Field Testing

The Physical Proof of Design Principles

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For the past four decades, Los Alamos has performed full-scale nuclear tests as part of the Laboratory's nuclear weapons program. The Trinity Test, the world's first man-made nuclear explosion, occurred July 16, 1945, on a 100-foot tower at the White Sands Bombing Range, New Mexico. The actual shot location was about 55 miles northwest of Alamogordo, at the north end of the desert known as Jornada del Muerto which extends between the Rio Grande and the San Andres Mountains.

The actual detonation of a nuclear device is necessary to experimentally verify the theoretical concepts that underlie its design and operation. In particular, for modern weapons, such tests establish the validity of sophisticated refinements that explore the limits of nuclear weapons design. In addition, occasional proof tests are conducted of fully weaponized warheads before entry into the stockpile, and from time to time weapons are withdrawn from the stockpile for confidence tests. Also, tests characterized by a high degree of complexity are conducted to study military vulnerability and effects.

Information from test detonations assures that weapons designs which match their delivery systems can be produced in a manner consistent with the availability of fissile material and other critical resources. The interplay of field testing and laboratory design is orchestrated to optimize device performance, to guarantee reliability, to analyze design refinements and innovations, and to study new phenomena that can affect future weapons.

The advent of versatile, high-capacity computers makes it possible to model the behavior of nuclear weapons to a high degree of similitude. However, subtle and imperfectly understood changes in design parameters, such as small variations in mass, shape, or materials, have produced unexpected results that were discovered only through full-scale nuclear tests. Whereas the symmetry and compression of mock fissile material can be studied by detonating high explosives in a controlled laboratory environment without producing a nuclear yield, the actual performance of a weapon, particularly one of the thermonuclear type, cannot be simulated in any conceivable laboratory experiment and must be done in an actual nuclear test.

Field testing is the culmination of the imposing array of scientific and engineering effort necessary to discharge the Laboratory's role in developing and maintaining nuclear weapons technology to support the United States national security policy of nuclear deterrence. Embedded therein is the paradox: How do you test a bomb, undisguisedly an instrument of destruction, without hurting anyone?

From the beginning, field testing of nuclear weapons has followed commonsense guidelines that accord prudent and balanced concern for operational and public safety, obtaining the maximum amount of diagnostic information from the high-energy-density region near the point of explosion, and meeting the exacting demands of engineering and logistics in distant (and sometimes hostile) environments. The extreme boundaries of the arena of nuclear testing encompass tropical Pacific atolls and harsh Aleutian islands, rocket-borne reaches into the upper atmosphere, and holes deep underground. Since 1945, tests have occurred atop towers, underwater, on barges, suspended from balloons, dropped from aircraft, lifted by rockets, on the earth's surface, and underground. The locations evoke the words of a once-popular song, "Faraway Places with Strange-sounding Names"—Bikini, Eniwetok, Amchitka, Christmas Island; and nearer to home, at the Nevada Test Site (NTS), Frenchman Flat, Yucca Lake, and Pahute Mesa, among others. These names, no longer so strange sounding, have become familiar parts of the test community's language.

At various times between June 1946 and November 1962, atmospheric and under-

Aerial view of subsidence craters from underground nuclear tests in Yucca Flat at the NTS. The so-called Yucca Lake is in the background, and the Control Point complex is to the right of the dry lake.

ground tests were conducted by the U.S. principally on Eniwetok and Bikini Atolls in the Marshall Islands and on Christmas Island and Johnston Atoll in the Pacific Ocean; at the Nevada Test Site; and over the South Atlantic Ocean. Since November 1962, even before the atmospheric test ban treaty of 1963 came into effect, all U.S. nuclear weapons tests have been underground, most of them at the NTS, as part of an ongoing weapons program. Three underground tests were conducted on Amchitka Island in the Aleutians. Some tests for safety studies, peaceful uses of nuclear energy, and test detection research were conducted on the Nellis AFB Bombing Range in Nevada, and at other locations in Colorado, Nevada, New Mexico, and Mississippi. The accompanying table summarizes testing activities.

A nuclear test moratorium initiated in 1958 was ended abruptly in August 1961 when the Soviets resumed atmospheric testing. During the period of nontesting, the U.S. made substantial progress in its mathematical modeling capability, but because substantial preparations for atmospheric tests had not been made, it was not until the late spring of 1962 that atmospheric nuclear experiments could be fielded. Underground tests had been resumed in the early fall of 1961.

In conjunction with ratification of the Limited Test Ban Treaty (LTBT) in October 1963, the Joint Chiefs of Staff defined four safeguards, which, with the strong support of Congress, were to have significant impact upon the Laboratory.

The first safeguard was, in effect, a promise that the nuclear weapons laboratories would be kept strong and viable. The second called for a strong underground test program. The third concerned maintenance of the capability to return to testing in the "prohibited environments"—the atmosphere, underwater, and space—should that be necessary, and the fourth recognized the need to monitor carefully the nuclear test activities of other nations.

The first two safeguards provided new justification for underground testing, including tests purely scientific in nature. The third safeguard led to nonnuclear atmospheric physics tests in Alaska, northern Canada, and the Pacific region. The facilities and capabilities held in readiness for nuclear tests were used in many scientific endeavors, including solar eclipse expeditions and auroral studies. The fourth safeguard was responsible for triggering Laboratory activity in space, as Los Alamos developed a satellite test-monitoring capability that arose from the Vela program. This in turn has led to a number of first-rate scientific space programs.

At present, the Los Alamos test program is carried out by approximately 385 Laboratory employees from the Test Operations Office and various divisions, including WX, P, ESS, MST, INC, M, X, and H. Their efforts are supplemented by about 740 contractor employees of the DOE's Nevada Operations Office working at the NTS. Notable among the contractors are the Reynolds Electrical Engineering Company (REECo) for drilling and field construction, EG&G for technical support, Holmes and Narver (H&N) for construction architecture and engineering; and Fenix and Scisson (F&S) for drilling architecture and engineering. The dedicated efforts of all these people are necessary to execute nuclear tests as a vital element of the Los Alamos weapons program.

Diagnostics and Testing Technology

Before the Trinity test, estimates of its yield varied from zero to 20 or more kilo-

NUCLEAR WEAPONS TEST OPERATIONS[a]

Operation	Announced U.S. Nuclear Tests[b]	Dates	Location
Trinity	1	July 1945	Alamogordo, New Mexico
Crossroads	2	June - July 1946	Bikini Atoll
Sandstone	3	April - May 1948	Eniwetok Atoll
Ranger	5	January - February 1951	Nevada Test Site
Greenhouse	4	April - May 1951	Eniwetok Atoll
Buster-Jangle	7	October - November 1951	Nevada Test Site
Tumbler-Snapper	8	April - June 1952	Nevada Test Site
Ivy	2	October - November 1952	Eniwetok Atoll
Upshot-Knothole	11	March - June 1953	Nevada Test Site
Castle	6	February - May 1954	Bikini and Eniwetok Atolls
Teapot	14	February - May 1955	Nevada Test Site
Wigwam	1	April 1955	East Pacific
Project 56	4	November 1955 - January 1956	Nevada Test Site
Redwing	17	May - July 1956	Eniwetok and Bikini Atolls
Project 57	1	April 1957	Nevada Test Site
Plumbbob	30	May - October 1957	Nevada Test Site
Project 58	2	December 1957	Nevada Test Site
Project 58A	1	February - March 1958	Nevada Test Site
Hardtack Phase I	35	April - August 1958	Eniwetok and Bikini Atolls; Johnston Island
Argus	3	August - September 1958	South Atlantic
Hardtack Phase II	37	September - October 1958	Nevada Test Site
Nougat	45	September 1961 - June 1962	Nevada Test Site; Carlsbad, New Mexico
Dominic	31	April 1962 - October 1962	Christmas and Johnston Islands
Fishbowl	5	July 1962 - November 1962	Johnston Island
Storax	56	July 1962 - June 1963	Nevada Test Site
Niblick	27	August 1963 - June 1964	Nevada Test Site; Fallon, Nevada
Whetstone	35	July 1964 - June 1965	Nevada Test Site; Hattiesburg, Mississippi
Flintlock	40	July 1965 - June 1966	Nevada Test Site; Amchitka, Alaska
Latchkey	27	July 1966 - June 1967	Nevada Test Site; Hattiesburg, Mississippi
Crosstie	30	July 1967 - June 1968	Nevada Test Site; Dulce, New Mexico
Bowline	26	July 1968 - June 1969	Nevada Test Site
Mandrel	42	July 1969 - June 1970	Nevada Test Site; Grand Valley, Colorado; Amchitka, Alaska
Emery	10	October 1970 - June 1971	Nevada Test Site
Grommet	12	July 1971 - May 1972	Nevada Test Site; Amchitka, Alaska
Toggle	11	July 1972 - June 1973	Nevada Test Site; Rifle, Colorado
Arbor	5	October 1973 - June 1974	Nevada Test Site
Bedrock	15	July 1974 - June 1975	Nevada Test Site
Anvil	18	September 1975 - August 1976	Nevada Test Site
Fulcrum	11	November 1976 - September 1977	Nevada Test Site
Cresset	16	October 1977 - September 1978	Nevada Test Site
Quicksilver	16	November 1978 - September 1979	Nevada Test Site
Tinderbox	15	November 1979 - September 1980	Nevada Test Site
Guardian	16	October 1980 - September 1981	Nevada Test Site
Praetorian	22	October 1981 - September 1982	Nevada Test Site
Phalanx	—	November 1982 -	Nevada Test Site

