Converging technologies and **new** issues

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In tomorrow's world, GPS or Galileo-type satellite positioning systems, which can accurately localize elements on the ground, may well provide other services when combined with sensors linked to people or property.

With the ascendancy of the nanotechnologies, and most importantly their convergence with other fields of science, the scene is set for major technological breakthroughs, bringing with them undeniable promise of progress but also facing us with new ethical issues.

Various innovations such as television, personal computing, the Internet and the mobile phone, have revolutionized our way of life. These innovations follow a relatively standard pattern: products appear, users see the potential benefits and get themselves kitted up. Prices fall, the offer expands, and, as the new products sweep the population, society gets organized and, in some cases, legislates.

The convergence of nanotechnologies and a host of other disciplines (such as information technology, cognitive science, or medicine) heralds not only major technological breakthroughs but also promises to revitalize innovation to such an extent that the traditional pattern described above may well be overtaken. Indeed, even though the results of foresight studies should not be taken as set in stone, some of the implications and the new issues raised simply cannot be ignored. As is always the case with major innovations, although we have started to recognize considerable benefits, there are nevertheless concerns raised over the potential risks and repercussions on society, the economy, and even our rights and interests. The debates in progress (research on stem cells, human cloning, the development of genetically-modified organisms, copyright and Internet, toxicity of **nanoparticles** – see *Accounting for risks associated with nanoparticles*) or around the corner perhaps provide the first clear illustrations of the new questions facing our society. The handful of examples set out in this article underline the scope of these questions and concerns.

New issues in information technology

A movement was started a few years back towards the multiplication of interconnected sensors and actuators. These devices will expand the possibilities for services support, especially since a host of elements are set to relay "setting"-related data, *i.e.* the objects operating in the surrounding environment and the identity of the user or client. Sensors linked to people or property they are carrying will relay geographical data (GPS(1), triangulation, cameras). This tracking capability can provide assistance, navigational aid, and "enhanced reality" vision. User identification is a key to payment security, on-line data access, events logging. Other fixed-location sensors

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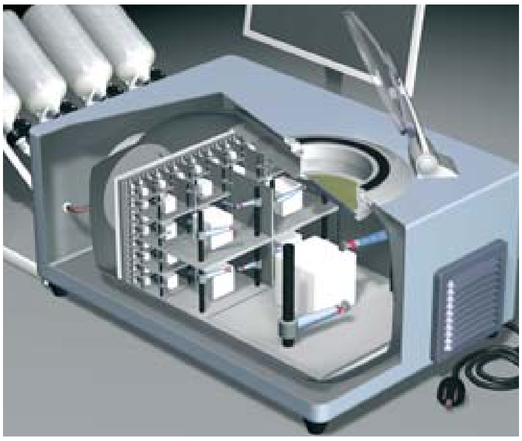
(1) Global Positioning System.

are set to optimize operations within infrastructures. Examples include the regulation of urban environments, transport control, or even the fight against crime. Lastly, in-home systems will be designed to provide a "smart" environment with a wide range of service support, especially targeting safety, education and entertainment.

Services with high added-value require a minimum level of interconnectivity. An extreme vision has been put forward where a worldwide Internet network links up all the billions of these elements into one, single information system.

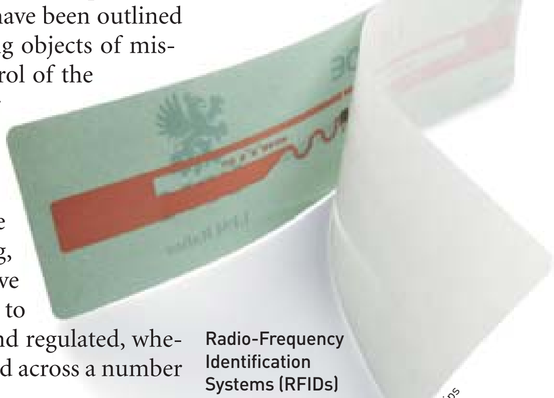
All of these devices produce packets of data that can be cross-referenced. The issue involved here is how to deploy user-empowering technical solutions while guaranteeing that citizens can maintain control over their personal information. The possibilities for fraudulent use together with data security are issues that need to be accounted for as from the design stage, since user trust will be the key factor in the deployment of these technologies.

