The most DEADLY WEAPONS in Iraq and Afghanistan aren't AK-47s or grenades—they're ROADSIDE BOMBS made out of gas cans, garage door openers, and fertilizer. How the US military is learning to FIGHT back.

State of the Art

by ADAM HIGGINBOTHAM

One afternoon at the end of March, inside a cinder-block bunker on a small island in Chesapeake Bay, Scott Schoenfeld is waiting to blow something up. On a video monitor in front of him is a grainy image of a rusty steel box about 20 yards away. Inside is an explosive charge and an experimental target. A big, soft-spoken computational scientist wearing a black polo shirt, jeans, and wraparound sunglasses, Schoenfeld is one of the chief armor researchers for the Joint Improvised Explosive Device Defeat Organization, or Jieddo, the Pentagon agency dedicated to combating IEDs. He won't tell me how much explosive he's using today, or what, exactly, the target is. The charge is modeled on an IED discovered overseas, and the details remain sensitive, if not classified. "We're trying not to give anyone ideas they don't already have," he says. But he will acknowledge that the charge is lethal. "Unprotected, it would kill many people. Pounds of high explosive are involved." He hands me a pair of ear defenders. "The boom," he says, "will be rather large." ¶ Outside, a siren blows three times. Standing at a rack of instruments in the corner of the bunker, the range operator announces, "Reset. Arm. Three. Two. One. Fi—"

photographs by TOM SCHIERLITZ

On the monitor, a cloud of gray smoke puffs from the box, which is open at one end, and then a fraction of a second later comes the boom—a sharp crack loud enough to be heard through cinder block and ear defenders, drowning out the conclusion of the countdown. A shock wave shakes the walls of the bunker.

After the all-clear, Schoenfeld leads the way outside. Nothing remains inside the testing chamber but a burnt smell and the charred wooden fragments of the framework that held the charge and its target. The 6-inch-thick steel-plate walls of the chamber are as ragged as wet cardboard, buckled and pockmarked by the blasts and shrapnel from hundreds of tests. Schoenfeld and his team have conducted experiments here at the US Army's Aberdeen Proving Ground for six years, and their research—which has contributed to the creation of everything from the first emergency armor kits for Humvees to the mine-resistant ambush-protected vehicle—is among the most successful sponsored by Jieddo. Schoenfeld has held weekly videoconferences with troops in the field for several years. There was a time he'd get to know soldiers only to have them sign off from a video chat and never return. "It was very sad," he says. "The output of these devices was devastating." These days, things are different. He shows me an 8-inch-thick block of military-grade steel—"rolled homogeneous armor," he calls it—with a 2-inch-wide hole blasted all the way through by shrapnel from a test IED charge. New armored vehicles can take damage like this, Schoenfeld says, and the occupants can tell him about it on video afterward. "I get people standing in front of holes like these, smiling," he tells me. "They say, 'Yeah: I got back out and shot the guy that did this.'"

Jieddo was formally signed into existence by the Department of Defense just four years ago, in February 2006. But it has its origins in a personal request written by the chief of US Central Command, John Abizaid, to his superiors at the Pentagon in mid-2004. As the number of casualties caused by IEDs in Iraq mushroomed, he insisted that the only solution was a "Manhattan Project–like" marshaling of scientific and military resources. Since then, Jieddo has gathered a staff of more than 3,600 government employees and contractors, established projects with all four military services and every intelligence agency, and spent more than $17 billion.

In Iraq, Jieddo has succeeded in drastically reducing the carnage caused by IEDs. At the start of the war in 2003, every device that troops encountered resulted in, on average, the injury or death of at least one member of the coalition forces; by 2009, insurgents had to put down nine IEDs to cause a single casualty. But even as the number of attacks on coalition forces in Iraq dwindles, IEDs remain the principal killer of US troops in combat. In Afghanistan—where the number of IED incidents doubled in 2009 and caused 75 percent of casualties in some areas—Jieddo faces a new generation of more ingenious, and bigger, bombs. Meanwhile, the first US troops to be killed in the Philippines in seven years died when their convoy was hit by an IED last September. Even excluding those in Iraq and Afghanistan, there were nearly 3,300 IED incidents around the world in 2009. US troops, once expected to battle Russian tanks and Chinese missiles, now face a long war against a new enemy, one whose weapon of choice is the improvised bomb. "The IED as a tactical weapon is a condition of our workplace in the armed forces," says Michael Oates, Jieddo's director. "We believe it will be a persistent threat."