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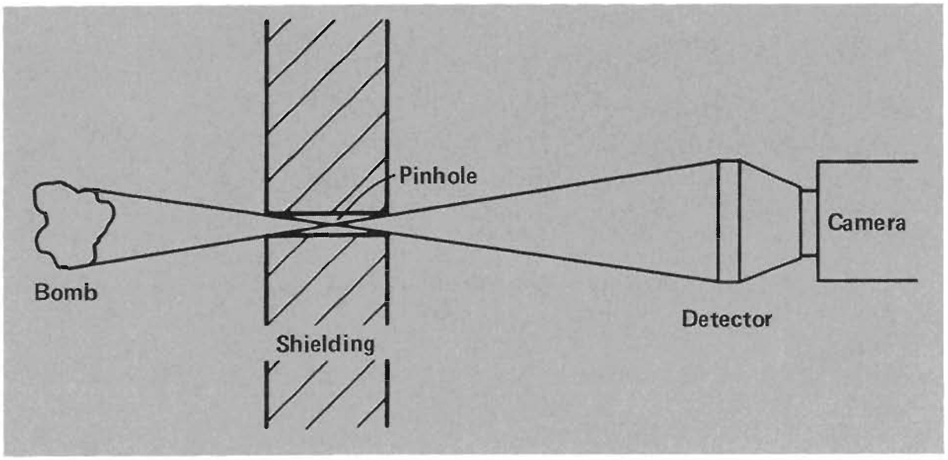
[a] ***The Hiroshima and Nagasaki detonations of World War II were August 5 and 9, 1945, respectively.***

[b] ***All tests before August 5, 1963, and after June 14, 1979, have been announced.***



Schematic of a pinhole imaging experiment.

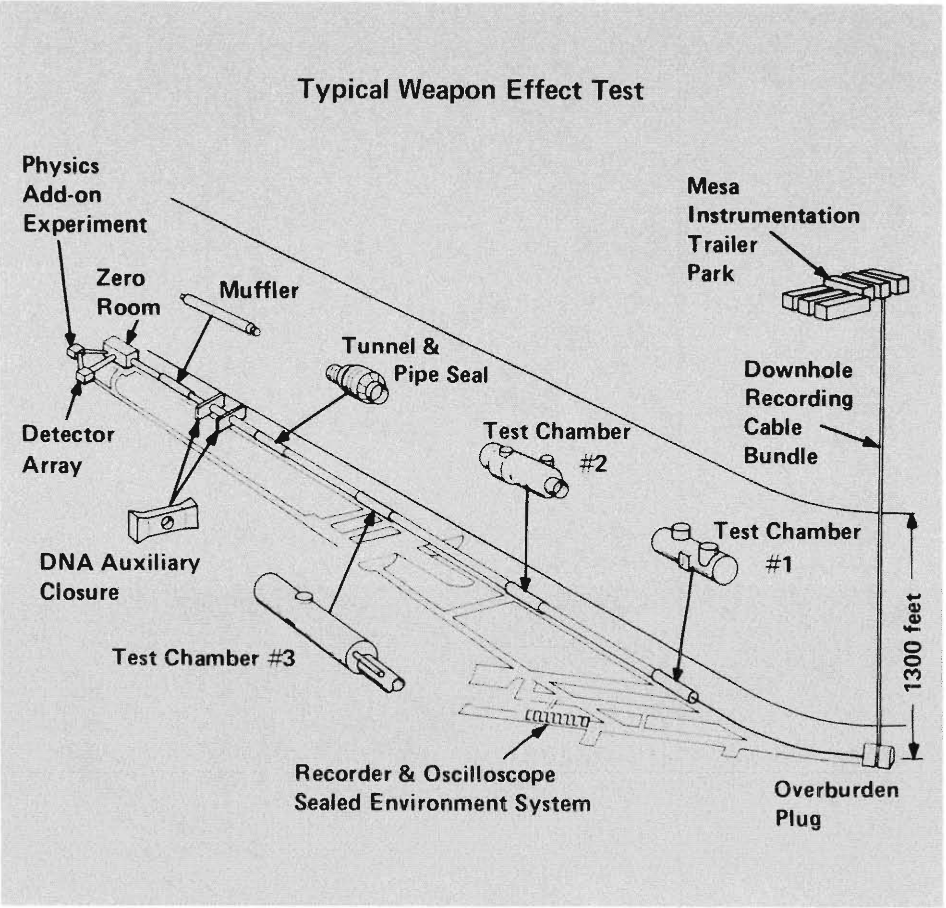
tons. Even if the yield had been known in advance, estimates of the effects of the explosion were based on speculation plus some extrapolation from a 100-ton shot of high explosive. This rehearsal shot, consisting of 100 tons of TNT laced with fission products, was made prior to Trinity to provide calibration of blast and shock measurement techniques and to evaluate fallout. The yield of Trinity was measured by observation of the velocity of expansion of the fireball as photographed by super-high-speed movie cameras, by radiochemical analysis of the debris, and by observation of blast pressure versus time and distance. If the yield had been disappointingly low, the most important diagnostic for understanding the reason for failure would have been measurement of the generation time, that is, the length of time spent in increasing the fission reaction rate by a given factor. Effects measurements were needed to predict the damage that would be done to the enemy by blast and radiation and also to evaluate possible damage to the delivery aircraft.

The Trinity measurements were amazingly successful considering it was the first shot observed. The photographic coverage was superb. The fireball yield technique was confirmed by radiochemical data. The generation-time data were successfully recorded on the only calibrated oscilloscope fast enough to make the measurement. Observations of debris deposition patterns led to the first fallout model. Dozens of other experiments, such as blast pressures versus distance, neutron fluences in several energy ranges, gamma-ray emissions, and thermal radiation effects, also gave useful data.

Postwar tests had the same general requirements for diagnostics as Trinity, but allowed more time for diagnostic development to improve the original techniques and to add new measurements. Yield is still measured by radiochemical techniques that were pioneered for Trinity, although they have been greatly improved upon since then. In addition, for as long as atmospheric testing was done, fireball measurements gave reliable yield determinations. Methods were developed to obtain the yield from accurate measurements of the spectrum of neutrons from the devices by careful observations of the emerging gamma rays, and, for underground shots, where a fireball cannot be observed, from the transit velocity of the shockwave through the ground. Generation-time measurements that covered only a small interval of the complete reaction history of the Trinity explosion have been expanded to cover changes in reaction rate and gamma output over as many as 17 orders of magnitude. Detectors and recording equipment have been developed to follow the later faster reacting devices. Methods have been developed to observe the flow of radiant energy that emerges from a device in the form of low energy x rays by observation of the x-ray spectrum as a function of time. Along with development of the various diagnostic detectors have been improved methods of transmitting data from detector to the recording stations. In addition to use of coaxial cables, which were first used at Trinity, we now use modern instrumentation that includes fiber optics, digital systems, and microwave transmission.

Photographic coverage of atmospheric events, starting with Trinity, reached a peak of perfection in the art of high-speed data recording, calling on the combined intellectual and technical resources of the Laboratory as well as a number of contractors, notably Edgerton, Germeshausen and Grier, who made significant contributions in oscilloscope and photographic technology, and the Naval Research Laboratory and the University of California Radiation Laboratory, who were successful in carrying out highly complex experiments. The innovations born of this expertise have proliferated beyond nuclear weapons testing to find application in many scientific activities requiring high-speed data resolution, ranging from endeavors as separate as studies of transient phenomena of interest in fusion energy release for civilian power to picosecond cameras used in studies of photosynthesis.

As a more detailed example of an experiment on a weapons test, consider a very useful diagnostic tool developed during atmospheric testing and modified and refined for underground use. A pinhole camera is used to take a picture of the actual shape and size of the fissile material of a fission bomb as it explodes or of the burning fuel in a thermonuclear bomb. A tiny pinhole through a thick piece of shielding located between the exploding device and a detector projects an image of the device onto the detector.



