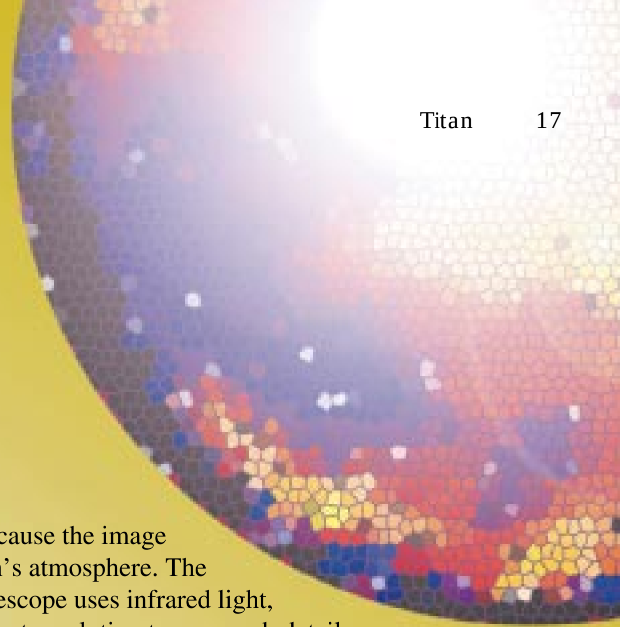


A Speckled Look at Saturn's Moon, Titan

THE stars and planets have fascinated human beings since time immemorial. Using the crude telescopes available at the time, the 17th century French astronomer Giovanni Domenico Cassini discovered the division in Saturn's rings and four of Saturn's moons—among them Titan, the largest.

Today, Titan holds particular fascination for astronomers. It is the only moon in the solar system with a thick nitrogen-dominated atmosphere, similar to Earth's, surrounding it. Also as on Earth, Titan's organic chemistry is driven by sunlight. Titan is several hundreds of degrees colder than Earth and has a methane-rich atmosphere, but its chemistry seems in some ways to be like that of Earth before life appeared.

Although imaging methods have improved enormously since Cassini's day, Titan is still difficult to see. Ultraviolet light changes atmospheric methane gases into a thick, smoglike haze that sits in the upper atmosphere. Imaging techniques that use visible light cannot penetrate this haze. When the Voyager spacecraft flew by Titan and took photographs with a telescope that used visible light, the resulting photos showed only a bright blob.

Infrared light can partially penetrate the smog. But Titan is so far away that conventional infrared telescopes on Earth also see only a blob because the image is blurred by Earth's atmosphere. The Hubble Space Telescope uses infrared light, but it lacks sufficient resolution to see much detail. Even with these deficiencies, both Hubble and ground-based studies have shown that Titan has a complex surface.

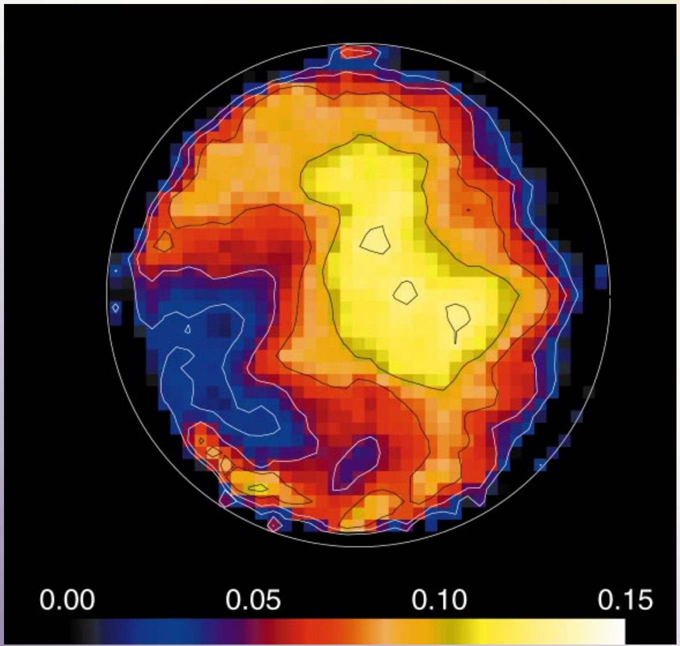
Hungry for more information about Titan and other celestial bodies, Livermore scientists adapted speckle interferometry, an imaging technique developed during the 1980s, for astronomical use. Until recently, speckle interferometry at Hawaii's 10-meter Keck I telescope gave the world the best look at this mysterious planetary moon.

