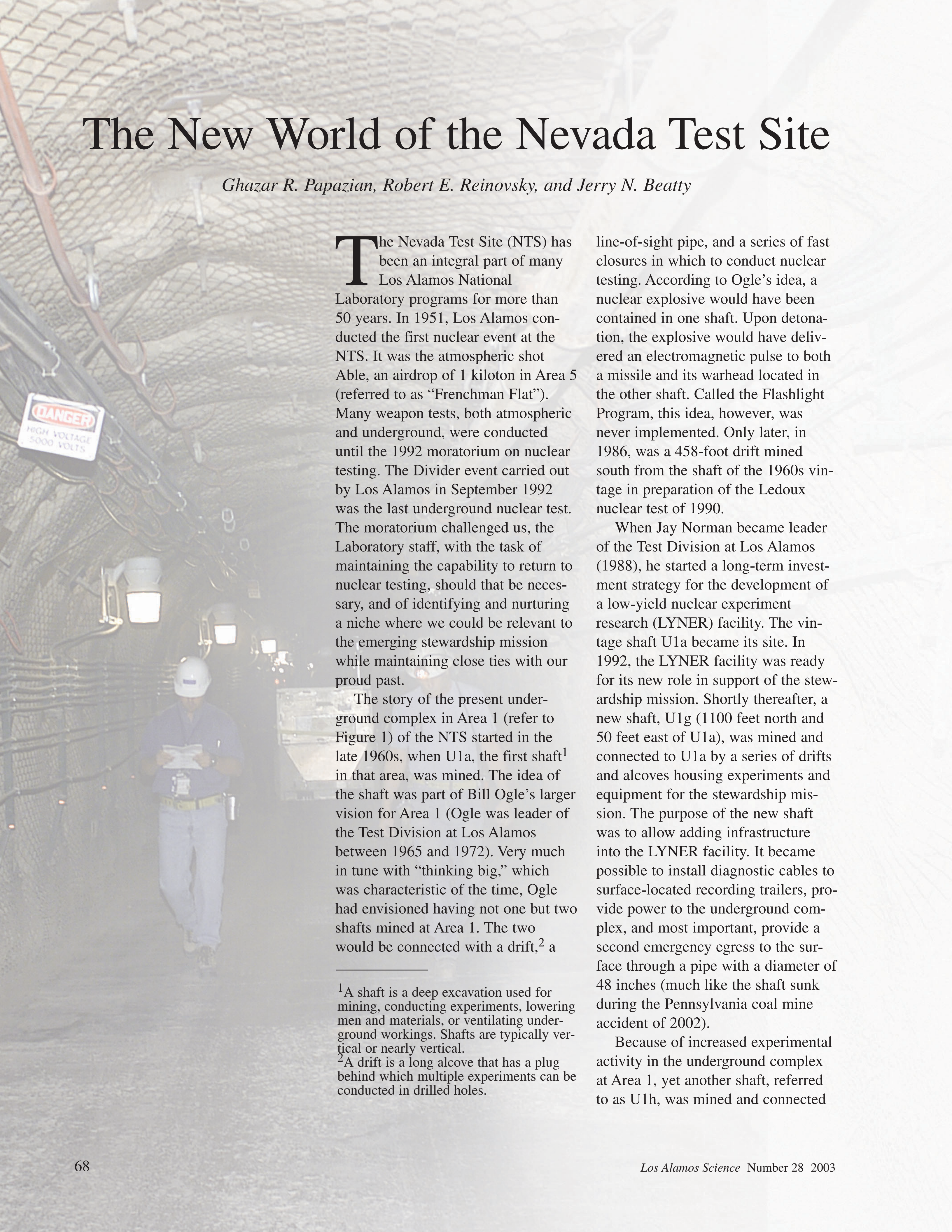


The New World of the Nevada Test Site

Ghazar R. Papazian, Robert E. Reinovsky, and Jerry N. Beatty

The Nevada Test Site (NTS) has been an integral part of many Los Alamos National Laboratory programs for more than 50 years. In 1951, Los Alamos conducted the first nuclear event at the NTS. It was the atmospheric shot Able, an airdrop of 1 kiloton in Area 5 (referred to as "Frenchman Flat"). Many weapon tests, both atmospheric and underground, were conducted until the 1992 moratorium on nuclear testing. The Divider event carried out by Los Alamos in September 1992 was the last underground nuclear test. The moratorium challenged us, the Laboratory staff, with the task of maintaining the capability to return to nuclear testing, should that be necessary, and of identifying and nurturing a niche where we could be relevant to the emerging stewardship mission while maintaining close ties with our proud past.