Cooperation between Los Alamos and the military services in weapons effects testing began soon after the close of World War II. The damage from atmospheric, underwater, and surface detonations was assessed by positioning a variety of military hardware at various distances from the device. When above-ground tests were prohibited, effects tests were transferred to horizontal tunnels deep underground. The figure shows a typical modern-day Defense Nuclear Agency effects test arrangement. A Los Alamos (or Livermore) supplied device is located in the Zero Room, which is connected to a long, horizontal line of sight (HLOS) containing several test chambers. Various rapid closure mechanisms in the HLOS allow radiation generated by the nuclear device to reach test chambers but prevent the escape of debris and radioactive gases. Following the test, military hardware and components that have been placed in the test chamber are retrieved and the effects of radiation exposure are evaluated at DNA contractor laboratories. The radiation output from the device provides a unique source for answering physics questions of interest to weapons designers. Occasionally such physics experiments are mounted simultaneously with effects tests. Usually the add-on experiments consist of one or more line-of-sight pipes with appropriate detectors as shown near the Zero Room in the figure.

Gamma rays and neutrons from the reacting material are transmitted through the bomb parts, such as high explosive and bomb case, and reach the detector (for example, a fluor) and cause it to light up with a brightness proportional to the intensity of incident radiation. The resulting image is a two-dimensional picture of the reacting fuel, as seen through the bomb debris. The brilliant light and x rays from the bomb surroundings are eliminated by a thin screen of metal between the bomb and the fluor. A TV camera then transmits the picture to a recording station. It is even possible by use of various schemes to produce gamma rays or neutron pictures of selected energies or to get several frames of motion of the reacting region separated by a few billionths of a second.

We were presented with new challenges when, in 1963 as a result of the LTBT, all tests had to be conducted underground. Underground emplacement of a nuclear device at the Nevada Test Site occurs in one of two basic modes: in a vertical shaft or a horizontal tunnel, with appropriate arrays of diagnostics for weapons development tests or for weapons effects and vulnerability studies. Of course, when any test is conducted for whatever reason, as many experiments and diagnostics measurements are added as can be accommodated in the limited volume of subsurface placement to make optimum use of the device's unique and costly output. Diagnostic information typically is obtained with sensors that "look" at the test device through a line-of-sight (LOS) pipe or by close-in sensors whose output is transmitted over coaxial or fiber optics cables to remotely located high-data-rate recorders. A variety of techniques is used to protect diagnostic equipment long enough to obtain and transmit data before being engulfed in the nuclear explosion.

During atmospheric testing, we measured yield, radiation, blast, and thermal effects, but we also studied weapons phenomenology: how the weapons' outputs interacted with the environment and the effects of weapons-generated electric and magnetic fields. Information on these subjects gleaned from early tests has been extremely helpful with respect to present problems, specifically, the interference of electromagnetic pulse (EMP) signals with power grids, communication links, and satellites, and typical

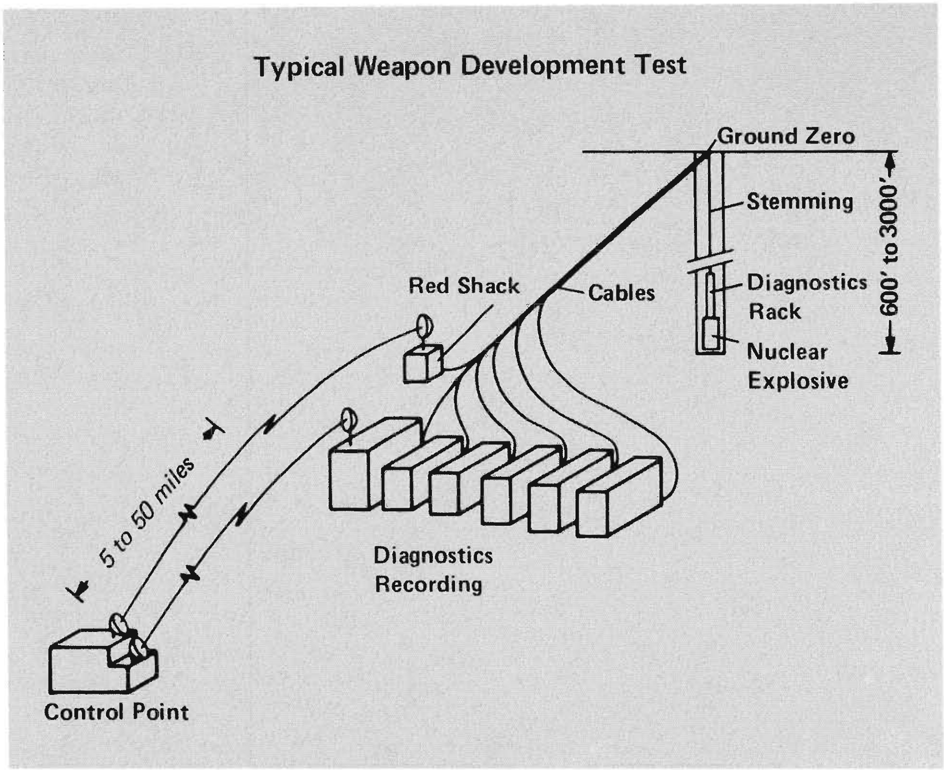
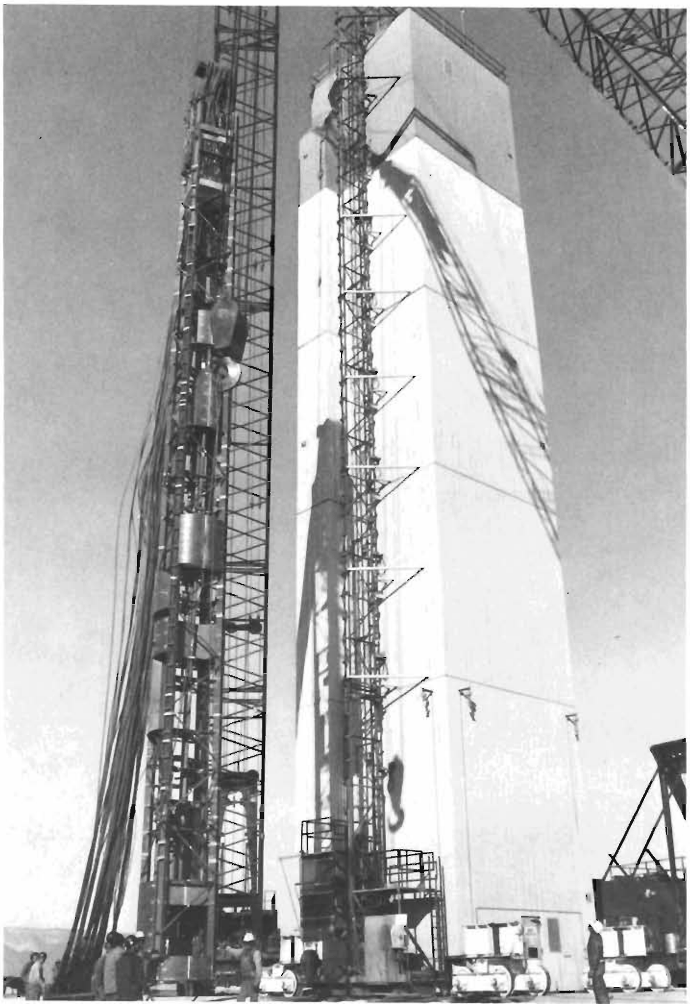
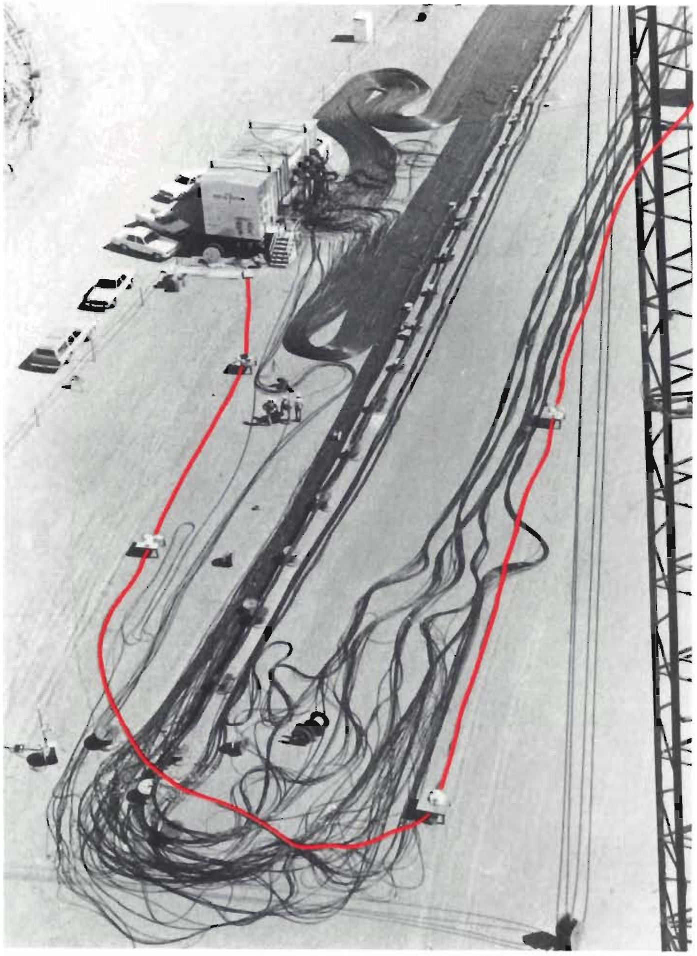


Diagram at left: Most weapons development tests are conducted in vertical shafts drilled deep into the ground. A rack holding the device, the associated firing components, and the diagnostics detectors and sensors is lowered into the emplacement hole and the shaft is backfilled with a combination of sand, gravel, concrete, and epoxy that stems the hole to ensure containment of the nuclear explosion. The test is fired by sending a specific sequence of signals from the Control Point to the "Red Shack" near Ground Zero. (The Red Shack houses the arming and firing equipment.) The diagnostics instruments detect outputs from the nuclear device and the information is sent uphole through cables. Usually within a fraction of a millisecond following the detonation the sensors and cables will be destroyed by the detonation, but by that time the data have been transmitted by cables to recording stations a few thousand feet from Ground Zero or by microwave to the Control Point. Photograph: Aerial view of Ground Zero rack tower, diagnostic cables, and diagnostic-recording trailer park. Final test preparations include emplacing miles of cable downhole. The cables will transmit vital test information to the diagnostics trailers in the foreground of the picture. A rack containing instrumentation to go downhole is assembled in the tower at the top of the picture.



