THE NEXT NUKE

US nuclear weapons scientists are designing a warhead that is meant to be 'reliable' without ever having been tested. **Geoff Brumfiel** asks whether it could renew the United States' ageing stockpile.

Wasteland: America's nuclear-weapons test ranges have lain silent since the country declared a testing moratorium in 1992.

NNSA/NEVADA SITE OFFICE

It's a hot spring day in the Nevada desert, and retired technician Ernie Williams is showing tourists how nuclear bombs used to be tested. Williams is short and gruff and a veteran of the US weapons complex. Since 1951, he has participated in around 80 nuclear detonations or 'shots'. By his estimate, he has received 0.6 sieverts of radiation over his lifetime — about 40 times the dose of a modern nuclear-plant worker. But his only ailment is slight deafness, for which he blames genes, not nuclear blasts.

From the tour bus, Williams points to a 15-storey tower rising above the pockmarked landscape of the Nevada test site. The tower was built for 'Icecap', one of the country's last three underground tests, which were cancelled in 1992 after the United States declared a testing moratorium. Workers simply left the tower baking in the desert sun, a monument to decades of nuclear explosions.

Five hundred kilometres west, at California's Lawrence Livermore National Laboratory, Doug East is explaining to visitors the new face of nuclear testing. East is a computer scientist who spent his early career programming large networks at places such as IBM and the telephone giant Pacific Bell. He came to the Livermore laboratory in 1992 — the same year the United States stopped testing nuclear bombs.

East leads the guests inside a cool, sterile vault that houses the lab's newest supercomputer, known as Purple. An array of black boxes, each stamped with 'IBM', Purple has the electricity needs of a small town and is one of the fastest computers on the planet. Inside the boxes, more than 12,000 high-speed processors crank through incredibly detailed simulations of nuclear-weapons tests. "This is the first machine", East says, "that really gives us button-to-bang capability."

The tower for the cancelled Icecap test still stands.

NNSA/NEVADA SITE OFFICE

Harnessing the power of supercomputers such as Purple and data from past tests, US weaponeers are working feverishly on an ambitious programme to design a new nuclear warhead that they can certify will work — even without a test explosion. They claim that the new weapon will replace the ageing warheads in the US nuclear stockpile; that it will be safer and more reliable than existing designs; and that it will be easier to build and cheaper to maintain. Some designers informally call it the 'wooden bomb', because theoretically it will be able to sit on the shelf for years with little maintenance. Formally, the new weapon is known as the Reliable Replacement Warhead, or RRW.

Virtual explosion

For Livermore and its sister facility, Los Alamos National Laboratory in New Mexico, the RRW is the future. It will provide a new generation of weapons designers the chance to work on a nuclear warhead, and give the weapons labs a well-defined project in the post-cold-war era.

CONVINCING THE GENERALS

Nuclear weapons scientists may believe that a new warhead, the Reliable Replacement Warhead (RRW) can be built without a test, but they must persuade others in the government if testing is truly to be avoided.

At least some Pentagon officials seem comfortable with the idea of using the RRW without a test. General James Cartwright, head of the US Strategic Command — the umbrella group that oversees the military's nuclear activities — recently expressed support for the programme. "The work that we are doing with the laboratories today would give us reasonable confidence," Cartwright said in a interview published in June in *Arms Control Today*[5].

But it remains to be seen whether scientists can convince generals in the Air Force and Navy. In the past, these officers have been enormously resistant to changes to existing weapons, notes Paul Robinson, former director of Sandia National Laboratories in Albuquerque, New Mexico, which maintains non-nuclear components for the warheads.

In the end, opposition often comes down to cash instead of confidence. When changes are made to warheads, the Navy and Air Force must also change their own software and hardware systems for delivering the bomb — all of which costs money.

The National Nuclear Security Administration, which oversees the RRW design competition, says it is requiring the new warhead to be compatible with existing missiles.

For now, the military has not had to pay for the RRW, and the higher-ups at the armed forces aren't paying too much attention to the programme, says one congressional staffer who deals with budgetary issues. But he thinks that as the new designs move forward, it will be increasingly likely that the Pentagon will have to supply funding: "At some point in time, the Department of Defense is going to have to step up to the plate." **G.B.**

US NAVY

A new type of warhead would raise costs for the Navy.

But critics of the programme — including some who designed the current generation of US nuclear warheads — doubt that the RRW can be guaranteed to work without a test. "I just can't believe anyone would prefer a new warhead that's designed by people who have never designed anything before and then made by people who have never built anything before," says Harold Agnew, former director of Los Alamos. "To me, that's ludicrous."

Despite the criticism, the programme is quietly gaining political momentum. Congressional appropriators, who killed earlier design programmes, gave the RRW project a respectable $25 million last year. If the programme continues on target, the warhead could enter military service in the next decade.