The story of the present underground complex in Area 1 (refer to Figure 1) of the NTS started in the late 1960s, when U1a, the first shaft[1] in that area, was mined. The idea of the shaft was part of Bill Ogle's larger vision for Area 1 (Ogle was leader of the Test Division at Los Alamos between 1965 and 1972). Very much in tune with "thinking big," which was characteristic of the time, Ogle had envisioned having not one but two shafts mined at Area 1. The two would be connected with a drift,[2] a line-of-sight pipe, and a series of fast closures in which to conduct nuclear testing. According to Ogle's idea, a nuclear explosive would have been contained in one shaft. Upon detonation, the explosive would have delivered an electromagnetic pulse to both a missile and its warhead located in the other shaft. Called the Flashlight Program, this idea, however, was never implemented. Only later, in 1986, was a 458-foot drift mined south from the shaft of the 1960s vintage in preparation of the Ledoux nuclear test of 1990.

When Jay Norman became leader of the Test Division at Los Alamos (1988), he started a long-term investment strategy for the development of a low-yield nuclear experiment research (LYNER) facility. The vintage shaft U1a became its site. In 1992, the LYNER facility was ready for its new role in support of the stewardship mission. Shortly thereafter, a new shaft, U1g (1100 feet north and 50 feet east of U1a), was mined and connected to U1a by a series of drifts and alcoves housing experiments and equipment for the stewardship mission. The purpose of the new shaft was to allow adding infrastructure into the LYNER facility. It became possible to install diagnostic cables to surface-located recording trailers, provide power to the underground complex, and most important, provide a second emergency egress to the surface through a pipe with a diameter of 48 inches (much like the shaft sunk during the Pennsylvania coal mine accident of 2002).

Because of increased experimental activity in the underground complex at Area 1, yet another shaft, referred to as U1h, was mined and connected

---

[1] A shaft is a deep excavation used for mining, conducting experiments, lowering men and materials, or ventilating underground workings. Shafts are typically vertical or nearly vertical.

[2] A drift is a long alcove that has a plug behind which multiple experiments can be conducted in drilled holes.

to the complex network of drifts. The U1h shaft was commissioned in 2001 and is located 1490 feet from U1a. Its primary purpose is to ensure worker safety because it provides additional egress from the complex during an emergency. A special lift basket is available to expedite rapid removal of underground workers during an emergency. Both U1g and U1h are within a few hundred feet of the experimental alcoves.

In over a decade since the moratorium on underground nuclear testing, the nature of testing at the NTS has changed considerably. To maintain the existing infrastructure in case of a return to nuclear testing and obtain data for the stewardship mission, we conducted high-consequence subcritical experiments. We then used results from those experiments to test models for computer simulations. In a subcritical experiment, high explosives (HEs) and special nuclear materials are used, but the experiment never achieves criticality, or a self-sustaining chain reaction.

This article highlights past and future subcritical experiments conducted at the NTS by Los Alamos with the operating partner Bechtel Nevada, the Atomic Weapons Establishment (AWE) in the United Kingdom, and the Lawrence Livermore National Laboratory. It also discusses the new Atlas pulsed-power facility residing at the test site and a possible future site for criticality experiments.

