Researchers Sift the Ashes of SDI

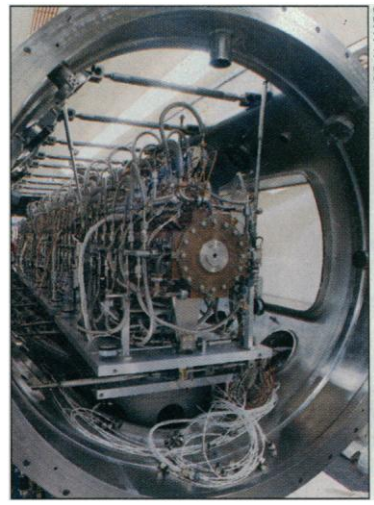
Star Wars left a host of unfinished devices and experiments, but a few technological offspring of the $33 billion program are finding surprising new niches in basic research

Imagine spending 8 years of your life and $380 million in public funds to build a unique experiment—only to have the plug pulled at the last minute. That's what happened 3 months ago to Edward Heighway, a physicist who supervised the building of a neutral particle beam machine at the Los Alamos National Laboratory in New Mexico. The big gun—designed to test technologies for hurling a high-energy beam of hydrogen atoms through space—is a relic of the once-opulent Strategic Defense Initiative (SDI). Now it's fading into history, unused.

Heighway's accelerator had plenty of company. The last lap of the Cold War arms race left scores of unfinished technologies, many of them conceived—then abandoned—by SDI in the service of its ambitious goal: shielding the entire nation from nuclear attack. The initial plan called for a network of defensive gadgets in space, including powerful lasers and beam machines. But these devices proved too weak to serve as weapons, and in 1987, "brilliant pebbles"—in effect, a plan for high-tech artillery in space—took their place. Then, in 1991, the plan began to shrink. Finally, last April, Secretary of Defense Les Aspin renamed the project the Ballistic Missile Defense Organization and narrowed its scope to defending battle areas against medium-range missiles (see chart). So, 10 years and $33 billion later, what legacy has the program left for science and technology?

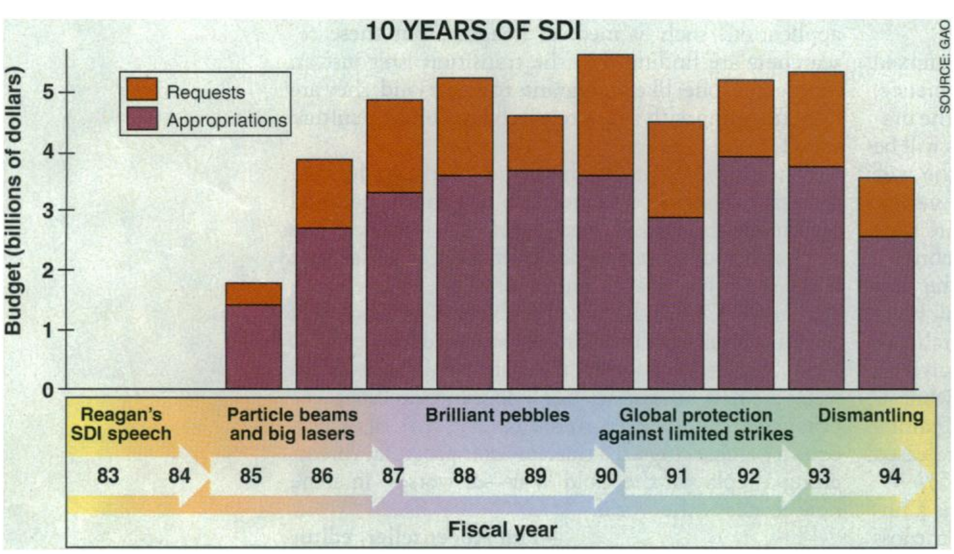
Some SDI supporters, like Richard Joseph, director of missile defense programs at Los Alamos, argue that this question is irrelevant; after all, they say, the program fulfilled its strategic purpose by helping to end the Soviet Union. But whether or not this claim is correct, many researchers say SDI did little to advance science and technology when it was up and running. The big Star Wars tests produced no new weapons and relatively few scientific results for the price; researchers say that in some areas SDI even slowed progress by a misplaced emphasis on weapons development (see box on opposite page). Asked what SDI had contributed to his field, Kurt Gottfried, chairman of physics at Cornell University and a longtime SDI critic, replies: "Beats me." But others argue that it's too early to write off SDI's contributions.