An example taken from early this decade is RFID(2) electronic labelling systems. When these devices are queried, they transmit an ID code that can be unique, with coverage ranging from a few millimetres to around 10 metres. They are already implemented for controlled access systems (badges, toll systems) and identification (anti-theft devices, animals), and they are expected to eventually cost the same as conventional labels. This would mean that the possibilities for use would be endless, for example stock tracking, anti-theft device labelling, vehicle registration, or the widespread deployment of objects capable of informing the local environment of their presence. Thus, a fridge or a washing machine would be "informed" of its contents, or it would become easier to find your glasses, mislaid documents, etc. In a nutshell, RFIDs are localization, identification and authentication systems. In late 2003, thirty-odd US-based associations, the most well-known being Caspian(3), drafted a manifesto summarizing the various issues involved in the use of RFIDs. First, they are easy to hide, and can give information on the carrier (what are they carrying?, how much money does the carrier have on them?) This data can then be cross-referenced to gain access to other information on the user, such as their identity, location, consumer patterns.


John Burch, Lizard Fire Studios

A conceptual "desktop nanofactory" for molecular-scale manufacturing, conceived as a series of machines assembling progressively bigger parts (the white cubes), for example computer cores equipped with billions of parallel processors.

A handful of general principles have been outlined to prevent RFIDs from becoming objects of mistrust, starting with positive control of the sensors: clear signalling of their presence and their features, transparency as to their ultimate purpose, ceilings on the data exchanged and limitation of the possibilities for cross-referencing, and making them simple to remove or block. In the same way, access to data should also be controlled and regulated, whether the data is a file or distributed across a number of interconnected systems.


DR/Philips

Radio-Frequency Identification Systems (RFIDs) offer a potential that goes way beyond the administration and authentication tasks they currently perform, raising doubts and even fears in the process.

Nanotechnologies are set to further increase the omnipresence of information technologies and make them more easily accessible, or even embedded in the "landscape", while also enhancing their specificity, particularly by giving them the ability to identify a given individual. This opens up staggering possibilities, but will also put societies before some difficult decisions. One of these decisions is going to involve dealing with the notion of privacy. Every individual has a right to a certain level of privacy in relation to others, be it through medical secrecy, behind closed doors, or anonymity. Rising insecurity, terrorism, or even an abject crime can lead a society to sacrifice some of this protected privacy for an increased sense of security, as was the case in the USA with Megan's Law. Following a particularly heinous crime perpetrated by a repeat child molester, the USA adopted a law authorizing the publication of personal data on sex offenders, which can easily be found on the Internet in certain States. In France in June 1998, the law on the prevention and repression of sexual offences led to the creation of the FNAEG(4), which was initially designed to pool the DNA fingerprints of individuals convicted for sex-related crimes. In response to particularly odious crimes, the terrorist attacks of 9/11 and an increasing feeling of general insecurity, the use of this file has been widely extended by successive governments from both sides of the political divide. This file is expected to contain 700,000 fingerprints, which is nevertheless lower than the UK equivalent which has already passed the two million mark.

Future developments could take two paths. First, increasing pressure on complex issues such as the where to draw the line between a right to privacy, which underpins social cohesion (the right to be different, to reintegrate society following errors in the past, the right to start a new life), and the well-being of society as a whole; second, deep discussion on how the techniques involved are evolving, in an attempt to find a way out from certain catch-22 problems. Would it be an option, for example, that only machines could "know" the private personal information of an individual and "act accordingly"?

(2) Radio Frequency Identification Devices.

(3) Consumers Against Supermarket Privacy Identification And Numbering.

(4) *Fichier NAtional des Empreintes Génétiques* (French National DNA Fingerprint File).

Crossover with the living world

By enabling the engineering of miniature systems that are extremely energy-efficient and that can potentially be interfaced with the body, nanotechnologies offer a vast horizon of possibilities in the field of medicine (sensors, artificial organs). Nanotechnologies also pave the way towards data implant systems, a convergence likely to have far-reaching impacts.

A first crossover involved using implanted RFIDs for identification purposes. This application is routine practice in pet identification, but it has also been used on human volunteers. A now-famous system is the *Verichip*^{TM}, a 2.1 mm-diametre cylinder that can be implanted under the skin. The company developing these devices intends to couple them with (external) GPS localization systems to track the carrier. There is a wide range of potential applications: infant protection and anti-kidnapping systems, tracking the movements of prisoners on parole (a more "internalized" version of the electronic bracelet) or patient tracking and monitoring, and extending to access control systems or even secure payment (no longer the card that carries the chip, but the customer). Feelings on this concept have run particularly high, even reaching pure disgust in some cases. Already, over a thousand people have been "implanted" for one reason or another. These users see the benefits: a way of asserting oneself like getting a piercing, peace of mind for worried parents, secure access, access badges and tags, means of payment. Unless major changes modify the current context, these practices are expected to remain relatively confidential, especially given that the benefits remain relative, as underlined by certain detractors: once a few crude "extractions" have occurred, these precious access keys will soon cease to be considered as "secure".

