scientist, looked into a software program called Computer Clear, which claimed to curb the harmful effects of electromagnetic field (EMF) from your computer, strengthen the immune system and bring the body back to health. How? By running in the background of your computer and releasing 34 000 bioresonance patterns through the computer monitor which will rebalance your biofield.

There is a chain of misinformation running through these claims. There is no scientific evidence to suggest EMF from your computer is harmful; *biofield* and *bioresonance* are not accepted scientific terms.

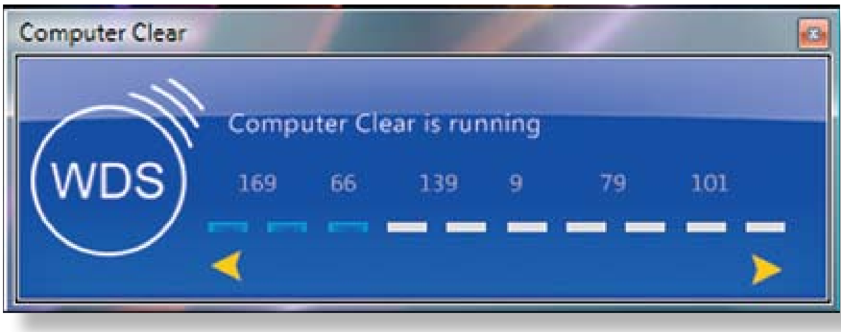
Tom rang up the manufacturer, World Development Systems, and questioned them about what evidence or published research they had to support the claims they had made about their product. Victor's (the inventor) response was that the evidence *"is anecdotal"* and *"the scientific bit is always, if you like, secondary and always a bit behind"*. Tom also asked about the "biofield" and how Victor knew the

We all work with computers – but are they harming our 'biofields'?



program was emitting "bioresonance patterns". Could you measure them and detect them if Computer Clear was running on a computer?

"No, because the EMF still remains the same, it's constant; all we do is modulate our signals in a combination between the monitor and the CPU itself. EMF remains the same but the quality of the EMF from a human point of view changes."



'Computer Clear' claims to curb the harmful effects of electromagnetic field

Scientific evidence which has been published in a scientific journal has been peer-reviewed meaning it has been checked for validity, significance and originality and is more reliable than unpublished research.

If the quality of EMF changes you should still be able to measure it, but Victor responded that as we don't have the technology to measure it there is no way to know it works. As Tom said, "*This is the problem: no science, no theory, no evidence. The only support for the product is anecdotal, subjective, and unreliable.*" Victor claimed to have sold 340 000 copies worldwide which means over £13 million has been spent on a product with no supporting evidence, no working theory and no conceivable mode of action.

Customer Concern

Not all of the products we looked at were as far-fetched as this. Some of the claims were from supermarkets who had removed certain chemicals from their products. Ramla Ali, a teacher, wanted to find out why the Co-op had removed the flavouring monosodium glutamate from their own brand products. The Co-op claimed it was because of "*potential links to food intolerance and fresh concerns about children's diets*" but Ramla couldn't find any scientific studies that supported these claims. She also wanted to know if they would be banning tomatoes and parmesan which have naturally high levels of MSG (they aren't). Co-op said:

"We've removed it because of customers' concerns about health hazards."

"So not because you think that there are health hazards?"

"No. We removed it because of customer concerns."

So why are the customers concerned if there is no scientific evidence that MSG is harmful? Co-op did a survey which asked the customers if they were concerned about a possible (unproven) link with MSG and food intolerance. Most of us if asked this question would say yes as we wouldn't want something in our food that sounds dangerous, so unsurprisingly most people said yes. The Co-op is responding to a concern they have created and at the same time perpetuating a myth about food and chemicals which is not based on any evidence.

Tomatoes have naturally high levels of MSG

As one of our researchers, Kate Oliver, said, "*Instead of saying that the science doesn't matter only public perceptions do, companies have a duty to tell the truth as accurately as they can. Ignoring science and evidence about safety is an abuse of trust.*"

Kim Reinick/Bigstockphoto

Crisps: Many crisps have the flavour-enhancer MSG, but not Co-op own brand ones.

So what can I do?

No qualifications are needed to do this. You just need an inquisitive mind and the tenacity to keep asking questions. Next time you see a claim for a product and it doesn't quite make sense, or you want to know more, phone up the company and ask them for their scientific evidence. Companies should be prepared to answer these questions and have the evidence to back up their claims, or put you in touch with someone who can. Sometime people do make genuine errors but if no-one is probing these mistakes, they will go uncorrected.

Look here!

We published some extracts from our experiences in the dossier *There goes the Science bit...* which can be downloaded at *www.senseaboutscience.org.uk/index.pho/site/other/175.*

See the article on peer review in CATALYST Vol 18 issue 1 *www.sep.org.uk/catalyst/download_article.asp?article_code=334*

Alice Tuff works for Sense About Science, www.senseaboutscience.org

The ISIS buildings in Oxfordshire; the new building at the front is the Second Target Station.

Aeroplanes, shampoo and super-microscopes

Where do protons travel at almost the speed of light, and neutrons see things 10 000 times thinner than a human hair? Take a trip to ISIS – one of the UK's world-leading research centres.

ISIS uses neutrons to study materials at an atomic level. It acts like a "super-microscope", and can be used for physics, chemistry, materials science, geology, engineering and biology. The Rutherford Appleton Laboratory in Oxfordshire is its home.

Neutrons are tiny particles found in the nucleus of nearly every atom. Neutrons can be released from their nuclei when hit by a very fast moving proton beam.

At ISIS, a proton beam travelling at 84 per cent of the speed of light is fired at a small tungsten target (no bigger than a packet of biscuits) to release neutrons (see numbers **1-3** on diagram). The protons are accelerated to high speed using a circular synchrotron accelerator. Every proton goes 10 000 times around the accelerator before being fired at the target. The whole process takes 10 milliseconds from start to finish. During this time, the protons have travelled 1655 kilometres. That's the same as a journey from London to Aberdeen and back! This happens 50 times a second.