Heighway and his SDI colleagues, along with many scientists outside the program, think some of the technologies that SDI researchers explored may end up being adapted for quite different purposes by civilian researchers. One much-touted (and much-debated) boon consists of SDI's medical and commercial spinoffs, such as the use of lasers for sculpting corneas to reduce myopia, which have been promoted since the mid-1980s. But SDI may also have contributed to fields ranging from particle physics to astronomy by equipping scientists with exquisite sensors and accelerator components — gadgets that might never have been developed outside a cost-is-no-object military program.



Beam gun. Built for Star Wars, accelerators like this one have been adapted for medical therapy and physics research.

Many of these high-tech tools require complex and expensive support, however—not the kind most academic labs can afford. And, whatever the value of these advances, some observers think SDI does not deserve exclusive credit. Richard Garwin, a physicist and weapons expert at IBM's Thomas J. Watson Laboratory, agrees that in several cases, SDI did make a contribution, but he argues that its role often was to support rather than to create new technologies. SDI, he says, came on the scene as the new ideas became practical, "just as the dawn broke." To SDI's defenders, however, the most convincing testimony to its legacy may be the scramble by scientists in accelerator physics, laser chemistry, and astronomy to get their hands on orphaned SDI technology.



The spoils of (cold) war

Take Heighway's neutral particle beam, which died an early death in November when Congress zeroed the budget for it and other military projects. Conceived as a device to shoot down warheads in space, it was given a new purpose in 1987: probing incoming warheads and discriminating real ones from decoys. The challenge was to build something small enough to fit on a rocket and rugged enough to operate in space. One small SDI accelerator did fly aboard a rocket in 1989 and actually emitted a hydrogen particle beam in space. And although Heighway's bigger model of this device, called the ground test accelerator, was never assembled, all its components have been built, including a compact front-end part of the beam generator called a radio frequency quadrupole linac (RFQ). Inspired by a Russian idea, Los

Alamos researchers developed a system that turns two continuous streams of protons into droplets, then interleaves the droplets into a beam of higher intensity. This technical ingenuity, physicists say, is winning the RFQ a new lease on life.

One small RFQ was adapted for use at the Loma Linda University Medical Center in 1990; it's now being used to treat about 40 cancer patients a day with targeted proton therapy. Because the RFQ makes such a bright beam, says Heighway, the Department of Energy also wanted one to serve as a proton source for the Superconducting Super Collider (SSC). Accordingly, Los Alamos built and delivered an RFQ to DOE in Texas, where it remains. Now that Congress has dumped the SSC, its state-of-the-art proton source is up for grabs. Distinguished scavengers—such as the Brookhaven National Laboratory and Canada's Tri-University Meson Facility in Vancouver—are eyeing it for use in kaon factories, a new generation of particle accelerators (*Science*, 4 October 1991, p. 36).

Another ill-fated SDI project—the x-ray laser effort at the Lawrence Livermore National Laboratory—has also left behind a prize for basic researchers, says John Holtzrichter, chief of intramural research at Livermore: the electron-beam ion trap, or EBIT. Livermore scientists created EBIT to capture heavy ions, strip away electrons, and study their energy transitions to provide hard data for calculations of the behavior of plasmas and x-ray lasers. (As with the RFQ, the inspiration for EBIT was Russian, though Russian scientists had tried unsuccessfully to use it as a source of ions.) Now the prospect of using EBIT to study the properties of highly charged heavy ions has attracted civilian researchers.

Before EBIT, it was hard to get data on ions heavier than beryllium. Accelerators or storage rings provide some information, but the motion of the particles as they whirl past detectors distorts their spectra. EBIT, in contrast, captures ions in a "cold" state. Moreover, EBIT is compact and cheap. At $1.5 million, it's about 100 times less expensive than a storage ring, the nearest competing technology for x-ray spectroscopy.