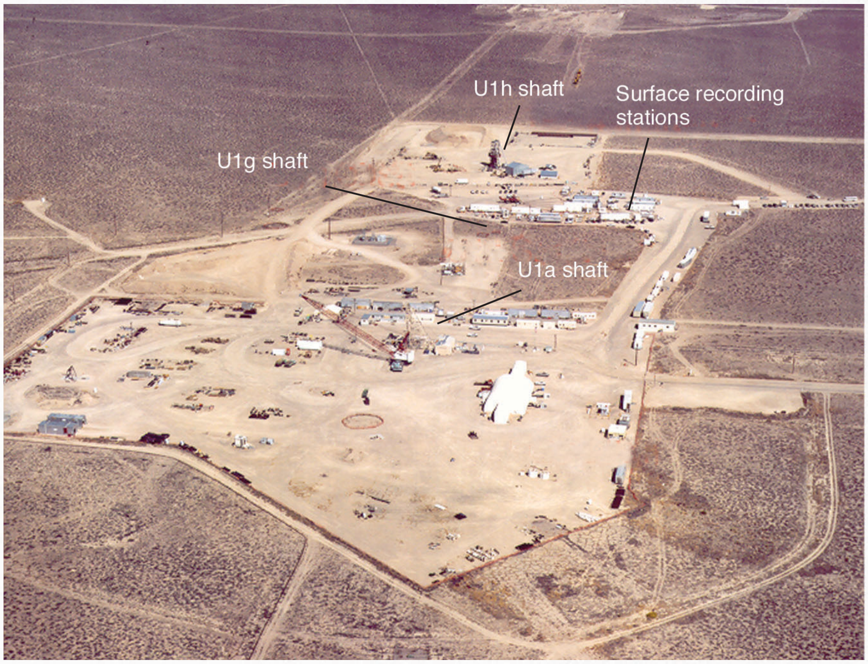


Figure 1. Aerial View of Area 1 at NTS

Subcritical Experiments

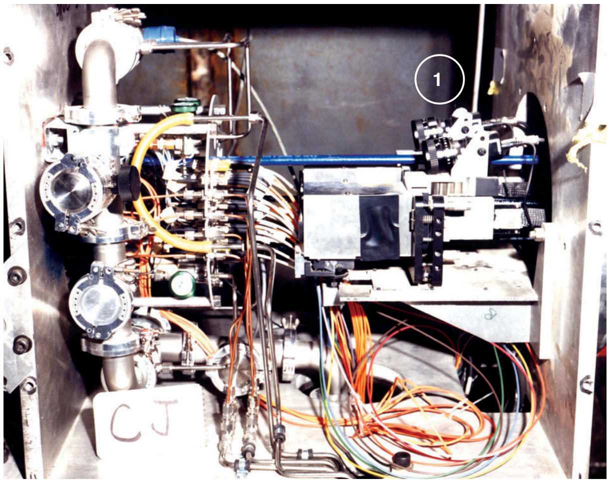
Kismet was the first experiment at U1a after the 1992 moratorium on nuclear testing. It was really a proof-of-principle test for determining the most functional layout plan for underground cavities, known as alcoves, that would house subcritical experiments supporting the readiness program and stewardship mission. In Kismet, we used only a small amount of HE to revive studies of downhole methods—for example, recovering data over very long lines. From the test, we obtained relevant information that helped us plan and prepare the test alcoves in the U1a complex.

A whole series of subcritical experiments followed Kismet. The first few were carried out in dedicated alcoves mined at the U1a complex for containment purposes, the traditional way of conducting experiments in an underground environment. Rebound and Stagecoach were the first and second subcritical experiments fielded by the Laboratory. For these and other past subcritical experiments described below, please refer to the pictorial summary on the next two pages. Rebound and Stagecoach were aimed at providing information about the behavior of plutonium alloys when compressed by high-pressure shock waves. Two different alloys were used in the experiments: new alloy in Rebound and aged alloy in Stagecoach (up to 40 years old). Diagnostic techniques derived from Rebound were refined in Stagecoach. The valuable data obtained on the equation of state of plutonium provided input to our modeling codes for certification of existing weapon pits. At the same time, those data gave useful information about aging effects and manufacturing site variability on plutonium alloys. During these experiments, we also developed diagnostics to be used in future experiments.

The next two subcritical experiments, Cimarron and Thoroughbred, continued our effort in support of the stewardship mission and readiness program and contributed to the development of diagnostics to study the dynamics of pit performance. These two experiments were conducted on mockup pit geometry inside mined alcoves. Relevant data were obtained on the performance of plutonium produced by different manufacturing methods and sources. In addition, an extensive list of lessons learned from the Cimarron experiment was implemented in the Thoroughbred experiment.

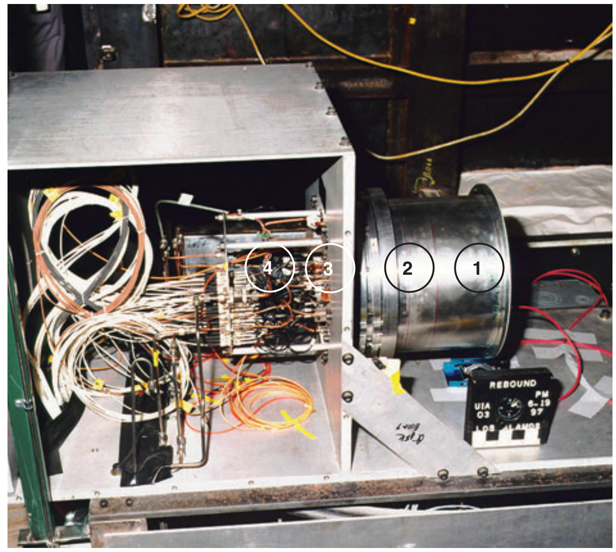
Alcove Subcritical Experiments

(b)