A device diagnostics rack suspended from a crane prior to being installed inside the Ground Zero rack tower. The modular rack tower is erected over the emplacement hole to provide protection against wind and weather while diagnostics equipment is installed and prepared for the test. Finally the rack and the device canister are lowered into the hole, the rack tower is disassembled, and the hole is backfilled with appropriate stemming material.



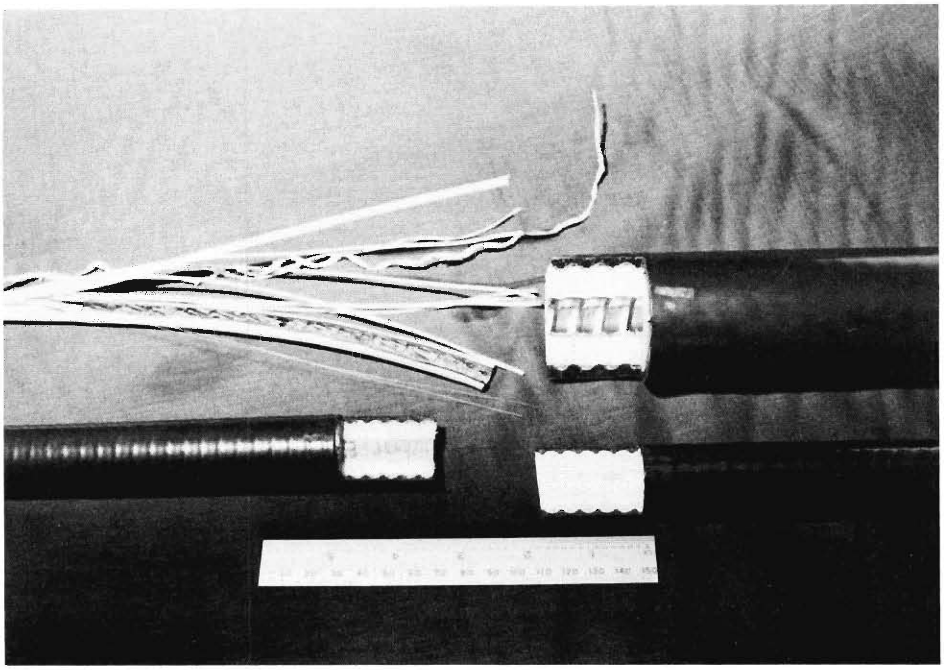
This photo contrasts the information capacity of fiber optics cables (orange) with those of coaxial cables (black). A single bundle of fiber optics cables (orange cable at lower right) carries data in the form of light signals from the underground diagnostics rack at Ground Zero to a photomultiplier station where the light signals are converted to electrical impulses. The coaxial cables exiting from that station transmit the data to the recording stations in the background. These stations house oscilloscopes that record the data on photographic film.

other weapons effects associated with prompt radiation and blast. While we can't study all of these problems underground, many weapons effects can still be observed. The Defense Nuclear Agency of the Department of Defense funds very complex tests of this nature and Los Alamos participates in these shots, frequently supplying and firing the nuclear explosive as well as making measurements of weapons effects.

From the time of the first nuclear explosion, there was speculation about nonmilitary uses for these devices. Among the first scientific applications were contributions to seismology and meteorology. Knowledge of the exact time and location of nuclear explosions is particularly useful in obtaining information complementary to that from earthquakes. New chemical elements have been produced by nuclear explosions; specifically, the elements einsteinium and fermium were discovered in 1952 in the debris from a high-yield Los Alamos thermonuclear device. Los Alamos scientists have also applied nuclear tests to the measurement of nuclear physics data concerning reactions of nuclei with neutrons, particularly on those isotopes whose self-radioactivity tends to mask the data generated from the lower fluxes available in the laboratory.

When the Limited Test Ban Treaty of 1963 resulted in all of our nuclear tests being conducted underground, the necessary engineering developments were made which produced a line of sight from a deeply buried bomb to the ground surface. This line of sight remained open long enough for neutrons and gamma rays from the bomb to reach the surface, but was closed off by a variety of shutters and valves and ground shock before any radioactive debris could escape. With this system, a very nicely collimated beam of neutrons could be produced that was ideal for study of neutron-induced reactions. From 1963 to 1969, eight of these experiments were performed and produced a mass of useful physics data.

Except for state-of-the-art improvements in solid-state electronics, digitization of data, and miniaturization, some test diagnostics have changed relatively little since early testing experiments, which bears witness to the ingenuity of pioneers at the Pacific and



A fiber optics cable compared to three types of NTS coaxial cable. The two smaller coaxial cables (RF-19 and RF-13) are used downhole and the larger cable (RF-16) is used only for horizontal surface transmission. Each coax cable provides a single data channel; the fiber optics cable provides eight data channels. Depending on the quality of fiber used, the cost per fiber data channel is 1/3 to 1/6 the cost of the cheapest coax (RF-13) shown here. The fiber provides a bandwidth (data capacity) far exceeding that of coax cable. Fiber can provide a bandwidth above 1 GHz for a 1 km length; RF-13 cable can achieve 1 GHz over a 50 m length. The fiber cable is much lighter and smaller than the coax. Since it is nonmetallic, it precludes coupling of electrical interference from the test into sensitive recording instrumentation. Inside a rugged plastic sheath, layers of stranded Kevlar protect and strengthen the inner bundle of fibers. Each fiber is in a small plastic tube (8 in all) and each tube is filled with a gel material. A central strength member provides most of the tensile strength. This design totally precludes transfer of radioactive gas along the cable while providing excellent protection for the delicate fibers inside.

Interior of a diagnostics recording station with oscilloscopes and cameras.

Nevada proving grounds. It is a tribute of considerable magnitude to realize that some of the gear fielded at Trinity represented a new branch of technology that was born essentially full grown.