The debate over the RRW has its roots in the 1992 testing ban, instituted by the former President George Bush as the first step towards signing the Comprehensive Nuclear Test-Ban Treaty. The United States never ratified the treaty, but the government has maintained its voluntary moratorium on testing.

Historic stockpile

"The test ban symbolizes that the nuclear arms race is over," says Robert Nelson, a physicist and arms-control expert at Princeton University in New Jersey. As long as the United States doesn't test, he says, other nations —including nuclear upstarts such as India and Pakistan — feel enormous pressure to follow suit. And the ban gives the United States a huge advantage over other established nuclear nations, because it already has data from 1,054 nuclear tests. China, by comparison, has conducted only 45.

The end of testing has left the United States with an ageing stockpile of nearly 10,000 nuclear warheads. Most are between 17 and 30 years old, says Nelson, and are of roughly a dozen different designs[1]. All use ordinary explosives to compress nuclear material, often plutonium-239, which then triggers a series of runaway fission and fusion reactions (see graphic). The warheads aren't easy to maintain because, in addition to normal ageing processes such as rusting, the plutonium in a weapon' trigger, or 'pit' — the component needed to initiate the chain reaction — emits a small but steady stream of radiation. That radiation changes the properties of the plutonium alloy by altering its crystalline structure[2], which in turn can cause the weapon to fail.

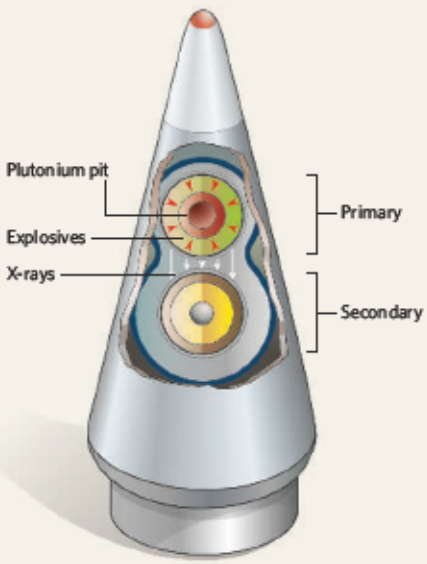
Over the past 14 years, researchers have studied these warheads with a battery of computer simulations and experiments. In recent years, those studies have revealed some significant new details about the old weapons, says James Peery, who directs the explosive-testing programme at Los Alamos. "They're discovering things and seeing things that they did not expect," says Peery. Details, of course, are entirely classified.

> "This is the first machine that gives us button-to-bang capability." — Doug East

Nobody believes that there are serious problems with the existing warheads, but the unforeseen discoveries are contributing to anxiety about how long they can be maintained. "I have great reservations that one could use pits that have aged for more than 50 years," says metallurgist Siegfried Hecker, a former director of Los Alamos who is now at Stanford University in California. At some point, Hecker says, the plutonium in the current pits will have to be melted down and remade into new ones.

And that is where the RRW comes in. During the cold war, physicists focused on making the lightest, most explosive weapons possible,

HOW TO BUILD A NUKE



Modern nuclear warheads consist of two stages: the 'primary' and 'secondary'. For the bomb to work, explosives in the outer shell of the primary must detonate, squeezing a hollow sphere of nuclear material, usually plutonium-239, and triggering a runaway fission reaction. X-rays from the primary then cause atoms in the secondary's fuel to fuse and release still more energy.

in order to fit many warheads on to a single missile, says Paul Robinson, a retired physicist who spent seven years directing the Los Alamos weapons programme. But in the post-cold-war era, where nuclear showdowns between superpowers seem less likely, missiles often carry fewer warheads, freeing up both space and weight for designers. "Today, you could do a lot to make the things more robust," Robinson says.

Vision of the future

Weapons designers at Livermore and Los Alamos are now working on RRW designs as replacements for the United States' most abundant nuclear warhead, the W76, which is deployed on submarine-launched missiles. Eight W76s, each destined for a different target, can sit atop a single missile. But today, most missiles routinely carry four.

At the centre of the Los Alamos campus, a gleaming glass-and-steel building houses the lab's alternative to the ageing W76. Past security turnstiles and fingerprint scanners, designers are using Los Alamos's supercomputers — only marginally less powerful than Livermore's Purple — to virtually test their RRW designs. Inside a secured room called 'the cave', 33 projectors display three-dimensional, stereoscopic simulations on the walls and ceiling. Using a joystick, designers can rotate, spin and zoom through each warhead design as it detonates, watching every stage of the explosion.