To those who use EBIT regularly, the experimental results it provides are "beautiful," according to Manfred Bitter, an x-ray spectroscopist at the Princeton Plasma Physics Laboratory. "With EBIT you can get all the details of the excitation process," Bitter adds. "It's very useful for [magnetic fusion] experiments where we want to observe x-ray spectra" and monitor ions that contaminate the plasma.

SDI's Mixed Legacy for the Free-Electron Laser

Some of the sensors and accelerators spawned by the Strategic Defense Initiative (SDI) are captivating civilian researchers, who hope to put them to use as scientific tools (see main text). But for one technology that was a centerpiece of SDI, the free electron laser, the attention from Star Wars was a mixed blessing.

"In some ways we are worse off than we were 12 years ago," says Patrick O'Shea, director of the FEL program at Los Alamos National Laboratory, noting that his peers became skeptical of the field because of its association with SDI's big promises. "We lost our credibility to some extent" because people made exaggerated claims about the laser's potential as a weapon. Now Congress has shut down all but medical research. However, O'Shea also notes that SDI's support of basic free electron laser technology set the stage for what could be an exciting second round of FEL experiments in physics, chemistry, and medicine.

What makes the FEL special is that, unlike other lasers, it doesn't generate light from a solid or gaseous medium; the energy is shaken out of an electron beam by a series of magnets called a "wiggler." This design, which physicist John Madey proposed and demonstrated in the early 1970s at Stanford University, efficiently converts electricity to coherent light, and it enables the laser to be tuned over a very broad spectrum. FELs, unlike other lasers, can generate ultraviolet frequencies, which scientists covet for basic photochemical research, for probing the structure of DNA, and even for medical uses such as imaging and surgery.

The free electron concept also appealed to SDI leaders because FELs are efficient converters of energy and can be tuned to do maximum damage. Some researchers welcomed the military support. But physicists at Los Alamos say it was a bit like a bear hug—so enthusiastic it hurt.

Consider that when SDI jumped into the game, FELs were yielding 1 to 2 watts. The military said it planned to boost the power quickly to a million watts. After spending $1 billion over a decade, SDI-backed researchers had pushed the top average power only to 10 watts, suggesting no weapon applications were likely to come out of the effort. More humbling still, the 10-watt record was achieved by Charles Brau at Vanderbilt University, who is funded by the Pentagon's medical account rather than its laser weapon program.

Still, the SDI program deserves credit for several key refinements of the FEL, says O'Shea—although in its rush to build a weapons-scale device, the Pentagon came close to squelching the basic research that led to those advances. The most important innovation was the photo-injector, invented by two Los Alamos physicists, Richard Sheffield and John Fraser. It provided high-quality "seed" photons, which Sheffield says increased the quality of the beam about 100-fold.

The achievement was all the more impressive because skeptics told the Pentagon it couldn't be done, and military officials ordered a halt to the research while it was still under way. According to Philip Morton, a retired physicist from the Stanford Linear Accelerator Center (SLAC) and a member of JASON, a science advisory group that reviewed FEL technology for the Pentagon, one colonel in charge of funding "was very much against" the photo-injector project. Morton recalls that "the SDI people wanted to…go for contracts, pour concrete," not conduct research. Says Sheffield, "We managed to keep it going just long enough to get an extremely good result."

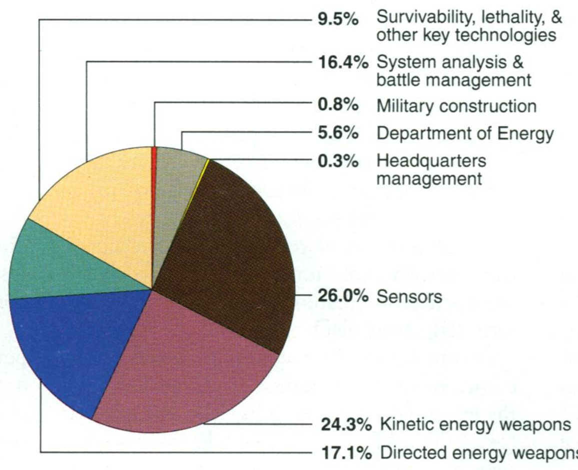
Now, nonmilitary researchers are eager to get their hands on these advances. Erik Johnson, a physical chemist at Brookhaven National Laboratory, says there's a "cottage industry" copying Los Alamos' work. In addition, scientists are hoping to acquire for their own use the wiggler magnets built for SDI, which include some of the world's finest—among them a 25-meter device at Lawrence Livermore National Laboratory called Palladin and two shorter ones built by Boeing.