Engineering, Construction, and Logistics

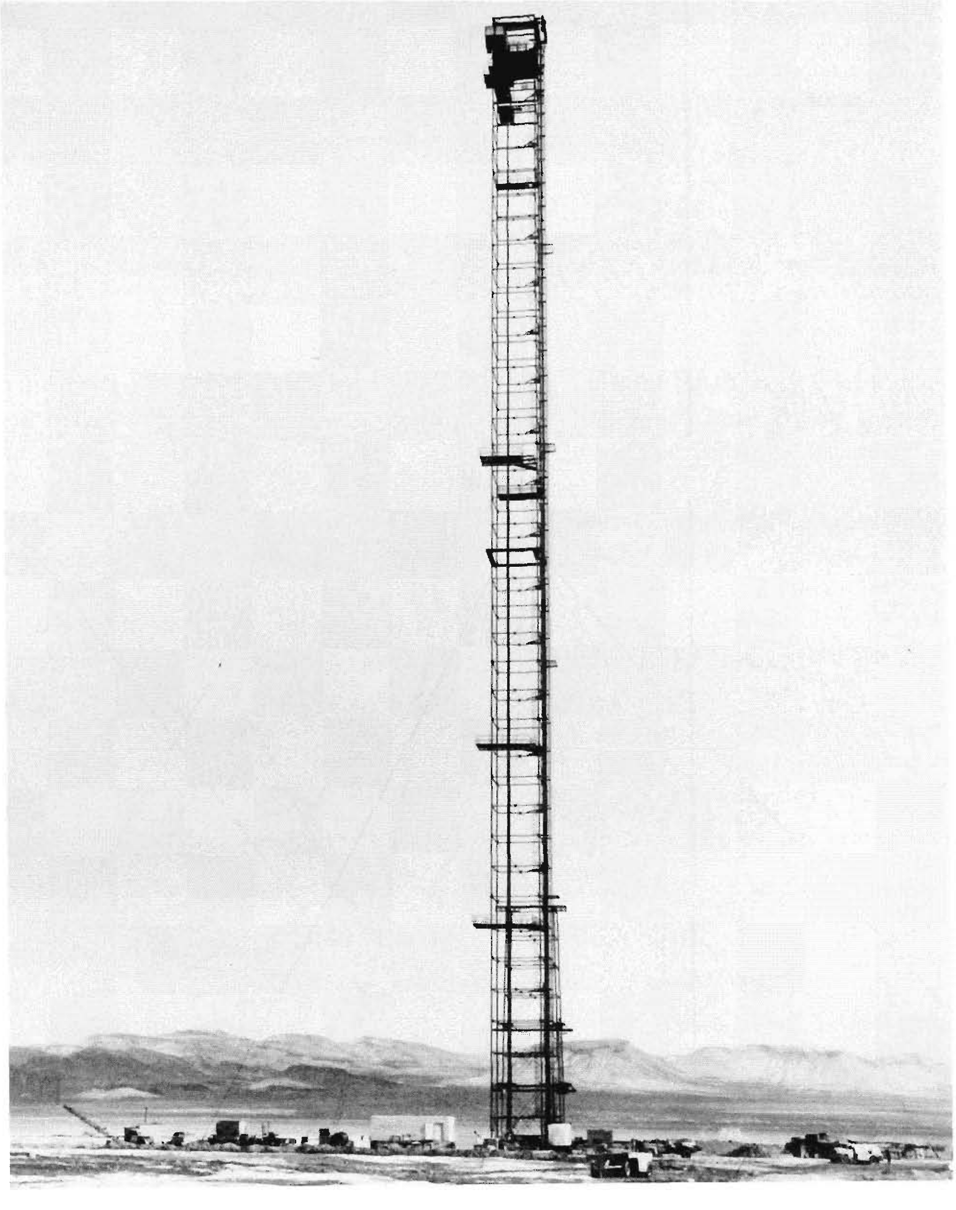
Early testing experience established a mode of operation, largely followed by Los Alamos participants ever since, that grew out of a habit of broad discussions among the experimenters and theoreticians leading to an agreed course of action. The early tests, apart from Trinity, were done on or near isolated islands in the Pacific. It was an enormous task to provide the necessary equipment, laboratory and shop facilities, spare parts, transportation, communications, living accommodations, and everything else needed to conduct test operations under difficult conditions on tight schedules far from home. Pacific operations typically required planning over a two-year period because they presented extraordinary situations compared to most scientific and engineering undertakings. Some of the *ad hoc* solutions to vexing and unique problems established precedents that have proved admirably sound in the light of subsequent critical examination.

One specific engineering task was the construction of towers to support the test devices above ground. Our appetite for shot towers that could support bigger loads at greater heights was insatiable. Early towers needed only to support the device itself, some firing hardware, and perhaps a few detectors and coaxial cables, but we continued to add shielding and collimator loads as our diagnostics techniques developed. By the end of the atmospheric testing period, we were routinely accommodating tower loads of 100 tons distributed on any two of the four legs. Our desire for higher towers was driven by the operational problems created by the Trinity shot when activated or contaminated particulate matter was engulfed by the fireball and entrained in the resulting cloud. The Trinity shot was fired on a 100-foot tower. We progressed to 200 feet for Sandstone, 300 feet for Greenhouse, 500 feet for Teapot, and 700 feet for the Smoky shot of the Plumbbob series.

There are many true and untrue tales regarding towers. The tower for Greenhouse George was heavily loaded, but the story that you couldn't withdraw a bit after drilling a hole in the tower leg because the weight caused the hole to immediately become elliptical is not true. It is true, however, that users of the taller towers reported very perceptible motion at the top on windy days, which produced little enthusiasm for working under such conditions. People did get stuck in elevators when winds whipped cables about and once technicians even disconnected the power needed to fire the device while they were removing the tower elevator after the device was armed.

Towers were necessary for shots with elaborate diagnostics, but there were other shots whose purpose could be satisfied by air drops from military aircraft, although we were not always skillful enough to build targets that the Air Force could hit. In the Plumbbob series, several tests were conducted with devices suspended from tethered balloons in a system engineered and operated by Sandia Corporation. The balloons could not be inflated in high winds, but they significantly reduced the operational problem of fallout by allowing us to fire as high as 1500 feet above ground level.

Beginning with the Castle series of 1954, we were able to repeatedly fire large-yield devices in Pacific lagoons near fixed diagnostic stations on land by placing the devices on barges moored at the four corners to anchors on long scope. By adjusting the individual winches on each corner, we could hold barges to within a few feet of their required positions. Mercifully, the tidal variations at Eniwetok and Bikini are slight.



A test device mounted on a 500-foot tower at the Nevada Test Site. Taller and taller towers were built (to as high as 700 feet) to minimize entrainment of ground debris by the fireball and thereby reduce fallout resulting from the test.

Power was a problem both in the Pacific and Nevada. At NTS, power was generated well away from the shot areas, but both the above- and below-ground distribution systems were subjected to ground shock which tended to make counting on postshot power a bit risky. In the Pacific, power was usually generated by diesel-driven generators near the point of use. The diesel engines would loaf along for hours under low loads and then die when the required large loads were

This photo of a balloon-carried test configuration was taken around 1957. The device is suspended from the balloon and the balloon is tethered to the ground by steel cables. With the balloon at the desired altitude (perhaps 1500 feet) the device was fired by sending electrical signals through the firing cables that connected the device with the firing system on the ground.

An early barge-mounted test configuration at the Pacific Proving Grounds. The nuclear device is housed in the shot cab (white structure).

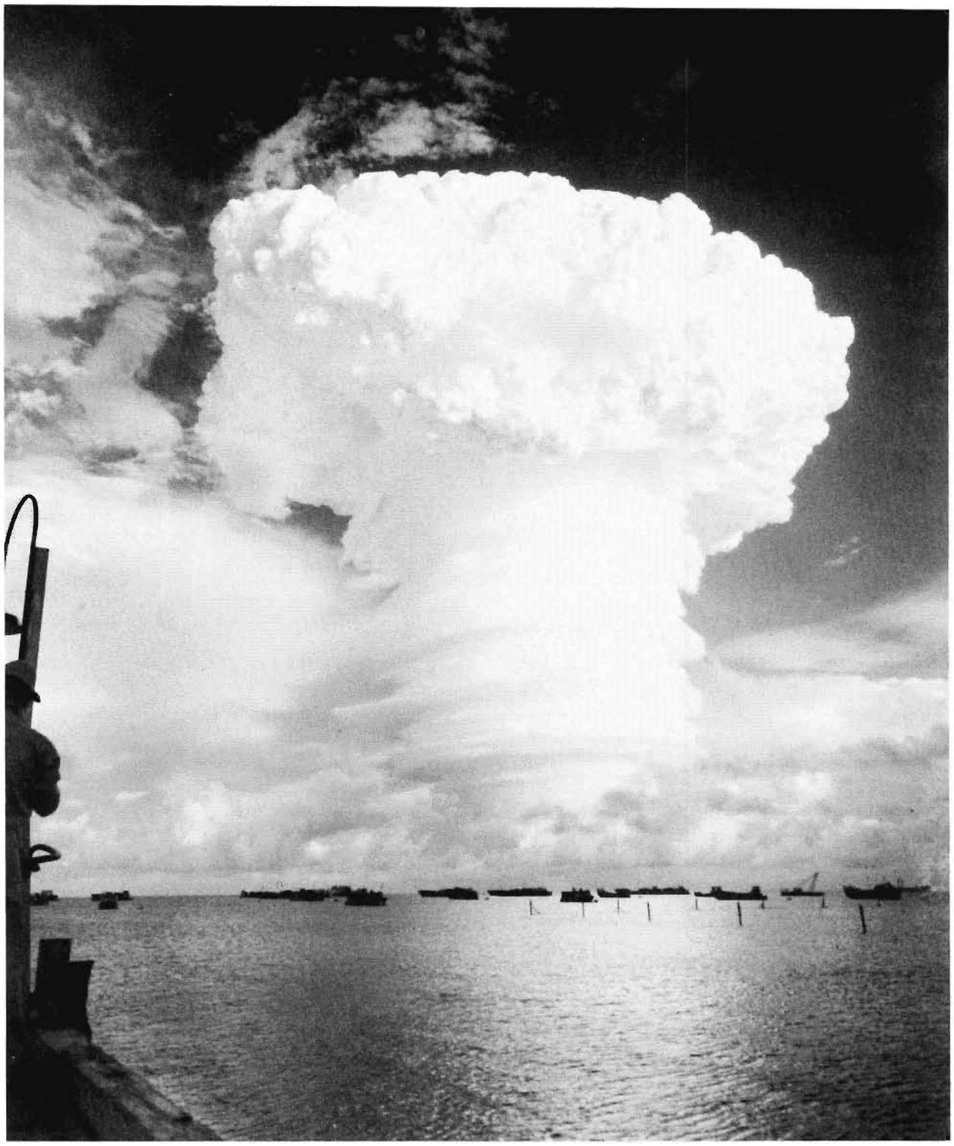
imposed minutes before shot time. Experimenters were plagued at both sites by the quality of the power and by the effects of the test-generated EMP carried on the power distribution system. EMP shielding ranged from continuously soldered solid-copper lining of the recording rooms, to screened rooms, to no screening except that provided by reinforcing bars in the structural concrete—each according to the tenets of the individual experimenter. Power and timing signals were sometimes brought in on insulated mechanical couplings (with a motor or relay outside the shielded volume coupled mechanically to a generator or relay inside). Continuity of power was sought by several stratagems that included replacing fuzes with solid wire. Breakers in substations were wired closed to prevent ground motion or EMP from operating them. Automatic synchronizing and transfer equipment was designed to run generators in parallel and pass the load back and forth as necessary. This proved to be unreliable, so we ended up running several generators, each of sufficient size to carry the whole load and each carrying a dummy load, each of which could be dropped if any one or more of the generators running in parallel failed.

