Nuclear weapons

Reliable evidence?

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America wants to ensure that its nuclear warheads would go bang rather than pop — but without letting them off to test them

OLD soldiers never die, they just fade away. Old weapons, on the other hand, hang around stubbornly. Those of the nuclear variety left over from the cold war are causing a bit of a nuisance. Thousands of them are ageing in silos. Ensuring that they do not deteriorate and would detonate if necessary is difficult. That is because of the Comprehensive Test Ban Treaty which, as its name suggests, forbids contracted parties from letting off nuclear explosives in peacetime.

Although America has yet to ratify this treaty, its policy is to act as though it had. It stopped the tests of real warheads (such as the one illustrated above) in 1992. That means scientists wishing to find out whether a particular batch is still potent cannot just pluck a warhead at random from the stockpile and try to explode it. One way to overcome this would be to replace the warheads with newer designs that, proponents argue, would not need to be live-tested in this way. The older warheads, the most elderly of which will reach the end of their

30-year design lifespan in 2008, could then be retired without compromising the country's nuclear shield.

The Reliable Replacement Warhead programme, as this scheme is known, has reached a crucial point. A full (and costed) design for the new warheads was supposed to be unveiled in December. However the National Nuclear Security Administration, the part of the Department of Energy responsible for the programme, said this week that the report is now expected by August 2008. Some people suspect it will be delayed yet further by the presidential election next year.

A year's delay will not matter much. But should the programme be cancelled (and funding for it, first authorised in 2005, was all but eliminated by Congress for this financial year), America risks finding itself without enough nuclear-weapons scientists to keep its arsenal in tip-top condition in the future. For the truth is that the Reliable Replacement Warhead programme is also a job-creation scheme, designed to persuade some of the country's best brains that it is worth trading a career in industry for one in national defence.

Testing without testing

Scientifically speaking, the programme's goals look possible. Earlier this year the National Nuclear Security Administration chose a design that it thinks could be developed without any further live tests. In September Jason, an elite group of independent scientists, published its evaluation of what technical information it could assess about this design. It concluded that, in principle, it would indeed be possible to develop a replacement warhead without conducting any new nuclear tests. It recommended, however, that the final design be scrutinised in an independent peer-reviewed process. That would be a first. Allowing outsiders to assess a design for its strengths and weaknesses is not something that the Department of Defence has done in the past—and it is not, at the moment, proposing to change its mind.

According to Bruce Goodwin, who is responsible for nuclear technologies at the Lawrence Livermore National Laboratory in California—which, with the Sandia National Laboratories in New Mexico, put forward the winning design—the proposed replacement warhead is based on a weapon that was tested but not deployed some 20 years ago. The richness of the existing test data is what gave this design its winning edge over an alternative proposed by the Los Alamos National Laboratory (also in New Mexico, and which also had Sandia as a partner). Those data help to give confidence that “virtual” tests, run inside a supercomputer, will produce results that correspond to what would happen if a warhead were tested for real.

The quantities of data involved in such simulated tests are phenomenal. Staff at Lawrence Livermore say it takes their best computers six weeks to simulate what happens inside a warhead when it is going off. Such detailed modelling has only recently become possible. The supercomputers used in the early 1990s, when nuclear testing stopped, would have taken 60,000 years to process the same data.

Part of the reason for this is that a nuclear explosion has three stages. First, a specially shaped charge of chemical explosives surrounding a plutonium pit goes off. That compresses the plutonium while it is simultaneously bombarded with neutrons from a trigger made of polonium, and thus begins the second stage. In response to the neutrons, some of the plutonium atoms split apart, releasing energy and more neutrons. These, in turn, split more plutonium.

This is the famous chain reaction that lies at the heart of nuclear warfare. It is not, however, the source of a modern bomb's main explosive power, for just as the chemical explosives trigger a fission explosion by compressing the plutonium, that fission explosion is used to ignite the third stage, a still-larger fusion explosion, by compressing and heating the main part of the bomb. This is composed of a mixture of deuterium (a rare isotope of hydrogen) and lithium (a light metal). These react to form helium, yet more neutrons and a whole lot more energy. The result, a thermonuclear explosion, is what destroys the target, but the entire three-stage process has to be mimicked if computers are to test weapon-designs reliably.

The models involved in the winning Livermore/Sandia bid are certainly good enough to recreate the results of earlier tests (a trick known as “hindcasting”). Whether they can accurately forecast things, no one knows for sure. But so-called subcritical tests are allowed by the test-ban treaty, and that may add confidence to the process.