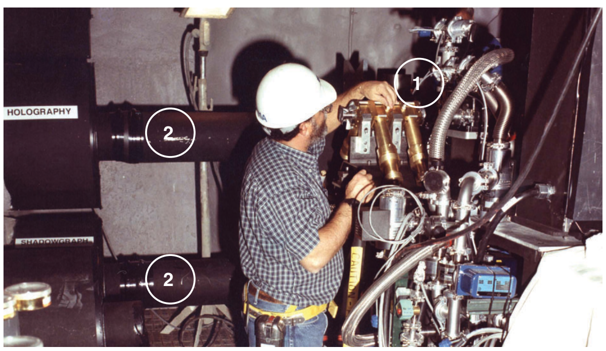
(1) Optic alignment gear

(a)



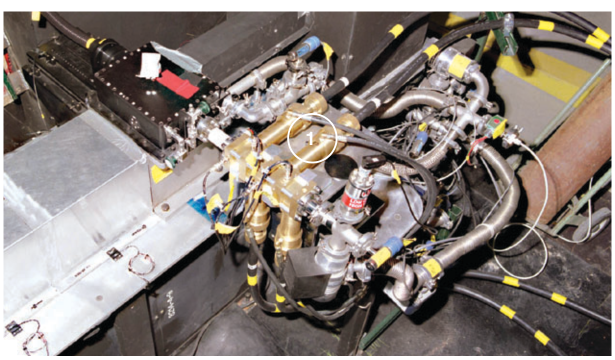
(1) HE package, (2) flyer plate, (3) sample plate, and (4) diagnostics and cabling

(c)



(1) X-ray diagnostics and (2) optical diagnostics (shadowgraphy and holography)

(d)



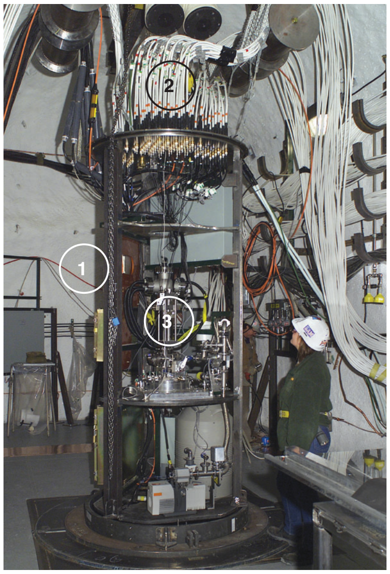
(1) Brass heads

(e)

Since the moratorium on underground testing, Los Alamos has been conducting important subcritical experiments, whose results help validate our computer modeling capabilities. Data about the equation of state of plutonium from Rebound (a) and Stagecoach (b) provided input to our modeling codes that contribute to the certification of existing weapons systems. For the Cimarron and Thoroughbred experiments, shown in (c) and (d), we developed techniques to measure pit performance. These two experiments were primarily intended for ejecta studies, or studies of particles propelled from a material's surface when the material is compressed by a powerful shock wave. The x-ray and optical diagnostics measured ejecta from a shocked plutonium surface. The black pipes in the background in (c) are line-of-sight pipes for the optical diagnostics shadowgraphy and holography, which can image ejecta particles in two and three dimensions, respectively. The x-rays generated in the four brass heads shown in (d) are directed through the plutonium ejecta. X-ray intensity is transformed into optical signals, which are then transferred to the recording system. High-frequency data were captured underground and were transferred to computers in a trailer (e). The data retrieved on the surface included timing and plutonium ejection characteristics.