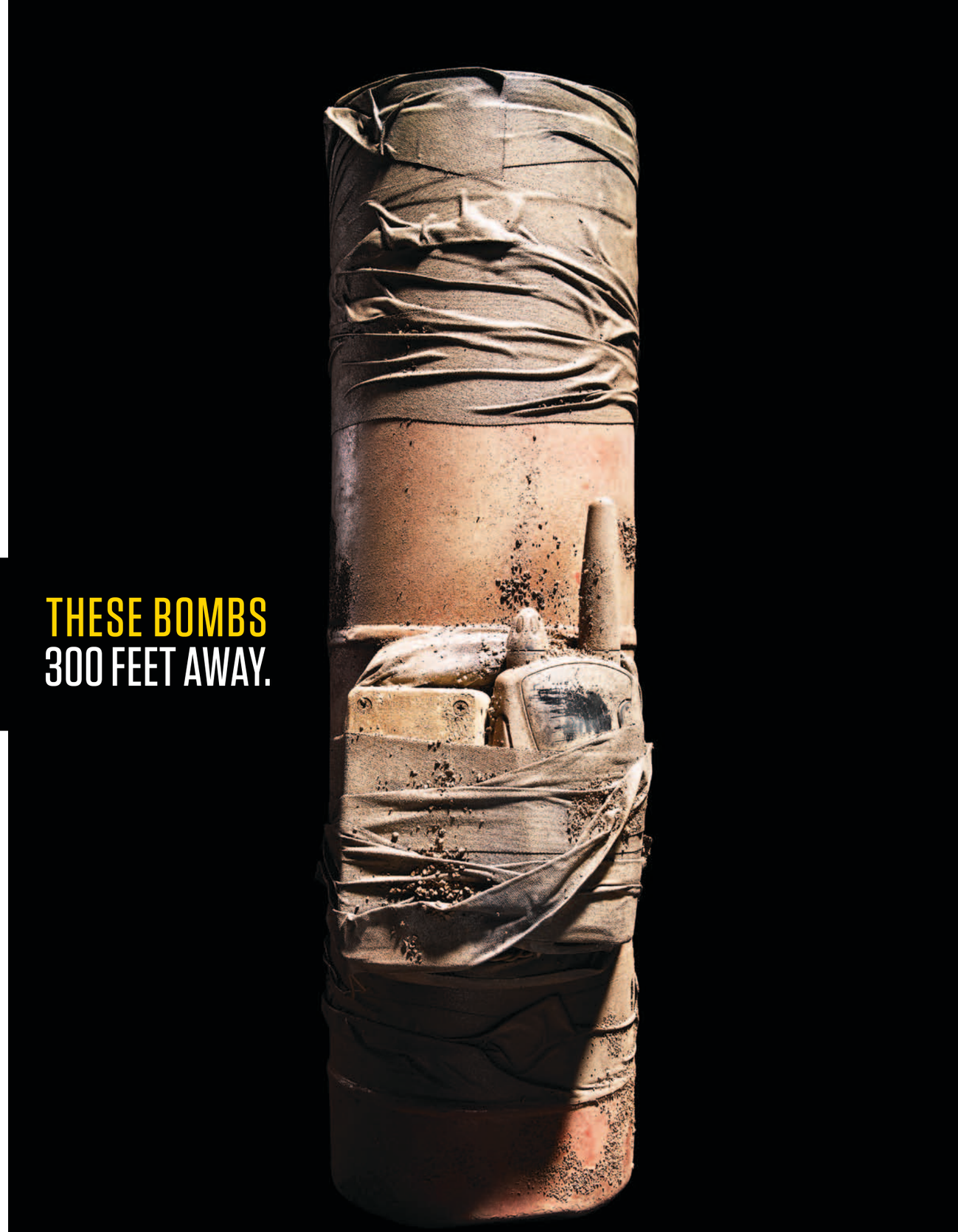
At the northern Virginia headquarters of Hazard Management Solutions, a private contractor that provides intelligence and training to Jieddo, Mark Maginess puts on his reading glasses and draws a simple diagram to illustrate the central problem of the counter-IED struggle. Maginess, a veteran bomb disposal technician who learned his trade with the British Army in Northern Ireland, is director of training at HMS and runs a "know the bombmaker" course for a US military agency—he won't say which. On a yellow legal pad, he sketches a graph plotting the technological sophistication of IEDs against time. He adds a diagonal line moving steeply upward: As time goes on and insurgents learn more about the art of bombmaking, he explains, their devices become more complicated. Jieddo must add new countermeasures to address each new device.