Scientists have suspected for some time that Titan may have liquid seas formed by ethane that has "rained out" of the atmosphere to produce reservoirs of liquid hydrocarbons. Livermore astrophysicists Claire Max and Bruce Macintosh believe that the extraordinarily dark, unreflective area in the lower left corner of the image below could well be an oily, black ocean of hydrocarbon. Brighter, more reflective patches appear to be continents of ice and rock.

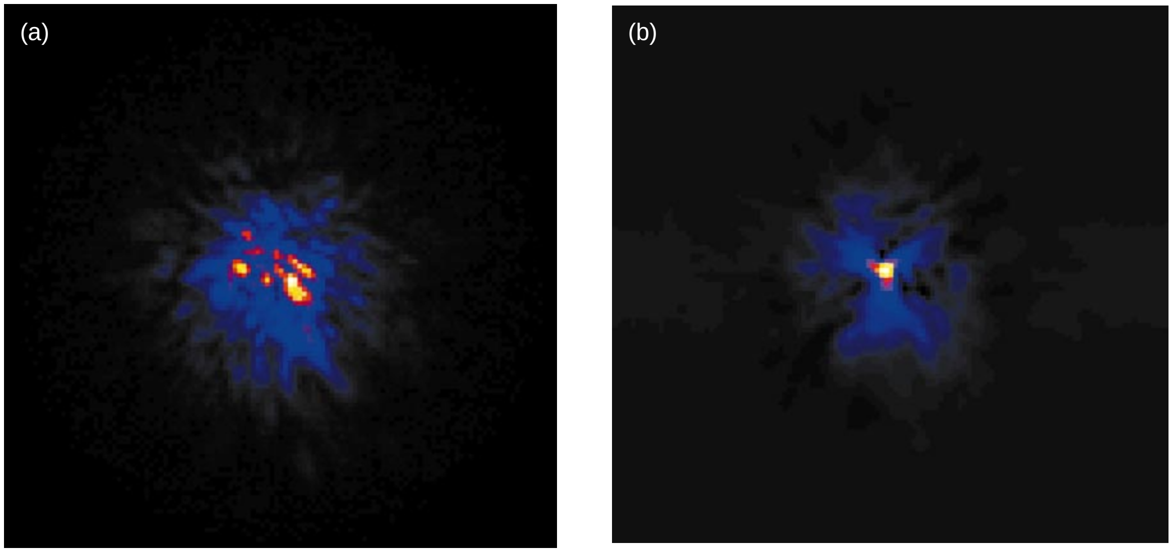
"If Titan does have a sea, it is the only other one in the solar system besides those on Earth, and we would like to know what is going on there," says Macintosh. "Titan seems to be similar to Earth 4 billion years ago, before life formed. Although Titan is too cold for life as we know it, it could be a laboratory for the processes that occurred here on our own planet."

Reflecting the Surface Only

Traditional astronomical imaging uses long exposures to gather as much light as possible into a single image. Because of Earth's atmosphere, that method often results in a fuzzy image for objects that are small or far away. In speckle imaging, several hundred pictures with short exposures are taken to freeze Earth's atmospheric turbulence. The pictures of Titan are taken using specific infrared wavelengths that are transparent "windows" through the methane spectrum, or haze. At wavelengths of 1.9 to 2.1 micrometers, scientists can more easily observe photons reflecting from Titan's surface, and thus the pictures have more contrast than would be possible at other wavelengths.



The 2-micrometer albedo (reflectance) of Titan from the Keck I telescope speckle images.



A complex computer algorithm combines (a) the interference patterns from 100 specklegrams taken over a 90-second period into (b) a single speckle image.