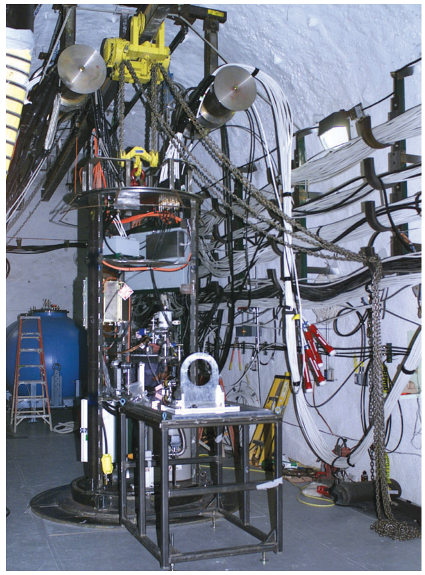
Drilled-Hole Subcritical Experiments

(f)

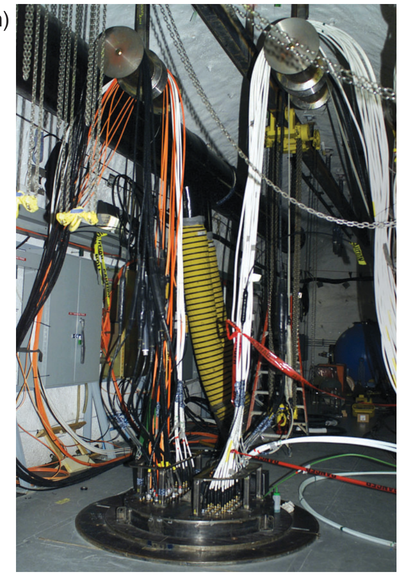


(1) Racklet, (2) fiber-optic cables, and (3) AWE package

(g)



(h)



(i)

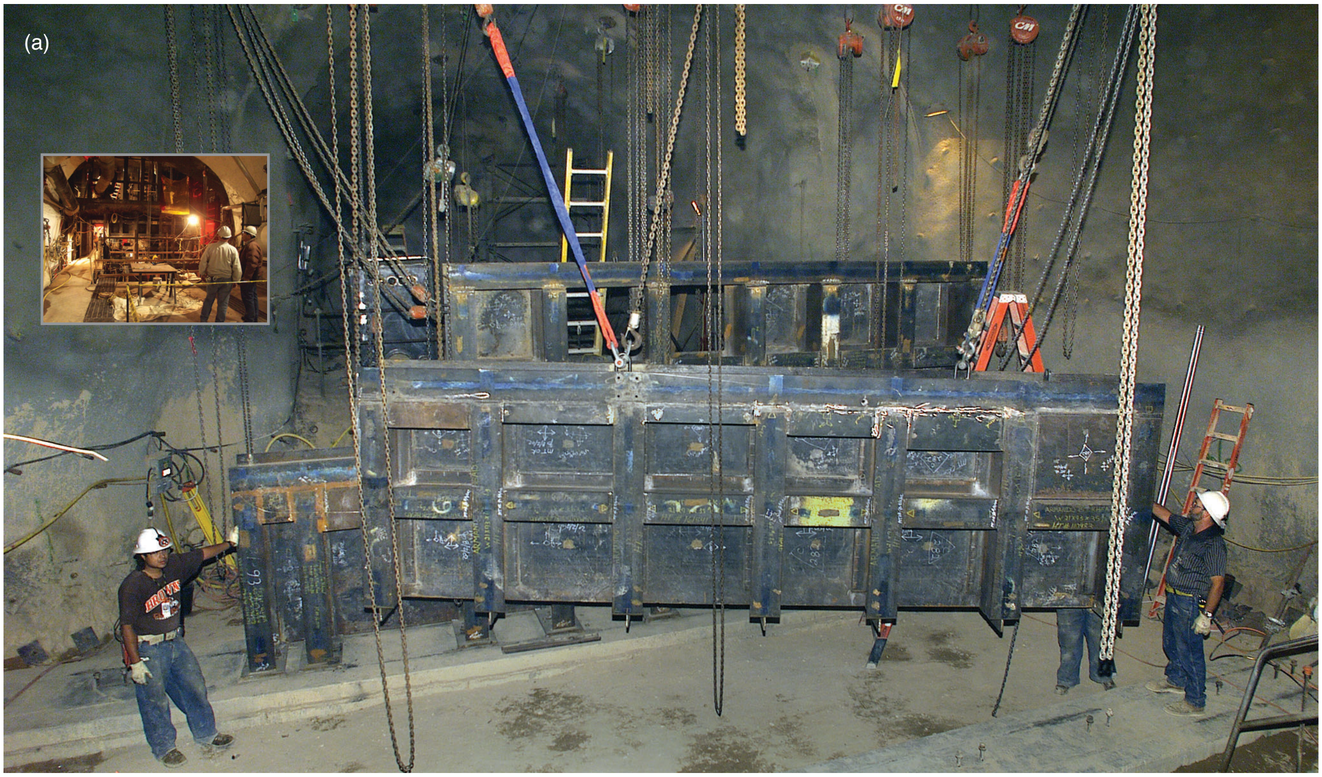
Like Cimarron and Thoroughbred, the Vito (Etna) experiment (f) was also primarily intended for ejecta studies. Conducted in a drilled hole at 35 feet below the drift floor (called "invert" in mining jargon), Vito tested our readiness capabilities. Shown here is the 10-ft racklet with the experiments, diagnostics, and vacuum equipment in place. At this point, we are ready to insert the experimental physics package, the last operation before emplacement. The Mario (g) and Rocco (h) experiments followed Vito and were primarily intended for studies of surface properties. They contained optical diagnostics that looked at spall. The racklet shown in (g) is ready to receive the subcritical package. In (h) the racklet is shown resting on the support collar while the emplacement hardware is being prepared for lowering it into the hole. The series of photos from (i) through (l) shows the steps observed for emplacing and sealing ("stemming" is the word used at the site) the racklet into the drilled hole. Before being emplaced, the racklet is carefully lowered into a canister (i). In (j), the racklet is shown almost inside the canister. Once the racklet is inside, technicians bolt it down, for safety, and lower it into the drilled hole (k). The racklet and canister are then stemmed, a process shown in progress in (l). The workers, each wearing a yellow safety harness, are pouring stemming materials into the hoppers, which have a hose connected to the spout and direct the materials where needed.