A second topic concerns the question of commoditizing human data. Micronanotechnologies make it possible to produce a fully-functional but miniaturized analysis laboratory, the so-called "**lab-on-a-chip**". The most classic embodiment of this is **DNA** analysis, which has a major ripple effect on the field of diagnostics. A major consequence of this has been the "desanctification" of our genetic identity and its relevant information, especially since we so generously spread our DNA through the environment (hair, blood, saliva, flakes of skin, etc.). There is reason to fear the emergence of previously unheard-of practices if DNA analyzers become commercially available without restrictions: profiling, and consequentially, genetic discrimination of individuals, probably without them knowing, which could serve employers or insurance companies for example to identify any proneness to illness. Following the success of graphology and astrology, it is not difficult to imagine specialist companies offering personality tests based on DNA profile. Just the word DNA would already lend them a certain credibility.

A third, more promising technology crossover is causing excitement in medical fields. Implant systems could be used to give constant, real-time diagnoses, or even perform drug delivery, giving freedom of movement to patients who would otherwise be immobilized. These techniques, which will be deployable in the near future, are expected to receive a warmer welcome. The longer term may well see the advent of a new generation of even more innovative devices: artificial retinas or inner ears, brain implants, artificial tissues. This kind of next generation device would open up possibilities for revolutionary new therapies, but would also pose questions that we have not had to face before (but which in fact have already been discussed, particularly in the USA). What will happen if we start building devices able to improve human beings? What would happen to societies refusing these revolutionary practices?

Reymond Pagé/ETC

A sharp parody on the convergence between nanotechnologies and biotechnologies. The cartoon was published by ETC group, one of the first organizations to systematically warn against the real or imagined dangers of nanotechnologies.

The final, more long-term example is the convergence of nanotechnologies and cognitive science. Already, this leads us to the concept of proactive systems capable of reacting according to the users habitual patterns, i.e. objects called "smart" even if they aren't really. This, too, will raise new questions. Some to do with marketing, like how should an object "behave" so as not to be refused. Initially, the application could be considered as a kind of futuristic ergonomics, but things go a lot deeper if we raise the question of the objects having some kind of "personality". There are other, more general questions, related to non-human decision-making for example: granting a machine the power to decide may be extremely useful for controlling the take-off parameters for a rocket or an airplane, but maybe less so when the decision is medical, or even legal.

Questions weighing on research

Whatever the theme being approached, the conclusion is always the same: nanotechnologies present a number of plus points, but the trade-off between the predicted advantages and breakaways raises still more questions: the impact on employment, security, social cohesion, individuals' well-being, and the list goes on. However, these questions and the debates they will surely generate will also impact on research itself, and any resulting products. Another factor to take into account is that many of these questions are truly global. For instance, trade requires the most consistent standards possible, together with a fair balance between the needs of the various actors, since the movement of people presupposes relatively standardized access rights and procedures.

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Accounting for **risks** associated with **nanoparticles**