At least eight research centers—with SLAC, the Lawrence Berkeley National Laboratory, and Brookhaven leading the pack—are now hoping to persuade the Department of Energy to fund new research on FELs, particularly to generate short wavelengths for chemical and biological experiments. Meanwhile, Madey and other have been investigating medical uses of FELs.

In response to the new interest in FELs, the Department of Energy and the Navy have asked the National Academy of Sciences to conduct a review of these lasers and determine whether they deserve more support. The panel met for the first time in Washington, D.C., on 13 December. According to its chairman, Donald Levy of the University of Chicago, the panel will make recommendations by next fall about a new life for this old Star Wars weapon.

–E.M.

WHERE THE $33 BILLION WENT



No surprise, says Bitter, that many researchers want duplicates of the Livermore technology. An Oxford University group even copied Livermore's plans, built two EBIT clones, and sold one back to U.S. researchers at the National Institute of Standards and Technology under circumstances that are "politically touchy," says another scientist. Now, according to Livermore physicist Richard Fortner, researchers are speculating about using a modified "super EBIT" as a source of charged particles for materials research. Once trapped, particles can be pulsed from EBIT and directed at a surface to create tiny defects—possibly useful for etching circuits or making other miniaturized tools.

Stars in their eyes?

Although EBIT has gotten some behind-the-scenes acclaim, another Star Wars package called adaptive optics has received much more publicity—but it also illustrates the difficulty of mating military technologies with civilian science. The idea behind adaptive optics is straightforward: Fast sensors and computers can measure the distortion in light passing through the atmosphere and adjust a flexible mirror to correct an image.

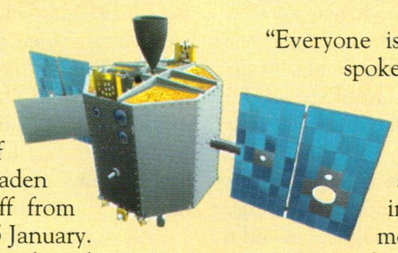
The concept isn't new. Astronomer Horace Babcock first proposed it in 1953, and researchers have been tinkering with simple adaptive optics ever since, hoping to sharpen the vision of ground-based telescopes. The European Southern Observatory, for example, is making observations in Chile using adaptive optics, without help from the U.S. military, and François Roddier of the University of Hawaii has been gathering data in the infrared spectrum. So far, the only astronomer who has used adaptive optics to obtain good images in the visible spectrum is Robert Fugate, an Air Force scientist at the Phillips Laboratory in Albuquerque, who was in the business before SDI. But SDI gets credit for pushing the field ahead, say Fugate and Peter Nisenson at the Harvard-Smithsonian Center for Astrophysics.

In particular, SDI contributed an astronomical laser beacon, which creates a luminous spot—an "artificial star"—high in the atmosphere. This method can reveal atmospheric turbulence, and SDI researchers hoped to use it to compensate for distortion when firing beams at incoming missiles. That changed when SDI's space weapons strategy was shelved in 1991. Instead, after spending $600 million on the program, officials declassified the R&D and turned over an entire $85 million package to astronomers Edward Kibblewhite and Walter Wild at the University of Chicago.

But it remains to be determined whether —and at what cost—a technology meant to detect relatively bright, nearby military objects can be modified to pick up the faint images of distant stars. Wild, for example, marvels at the gadget in his lab—"no ex-

A Debut for Star Wars' Darling, Clementine

For the past 2 years, Daniel Goldin, head of the National Aeronautics and Space Administration (NASA), has been preaching the gospel of faster, cheaper, more flexible space projects. Star Wars may have just the kind of technology he's looking for: a small, camera-laden spacecraft called Clementine that lifted off from California's Vandenberg Air Force Base on 25 January. Its circuitous voyage to the moon and out into the solar system will put Star Wars sensor technology—intended to detect enemy warheads and satellites—to a rigorous test. But if it works , it could herald a revolution in the design of space probes and collect some unprecedented scientific data.