(j)

(l)

(k)

(a)



(b)

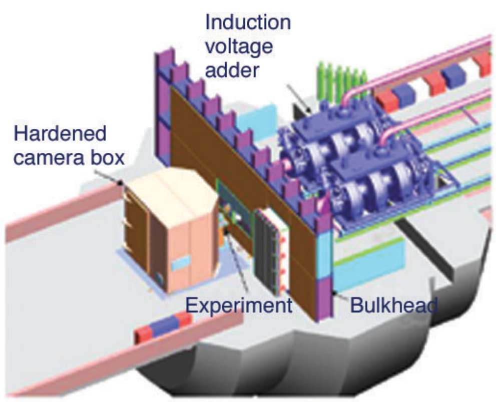


Figure 2. Armando

Spall measurements are the focus of the Armando subcritical experiment. In (a), ironworkers are positioning a bulkhead for the Armando alcove, and the inset shows the almost completed alcove. The area facing the bulkhead corresponds to the right part of the schematic in (b), where two x-ray systems are placed. The induction voltage adder increases the electron energy and is a technically sophisticated part of those systems. The area to the left of the bulkhead in (b) includes the physics package containing the HE. Typically, the experimental complex is destroyed by the blast. For cost-effectiveness, we propose to contain the package in a specially designed vessel that will protect the experimental complex and permit multiple uses of the equipment. Together with the Sandia National Laboratories, Albuquerque, we developed the x-ray prototype, which is being replicated commercially by PSI-TITAN, our industrial partner. Naval Research Laboratory staff have configured the x-ray diode.

The Vito experiment (called Etna by our British partners) was jointly fielded by the AWE of the United Kingdom and Los Alamos in the U1a complex. Because we had been tasked to do more experiments in a cost-effective yet safe manner, we came up with the idea of conducting experiments inside holes drilled in a dedicated drift, rather than in expensive alcoves. To do so, we miniaturized the traditional racks used in the days of nuclear underground testing and placed the subcritical experimental package, diagnostics, timing and firing equipment, and cabling into these new structures called "racklets." The racklet and its cargo would then be lowered 35 feet below the drift floor into a drilled hole, whose top would be stemmed (or sealed). That is how Vito (Etna) was conducted, and it allowed us to exercise our readiness capabilities. It also allowed our British partners to conduct studies of actual pit dynamics, including timing, HE performance,