The simulations are not pure abstractions; they are heavily based on years of experimental data, including those from non-nuclear explosive testing. Both Los Alamos's and Livermore's RRW prototype designs are based on earlier warhead designs that were tested underground, according to one weapons laboratory scientist who requested anonymity. "The designs will be so close that even sceptics will accept the simulations," he says.

LOCKHEED MARTIN

Lighter load: since the end of the cold war, submarine missiles often carry half the warheads they once did.

Few outside the weapons labs know what these simulated alternatives to the W76 look like. But congressional testimony, unclassified laboratory studies, and media reports all point to a number of likely changes.

The most obvious alterations could be made to the weapon's plutonium pit. Adding more plutonium may ensure that the device detonates properly, even after years of sitting on a shelf. Pits could also be redesigned for ease of manufacture, says Hecker. During the cold war, pits were fashioned by shaping sheets of heated plutonium metal — a fast but imprecise technique. "We had very rough specs and then we went and conducted a nuclear test," Hecker says. "As we look to the future, I would definitely vote against doing it that way." He says that the pit for an RRW could instead be cast in a mould.

A difference of design

Toxic materials in the warhead may also be replaced with more benign substances. Currently, plutonium in the W76 warhead is surrounded by a shell of beryllium, which helps to amplify the initial nuclear explosion. But beryllium is also toxic and carcinogenic, so replacing it with heavier material such as stainless steel would reduce the environmental hazards associated with manufacturing the warhead.

Finally, a report from the weapons labs indicates that designers are considering replacing the lightweight but volatile explosives on the W76's outer shell with a less powerful and more stable explosive called an 'insensitive high

BRITISH SECRET FORCES?

Is Britain taking part in the Reliable Replacement Warhead (RRW) programme? A recent investigation by *The Sunday Times* claimed that British nuclear scientists "have been secretly working with Americans on a replacement".

Ministry of Defence officials deny any British involvement in the project. "The article contains a number of inaccuracies and misleading statements," notes Matthew Willey, a spokesman for the ministry. In particular, a joint US–UK test cited as being part of the new RRW programme was, according to Willey and US officials, just a routine test of an existing, ageing warhead.

That isn't to say that UK weapons scientists aren't following what their US counterparts are doing. Britain's nuclear deterrent consists entirely of submarine-launched, W76-style warheads — the kind now being considered for replacement by the RRW programme.

British weapons scientists are trying to determine what to do about these weapons, says David Overskei, a California-based weapons consultant who chaired a US panel last year that examined the RRW and the US nuclear complex. "As far as I know, they are not involved with the RRW," he says. "But they are keenly, keenly interested." **G.B.**

explosive'. This would increase the weapon's size and weight but decrease the likelihood of an accidental detonation during storage.

But will these changes really lead to cheaper warheads without the need for testing? A dozen current and former designers unanimously agree that changes might simplify the process of maintaining warheads. But there is far less accord on whether the new warheads would require testing, or whether they would be affordable when compared with remanufacturing the existing stockpile.

Agnew, who oversaw Los Alamos during the design of the W76, is among the most vociferous critics of the RRW programme. Very little, he argues, is known about how alterations affect performance. "These nouveau designers don't know what the margin is. In fact, no one knows what the margin is," he says. For example, adding more plutonium to a warhead's pit doesn't necessarily make it more reliable, he argues. It could instead make the warhead more likely to accidentally explode, or it could overheat the 'secondary' fuel which produces most of the weapon's power. There's simply no way to tell without a test, he asserts. "If you really believe that the nuclear deterrent is important," he says, "you shouldn't put things in the stockpile that aren't tested."

Sidney Drell, a Stanford University physicist, and others also question whether the changes are much of an improvement. A 1994 study by Drell and Robert Peurifoy, formerly at Sandia National Laboratories in Albuquerque, New Mexico, showed that rocket fuel, not high explosives, would be the most likely cause of an accidental explosion[3]. As a result, the Navy decided not to use insensitive high explosives on the W76.