Concrete was a problem in the Pacific, since the only available aggregate was coral and we had to use salt water. Several mixes were invented, some to provide the required strength for recording stations and some to match the strength of normal construction concretes so that we could have valid effects tests on typical military and civilian structures. At both sites we learned to calculate and design shielding for collimators and their recording equipment. The resultant design of massive structures tended to err on the conservative side. The high-density concrete made by loading the mix with limonite ore, iron punchings, and the like gave densities triple that normally encountered, but was rough on mixing equipment and difficult to emplace. On some stations that had to function in close proximity to megaton-class devices, the center-to-center spacing of reinforcing steel approached its diameter and presented a very difficult job for the construction worker. There was a legend, never confirmed, that some iron bars which had been included for shielding in the design of a structure near Ground Zero were omitted in the construction because the superintendent "knew very well that the structure would stand without them."

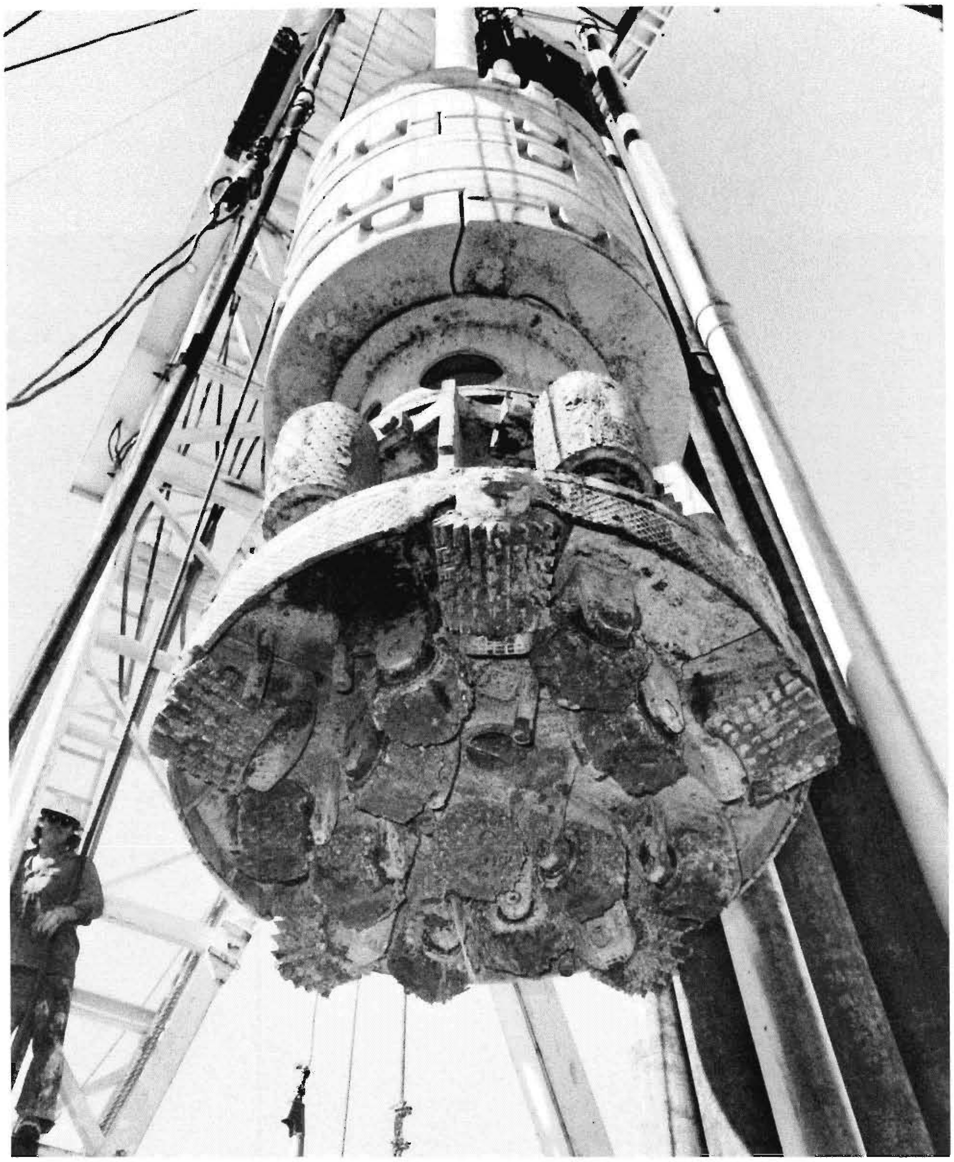
Our initial experience in drilling the deep emplacement and postshot sampling holes was instructive. It must be the custom in the drilling industry to do whatever the man paying the bills asks, and not proffer any suggestions, for we were permitted to reinvent a number of existing drilling techniques, particularly in postshot drilling for radiochemical samples. Once Fenix and Scisson, Inc., came aboard as drilling and mining architect-engineer (A-E) and REECo took over enough of the drilling previously done by contract drillers to provide continuity, our lot improved. Big-hole drilling techniques were developed which are now accepted throughout the industry. We learned to extract postshot samples of device debris without releasing radioactivity to the atmosphere. Drilling times have improved even though the diameters of emplacement holes have increased from two to eight feet, and postshot operations that once took more than a month are now done in a safer and contained fashion in less than a week.

None of this work could have been done without the complete cooperation of the contracting officers and the sometimes heroic efforts of the architect-engineers and constructors in support of the laboratories. A real "can-do" attitude on the part of all concerned has been the trademark of the weapons testing community since Trinity.

For the earliest tests, namely Trinity and Crossroads, engineering and construction of scientific facilities, camps, utilities, communications, and the like were accomplished by military forces. For Sandstone, Army Engineers were used by the AEC because there wasn't time to obtain private contractors, but much of the building design and specifications were done by the firm of Johnson and Moreland. Liaison between these two parties was done by the Sandia Laboratory, whose engineers handled many details for Los Alamos. The Santa Fe Operations Office (SFOO), Office of Engineering and Construction, employed Holmes and Narver (H&N) as architect-engineer (A-E) and constructor for Greenhouse; and all subsequent Pacific testing and liaison with the AEC and its contractors became the responsibilty of a small group, J-6, at Los Alamos. For logistics of construction for Ranger, SFOO employed the Reynolds Electrical Engineering Company (REECo) in a joint venture with R. E. McKee and Brown-



A multimegaton barge shot on Eniwetok in 1958.



A modern large-diameter drill bit, weights, and rigging used to drill device emplacement holes. Holes typically range from 600 to 3000 feet in depth and from 4 to 8 feet in diameter.

Olds. For Buster-Jangle, SFOO employed H&N as A-E although some of the later engineering was done on site by Haddock Engineering. At NTS, Haddock built Control Point Buildings 1 and 2 as well as the required construction work for Buster-Jangle in Areas 7, 9, and 10. For the Tumbler-Snapper series, REECo returned in the same type of arrangement as before, while maintenance work was done by the Nevada Company, a Haddock subsidiary. During this time, Haddock built the first structure at Camp Mercury—plywood hutments. REECo did construction and maintenance on Upshot-Knothole and all subsequent Nevada operations. Silas Mason served as A-E for operations Tumbler-Snapper through Teapot. REECo provided A-E support in addition to doing the construction for Projects 56 and 57. Holmes and Narver returned as A-E for Plumbbob and subsequent operations.

Firms and people have come and gone, but the fact that they sometimes had reason to believe our requests were unusual never reduced their fervor to help us field an operation. They, too, were pioneering to produce the facilities we needed to conduct this totally new business of testing nuclear weapons.

Readiness

Halloween night of 1958 saw an abrupt halt to the weapons tests that had continued more or less regularly since Trinity. During the test moratorium, which was agreed to by the U. S. and the Soviet Union in order to promote arms control and disarmament negotiations, no preparations for test resumption were authorized in the U. S. Nevertheless, when the Soviets resumed testing without notice in 1961, the test organization and the laboratories responded heroically; only ten days later they were able to fire the first United States underground test since the 1958 moratorium.