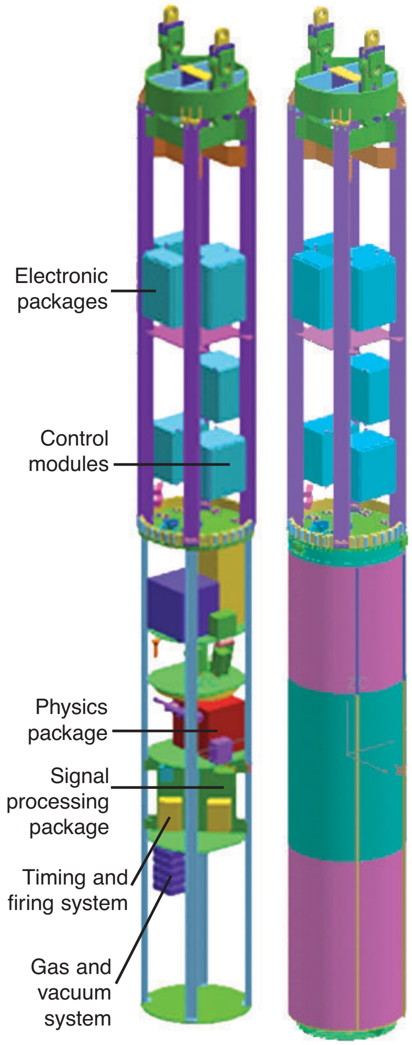


Figure 3. Unicorn
The Unicorn subcritical experiment will measure early-time behavior in a pit. The data and information obtained from this experiment will be integrated with those from previous experiments to enhance our modeling codes as part of the stewardship mission. Unicorn will also allow us to exercise our readiness capabilities. Shown at left is a cartoon of the Unicorn rack (30 ft in height) and its canister.

and plutonium ejecta characteristics.

The Mario and Rocco subcritical experiments were also placed in drilled holes, and they measured the early-time hydrodynamic behavior of plutonium mockup segments manufactured at different facilities and machined by different techniques. Wrought plutonium from Rocky Flats was used in the Mario experiment, and cast plutonium from Technical Area (TA) 55 at Los Alamos, in the Rocco experiment. The two experiments provided comparison data for the shift of pit manufacturing sites from Rocky Flats to Los Alamos.

The Armando (Figure 2) and Unicorn (Figure 3) experiments will be conducted in 2004 and 2005, respectively. Armando will enable comparative studies of the performance of plutonium pits of actual geometry manufactured by the Los Alamos and Rocky Flats methods. A sophisticated x-ray system, built by Los Alamos and Sandia National Laboratories staff in collaboration with Bechtel Nevada, was tested at Los Alamos and will be transported to the test site. The x-ray diode was configured by the Naval Research Laboratory, and the whole system is being replicated by PSI-TITAN, our industrial partner. The two radiographic systems will be installed in a special alcove and prepared to measure spall characteristics from each pit simultaneously. For worker safety, the x-ray system must be properly integrated with the underground environment, a crucial but difficult task.

A subcritical experiment as well, Unicorn will be lowered from the surface down a 600-foot-deep hole. It will thus more closely resemble the physical conditions of an underground test and give a better measure of our readiness capabilities.

In addition, four other subcritical experiments are planned in support of the W88 Certification Project. As we complete this project, we will develop the next series of subcritical experiments, including fundamental physics experiments intended to support the enduring stockpile.

Activities of Lawrence Livermore National Laboratory

The subcritical experiments conducted by our sister laboratory, the Lawrence Livermore National Laboratory, in the U1a complex and at aboveground complexes such as the Big Explosives Experimental Facility parallel Los Alamos work at the NTS. Similar to Los Alamos studies, Livermore studies have focused on smaller scale tests (but Livermore conducts more such tests than Los Alamos) to obtain data on plutonium spall, ejecta, and other dynamic properties. The variances in aging, manufacturing methods, and changes in plutonium production facilities are also part of Livermore's program. Livermore is also developing the Joint Actinide Shock Physics Experimental Research Facility, referred to as JASPER, in Area 27 of the test site. JASPER (refer to Figure 4) is a two-stage light gas gun that fires projectiles at plutonium samples at speeds of up to 8 kilometers per second. As a result, very high pressures (6 megabars) are generated in the sample.

Figure 4. JASPER
This two-stage light gas gun is a significant scientific achievement because samples can reach very high pressures.

Atlas, the Pulsed-Power Facility

The last few years have seen the emergence of a new capability for exploring material behavior under the unique conditions associated with the operation of a nuclear device. Called pulsed-power hydrodynamics, this capability has become an essential tool for stockpile stewardship.

In a pulsed-power facility (Figure 5), very high magnetic fields produced by very large electrical currents implode a relatively thin-walled conducting cylinder, called a liner, to high velocity while maintaining the imploding material at near-solid density—and largely unmelted, as shown in Figure 6(a). Pulsed-power hydrodynamics produces implosions of unprecedented precision. When liners are imploded, their circularity can be maintained to far better than 1 percent of the initial radius, and their axial uniformity can be preserved to the limit of the imaging resolution. This level of precision allows liners to be used as drivers for materials properties and hydrodynamics experiments that are in a converging rather than a planar geometry (planar geometries—for example, those in a light gas gun—have long been the standard ones).