Some of these tests involve smashing or shooting at small shards of plutonium. Blowing up little bits of the metal this way, without compressing them in a symmetrical manner, is allowed because it does not result in a chain reaction. And the chemical-explosive detonator can also be tested using “simulants” that are not fissile but mimic the behaviour of the plutonium pit in other ways. Scientists can thus find out whether the charge would have detonated, had it been made of plutonium.

The fusion stage can also be examined within the rules. An enormous—and enormously expensive—system of lasers called the National Ignition Facility is being built at Livermore. It is designed to cause thermonuclear fusion in tiny pellets of deuterium (so small that they would not be covered by the test-ban treaty) and is expected to be completed in 2009.

For weapons scientists this is all exciting stuff. Not quite as exciting, perhaps, as letting bombs off for real, but not a bad substitute. The question for the politicians is whether that excitement—and the personnel and new bombs that will result from it—are worth the money. And that, in turn, depends on just what sort of nuclear arsenal America thinks it really wants.

Human reproduction

Stress city

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The sex of a child may depend on how stressed its mother is

A BOY or a girl? That is usually the first question asked when a woman gives birth. Remarkably, the answer varies with where the mother lives. In rich countries the chances of its being a boy are about 5% higher than in poor ones. Equally remarkably, that figure has been falling recently. Several theories have been put forward to explain these observations. Some argue that smoking plays a role, others that diet may be important. Neither of these ideas has been supported by evidence from large studies. But new research points to a different factor: stress.

Strange as it might seem, the terrorist attacks of September 11th 2001 shed light on the enigma. Studies noting the sex of babies conceived in New York during the week of the attacks found a drop in the ratio of males to females. That is consistent with earlier studies, which revealed a similar shift in women who became pregnant during floods and earthquakes and in time of war. Moreover, a study carried out eight years ago by researchers at the University of Aarhus, in Denmark, revealed that women who suffered the death of a child or spouse from some catastrophic illness (such as a heart attack) around the time they conceived were much more likely to give birth to girls than to boys.

Taken together, these results suggest that acute stress to a woman at the time of conception shifts the sex ratio towards girls. However, Carsten Obel, a researcher at Aarhus who was not involved in the earlier study, wondered if the same might be true of chronic stress too. In a paper just published in Human Development, he shows that it is.

Dr Obel used a set of data collected between 1989 and 1992. During that period 8,719 expectant mothers were asked to fill in questionnaires that inquired, among other things, about their level of stress. Dr Obel found that the more stressed a mother had been, the less chance she had of having given birth to a boy. Only 47% of children born to women in the top quartile of stress were males. That compared with 52% for women in the bottom quartile.

Dr Obel suspects the immediate cause is that male pregnancies are more likely to miscarry in response to stress than female pregnancies are, especially during the first three months. However, that is difficult to prove. More intriguing, though, is the ultimate cause, for he thinks it might be adaptive, rather than pathological.

That is because the chances are that a daughter who reaches adulthood will find a mate and thus produce grandchildren. A son is a different matter. Healthy, strapping sons are likely to produce lots of grandchildren, by several women—or would have done in the hunter-gatherer societies in which most human evolution took place. Weak ones would be marginalised and maybe even killed in the cut and thrust of male competition. If a mother's stress adversely affects the development of her fetus (as it is likely to do) then selectively aborting boys, rather than wasting time and resources on bringing them to term, would make evolutionary sense.

That, in turn, would explain why women in rich countries, who are less likely to suffer from hunger and disease, are more likely to give birth to sons. That this likelihood is, nevertheless, falling suggests that rich women's lives may be more stressful than they used to be.

Optical materials

Catching rainbows

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How to halt light and bottle it

A FUNDAMENTAL law of physics says that nothing can go faster than light, which zips along at around 300m metres a second. But light can also travel at a more leisurely pace, slowed, for example, by air or water. This week a group of researchers led by Ortwin Hess of the University of Surrey, in England, announced a plan to stop light completely and store it, using materials that possess some odd properties. If the plan works, halting and hoarding light in this way could eventually lead to better computers.

The odd property on which Dr Hess's plan rests is called negative refraction. When a ray of light encounters a boundary, such as that between air and water, its speed changes; so does its angle of travel. This is why an object at the bottom of a pool seems to be closer to the surface than it truly is. The ratio between the speed of light in a vacuum and that in a material is known as the material's refractive index. Natural materials all have a positive refractive index. But what if a material could be built that had a negative refractive index, so that light was bent in the opposite direction and an object appeared to be farther from the surface than it really was?