Once the neutrons have been released from the target, they fly down beam pipes (see **4**) leading to instruments (see **5**) that are used for experiments.

Because neutrons have no electric charge and are so small, they can penetrate deep into materials. By looking at how they scatter off the atoms inside materials, they reveal the atomic structure of the material under study.

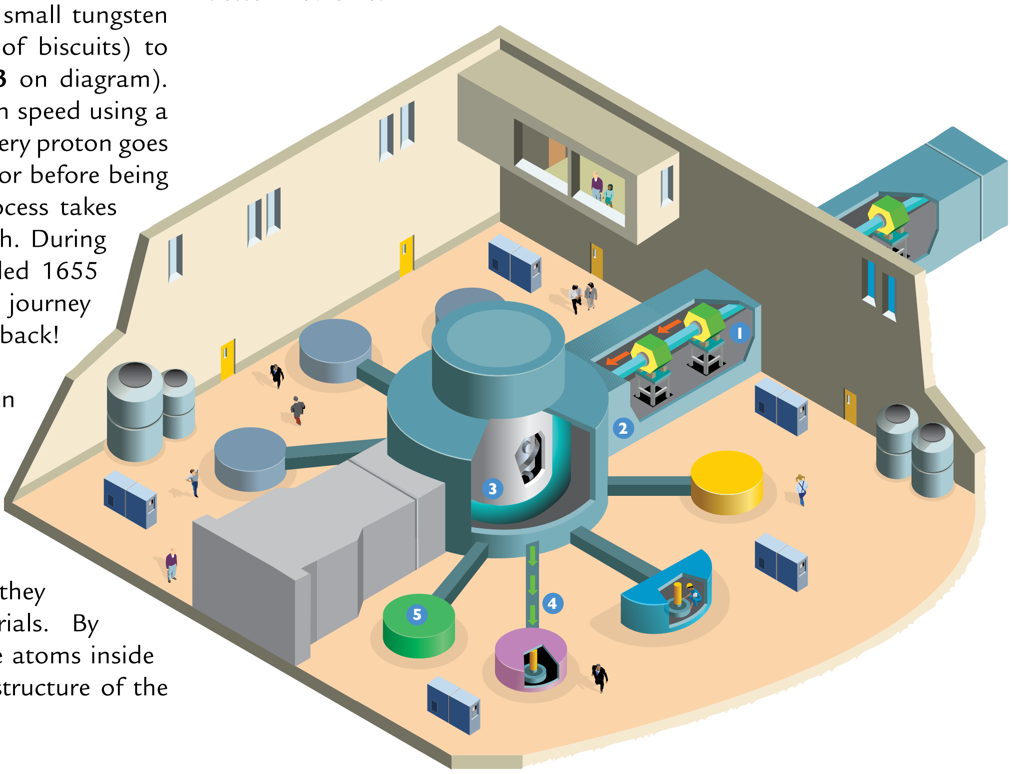
At ISIS, it is possible to see detail at scales 10 000 times thinner than a human hair. This makes it much easier to see the exact make up of things and understand how they behave.