Each exposure of about 100 milliseconds produces a specklegram, which is the pattern caused by the interference of light rays as they travel through Earth's atmosphere. As shown above, a complex computer algorithm combines the interference patterns from 100 specklegrams taken over a 90-second period into a single final image.

These composite images can then be used to measure the reflectance, or albedo, of Titan's surface. Livermore astrophysicist Seran Gibbard adapted a radiative transfer model to separate reflectance data of Titan's atmosphere from those of its surface so scientists can map surface features only. Albedo measurements range from 0 to 1, with 0 being black and totally unreflective and 1 being white. The dark area on Titan that scientists believe may be a hydrocarbon sea has an albedo of nearly zero. The brightest, ice- or rock-like continental area has an albedo of 0.15.

Using speckle imaging, the Livermore team has mapped both of Titan's hemispheres, one of which is shown in the figure on p. 17.

Probing Titan

For several years, speckle imaging has been the best way to view small, distant celestial objects such as Titan. But better ways have been developed. Constructing a final image using speckle imaging takes considerable time on both the telescope and the computer. A faster method that produces almost immediate results is adaptive optics, which allows telescope mirrors to compensate directly for the distortions generated by Earth's atmosphere. An adaptive optics system has been installed at the Keck observatory and has recently produced even clearer images of Titan. (See p. 2 of this issue and *S&TR*, July/August 1999, pp. 12–19.) Spectroscopic data obtained using adaptive optics will also help improve models of Titan's atmosphere.

In late 2004, the most detailed information yet about Titan will begin to arrive on Earth from another source altogether. The spacecraft Cassini, which blasted off in October 1997, will begin to orbit Saturn to learn more about its famous rings, its magnetosphere, and its moons, Titan in particular. The primary contributors to the Cassini program are NASA, the European Space Agency, and the Italian Space Agency.

In November 2004, Cassini will drop a probe called Huygens (named for a Dutch physicist and astronomer) into Titan's upper atmosphere. As it breaks through the cloud deck, a camera will capture pictures of the Titan panorama. Other instruments will measure the organic chemistry of Titan's atmosphere as the probe descends to Titan's surface on the rubber duck–shaped continent visible in the figure on p. 17. Designed by the European Space Agency, Huygens can both bounce and float, so it is prepared for whatever surface it finds. But Huygens will only send information for a few hours because it must operate on batteries. Titan's haze is too thick for solar power. Cassini will continue to orbit Saturn and Titan for years, sending data back to information-hungry, Earth-bound scientists.

—*Katie Walter*

Key Words: adaptive optics, Saturn, speckle imaging, Titan.

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Remote Sensor Test Range
Proving Ground for Tomorrow's Sensing Technologies

IT'S 1:30 on an August afternoon at Frenchman Flat at the Nevada Test Site. The temperature outside is sweltering. The wind, which blew erratically that morning, has settled down to a steady southwest to northeast, clocking in at 24 kilometers per hour. Dust and grit whip through the heated air, coating clothes and skin. Metallic surfaces burn when touched with a bare hand.

It's perfect weather.

Perfect, that is, for open-air tests at the Remote Sensor Test Range (RSTR). The RSTR, operated jointly by Lawrence Livermore and Bechtel Nevada, is the proving ground for nascent remote-sensing technologies developed by the Department of Energy's national laboratories. Five laboratories conduct experiments at the range: Lawrence Livermore, Los Alamos, Sandia, Pacific Northwest, and Brookhaven.

Home on the Range

The range had its genesis in 1984 when DOE was looking into the pros and cons of liquefied natural gas as a possible energy source. Needing more information about the safety aspects of this gas, DOE developed a site for large-scale chemical releases at Frenchman Flat at the Nevada Test Site. Through 1988, DOE and Lawrence Livermore conducted a series of large-scale tests at this site, including tests of ammonia and nitrogen tetroxide spills and releases of hydrogen fluoride.