But not only will the insurgents keep inventing new bombs and techniques, they're also free to fall back on any one they've already used: "They can move up and down this spectrum, from complex to easy," Maginess says. Jieddo, on the other hand, must always deploy every countermeasure in its arsenal, adding more as each new device appears. "It's only ever going to get worse for us." And the way the Department of Defense works, a new IED need appear only once to require a corresponding, costly antidote. "I can take $600, go into a bazaar, and make a device," says one senior Jieddo officer. "And I can tie up $1.2 billion to $2 billion of US money by doing it."

A RAGGED SLUG FROM ONE OF THESE BOMBS CAN PENETRATE TANK ARMOR 300 FEET AWAY.

This escalating arms race, pitting kitchen-table bombsmiths against US government technologists, began in the early months of the Iraqi insurgency. The first IEDs were often simple radio-controlled bombs, made from two or three 155-millimeter artillery shells set off by a signal from a cheap household gadget, like a key fob car alarm switch or a wireless doorbell buzzer. US troops, traveling in unarmored Humvees, were defenseless against them until each of the services hastily bought hundreds of radio-frequency jammers—with codenames like Cottonwood, Ironwood, MICE, ICE, Warlock Red, Warlock Green, Jukebox, and Symphony—capable of generating an invisible hemisphere of electromagnetic energy that could drown out those trigger signals. Eventually, Jieddo would oversee the deployment of more than 40,000 jammers in Iraq.

The bombers quickly learned how to circumvent the electronic countermeasures. They used handheld radio-frequency meters and bombs with dummy trial-and-error firing circuits to figure out what part of the spectrum the jammers blotted out and how big the jamming field was. Then they simply switched to new remote controls that used bandwidths beyond the jammers' range. When US tech-



IED MODELS: BASED ON ACTUAL BOMBS CONSTRUCTED BY PROP HOUSE WEAPONS SPECIALISTS LTD.

nicians introduced electronic countermeasures to jam low-power radio-control devices like garage door openers and car alarms, insurgents moved to high-power devices, including two-way radios and extended-range cordless phones. Then they moved on to mobile phones in every local cell network, from 1G to 3G.

While this race had been run before, it had never taken place at such speed. With one of the most intensive and ingenious programs of homegrown bombmaking R&D in history, Northern Ireland's Provisional IRA worked its way through every available bandwidth from model airplane controllers to cell phones. It took them 30 years. But Iraqi insurgents innovated on Internet time. By February 2005, they'd managed the same evolution in just 18 months.

Yet radio-control devices, however sophisticated, only represented the middle of the IED technical spectrum. It wasn't until the summer of 2004 that Iraqi bombsmiths reached into the high end with the explosively formed penetrator, or EFP. Using technology developed during World War II, today's EFPs are made from a short length of steel or PVC pipe packed with explosives, sealed and capped with a concave copper disk. When the explosives detonate, the blast energy inverts the copper plate into a ragged slug traveling more than a mile per second and capable of punching through tank armor 300 feet away. Iranians used EFPs during their eight-year war with Saddam Hussein and later supplied the technology to Hezbollah guerrillas in Lebanon. Bomb-builders there added passive infrared triggers, sensors that detect motion by responding to changes in temperature—like that created by the engine of a passing truck. Because they don't use radio frequencies as triggers, they're invulnerable to electronic jamming.