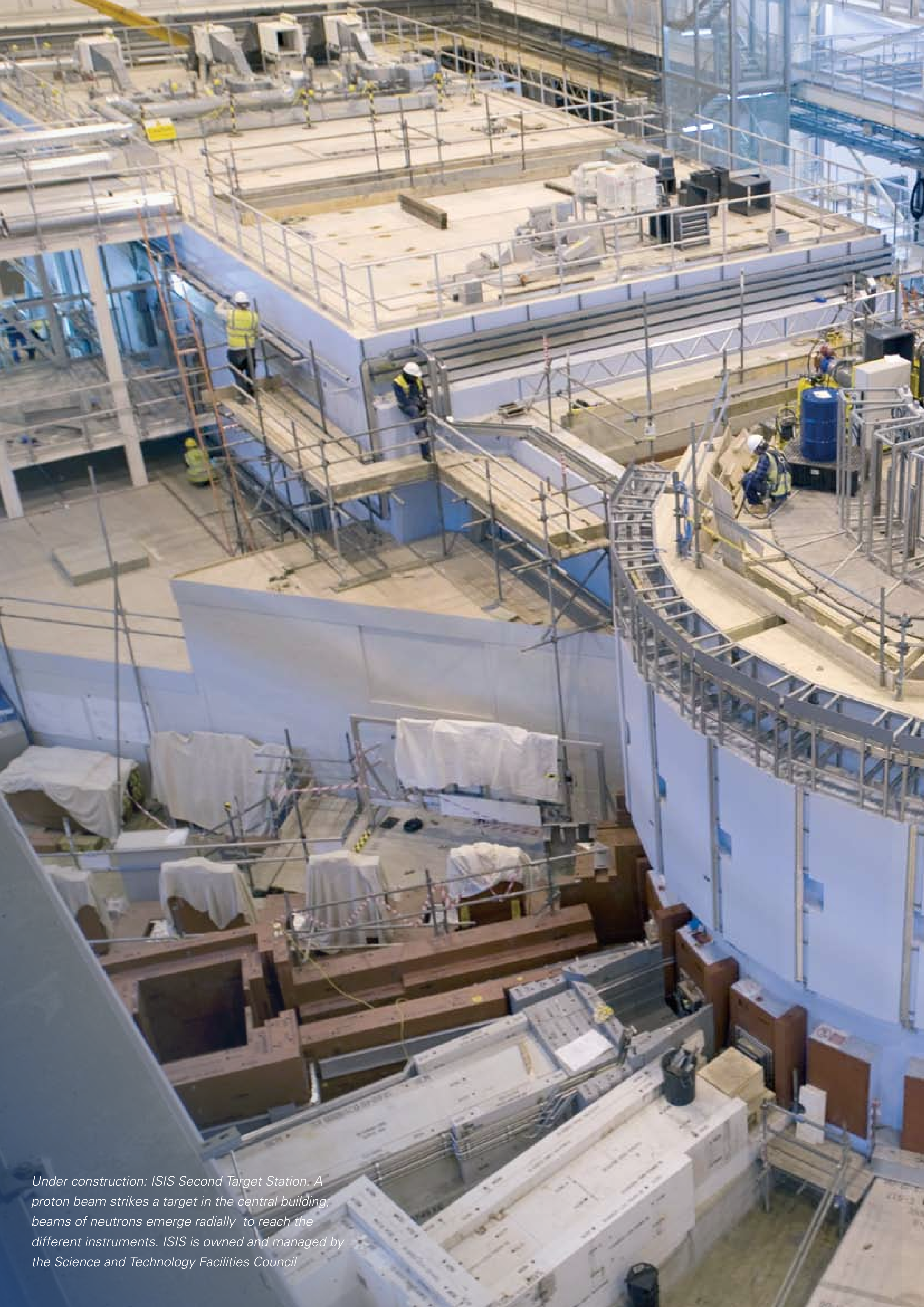
The big picture

Different instruments are used to do different types of experiments. There are currently 20 instruments already in use, and ISIS has just doubled in size, adding seven new instruments with more to follow in the new 'Second Target Station' building. The photograph on pages 10-11 shows the Second Target Station under construction.

Scientists use the instruments to look at samples ranging from aeroplane wings to shampoo.

Understanding materials at an atomic level can lead to exciting discoveries that impact our lives. ISIS can help to create super-fast computers, make transport safer and more efficient, and provide better medicine.





Under construction: ISIS Second Target Station. A proton beam strikes a target in the central building; beams of neutrons emerge radially to reach the different instruments. ISIS is owned and managed by the Science and Technology Facilities Council

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www.sep.org.uk/catalyst

ISIS sees through muddy water

One of the really useful things about using neutrons is that they allow scientists to see clearly both organic and inorganic (non-living) material.

Recently, ISIS scientist Steve King experimented on a sample of river water to try to understand how tiny particles of pollutants bind together and how they are transported through the river.

Working alongside Helen Jarvie at the NERC Centre for Ecology and Hydrology, Steve was able to see the exact shape of certain tiny inorganic particles present in the water and how the organic matter either keeps them suspended or causes them to settle. Steve found the tiny particles had a ragged and porous fractal shape, resulting in much higher surface area than previously assumed. The larger the surface area the greater the potential for pollutant uptake and transport.

This makes it easier to understand how pollutants like pesticides or excess fertiliser attach themselves to these particles and get carried downstream. With experiments like this, we can better understand how humans affect the ecology of rivers and can then take steps to make our water systems cleaner.

Helen Jarvie of the Natural Environmental Research Council works alongside Steve King.

Steve King collects water samples from a polluted watercourse.

Making aircraft safer

Neutron science can also be valuable in testing the strength of engineering parts, such as aircraft wings. Airplane company Airbus used ISIS to see how best to manufacture a new airplane wing.

The strength of an aircraft wing depends partly on how strongly the different components are joined together with welding. It is important to understand any areas of weakness that may be present in the structure before it goes into production.

Using neutrons, scientists at ISIS are able to see deep within engineering components and structures and determine if there are any areas of stress and strain that might lead to cracks appearing in the future.

Once manufacturers understand any potential flaws in their components, they can adjust their processes to make sure that aircraft parts are as safe as possible.

This makes air travel safer for all of us.

A section of an Airbus wing being positioned for examination in one of ISIS's test stations.

Stephen Kill, Science Photographer

Stephen Kill is a photographer at the Rutherford Appleton Laboratory (RAL) in Oxfordshire. RAL is part of the Science and Technology Facilities Council, one of the UK's Research Councils and provides large scale scientific facilities for academia. He sees his role as producing striking images to help promote these facilities and science in general. Here he tells us about his life in science.

My interest in photography and science started at an early age with the encouragement from an uncle into natural history, in particular birds. This led to me participating in field survey work for a local bird club and the British Trust for Ornithology and also later to my interest in photography. I spent hours in hides observing and photographing birds. To fund the camera and the film which was then a necessity, I had a paper round and worked on Saturdays in a photographic shop.

After A-levels, I wasn't sure what I wanted to study at University and a teacher suggested that I consider photography. I applied for both arts and science based courses and chose a course in Photographic Science at what is now Westminster University. The course was about the science behind photography: optics, making films, processing chemistry and specialist photographic techniques and included large amounts of maths, physics and chemistry as well as some photography!

After University I joined my current employer at its Appleton Laboratory near Slough. I was initially employed to produce satellite images from computer data, to provide AV (audio-visual) facilities and to work in the darkrooms. Gradually I did more and more of the photography and today I am the Chief Photographer at the STFC's Rutherford Appleton Laboratory on the Harwell Science and Innovation Campus in Oxfordshire.

My job has evolved over the years. The darkrooms have gone, we are totally in the digital era and the photography is more and more geared for PR (public relations) to promote the facilities and science. The photography is very varied with people featuring heavily; scientists and engineers from the laboratory or visiting from anywhere in the world, school children, the general public and VIPs. I also do quite a bit of record photography of the new facilities currently being built, pieces of equipment and people at work. I have even done some aerial photography on occasion too.