More difficult to accomplish than the bomber-dropped air bursts that comprised most of the early atmospheric tests after resumption of testing was the renewal of high-altitude testing, which employed rockets fired from Johnston Island to carry a variety of weapons to a wide range of altitudes, mainly to explore the effects that had only been hinted at during the last days of the Hardtack atmospheric operation. In 1963 the Limited Test Ban Treaty (LTBT) prohibited tests in the atmosphere, underwater, and in outer space, but it left underground testing unrestricted so long as no radioactive debris crossed international borders. Underground testing continues, limited by the Threshold Test Ban Treaty (limiting yields to 150 kilotons) which is observed although not ratified. The present testing activity provides some technological continuity that was not available when it became necessary to resume testing in 1961.

Maintenance of the capability to resume testing in the prohibited environments required not only continued training of a cadre of test personnel but also upkeep and modernization of extensive and sophisticated instrumentation, hardware, and facilities. Capabilities provided, for example, by operation of the NC-135A "flying laboratory" aircraft and the small-rocket range in Hawaii were periodically utilized to address questions about high-altitude detonations that were raised as a result of the 1962 atmospheric tests.

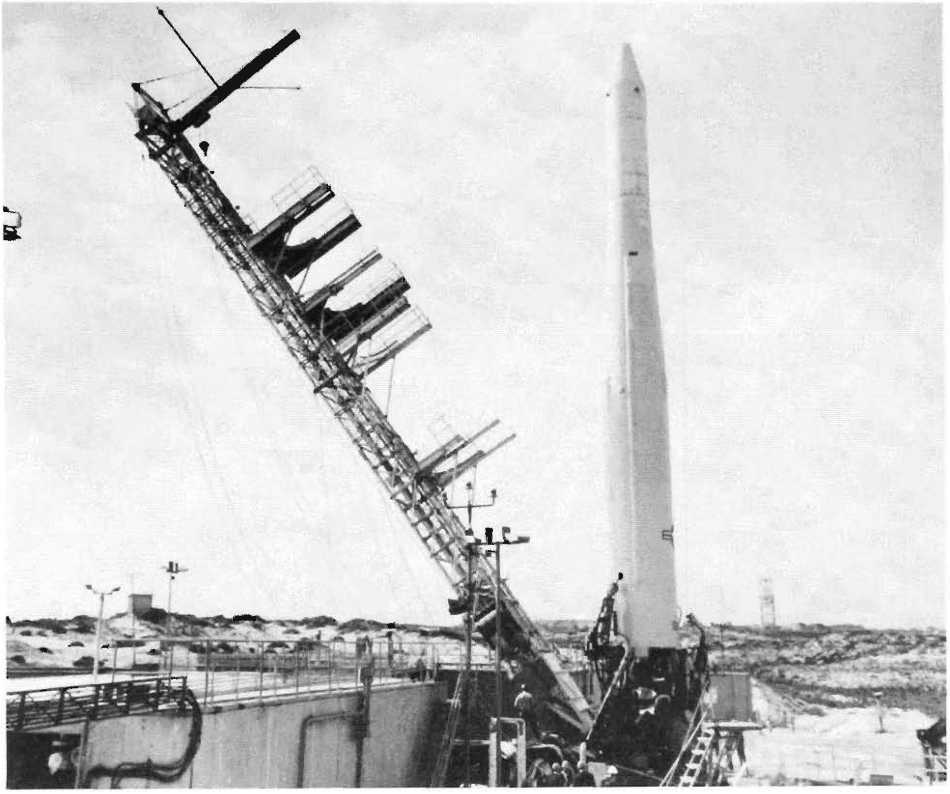
Experiments of a purely scientific nature, such as a series of solar eclipse observations from the aircraft, resulted in original scientific achievements while attracting other Laboratory scientists to the testing environment and preserving the scientific credentials of the base test cadre.

Our mandate to monitor international nuclear testing led to the birth of a space instrumentation and space science capability within the Laboratory. Beginning from design and fabrication of instruments for satellite-based test detection, this activity has evolved over the years to include a broadly based scientific space observation program with worldwide recognition.

Safety Considerations

Throughout the entire history of testing, operational and public safety have always been principal concerns. While the government agencies—first the Manhattan Engineer District, then the Atomic Energy Commission, later the Energy Research and Development Administration, and now the De-

The USAF NC135A-369 containing the Los Alamos Airborne Diagnostics Laboratory. This plane, part of the atmospheric test readiness program, was available and ready to measure device performance in the event that atmospheric testing was resumed. Used during the 1960s and 1970s for several test readiness exercises and numerous purely scientific missions (solar eclipse, cosmic ray, auroral, and other), this plane is now retired.

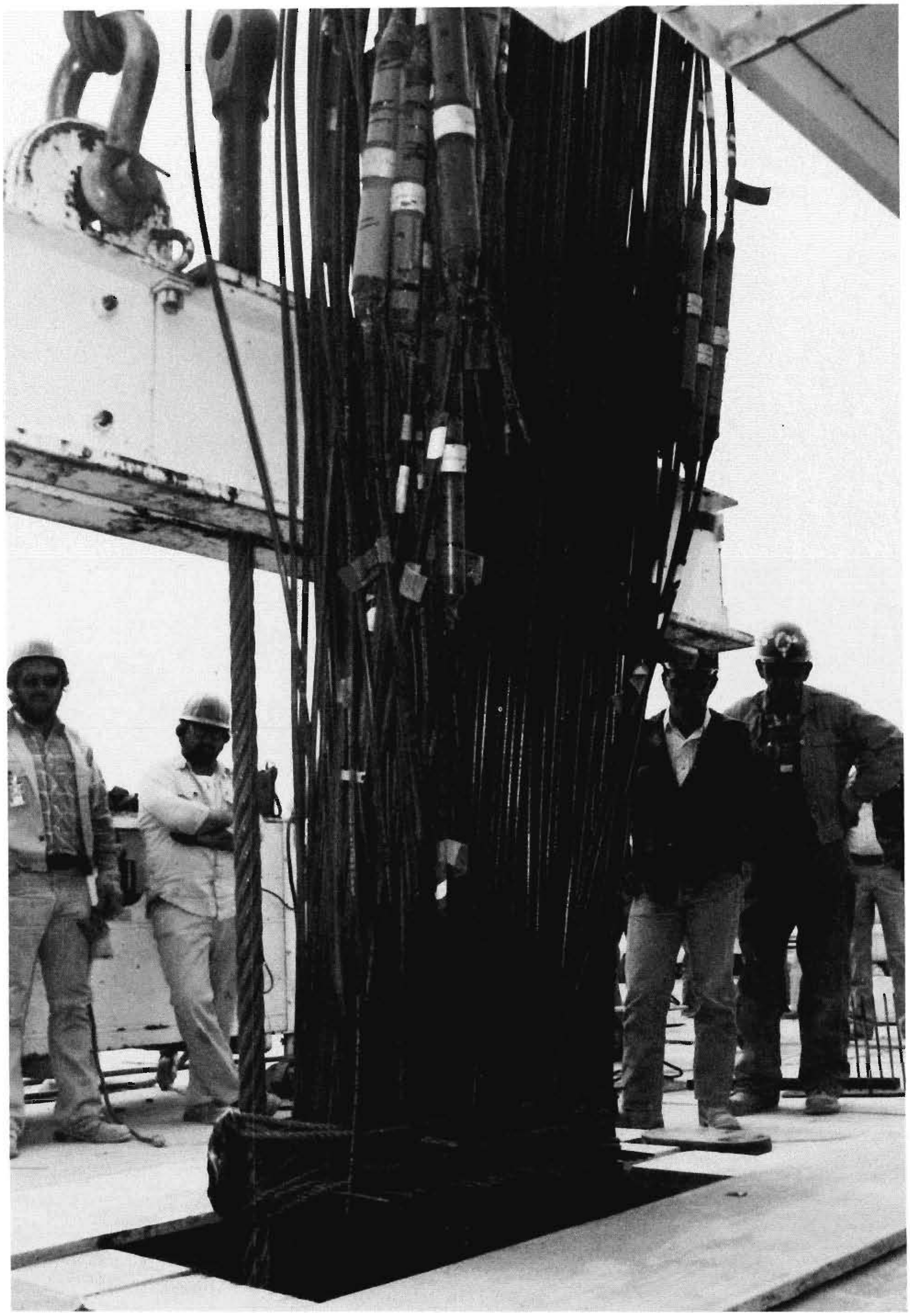


A Thor missile, with gantry to the left, used in an ICBM weapon system simulation test on Johnston Atoll, August 1970. Some Los Alamos personnel served in an advisory role to the Task Force commander, while others aboard the Los Alamos flying-diagnostic-laboratory aircraft observed the missile launching and flight. This readiness exercise served as a very valuable and effective checkout of the missile system.

partment of Energy—have the responsibilities for the safe conduct of test operations, the Laboratory has always played an active role in safety matters. Because nuclear energy was totally new, every question related to nuclear hazards had to be formulated before instrumentation could be built to gather the necessary data. This was as true for safety matters as for weapons diagnostics. In retrospect, the effort devoted to public safety, particularly as one notes the profusion of problems and unknowns, is very impressive. Pressure was applied from within the Laboratory to learn as much as possible, but to be very conservative in experimental design. As a result, the testing community has accumulated an outstanding safety record. In fact, the record is unique for a new, evolving technology.