In Iraq, the effectiveness and frequency of EFP attacks soon proved so devastating that individual soldiers began improvising their own countermeasures. One simply bought a toaster in a bazaar and hung it from a pole welded to the front of his Humvee—a heat decoy. According to *The Washington Post*, this and similar ideas led, in May 2006, to one of Jieddo's first innovations: the Rhino. The Rhino used a glow plug—an electric heating element for warming diesel engines before ignition—housed in a steel box on the end of a 10-foot boom. It worked so well that it could not only trigger an EFP and take the impact of the high-velocity metal slug but, on at least one occasion, continue working afterward.

It took only six weeks for the insurgents to respond. They adjusted the firing angle of their EFPs so that the slug struck 10 feet behind the decoy. Jieddo countered with the Rhino II, fitted on an adjustable-length boom. Along with electronic jammers, the Rhino II became standard on US vehicles in Iraq. More than 16,000 of the gadgets had been deployed to the Army and Marines by the end of 2008.

But at the beginning of this year, US forces in Iraq reported a new version of the passive infrared trigger, nicknamed the Black Cat. It looked exactly like a regular passive infrared sensor, but the motion detector was altered to be triggered instead by radio frequencies. Shielded to prevent it from being set off by household radios and with reduced reception range, the new device is one of the most devious yet. Designed to detect the passing bubble of a coalition jamming system's powerful radio field, the Black Cat has brought Jieddo full circle: It is an IED that will detonate only when it detects an IED countermeasure.

Sitting in his kitchen in northern Virginia, Mark Wickham sips from a mug of Diet Coke and carefully arranges three books on the table in front of him. The lieutenant colonel wrote the first two himself: *The Weapons Technical Intelligence Handbook*, a dense government manual marked OFFICIAL USE ONLY, and a companion volume with a plain white cover called *The WTI IED Lexicon*, a standardized guide to the language of improvised bombs.

The third, a thin softback volume with a skate-punk cartoon cover depicting a slavering ghoul brandishing a bubbling coffee can, suggests what Wickham's work is up against. It's a bombmaking manual called *Home Workshop Explosives*, credited to "Uncle Fester" and released in 2002 by Festering Publishing. "I bought this at Borders," Wickham says, shaking his head in disbelief. "Twenty dollars."

At 55, short and bespectacled with stiffly parted salt-and-pepper hair, Wickham has spent his entire career studying the methods and networks of improvised-bomb makers. It's a subject he addresses with an intensity born of personal experience. "He was blown up," his wife explains. "That's why he's so passionate about getting IEDs right: He got it wrong." While a captain with the 321 Explosive Ordnance Disposal Squadron of the British Army in Northern Ireland, Wickham was working to defuse a blast incendiary device one night in 1980 when it exploded, engulfing him in a ball of flame. He sustained burns on his hands, head, and chest before his blazing protective suit was removed. Wickham was on life support for days, underwent extensive reconstructive surgery, and never regained the hearing in his left ear. Later, he became one of the UK's most senior IED specialists; five years ago he became Jieddo's expert in weapons technical intelligence—using forensic techniques to understand improvised bombs and their makers.

The process begins on the battlefield. Military bomb-squad teams collect and bag forensic material from the scenes of IED events and send it to labs nearby, where DNA and latent fingerprints are collected and checked against local databases. Bombs that are recovered intact are dismantled and flown out for analysis at facilities around the world, including an FBI lab in Quantico. From there, the components are distributed: At Aberdeen, Scott Schoenfeld's team builds surrogate charges to test against different armors. In Virginia, members of Jieddo's Technical Gaming Team replicate the triggers for trials of experimental countermeasures to be carried out in Arizona. At the Army's National Training Center at Fort Irwin, California, analysts build their own versions of the weapons and conceal them in the combat simulation zone known as the Box, to test troops in their final weeks of training. Finally, back in Afghanistan and Iraq, the forensics and biometrics are used in pursuit of the bombmakers.