It's essential to have an interest in and know something about what you are photographing. This is equally true in all fields of photography. I need to be able to talk to the scientists about their work and explain why I am taking the images in the way that I am. You have to get the person that you are photographing into the role you want and to get a good image they often have to exaggerate what they are doing. Scientists often do not want to be photographed so have to be encouraged and their presence usually makes all the difference. One

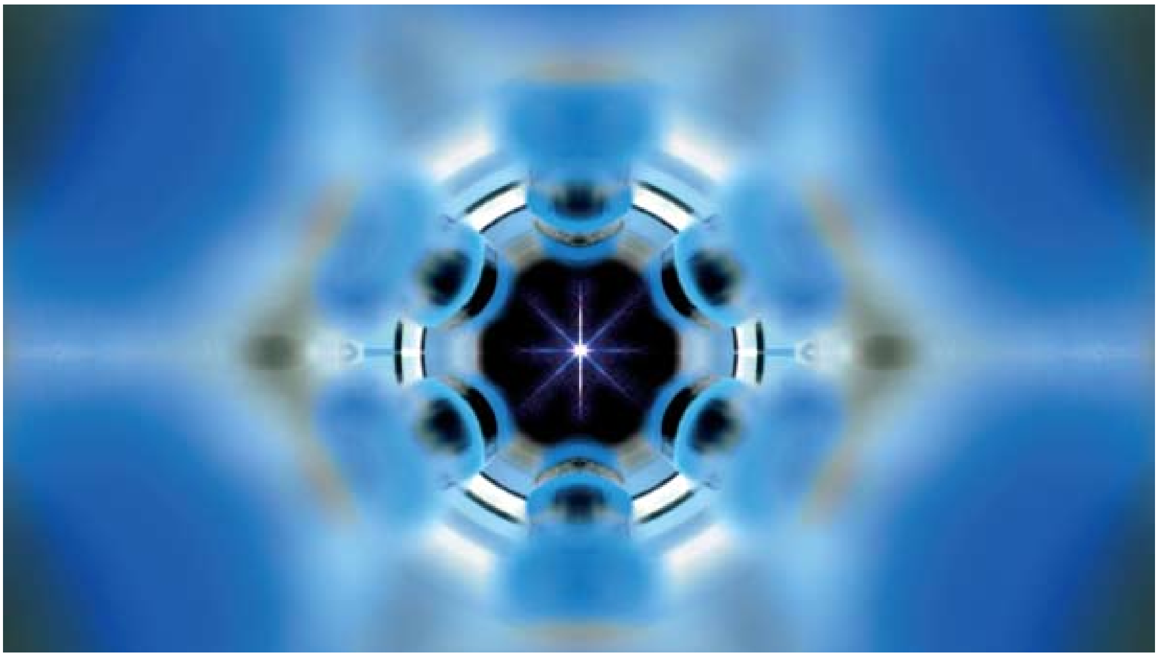
This image of a laser target is one where Stephen looked beyond what was commissioned with a striking and original result.

Stephen's photographs have appeared in a large number of publications all around the world, including CATALYST, *New Scientist*, *Nature* and national newspapers. They have also been used in local papers and school prospectuses, especially when school trips to the site have taken place. One has been used on a credit card; a framed print of one was presented to the then Prime Minister Tony Blair when he visited and one is on display in the British Embassy in Paris.

of the big advantages of digital photography is that I can show the person who I am photographing the pictures as I take them and use this to explain why I want them to do things in a certain way.

My philosophy is that wherever possible I like to look for images beyond the original commission and it is often these extra shots which are the most successful and enduring. I see the main point of my role as helping with the public understanding of science, capturing interest and opening up what the laboratory does to people who might not otherwise know about it.

Above right: *Stephen at work.* ***Above left:*** *Working in cleanroom conditions Stephen was dressed from head to foot like the scientist in this image.*



One of Stephen's favourite images, this picture of sextupole magnets at the Diamond Light Source was presented to Tony Blair when he visited and has been displayed in the British Embassy in Paris.

Photographing VIPs is part of Stephen's work. Here Stephen photograped Prime Minister Tony Blair during a visit to the Diamond Light Source.

Look here!

The Science and Technology Facilities Council website has several images of their work, many of which were taken by Stephen: *www.scitech.ac.uk/PandS/Gallery/contents.aspx*

The Wellcome Foundation has an Images of Science competition each year. See the images which made the finals here: *www.wellcome.ac.uk/en/wia/index.html*

Stephen Kill was talking to Vicky Wong. All the images in this article were taken by ***Stephen Kill*** *except the image of Stephen at work which was taken by Eric Jenkins, UKAEA.*

Peter Cole

Risky radiation

Comparing mobile phones and UV sunbeds

It is not uncommon for the general public to be misinformed about the risks associated with radiation. In this article, Peter Cole of Liverpool University contrasts two examples of technology that emit non-ionising radiation.

Mobile phones emit radiofrequency (RF) radiation. Tanning beds emit ultraviolet (UV) radiation. These are both types of non-ionising radiation. In recent years both have received considerable media coverage, and they are emotive topics for the general public.

In assessing radiation risks, we need to consider two factors:

- the type of radiation and the effects it may have on the human body
- the amount of radiation to which a person is exposed.

Mobile phone radiation

There are approximately 50 000 mobile phone base stations in the UK. These are the low-power antennae often seen on towers or on top of buildings. They transmit a few tens of watts at frequencies of around 2 GHz. This is electromagnetic radiation in the radio wave region of the electromagnetic spectrum and is known as **RF radiation**.

The photograph (Figure 1) shows two types of transmitters: tall, thin 'sector' antennae which communicate with mobile phone handsets, and 'dish' antennae which connect one base station to another.

Figure 1 *Two types of antennae at a mobile phone base station. Each type both transmits and receives RF radiation.*

RF radiation from a sector antenna is directed outwards in the form of a conical beam (Figure 2). This is aimed at the horizon (like the beam from a lighthouse) with a slight downward tilt of approximately 10 degrees. The beam usually touches the ground at a distance of about 150 metres

Key words
electromagnetic radiation
ultraviolet
radio waves
mobile phones

A frequency of 2 GHz (2 gigahertz) is 2 billion hertz or 2×10^9 Hz.

depending on the height of the tower. Because the beam spreads out, the intensity of the radiation (measured in watts per square metre) reduces very quickly with distance from antenna.