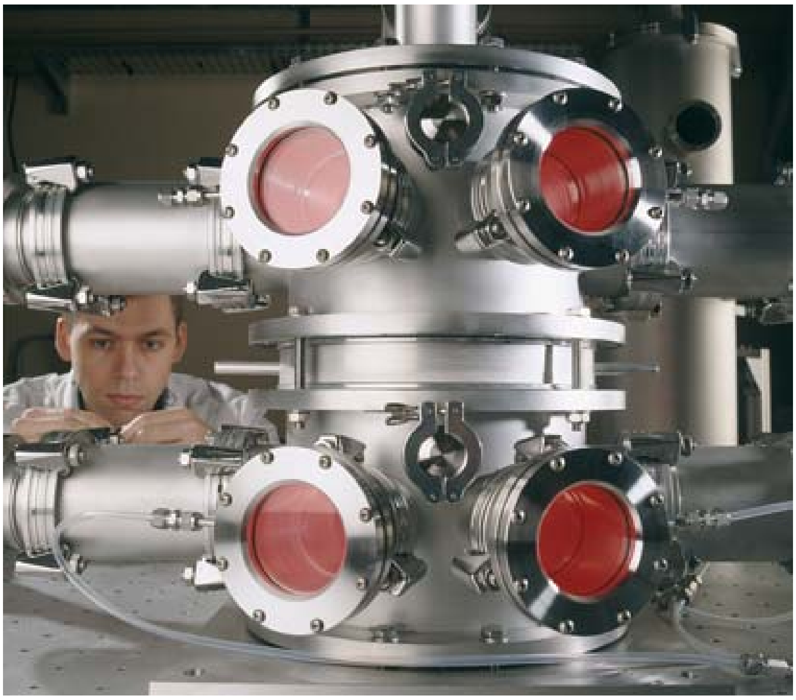
Among the actual or potential risks associated with nanotechnologies, the possible toxicity of nanoparticles deserves particular attention. While there are nanoparticles that already exist in nature or that have already been mass-produced industrially, the forthcoming mass introduction of new-engineered nanoparticles straight from the laboratory has toxicologists working overtime.

The **nanoparticles**, which is a term habitually used to describe particles smaller than 100 nm, are finding new industrial applications every day in fields as diverse as electronics, biomedicine, pharmaceutics, cosmetology, chemical catalysis, new materials, and others. This boom is due to the properties of nanoparticles that are sometimes fundamentally different within the same materials at microscopic or macroscopic scale in terms of mechanical strength, chemical reactivity, electrical conductivity, or **fluorescence**, etc. Nanoparticles can be made of highly diverse organic or inorganic matter and display very different morphologies, taking on forms such as fibres (SiC for example), **nanotubes** (carbon), spheres, etc.

We are about to witness the advent of a new era in the industrial history of nanoparticles. New types of nanoparticles that until now were under laboratory development are on the verge of mass-production. Nevertheless, it is important to note that certain nanoparticles, such as silicon, titanium and aluminium oxides, have been produced in high volumes for several years already. Economists are now talking about the dawn of a new industry for the 21st century, with annual turnover forecasts as of 2010 cited at around 340 billion euros worldwide, which would rank it alongside the automobile and microelectronics industries, i.e. somewhere between a third and half of the total turnover attributable to nanotechnologies (Figure). This industry is expected to directly employ over two million salaried staff.

Given this context, over the last few years the CEA has been continuing its research into nanoparticles, both prospectively and in relation to its own needs in the domain of energy, particularly for developing the highly-advanced materials needed for the nuclear reactors of the future and for fuel cells(1).

Although nanoparticles have always been around in the natural world, including in our supposedly pure mountain air, in very high concentrations (around 10,000 particles above 10 nm per mL), great care should be taken with the potentially very different physical properties of the new engineered nanoparticles. This is especially true where concentrations are expected to be highest: in production workshops and, later on, when working with artificial particles. To compound the situation, their small size makes it difficult to confine them solidly over time and promotes rapid dispersion in the air via diffusion processes, while their persistence is likely to promote exposure to the personnel.


A. Gonin/CEA

Laser pyrolysis pilot for nanopowder synthesis installed at CEA Saclay. The method consists in creating an interaction under argon between a power laser and a flow of liquid or gas reagents which allows modulate the physico-chemical characteristics of the nanopowders. The production capacities targeted are of the order of a kilogramme per hour.

Conventional risks and specific

Nanoparticles present two types of risk: the objective "conventional" risks, and the potential risks related to specific properties induced by their ultrasmall size. In terms of conventional risks, the first obvious point is that while nanoparticles are composed of toxic materials (especially heavy metals), they can expose humans to at least the same risks as the same quantity of toxic material in its macroscopic form. Furthermore, as they are first and foremost powders,

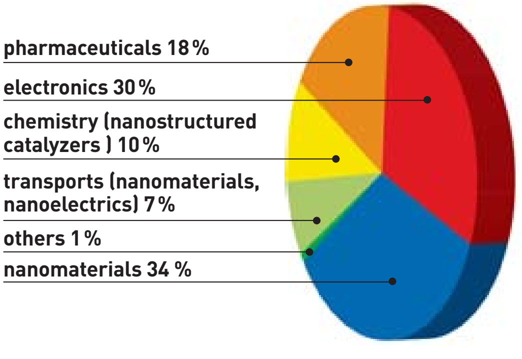


Figure.
Forecast market breakdown of nanotechnologies in 2010, for a total worldwide turnover estimated at between 700 and 1,000 billion euros (Source: Prospective study on nanomaterials – DIGITIP (French State Secretary for Industry) 2003).