By 1994, interest in remote-sensing technology had increased to the point that a site was needed to test these technologies on open-air gas releases. The spill test facility, now called the HAZMAT Spill Center, was chosen as the best site. "There were several critical elements in its favor," explains Lawrence Livermore physicist Henry Goldwire, project leader for the RSTR. "Frenchman Flat is isolated from populated areas and has unusually stable weather, particularly wind patterns." The Laboratory's RSTR group and Bechtel Nevada joined up to improve the site's communications, site power, and chemical release mechanisms.

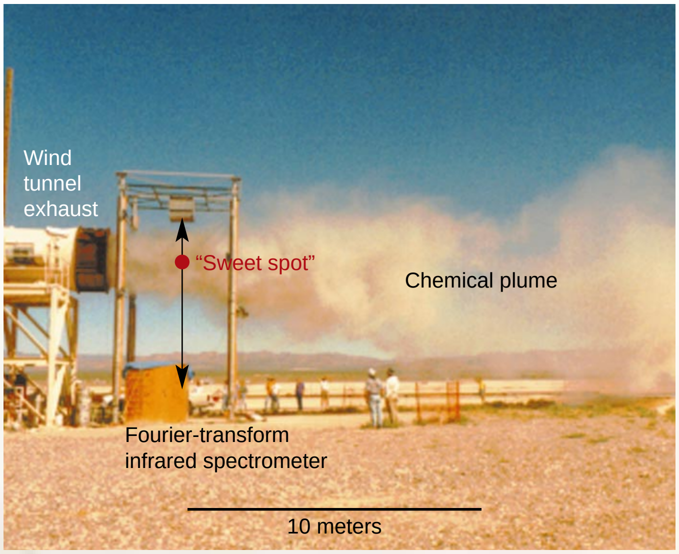
In developing the range, the Livermore team, then headed by Dennis Slaughter, sat down with sensor developers to discuss what kind of sources would be best for field tests. As Goldwire notes, "You can't just open a gas canister on the ground, let the gas escape, and point your instrument at it. If you do, you can't control the release or verify your results. In other words, you have no 'ground truth.'"

The RSTR group developed a reliable and verifiable chemical release system based on a wind tunnel originally built in 1987 for hydrogen fluoride tests. In addition, two stack sources were developed later that more closely imitate the conditions under which chemicals must be sensed. Ultimately, the sensors will be used in aircraft, but as tested at the RSTR, they are not usually flyable systems.

Wind-Tunnel Truth

In the wind-tunnel-based source designed by Lawrence Livermore engineer Steve Yakuma, test chemicals are injected into the tunnel, atomized, and mixed with ambient air before being released horizontally at high velocity (about 1,540 cubic meters per minute).

The wind tunnel provides a calibrated and well-characterized, 2-meter-diameter chemical plume at which



The range's wind tunnel exhaust plume creates an open air gas calibration cell target for remote sensors. The point at which most sensors aim is called the sweet spot.