RF exposure limits are set by the International Commission on Non-Ionising Radiation Protection. On the ground the levels of RF exposure are small fractions of a percentage of the safe limit. So low is the amount of RF at ground level that it is extremely difficult to measure. Also, due to the horizontal direction of the beams, the lowest power emissions from a tower are actually to be found directly underneath the antennae at the foot of the tower itself. You would have to be directly in front of a base station and just a few metres from it to exceed the internationally agreed limits of RF exposure.

like those from mobile technology actually *cause* health problems such as cancer? Research on this tricky question is fairly incomplete, largely inconsistent, and vastly misunderstood.

The energy of a radiofrequency photon is about one million times less than the energy required to break a chemical bond. So the emissions from mobile phone technology cannot directly break a DNA molecule. If there is a causal mechanism that links RF to cancer then it has proven to be most elusive and must involve an extremely subtle physiological or biochemical process. To date no such mechanism has been identified. The risks to health, if any exist, are likely to be exceedingly small. Some studies may show a correlation between RF and cancer but that does not mean that there is any

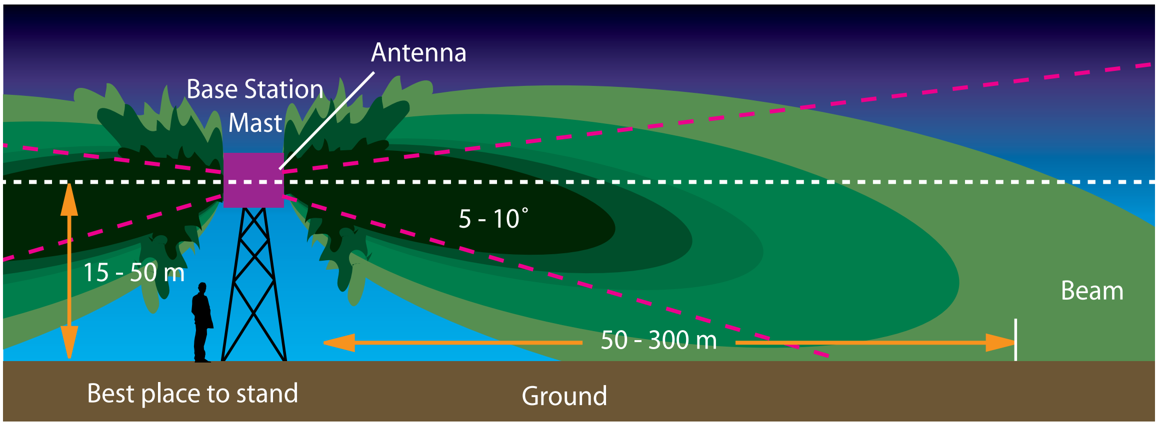


Figure 2 *RF radiation spreads out from a sector antenna in the form of a widening beam. The darker the shading, the more intense is the radiation.*

direct link, or that exposure to RF causes cancer.

Try to put this all in perspective. More than 100 000 people in the UK die each year from smoking. Approximately 20 000 UK citizens die annually from alcohol related illnesses. Even peanut allergies kill 50 members of the British public a year. To the current knowledge of all the scientists in the world, nobody has died as a direct result of the RF radiation emitted from mobile phone technology. Yet headlines such as "16 Masts in Cancer Street" and "Plague of the Phone Masts" often grace the pages of the tabloid newspapers.

In May 2000, the Independent Expert Group on Mobile Phones (IEGMP), chaired by the eminent scientist Sir William Stewart, published their comprehensive review entitled *Mobile Phones and Health*. They concluded:

"... the balance of evidence indicates that there is no general risk to the health of people living near to base stations on the basis that exposures are expected to be small fractions of the guidelines."

Building materials absorb and so attenuate RF to a certain extent but not completely, otherwise you'd never receive a phone call indoors.

The National Radiological Protection Board (now called the Health Protection Agency) have carried out surveys throughout the UK of RF emissions from base stations sited near schools or within school premises, on blocks of flats and other residential areas, and on office blocks. In all cases the RF power density measured was less than 0.2% of guideline exposure values.

Biological effects

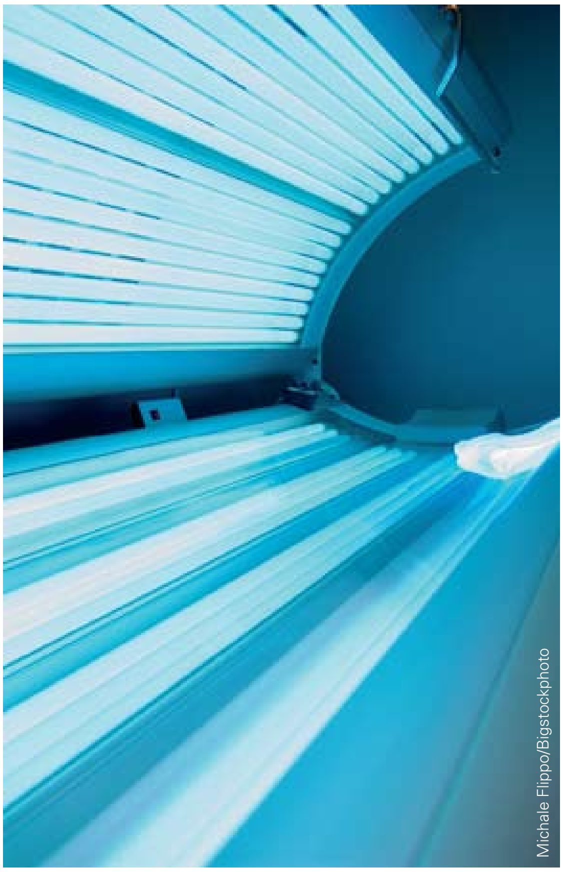
The biological effects of RF electromagnetic radiation can be divided into two categories. Thermal (or heating) effects are incontrovertible and scientifically well understood. These are how a microwave oven heats up food. They are also the effects on which RF exposure limits are based. Protection from these effects is simply a matter of staying more than a few metres away from a base station antenna.