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(1) See *Clefs CEA* No. 50/51 (winter 2004-2005).

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Extracting SiC nanoparticles obtained by laser pyrolysis at CEA Saclay. As a precautionary measure, during this kind of handling exercise the CEA applies confinement techniques borrowed from the nuclear sector.

the majority of nanoparticles are prone to oxidize with extremely fast kinetics due to their large available surface, meaning they are potentially explosive. If an explosion would happen in a production factory, a significant amount of nanoparticles may be released into the air. However, this "dust explosion" phenomenon is only likely to occur at high concentrations.

The second type of risk is related to specific properties of nanoparticles, particularly the chemical reactivity, and surface impurities. The most extensively-documented research has been achieved in environmental impact studies on urban pollution which may generate concern over the effects on human health caused by artificially-engineered nanoparticles. Peters and coworkers in 1997 and Pekkanen's team in 2002 highlighted the effects of urban carbon based particles on respiratory function and the on the cardiovascular system parameters, respectively. The frequent presence of pollutants such as carbon monoxide, nitrogen oxides or ozone adsorbed on the nanoparticles makes it a difficult task to discriminate between their respective contributions.

Outside these studies on "urban" particles, relatively little data is available on the short- or long-term toxicological effects of nanoparticles even nor on the precise mechanisms able to induce this toxicity. The first studies published worldwide nevertheless reported interactions between nanoparticles and cells, which should also be cause for concern.

Unfortunately, in these studies the exact physico-chemical nature of the nanoparticles studied was not characterized, whereas today latest developments seem to indicate that this is a decisive parameter - carbon particles can be made of single or multi wall carbon nanotubes or soot-. This uncertainty makes it difficult to compare the first results obtained between laboratories.

Several routes of entry into the organism

Back in 1992, Oberdörster's team working with animals had already demonstrated effects linked to the specific properties of nanoparticles.

The respiratory system seems to be the main route of particle entry into the organism, as confirmed by Daigle's study in 2003. This effect becomes more intense in people who exercise. Compounds such as Teflon™ normally considered harmless can be hazardous at nanometric scale. Isolated nanoparticles become lodged in the pulmonary airways, especially in the deep lung, in markedly higher proportions than for micrometric particles.

Ferin, in 1991, reported that nanoparticles are in fact able to penetrate the pulmonary epithelium far more rapidly than micrometric particles, and migrate into the lymphatic pathways, where they accumulate in the closest lymph nodes. Systemic distribution via blood circulation has also been demonstrated.

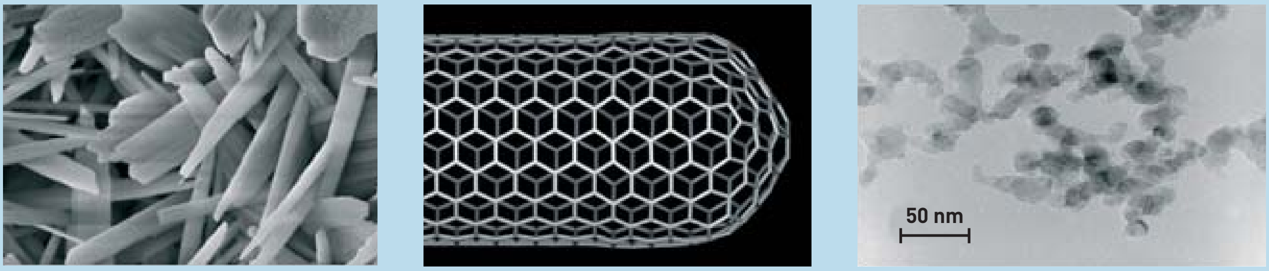
Chui-Wing Lam showed that mice having inhaled fragments of carbon nanotubes measuring just a few micrometres displayed the same responses as to ordinary dust, whereas when challenged with individual nanofibres they developed pulmonary and intestinal lesions.

Another animal study performed by Yiu and coworkers in 1990 revealed that the observed pulmonary effects were related more to the total surface area of the nanoparticles than to their mass, thereby underlining the importance of surface reactivity.

Furthermore, a possible cutaneous route of entry, as well as secondary transfer via the gastrointestinal route, cannot be ruled out.