All bombmakers leave a technical signature in their devices—whether it's a pattern of hot-gluing wires to a circuit board or the repeated use of a favored component. One Afghan IED builder has been linked to at least 90 separate pressure-plate triggers made from plywood and the four heavy springs from old-fashioned bicycle seats. Every one of his triggers has five separate mechanical characteristics in common. And there is biometric evidence, too: "When he wound the wires together to attach them to the springs for the contact, he left his DNA behind," Wickham says.

The weapons technical intelligence process has also revealed a broader scheme at work. The tactics of today's insurgent bombmakers are the product of a long-simmering melting pot of global terrorism: expertise developed by the IRA and disseminated in a clandestine exchange of bombmaking wisdom that included members of the Spanish separatist group ETA and the FARC guerrillas in Colombia. In Iraq, Wickham recognized techniques he'd seen in Northern Ireland 30 years ago. "I can take you to Baghdad and show you a command wire set up in October '07," he says. "I can take you to South Armagh and show you exactly the same tactical design from 1980." US military intelligence analysts already suspect that the lessons learned by IED cells in Baghdad are being put into practice by the Taliban. "If it works in Iraq long enough," one analyst says, "they'll start moving it into Afghanistan."

In the past two years, the narrow mountain passes of the Hindu Kush and the sparsely populated desert flatlands of Helmand have become the new front line in the battle between bombmakers and Jieddo's counter-IED technicians. Afghan bombmakers, faced with the sophistication of US countermeasures developed in Iraq, have begun moving backward down the continuum represented by Mark Maginess' graph. After their radio-control bombs were smothered by jammers, the Taliban turned not only to "command wire"—physical connections between trigger and bomb—but also to the even more reliable "command pull," a simple switch attached to monofilament fishing line or even a piece of string. With these, at least, the triggerman must remain nearby for the attack and is therefore relatively easy to catch or kill. But almost all of the devices encountered during 2009 by Jieddo's Afghan operation, Task Force Paladin, were simpler still and harder to locate: large bombs triggered by pressure plates buried in the middle of dirt roads. "You drive over it, your weight initiates the pressure plate—blows up under your belly where it's most effective," says Jeffrey Jarkowsky, Paladin commander until late last year.

These rudimentary mines can sit for days or even months waiting for a victim. They're often made from whatever is at hand in a rural environment, like the bicycle seat springs or two carpentry saw blades tensioned into a bow—anything that lets two contact surfaces meet to complete a circuit. More recently, the pressure plates have been built with less and less metal. One type of device uses only two strips of aluminum tape; another, single strands of wire and contacts made from fragments of the graphite core from a C-cell battery. As a result, the metal detectors used by US route-clearance teams are becoming ineffective.

And since the stocks of military ordnance left over from the Soviet war have been depleted, three-quarters of Afghan IEDs have been made not with pilfered artillery rounds but with more common agricultural ingredients like ammonium nitrate fertilizer. Packed into 5-gallon plastic containers and buried in a dirt road, these charges are utterly invisible to metal detectors. Task Force Paladin is using ground-penetrating radar to find them, but that works only from

CAT AND MOUSE: A CASE STUDY

When insurgent bombmakers come up with a new way to trigger a weapon, the US military devises a countermeasure. Insurgents figure out how to get around it, and the cycle continues. Here's how that played out with a device called an explosively formed penetrator.

1 / JAMMER-PROOF BOMBS (SUMMER 2004) Insurgents start using EFPs—lengths of pipe packed with explosives that launch a molten slug of copper. Because they're tripped by the engine heat of passing vehicles, coalition electronic jammers prove useless.