It is the athermal (or non-heating) effects that are still open to debate throughout the worldwide scientific community. Can EMF exposure lead to athermal biological effects? Do the RF transmissions

UV, tanning and solaria

Ultraviolet (UV) tanning beds were introduced into the UK in the 1970s. A cause for concern is their increased use by young people with about 24% of British 16–24 year-olds using sunbeds, and there are a growing number of children under the age of 16 who frequent solaria.

Typically a bed will contain forty 200 W fluorescent tubes plus 12 to 24 smaller 25 W tubes incorporated between the main tubes within the lid. The tubes emit both UVA (95%) which causes skin aging and UVB (5%) which induces erythema (skin inflammation) and ultimately burns.



Michale Flippo/Bigstockphoto

More importantly, long term exposure to UV can lead to various forms of skin cancer. About 65 000 cases of skin cancer are reported in the UK each year with 2000 proving to be fatal. Malignant melanoma is now the most common form of cancer in young adults aged between 15 and 34 and it is often fatal. It has been estimated that 100 UK skin cancer deaths per year are attributable to the use of tanning beds.

Overdosing on UV

A recent study by the Photobiology Unit at Ninewells Hospital in Dundee found that 83% of sunbeds tested produced UVB radiation levels that exceeded European standards. The UVB emitted has reportedly increased by a factor of 3 over the last ten years, due to the increasing use of high-powered 'fast-tan' lamps.

Another worrying aspect is the increasing number of unmanned solaria where unsupervised users can purchase as many 'UV tokens' as they wish from a coin-operated machine. Each token switches on the bed for no less than three minutes which, on average, is the maximum recommended UV exposure for un-tanned skin. Six minutes on an average sunbed is enough to induce erythema in people with skin type 2.

Yet vanity prevails. The quest for that 'healthy looking' tan goes on unchecked by a significant proportion of the population who are either ignorant of the undeniable cancer risks represented by sunbeds or simply chose to ignore them. In addition, both local and national government seem remarkably slow to introduce any legislation or licensing regime to control solaria.

Despite the wealth of scientific data that causally links UV exposure to skin cancer, it seems that the general public are more worried about, and the media more fascinated by, the potential cancer risks from mobile phones than the irrefutable cancer risks due to sunbed usage.

To summarise, and all other things being equal, a tanorexic telephonophobe probably stands a greater risk of developing some form of fatal cancer than a pasty chatterbox with a mobile phone.

BOX 1 Tanning and skin type

marilyn barbone/Bigstockphoto

The sensitivity of skin to UV exposure depends on many factors. Previous tanning history, ethnic group, medical history and medication are all contributors. The Fitzpatrick scale categorizes skin into 6 'photo-types', with type 1 being the fairest and type 6 being the darkest. It is believed that the majority of solaria clientele fall into the skin type 2 category. Type 2 means fair-skinned Caucasians with poor tanning ability and a susceptibility to sun-burn.

The relationship between UV radiation dose and skin erythema has been thoroughly investigated by the scientific community and is largely understood. Erythemal UV dose is also acknowledged as a surrogate for carcinogenically-effective skin exposure, particularly for Squamous Cell Carcinoma (SCC). In other words, each time your skin goes red, you are increasing your chance of getting skin cancer.

Peter Cole is the Radiation Protection Adviser in the Physics department, Liverpool University.

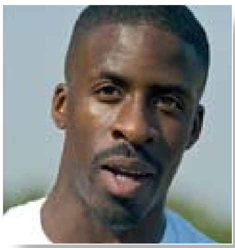
Michael Reiss

The ethical maze

Deciding what is right and what is wrong in biology

Key words
ethics
cost-benefit analysis
GM crops

Modern science raises many ethical questions. How can these be answered? Is ethics just a matter of making up one's own mind on issues? In this article, Professor Michael Reiss looks at how ethical frameworks can be used to address ethical questions and then applies them to the case of genetically modified food.



Dwain Chambers

In 2004, European 100 metres champion Dwain Chambers was found guilty of using a prohibited drug (the designer steroid tetrahydrogestrinone, THG) and banned for two years. He has now controversially returned to athletics. Should this be permitted?

It sometimes seems as if almost every decision in modern science raises ethical issues. Should we use genetic engineering to boost food production? Should we build more nuclear power stations? Should we use stem cells from embryos to try to find new cures for diseases? What, if anything, is wrong with athletes taking performance-enhancing drugs?

Answering such questions requires two things. First you need to have a valid **ethical framework**. An ethical framework is a sort of toolkit. It gives you a generalised way of tackling ethical problems rather as a saw gives you a generalised way of cutting wood. The second thing you need is a good understanding of science so that you can apply the ethical framework to the question you are interested in.

Just to make things a bit more interesting, there isn't a single ethical framework that everyone accepts. There are several different ones. You may find that you prefer one of these. That's fine, but it's a good idea to understand something of all of them. That way you'll appreciate how other people may see the same ethical issue in science differently from you.

First we will look at three of the major ethical frameworks and then we will see how these could be applied to the issue of GM crops. We will end by referring to some other ethical issues in science that can be addressed using these frameworks.

Cost-benefit analysis

Perhaps the most common ethical framework is to carry out a **cost-benefit analysis**. What you need to do is to consider all the costs (i.e. disadvantages or harms) that might result from a course of action and then compare these with all the benefits. If the costs outweigh the benefits, then it's best not to go ahead with the suggested course of action. If the benefits outweigh the costs, go for it.

Suppose, for example, you were trying to decide whether or not to cull (i.e. kill) badgers on farms with cattle so as to try to reduce the spread of bovine tuberculosis (a disease that infects both cattle and badgers and which they can catch from each other).

Benefits of culling badgers might include fewer cows getting ill and less money having to be spent as government compensation for farmers whose cows get bovine TB. Costs would include suffering experienced by badgers, the distress to all those people who like badgers, and the financial costs of killing the badgers.