Most Star Wars projects have only had a scientific payoff after the fact—if ever (see main text). But the end of the Cold War and the budget pressure on weapons programs have encouraged the Ballistic Missile Defense Organization (BMDO), which is sponsoring Clementine, to make public everything about the mission. The data collected by Clementine's sensors will be released promptly, and the BMDO also hopes that the light, cheap sensor technology will inspire spinoffs in the civilian space industry.

Clementine's roots, however, are fully military. It is derived from Brilliant Pebbles, a missile-defense concept that called for deploying "small and cheap" spacecraft ($55 million for Clementine) in such large numbers that the enemy couldn't hope to shoot them all down. But Brilliant Pebbles got shot down in another way—by changes in international politics. After the Soviet Union collapsed, Congress in 1991 effectively shelved plans to deploy Brilliant Pebbles. However, the R&D continued, and Clementine is the result.

"Everyone is excited about the mission," says Pentagon spokesman Lt. Col. Pedro Rustan, "but everybody's also keeping it at an arm's length" until they see whether Clementine's light-weight sensors really function under the thermal and radiation stresses of space. Rustan says each of the six infrared, ultraviolet, and other cameras weighs no more than 2 pounds, as compared with 50 pounds for traditional space imaging systems.

After circling Earth during January and February, Clementine is scheduled to go to the moon, which it will orbit for 2 months. There, it will collect multispectral data over the entire surface, possibly providing new information about minerals. From the moon, Clementine will swing back by Earth and then out into the solar system toward the asteroid Geographos. It will pass and photograph this small object in late summer from a distance of about 100 kilometers, providing what could be the closest look at an asteroid to date. NASA is providing $2 million for the research, and NASA mission scientist Jurgen Rahe says he expects to obtain some "spectacular visual images"; the whole trip, he says, "should be full of surprises."

Researchers agree, but they recognize that science isn't the mission's top priority. Says asteroid expert Clark Chapman of the Planetary Science Institute in Tucson, Arizona, "We hope that people won't go away [after Clementine] and check the box, 'Asteroid Done.'" Adds Richard Binzel, a planetary scientist at MIT who's helping to plan Clementine's trip to Geographos, "We have to keep in mind that Clementine is primarily an operational test; any scientific return is just icing on the cake."

–E.M.

pense was spared" to build it, he says—but it won't be connected to a telescope until March, when renovation of a 40-inch reflector at the Yerkes Observatory in Wisconsin will be finished. With support from the National Science Foundation, the Kibblewhite group plans to have it ready to observe the collision of a comet with Jupiter in July. Then comes the challenge of building similar systems for other telescopes, something Jacques Beckers, director of the Kitt Peak Solar Observatory, thinks "will take major efforts." Wayne van Citters, who runs the technology support program for astronomy at the National Science Foundation, says, "We are trying to develop something that is affordable to astronomers," but the cost of each unit remains "extremely high."

Eventually, however, many astronomers think the SDI artificial-star technology will prove its value. "By the end of the decade," says astronomer Laird Thompson of the University of Illinois, "this will be a very active field for astronomers—and for the military."

A disputed legacy

These are three of the most successful and best-known technologies for basic research that came out of SDI—a scanty harvest for a $33 billion program. But researchers at the national labs and in the former SDI office insist that's not the end of the story, citing commercial and medical technologies they say were helped along by SDI funding. For example, Science Research Laboratories of Cambridge, Massachusetts—an ex-SDI research contractor—is building a compact proton accelerator that it hopes to sell to hospitals to produce isotopes for PET scanners. Other companies are making SDI-inspired magnetic bearings, nondestructive surface measuring instruments, and sophisticated infrared cameras. Dwight Duston, director of the former SDI office of innovative science and technology, says that a decade ago it would have cost $1 million to buy a large infrared camera; now, thanks to SDI, he claims, you can buy one with superior sensors for about $80,000. Meanwhile, Livermore is trying to interest companies in developing a digital mammography device based on software developed for the x-ray laser program. And others have adapted military x-ray microscopes into tools for studying industrial composite materials.