2 / BOMB-PROOF DECOYS (MAY 2006) Individual soldiers improvise heat decoys, like a toaster hung on a pole in front of a truck, which inspires a countermeasure: the Rhino. It consists of a heating element housed in a steel box and extended on a 10-foot boom.

3 / DECOY-PROOF TARGETING (SUMMER 2006) Insurgents recalibrate the aim of the EFPs, angling them backward to account for the decoy. EFPs comprise just a small percentage of roadside bombs, but they soon account for hundreds of fatalities.

4 / BOMB-PROOF ADJUSTMENTS (FALL 2006) The Rhino II, which costs less than $2,000 and has an adjustable-length boom, changes the position of the decoy. More than 16,000 Rhino IIs are deployed overseas in just 30 months.

5 / JAMMER-TRIGGERED BOMBS (EARLY 2010) New EFPs ignore heat signatures and are triggered by the high-power radio waves emitted by coalition jammers. In other words, the latest bomb is set off by the countermeasure that defeated its predecessors.

ILLUSTRATIONS BY Nook

right on top of a bomb, increasing the risk of setting it off. And many chemical sniffers deployed in Iraq detect only the molecules produced by decaying TNT—not ammonium nitrate. Jieddo scientists have been working for four years on a means of detecting homemade explosives at a distance; a solution has so far eluded them. They have also been trying to figure out how to detect the electrical blasting caps used to detonate many types of IEDs, so they can be set off from a safe distance.

Perhaps inevitably, some of the best means of beating the Afghan bombers have proved to be the simplest: Many vehicles are now protected by front-mounted rollers that trigger mines ahead of a convoy. If in doubt, troops are trained to simply get out and look for clues like disturbed ground or a pile of trash that wasn't there the day before. "Even today, with all the technology," says Jarkowsky, "the best detector of an IED is the human eye."

In the meantime, the kitchen-table arms race continues. At the National Training Center at Fort Irwin, Jieddo hosts 10 one-month-long rotations of troops a year, hoping to make them familiar with IED innovations just as insurgents start using them. "As soon as we stop training in one type of device, that's the one they start using, because that's the device that becomes effective," says Jeffrey Gagnon, who oversees Fort Irwin's Jieddo unit. "So we have to keep the training up across the whole spectrum."

The task of trying to keep up with the Afghan bombsmiths falls to the men of the Terrorist Exploitation Network workshop, housed in a dun-colored metal shed on the outskirts of the Fort Irwin complex. From here, Rodolfo Llamas and his men—with the help of two contractors who do nothing but make IEDs five days a week—distribute 300 to 500 replica bombs a month into the replica Afghan and Iraqi towns that make up the Box. Each device is handmade and works exactly like the original, but detonates a pair of nonlethal M-80 simulated charges.

Late one afternoon in April, Llamas shows me the latest device they've been working on, just in from Afghanistan. A neatly made plywood box about 8 inches high and 5 inches square, it has a length of replica detonation cord emerging from the base. Llamas pulls the box open, revealing a layer of soft foam and a wooden plunger attached to the lid. When stepped on or driven over, he says, the foam is compressed and the tip of the plunger, which is saturated with a chemical, descends into a chamber at the bottom of the box. That chamber contains a second substance, and when the two chemicals mix, a pyrotechnic reaction ignites the end of the detonation cord, which leads to an explosive charge.

The box is the logical conclusion of years of reverse evolution in insurgent weapons technology. Without a power source, a blasting cap, or a single piece of wire or metal contact, it has no electromagnetic or metallic signature. Linked to a charge mixed up from odorless homemade explosives, packed beneath a dirt road, it would be all but impossible to detect: a Flintstones land mine. "It's a block of wood, basically," Llamas says.

And although the wooden IED was found and photographed in Afghanistan and has been carefully reconstructed thousands of miles away here in the Mojave Desert, the Taliban insurgents apparently remain one step ahead of technicians here. The pyrotechnic chemical mix remains a mystery.

"We don't know what it is yet," Llamas says. "We're still trying to figure that out."

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