As you can imagine, it is difficult to compare the benefits and costs in this case which is why the idea of culling badgers is controversial. Furthermore there are still disagreements as to some of the scientific issues. It is still unclear how many badgers and over what area would need to be killed to reduce bovine TB.

Rights and duties

A different ethical framework looks at whether there are any **rights** or **duties** in the case. Consider, for example, the proposal that 17-year-olds have the right to drive a car provided they have passed their driving test. Everyone would agree – no controversy here.

But pedestrians presumably also have rights – including the right to walk safely on pavements and across roads. This is one of the reasons why drivers have corresponding duties, including the duties to keep to the speed limit, have valid insurance and pay attention while driving (rather than using a mobile).

Alexandr Stepanov/Bigstockphoto

He's got the car, he's got the licence, he's got the shades – but what are his duties to other road users?

Virtue ethics

A third ethical framework doesn't look so much at the results of particular actions but at the character and motivation of the people in question. Hence the rather quaint term **virtue ethics**. The issue is whether people are acting virtuously or not. Virtues include characteristics like honesty, truthfulness, kindness and loyalty. Think back to the case of drivers and passengers. A virtuous driver would keep to the speed limit, have valid insurance and pay attention while driving even if there was no chance of being caught breaking the law. As the saying goes, virtue is its own reward.

The case of GM crops

Now let's consider **GM crops**. First, some science. 'GM' stands for 'genetically modified'. GM crops have had their DNA altered so that they contain some of the DNA of another species.

For example, GM maize is widely grown in the USA and a number of other countries, though not in the UK. It has been genetically engineered so that it is resistant to an insect, the European corn borer. Despite its name, the European corn borer is a pest in the USA and in many other countries. When adult, it is a moth and does no harm. The problem comes when it is a caterpillar. It burrows ('bores') into the stems of maize and damages the crop.

GM maize has been genetically engineered to carry a gene from a bacterium. As a result, the maize makes a particular bacterial protein. This protein is fatal to the corn borer (and other insects) when they eat it, but harmless to humans.

Dave Hoisington/CIMMYT

Genetically modified maize looks like ordinary maize. It is grown in many countries of the world. Here, Kenyan farmers are examining an experimental plot.

Keith Weller, USDA

The European corn borer Ostrinia nubilalis *is an insect that attacks maize, reducing yields.*

See the article on badgers and TB in CATALYST volume 18 issue 1 in our archive, www.sep.org.uk/catalyst.

So, is it ethical to grow and sell GM maize or not? First of all, let's look at the question within a cost-benefit framework. Here are some possible benefits:

- The farmer gets a higher yield for the crop.
- Fewer insecticides are used.
- The company that sells the technology may make more profits.
- Are there any possible costs? Well, there could be some:
- Non-pest species of insects that feed on the maize might be killed.
- The farmer has to pay more for the new varieties of GM crops.
- The GM maize might hybridise with wild maize (in Central America) leading the introduced gene to escape into the wild.

Luri Lupol/Angelo Gilardelli/Bigstockphoto

Do the benefits of GM maize outweigh the costs?

Note that the balance between these costs and benefits might depend on where the crop is being grown, and it might vary from year to year. For example, there is no wild maize in Europe so there is no risk of the introduced gene escaping into the wild. In Mexico, though, the situation is very different. Here there are still wild strains of maize.

Now let's examine whether GM maize is morally desirable within the ethical framework of rights and duties. On the one hand, crop breeders and farmers might argue that they have a right to carry on with their lawful business, developing new varieties to improve crop production.

On the other hand, those opposed to GM crops might argue that they have a right not to have GM food forced on them. At the very least, this would mean that food made from GM crops need to be labelled as such.

The framework of virtue ethics probably doesn't help much in the case of GM crops. It is often of more value in medical ethics, thinking about the right way to treat patients, for example.

Other ethical issues in science

Now let's return to the other ethical questions we referred to at the beginning of this article: nuclear power, stem cell technology, and performance-enhancing drugs. Hopefully, you can use the ethical frameworks introduced in this article to help you address these questions. Of course, you may not reach clear-cut answers but you should be able to examine the issues rigorously – and to detect when others are using poor arguments.

Conclusion

Sometimes ethical argument in science leads to agreement. Often, though, it doesn't – people may continue to argue about whether certain things are morally right or wrong till the end of time. This doesn't mean, though, that ethical analysis is irrelevant.

Ethical analysis can help to clarify where there are disagreements and to see whether certain scientific data can be obtained that would lead to the disagreement being resolved.

In any event, using a well established ethical framework can help you to produce better arguments for and against the use of science than simply saying 'I don't think that's a good idea' or 'I don't believe in that'.

Michael Reiss is Professor of Science Education at the Institute of Education, University of London.

Martin Allinger/Bigstockphoto

Extracting iron from cornflakes

Many breakfast cereals claim to be fortified with iron. It is possible to extract this from the cereal and, perhaps surprisingly, it looks just like iron filings.

Thomas Mounsey/Bigstockphoto

You will need

- Breakfast cereal fortified with iron, cornflakes work well
- Plastic cup
- Spoon
- Rolling pin or pestle and mortar or bowl and potato masher
- Hot (not boiling) water
- 2 clear, sealable sandwich bags – the zip-lock type is best
- Strong magnet – the stronger the better
- Piece of white paper

What you do

- Take about 2/3 of a cup of cornflakes and grind it to a fine powder. You can do this by bashing it with a spoon in the cup, by putting it in a sandwich bag and taking the rolling pin to it, crushing in a pestle and mortar, with a potato masher or zizzing in a blender. Whichever method you use, the finer the powder the better your results will be.
- Put the crushed flakes into the sandwich bag (use a new bag if you have been using one for crushing as it will probably have small holes in it). Carefully add about a cup of hot water to the powder, let out most of the air and seal the bag. Leave it for about 15-20 minutes so that the powder soaks up plenty of water. If all the water is soaked up, add a bit more.
- Lay the bag flat on the table and stroke it with a strong magnet, working all the time to one corner. Hold this against the white paper to make it easier to see the results.