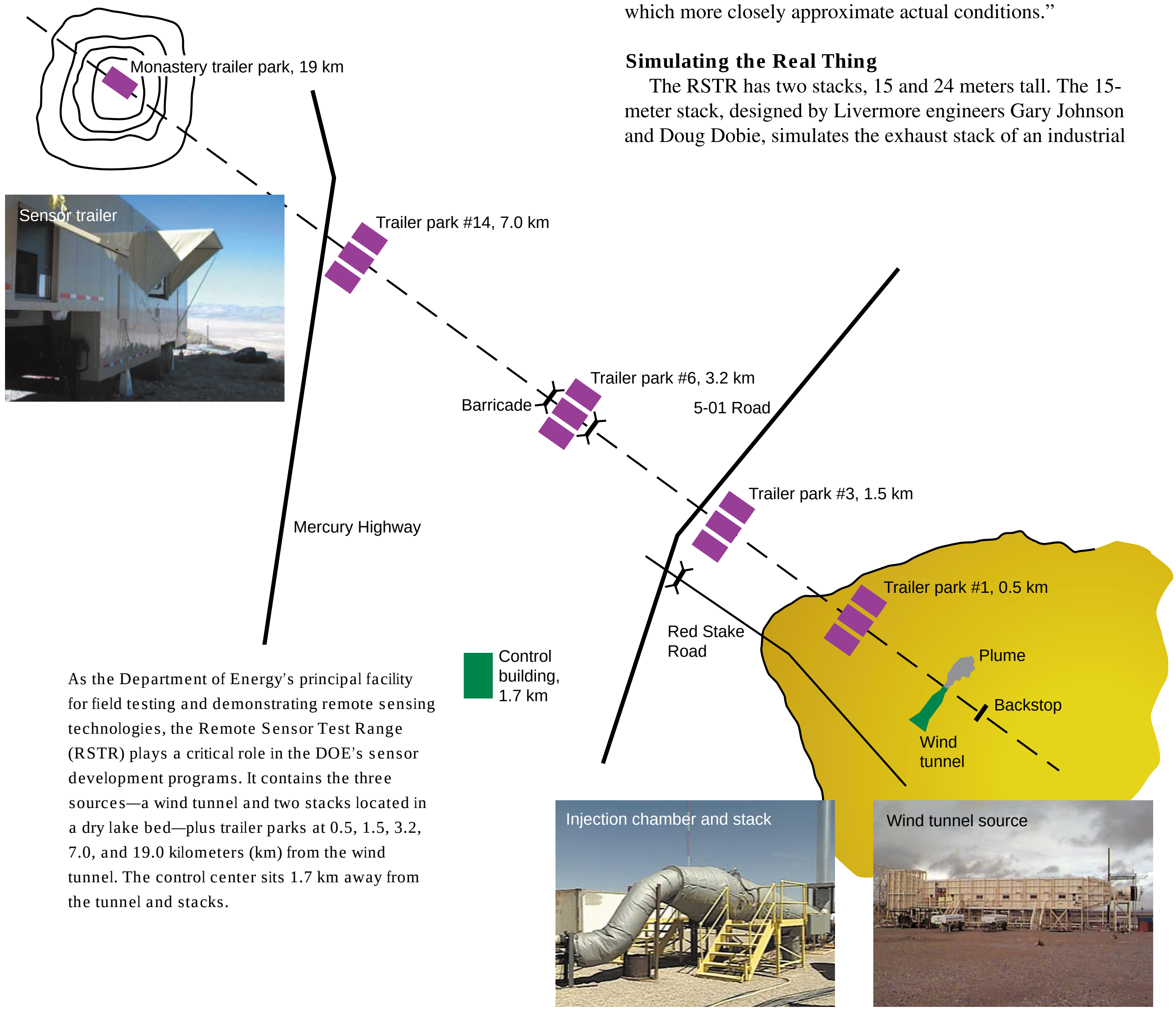
developers can aim their remote-sensing instruments. Plume concentrations of up to four gases can be independently controlled over a range of 1 to 1,000 parts per million. The concentration is determined by measuring the mass flow of the chemical as well as the airflow through the wind tunnel and taking the ratio of the two. “The system is expertly operated and maintained by mechanical technicians Jack Robson and Tom Schaffer. We’ve not had a single day lost to source failure in our five years of operation,” notes Goldwire.

Diagnostics include infrared gas sensors inside the wind tunnel and a Fourier-transform infrared (FTIR) spectrometer at the exit to the wind tunnel. These diagnostics provide important backup data that validate the wind tunnel’s performance and provide the ground truth against which sensor developers can compare their results.

“The wind tunnel was designed to be a research tool,” Goldwire said. “It’s a place where sensor developers can prove their technologies. Technologies that are further along the development path can be tested on our stack sources, which more closely approximate actual conditions.”