Several years ago Sir John Pendry, a physicist at Imperial College, London, who was musing on this idea, realised that such a material would make a perfect lens. It could also be woven into an invisibility cloak. Other scientists have taken steps towards realising these ideas using materials that contain tiny metal structures which alter the electromagnetic properties of the material and thus its interaction with light. (Light is a form of electromagnetic radiation.) Now Dr Hess and his colleagues believe that a material with a negative refractive index could also stop light in its tracks and hold it there. They report their ideas in the current issue of Nature.

Dr Hess envisages a ray of light travelling down an optical fibre made from two materials: a core with a negative refractive index and an outer sheath with a positive one. The light would bounce along the core, reflecting from the boundary between core and cladding. Owing to an optical effect called the Goos-Hänchen shift after the duo who discovered it, the ray would be knocked slightly off course on each reflection.

In normal optical fibres made from materials with positive refractive indices, this makes the effective thickness of the cable greater than its physical thickness. That is a boon for sending information. But for reflections from boundaries between two materials, the inner one of which has a negative refractive index and the outer one a positive refractive index, the Goos-Hänchen effect instead narrows the width in which the light ray can bounce about. If the optical fibre is tapered, the light ray will become trapped at the point where the fibre is no longer wide enough to let it pass any farther. The light will be halted and held there.

This technique could, in principle, be used to store light of many colours separately. Because the precise thickness at which the fibre traps the light depends on the wavelength of that light, the proposed technique would halt the colours of the rainbow at different points.

The idea is just that at present—an idea. But materials that have negative refractive indices have already been made (at least for light with wavelengths that are too long to be visible), so the idea could be tested fairly easily. Moreover, Dr Hess and his colleagues think it would be straightforward to attach their invention to more conventional optical devices, because at points where the core of the optical fibre is thick, it would behave quite normally. And because it does not rely on any quantum-mechanical jiggery-pokery to perform its magic, their idea should work at everyday temperatures.

Catching a rainbow could be useful as well as merely cool. Engineers have long sought to do away with slow and messy electronics when building computers and instead to rely on light, which is far faster and does not get hot. That beams of light cannot be held stationary, and thus used as a form of memory store, is a big obstacle to doing this. Slowing the fastest thing in the universe to a standstill, therefore, could speed things up elsewhere.

Geophysics

Going to extremes

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Mapping the Earth with neutrinos

TELESCOPES that point down instead of up sound like a weird idea but, if they are designed to detect subatomic particles called neutrinos, they can tell astronomers what is happening in the sky on the other side of the planet. That is because most of the neutrinos that reach the Earth pass right through it. The planet thus forms a useful screen against other sorts of particles that might confuse the telescope. Such devices could, however, also see what is happening deep inside the Earth. At least, that is the suggestion made this week by a team led by Maria Gonzalez-Garcia of Stony Brook University, in New York state.

At the moment, the only data on the Earth's interior are the paths of earthquake waves that are reflected and refracted by the various layers of the planet's interior. These, together with reasonable guesses about the Earth's overall composition, have been used to put together the familiar model of an iron core, a rocky mantle and a thin crust. But the evidence is indirect. If Dr Gonzalez-Garcia is correct, then physicists will have opened a direct window on the subterranean world—at a minimal extra cost.

Most of the neutrinos that travel through the Earth come either from the sun or from sources far beyond the solar system. Some, however, are the result of collisions between cosmic rays and the gases of the upper atmosphere. As luck would have it, these tend to have about the right level of energy to be absorbed by rock more often than their extraterrestrial counterparts. That means they can, according to Dr Gonzalez-Garcia, be used like X-rays passing through a human body, to pick out denser rocks from lighter ones.

Of course, you would need an appropriate neutrino telescope to do this. Luckily, one is being built at the South Pole at the moment. Called IceCube, it will work by detecting the flashes of light generated on those rare occasions when a neutrino hits one of the atoms in a molecule of water in the ice.

When IceCube is completed in 2011, it will be a boon to astronomy. But it will also be the first telescope capable of spotting enough neutrinos to make it worthwhile to take measurements of the interior of the Earth. If Dr Gonzalez-Garcia is right, it will thus be the world's first geoscope as well.