The role of chemical nature

In addition to certain occasionally predominant physical parameters such as particle surface, the chemical nature of nanoparticles also plays an important role, as revealed by comparative studies between nanoparticles led by the teams of Murphy (1998), Dick (2003), Aust (2002) and Huang (2003). For instance, a study by Oberdörster (1992) showed that identically-sized particles of titanium dioxide (TiO2) and carbon black led to completely different penetration patterns into the alveolar interstitium (50% vs. 4% of the dose load, respectively). Furthermore, in 2004 Oberdörster also demonstrated that nano-



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Nanoparticles can come in a wide range of forms, as shown in these examples of (left) silicon carbide fibres, (centre) carbon nanotubes and (right) "spherical" particles obtained by laser pyrolysis.

The NanoSafe2 project

The first Subproject of NanoSafe2 is dedicated to the detection, traceability and characterization of nanomaterials. The nanoparticle detection element is a key factor in reducing and then monitoring personnel exposure levels, validating appropriate filters, optimizing production equipment for leakage-reduction, etc.
Subproject 2 covers the development of generic technologies and methods for determining the real toxicity of various types of nanomaterials. It also entails creating an open-access database containing all the toxicology data obtained within the project, supplemented by data collected from other sources worldwide.
New technologies to cut down exposure to staff at work stations and to leakages from production workshops into the environment are developed in Subproject 3, which also covers the qualification of means and measures for protecting individuals from nanoparticles.
Lastly, Subproject 4 is tasked with publishing the results obtained under the project, issuing proposals to international standardization bodies, and organizing training sessions for personnel at risk of exposure to nanoparticles.

Partners in the pan-European NanoSafe2 project

particles are able to reach the brain by following the path of the olfactory nerve.
At the same time, many other studies have however demonstrated that certain nanoparticles are completely harmless, or even have potentially beneficial effects (*e.g.* the capture of free radicals by **fullerenes**). In fact, it is likely that it will take years to determine the exact types and doses of nanoparticles that are genuinely hazardous for humans and the environment.
Given the stakes involved for industry, a large number of research programmes have been launched to study nanoparticle toxicity, particularly in the USA (the National Institute for Occupational Safety and Health (NIOSH), the Environmental Protection Agency (EPA), Rice University, and others), in Canada at Toronto University, and in Europe, through national project initiatives led in the UK, Germany and Switzerland as part of the 5th and 6th FPRTDs. These research projects deal with subjects such as nanoparticle transport through the skin barrier (Nanoderm), nanoparticle/human body interactions (Nanopathology), and the toxicology of ceramic-silicon nanoparticles (Siliceram).

A project to study the complete production chain

The CEA has elected to play its role in this thematic by launching a national research platform through the Ecrin(2) club along the theme of "nanomaterials and safety", and by setting up the European NanoSafe2 project. This project is dedicated to risk management in the industrial production of nanoparticles, and the kick-off meeting was held in April at the CEA-Grenoble centre. This integrated project aims to deal with a limited number of nanomaterials and typical industrial settings but will cover the complete production line, from manufacture to packaging, storage and transport, until the incorporation into final products. NanoSafe2 is expected to supply the first technological solutions and procedures for nanomaterials industry and laboratories. The project has four main parts (see Box).
NanoSafe2 has mobilized six different CEA units located in Grenoble and Saclay and over 24 European partners including universities, institutes, SMEs and industrialists. The teams count aerosol specialists, technologists, biologists and occupational health officers (Box figure).

Applying the principle of precaution

Long before the final conclusions of toxicology research studies on nanoparticles, the CEA is already applying the principle of precaution by implementing confinement techniques and methods used in nuclear field for environmental and personnel protection in its nanoparticle research centres.

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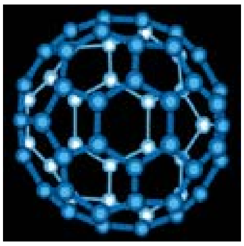
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Fullerenes, which were discovered in 1985, are one of the forms of nanoparticles that could be used in medicine to store drugs or capture free radicals.

TO FIND OUT MORE

For toxicology issues: Dr Daniel Bloch, occupational health officer at the CEA-Grenoble centre (daniel.bloch@cea.fr).

For information on the Nanosafe2 programme and the "nanomaterials and security" research platform at ECRIN: Frédéric Schuster, project coordinator at the CEA (Fontenay-aux-Roses centre) (schuster@zoe.cea.fr).

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(2) http://www.nanomateriauxetsecurite.fr