Simulating the Real Thing

The RSTR has two stacks, 15 and 24 meters tall. The 15-meter stack, designed by Livermore engineers Gary Johnson and Doug Dobie, simulates the exhaust stack of an industrial



As the Department of Energy’s principal facility for field testing and demonstrating remote sensing technologies, the Remote Sensor Test Range (RSTR) plays a critical role in the DOE’s sensor development programs. It contains the three sources—a wind tunnel and two stacks located in a dry lake bed—plus trailer parks at 0.5, 1.5, 3.2, 7.0, and 19.0 kilometers (km) from the wind tunnel. The control center sits 1.7 km away from the tunnel and stacks.

facility. It can independently control and release up to six chemicals at a time. "Start carts" (the kind used to warm up jet engines) produce a 200°C air stream that projects and evaporates the injected chemicals. The stack provides realistic scenarios as the chemicals exit the stack and are whipped about by the wind. In addition, the stack can handle a wider range of chemicals than the wind tunnel source, including some that are highly toxic or have high boiling points. The stack releases the chemicals into a 0.56-meter-diameter plume of fully mixed, heated air and chemicals. Chemical concentrations can vary from 10 to more than 8,000 parts per million.

The stack also has an FTIR to provide ground truth that developers can check against their sensor results. Goldwire notes that the source flow data, together with FTIR data provided by Livermore chemist August Droege, have withstood all challenges from the users.

Preparing and Delivering on Test Day

Planning for each test series begins in January. The sensor developers present their needs; Goldwire—with guidance from DOE—helps set priorities. "Over the years, the users have learned to work together, negotiate, and do a little horse trading at the table," says Goldwire. "They've also found out they can piggyback on each other's experiments." It takes about 20 weeks to plan and prepare for the annual 4- to 6-week series of tests—not surprising, considering the complex nature of the tests and the wide range of chemicals involved. For example, in the Mountain Lion test series of 1998, five groups from three national laboratories fielded sensor systems from two trailer parks and from four types of aircraft. During that test series, a team of 16 operators—eight from the RSTR group and eight from Bechtel Nevada—loaded and released 108 chemicals in 21 test days, with an average of five chemicals per day.

Days are planned to use every minute of testing time to maximum effectiveness. "We try to match the chemicals to the source," explained Goldwire. "For instance, a chemical's physical state and boiling point determine the types and sizes of nozzles used to inject the chemical into the heated air. Acids and bases use different systems. Between runs, we purge the systems with nitrogen. In 24 hours, we can clean up after the previous tests, change out all sources and chemicals, and be ready for the next day's test." Tests are usually conducted for four to five hours each afternoon and occasionally in the early evenings.

For the 21 test days of Mountain Lion, 56 releases were performed with the wind tunnel system and 50 with the two stacks. Plume concentrations varied from 1 to 8,000 parts per million. The data-acquisition systems recorded about 250 channels of data and controlled about 600 system components.

Annual Tests at the Remote Sensor Test Range.

Year/Series	Chemicals	Number of Tests	Hazards
1994 Iguana	11	26	Toxic, flammable
1995 Jack Rabbit	17	20	Toxic, flammable
1996 Kitfox	~30	30	Toxic, flammable
1997 Lynx	~30	4	Toxic, flammable
1998 Mountain Lion	~30	21	Toxic, flammable
1999 Nighthawk	~30	10	Toxic, flammable

"A major factor in our success, year after year, is the dedicated team supporting the range," says Goldwire, "Key individuals have been with the range from its inception." Weather, however, can sometimes preempt the carefully prepared schedule. In Mountain Lion, for instance, four days were lost to El Niño storms.

In addition to the requests put in by users, the Livermore–Bechtel Nevada team ran three-scenario days for the Mountain Lion test series. These scenario days are essentially final exams, in which sensor developers pit their technologies against unknown (to them) releases of chemicals and mixtures. "If a new technology passes these tests, there's a good chance it will be viewed positively for further development by the sponsor," said Goldwire.

Travis White from Lawrence Livermore's Engineering Department praises the test range and its personnel. "The Livermore and Bechtel Nevada teams do an outstanding job," says Travis, a three-year veteran user of the RSTR. "For people like me, the range provides a scientific and methodical way to evaluate technologies and to test concepts. It's a unique capability, unparalleled anywhere else in the nation."

—Ann Parker

Key Words: chemical release testing, Frenchman Flat, HAZMAT Spill Center, Mountain Lion test series, Nevada Test Site, Remote Sensor Test Range (RSTR), remote sensing.

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