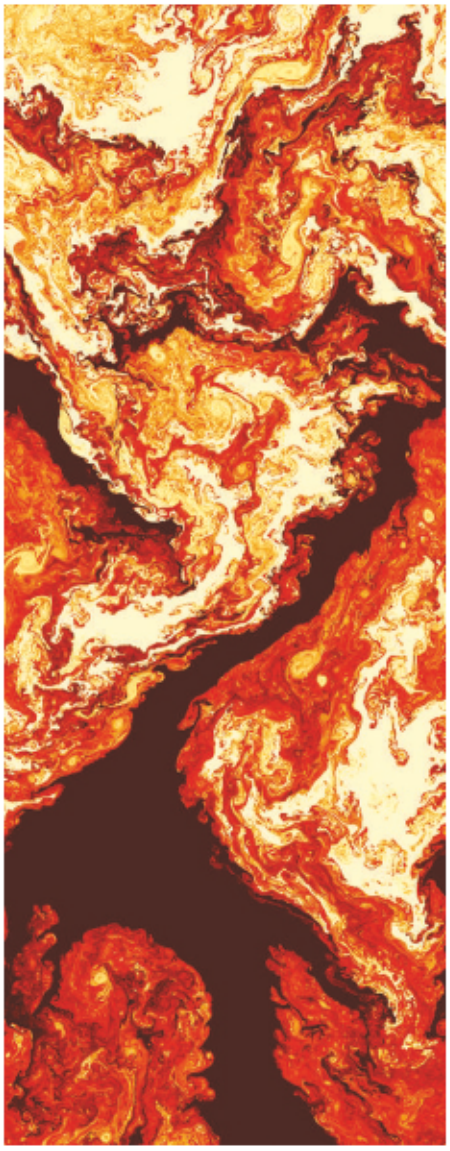
Where doves meet hawks

And then there is the question of cost. The programme to look after the existing US nuclear stockpile is expensive — more than $1.4 billion a year. Members of Congress are interested in the RRW because of claims that it could save money, even though the labs have not released a total cost estimate. But Richard Garwin, a former bomb designer, argues that the reason the stockpile costs so much has more to do with its size than with its age. More money could be saved by cutting the number of existing weapons from 10,000 to 2,000, he says. With a diminished arsenal, says Garwin, "we will be able to maintain current weapons indefinitely."

> "These nouveau designers don't know what the margin is." — Harold Agnew

Not all former weapons designers are so critical of the RRW programme. Herbert York, Livermore's first director, believes that early warhead designs, which have already been tested, could provide a reliable basis for designing a much simpler but much heavier warhead. "I'm not sure it would be practical, but I believe they could be designed to be stockpiled without testing," he says.

Despite the criticism, Republicans and Democrats are looking favourably on the programme. Hawks like the programme because it will allow the United States to train a fresh generation of weapons designers. And doves, who have torpedoed earlier weapons programmes[4], are wooed by the claim that the RRW will not need to be tested. Congress is likely to more than double the programme's budget for next year. And the military has lent its tentative support to the project (see 'Convincing the generals').



A. CALDER & D. SHEELER/ASC FLASH CENTER

Computer simulations of turbulent mixing are relevant to modelling how warheads might perform.

All this is good news for the country's ageing nuclear weapons complex, according to long-time observers. "The US nuclear programme has been in a cul-de-sac since the end of the cold war," says John Foster, a former director of Livermore who is chairing a panel on the complex for the Pentagon's Defense Science Board. Since the collapse of the Soviet Union, lab morale has sagged and efforts to refurbish warheads have fallen behind schedule, Foster says. The RRW programme provides the labs with a fresh challenge and clear vision. "The RRW", he says, "would catalyse the enterprise from design through production."

And, indeed, the programme does seem to have a reinvigorating effect (see 'British secret forces?'). Weapons designers are thrilled to be working on their first new warhead in two decades. Earlier this spring, the Livermore team ran a huge simulation of its RRW design. At Los Alamos, scientists are about to conduct a non-nuclear explosive test to check some of their calculations.

Both teams have submitted their designs to a review committee, where they are being peer-reviewed. One of the two designs will be selected as the basis for a development programme later this year. A second competition may even be held in 2007, for designs for an another RRW. If all goes well, pits for the first warhead could be manufactured as early as 2012

For now, the Reliable Replacement Warhead remains a series of zeros and ones, in the huge supercomputers at Los Alamos and Livermore. But back in the Nevada desert, the structure that once housed Icecap still looms above the Joshua trees. The rigging to hold a bomb — all 225,000 kilograms of it — remains in place, along with hundreds of metres of copper cable designed to carry data signals a few nanoseconds ahead of the blast.

Icecap, in short, is ready for the next US underground test. "Should we come back to nuclear testing," Ernie Williams cheerfully tells his visitors, "it seems reasonable we'd start with this one." ■

Geoff Brumfiel is *Nature*'s physical sciences correspondent in Washington DC.

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1. Norris, R. S. & Kristensen, H. M. *Bull. Atom. Sci.* **62**, 68–71 (2006).
2. Hecker, S. S. *MRS Bulletin* **26**, 672 (2001).
3. Drell, S. & Puerifoy, B. *Annu. Rev. Nucl. Part. Sci.* **44**, 285–327 (1994).
4. *Nature* **438**, 139 (2005).
5. Boese, W. & Pomper, M. A. *Arms Control Today* www.armscontrol.org/act/2006_06/CartwrightInterview.asp (2006).