As additional experience was gained, the question "How can we reduce fallout?" became increasingly important for all tests. The first nuclear test at Trinity was conducted near the earth's surface, but then to reduce fallout we went to taller towers, then air drops, balloons, and tunnels, and now to completely contained underground explosions.

Our first experiments in underground testing were done in 1957, initially using only high explosives. The first underground nuclear test, Pascal A, was in a three-foot-diameter hole at a depth of 485 feet. In lieu of completely filling the hole, a combination plug-collimator was placed near the bottom of the hole. Fired at 1:00 a.m., Pascal A ushered in the era of underground testing with a magnificent pyrotechnic Roman candle! Nonetheless, the radioactive debris released to the atmosphere was a factor of 10 less than what would have resulted had the test been conducted in the atmosphere. Theoretical models were constructed concerning possible containment schemes and 20 underground nuclear tests had been conducted before the intervention of the test moratorium. Theoretical work continued during the moratorium (1958-1961) and



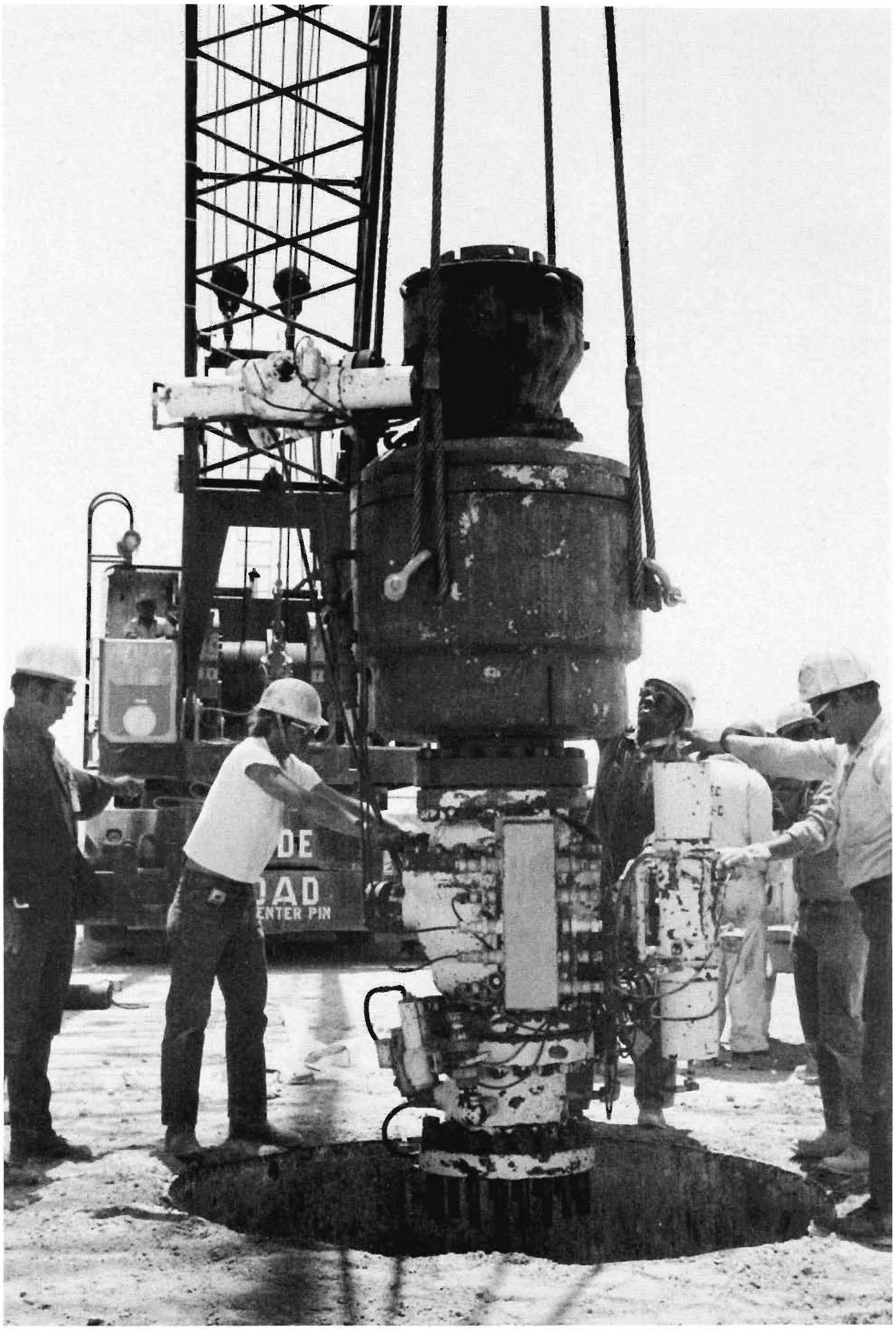
View of surface Ground Zero during the emplacement operation showing emplacement hardware and diagnostic cable bundle that connects the downhole equipment with the recording trailers. The small cylinders on the cables are gas blocks that prevent the flow of downhole gases through the cables to the atmosphere.

when testing resumed, additional containment experience was obtained from a number of underground tests. By 1963, containment was sufficiently well understood to permit the U. S. to sign the LTBT with confidence that required tests could be contained underground—including those with extended lines of sight. The language of the treaty text prohibits detectable radiation levels beyond national borders.

The U. S.-assumed necessity to prevent even gases from escaping into the atmosphere at test time spawned entirely new disciplines in containment, and prompted the development of a number of special technologies to help achieve complete containment. With the exception of a few releases (none since 1970), the containment record of U. S. nuclear testing has been excellent since the LTBT was initiated in October 1963. No off-site radiation exposures exceeding national guidelines have been experienced.

There were some diagnostic cable related seeps and some sizable leaks associated mainly with LOS pipes. There were also a few prompt ventings; however, in no instance did off-site radiation levels violate guidelines. Only the close-in areas were evacuated for test execution. Containment effort was largely on an *ad hoc* basis and had little effect on operations.

After the Baneberry event of December 18, 1970, in which a large prompt venting produced off-site radioactivity, but not exceeding guidelines, the admonition became "not one atom out!" A more formal containment program was initiated, and the subsequent containment has been virtually perfect. Containment Evaluation Panel (CEP) procedures are more rigorous and formal. The Los Alamos containment program is extensive and involves about 35 employees in the Laboratory, plus NTS support. There are detailed geologic site investigations. Devices are buried deeper. Gas-blocked cables and impervious stemming plugs are used. All



Postshot drilling blowout preventer, a device used to preclude the escape of radioactive products into the atmosphere during postshot operations. This is a direct adaptation from oil field technology.

Aerial view of the formation of a postshot subsidence crater at the moment of collapse. This collapse may occur from a few minutes to many hours after a shot is fired. Note the dust caused by falling earth.

operations are more conservative, and anything new or different that has any conceivable effect on containment must be well understood and justified. Longer lead times are required for geologic studies, document preparation, and the DOE approval process. Emplacement and stemming time and expense have increased. All of the NTS north of the Control Point is evacuated for every event. Although these steps have resulted in added expense and operational complications, they have provided increased confidence in complete containment of radioactive debris and the overall safety of test operations.

Conclusion

Nuclear testing has always been and will continue to be a vital element in the Los Alamos weapons program. Only with full-scale tests can the validity of complex design calculations be confirmed and refined. In a similar manner, only in the nuclear crucible of weapons tests can the physical behavior of weapons materials and components be investigated. Without testing, it would be difficult if not impossible to maintain a complement of knowledgeable weapon designers and engineers. Possible stockpile degradation could go undetected. Innovative solutions to national security problems would remain only paper designs, without proof of their validity in nuclear tests. As long as the United States national security is dependent upon nuclear deterrence, the weapons program will need nuclear tests to maintain its credibility. The Los Alamos history of successful and safe nuclear testing over the past 40 years is strong evidence that the program can remain a vital element of the national nuclear weapons program without detriment to the citizens of the United States or the world.

For any participant in the testing program, indelible impressions remain. Among those are the unique elements of romanticism and camaraderie associated with "where it was at" and the excitement of successfully meeting difficult objectives and schedules. Another is the strong and consistent military-civilian partnership that grew throughout the 1950s to become an integral part of the testing philosophy and operation. Not the least of them, however, is the sense of purpose and accomplishment that comes from the conviction that we are doing something good for our country. ■