What you find

You will see small black blobs coming out of the cereal as they are attracted to the magnet. These blobs are iron which has been added to the cereal. (You will not get large amounts of iron – certainly not as much as in the photo of the magnet.)

What happens when you eat it?

Your stomach juices contain hydrochloric acid which reacts with the iron to make iron (II) chloride. This contains Fe^{2+} ions which can be absorbed into the blood. Any unreacted iron passes through the digestive system and out the other end.

Further investigations

You could gather as much iron as you can from the cereal and weigh it (you will need to use an accurate balance – ask your teacher if you can use one in school). If you also weigh the breakfast cereal you could find out if it seems to contain the amount that is stated on the side of the packet. You could also try different types and brands of cereal.

Look here

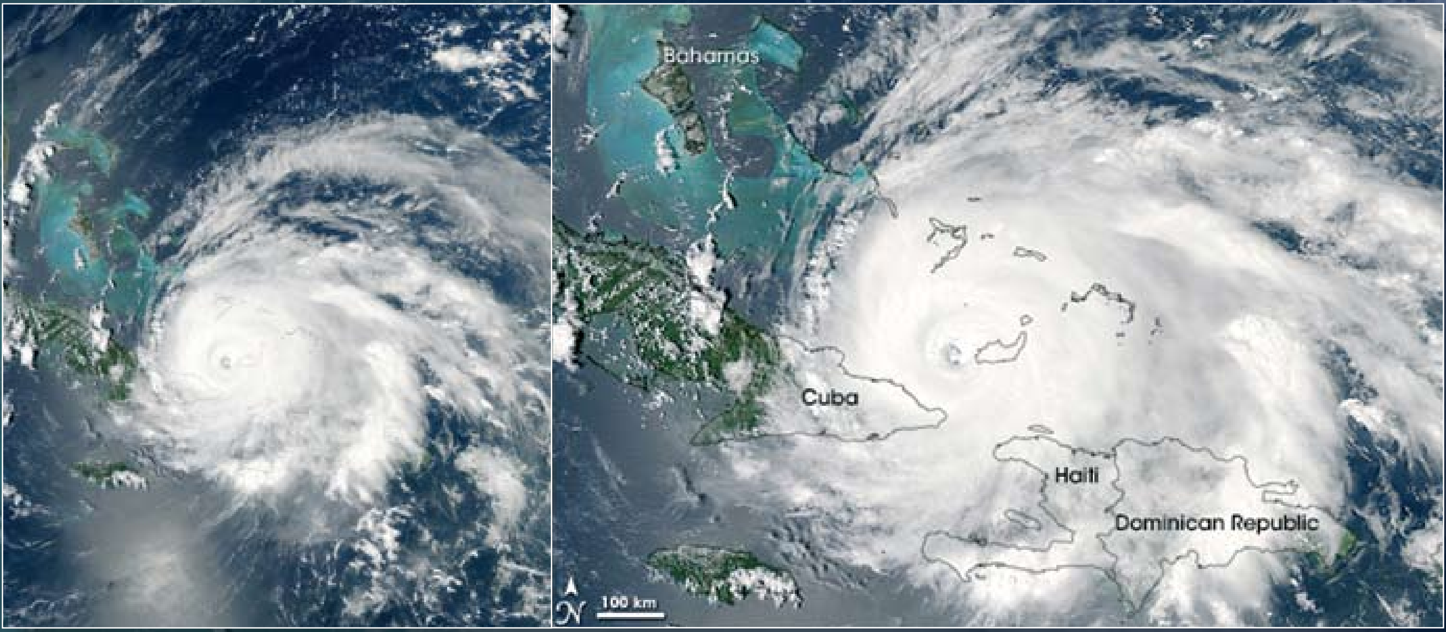
Watch Ivan and Mick from New Scientist as they carry out the experiment: *www.youtube.com/watch?v=ZIyKe9VE6o8* .

Vicky Wong is chemistry editor of CATALYST.

Tracking Ike

In September 2008, Hurricane Ike swept across the Caribbean and into Louisiana and Texas. NASA's satellites provided a range of images both during and after the event.

NASA's Aqua satellite photographed Ike as it was about to make landfall on Cuba. It was seen to be a Category 4 storm (winds up to 135 mph). The images below were made by combining visible and infrared data.



Jeff Schmaltz, NASA's MODIS Rapid Response Team

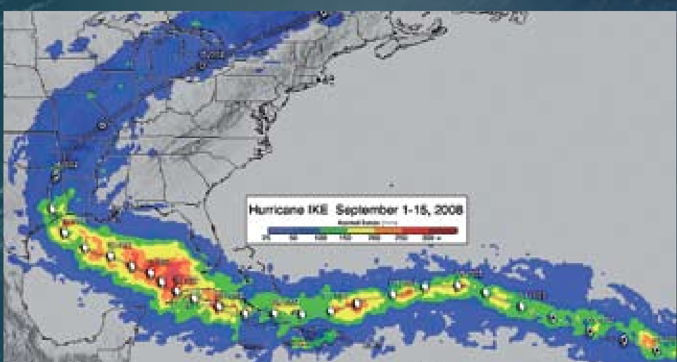
Right: The Terra satellite showed the aftermath of Ike. The brown strip along the coast, stretching up to 50 km inland, shows how the storm surge flooded coastal wetlands of Texas and Louisiana.

Jeff Schmaltz, NASA's MODIS Rapid Response Team

NASA

Hurricane Ike from the International Space Station.

Below: The Tropical Rainfall Measuring Mission satellite recorded the amount of rain falling from Ike. Some places received over 300 mm in under a day – that's half London's annual rainfall. The TRMM satellite uses radar and microwaves to detect rainfall.



SSAI/NASA, Hal Pierce

Flooding in Galveston, Texas.