The list of spinoffs is long, but it's difficult to sift out the contributions of Star Wars from those made by other weapons programs and by civilian research. It's also hard to find agreement in the research community on the significance of any particular SDI-inspired gadget. As the battleground of the Cold War's last great ideological clash, SDI and all that sprang from it remains contentious territory.

–Eliot Marshall

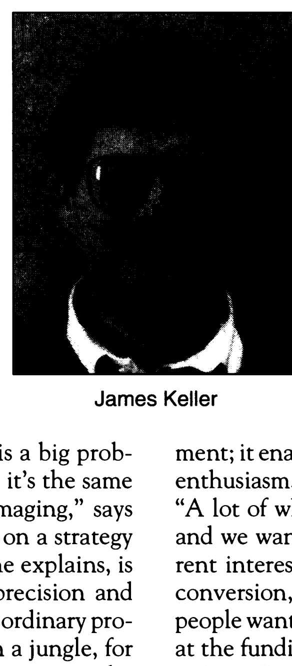
CULTURAL SHIFTS

Ex-Defense Scientists Come in From the Cold

For many researchers who have spent their careers working on military projects, the end of the Cold War has brought an end to an era of secure funding. Uncertain new priorities such as "technology transfer" and "economic competitiveness" now determine whether their work will continue to be supported–and at what level. As a result, thousands of researchers who depended on defense money in national labs and universities are struggling to make the transition to civilian science in a research culture very different from the closed world of secret research. Many of them have found some seemingly unlikely uses for their skills: The computer algorithms developed to detect incoming missiles can also identify errant cells in the human body, and the plasma physics vital to understanding the detonation of a hydrogen bomb can also be applied to pollution control. But these gentler research goals don't always mean a gentler research environment, say some ex-military scientists. Cold War veterans are finding that the civilian research world, rife with the struggle for funds and the search for "spinoffs," can be a pretty cold place itself.

Target Recognition Goes From Tanks to Tumors

The software algorithms developed to help identify tanks in the jungle wouldn't seem to have much future outside the military. But University of Missouri computer scientist James Keller has hit upon a novel use for them. He has repackaged the basic research that occupied him during the Cold War—and found that it's equally relevant to civilian concerns. After 12 years developing algorithms for target recognition for the Air Force and a defense contractor called Emerson Electric, he's applying the same strategies to automated cancer screening.


James Keller

"Separating target objects from the things around them is a big problem for target recognition, and it's the same kind of problem in medical imaging," says Keller. Keller's algorithms rely on a strategy called fuzzy logic. Fuzzy logic, he explains, is designed to deal with the imprecision and vagueness of the real world. An ordinary program designed to find a tank in a jungle, for example, might classify every point in the scene as either tank or tree. Fuzzy logic would instead define ambiguous points as, say, 30% tank and 70% tree—then wait until all the points are tallied before finally deciding whether or not a tank is hiding in the scene. That strategy boosts the amount of data needed to describe a scene, but in the end, Keller says, it enables a computer to simulate the mix of intuition and judgment that humans use to solve complex problems.

Doctors face such problems each time they interpret a tissue slide or x-ray image. Generally, human beings are much better at such tasks than computers, says Keller, but he's convinced fuzzy logic can endow machines with a much closer approximation to good medical judgment. He and colleagues at the University of Missouri medical school are working on a project to apply fuzzy logic to mammography. Their system, they hope, will be able to give mammograms a preliminary screening and alert doctors to suspicious patterns. Meanwhile, other researchers are looking into fuzzy logic programs based on Keller's algorithms to help them identify abnormal cells in biopsied tissues.

Keller says he's happy working in this new environment; it enables him to keep pursuing his real enthusiasm, which is computer algorithms. "A lot of what we do is very basic research, and we want to apply it to problems of current interest," he says. The trick to defense conversion, he adds, is to listen to what other people want. "All we've got to get is someone at the funding agencies to agree with us and we're in."

Military Electronics Follows a Rougher Road

Applied physicist William Youngblood spent 11 years at Georgia Tech Research Institute working on "electronic warfare"—developing sensors to help military aircraft detect enemies and jam the enemy's own sensors. But by 1990, he says, he "could see the writing on the wall." The communist world