Figure 5. Atlas
The Atlas pulsed-power system is essential to the Laboratory's stockpile stewardship mission.

The most attractive pulsed-power system for driving such experiments is an ultrahigh-current, low-impedance, microsecond-time-scale source that is both economical to build and reliable to operate. The Atlas system, shown in Figure 5, is the world's first pulsed-power system to be specifically designed and optimized for pulsed-power hydrodynamics experiments. Atlas was designed and built at Los Alamos and entered experimental service in September 2001. Within one year of having completed shakedown experiments, Atlas was disassembled and is being moved to a new facility in Area 6 at the NTS, where it is scheduled for recommission in 2004. Atlas will resume experiments shortly thereafter. Atlas is capable of delivering 30-mega-ampere currents in a heavily damped sinusoidal waveform with a 5- to 6-millisecond risetime and is ideal for driving liners up to 10 centimeters in initial radius and up to tens of centimeters in initial length.

Magnetically imploded liners offer unique advantages as drivers for pulsed-power hydrodynamics applications. Because energy is delivered to the liner from the magnetic field at the speed of light, magnetically imploded liners can reach velocities higher than

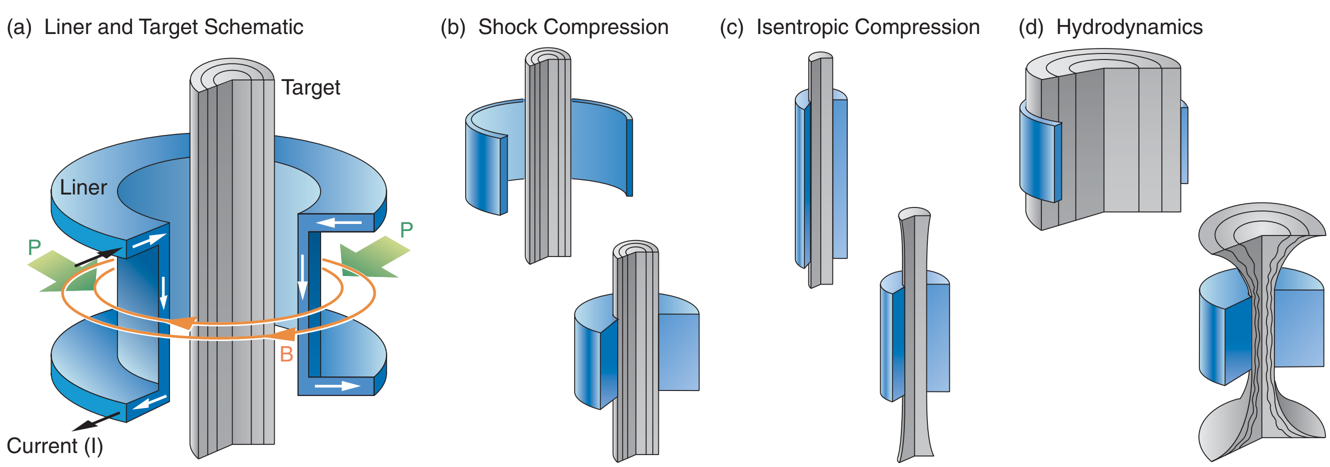


Figure 6. Magnetically Imploded Liners
(a) This schematic shows a metal liner surrounding a target cylinder. A very large current sent through the body of the liner (black arrows) creates a very strong magnetic field (orange field lines). The interaction between the current and the magnetic field produces an inward-directed force that implodes the liner, driving it toward the target. Data about the behavior of the target as it is being compressed are used to validate modern computer codes. We have precise control of the implosion process, and can (b) drive the liner at extremely high velocities to deliver a strong shock to the target, (c) compress a target at nearly constant entropy (isentropic compression) to reach states of matter not accessible from a single shock, and (d) compress targets hydrodynamically to study instabilities and interfaces. Because of the cylindrical geometry of both the liner and the target, we also have good diagnostic access to the target transverse to and down the cylinder's axis.

those available from gas guns or planar explosive systems. Higher velocity in the liner (or impactor) means higher pressures and temperatures in a strong shock delivered to the target located at its center, extending the range of traditional Hugoniot data to well above 1000 gigapascals—see Figure 6(b). Because the parameters of the electrical drive can be continuously adjusted over a wide range, the liner acceleration profile, and hence final velocity, can be continuously and controllably varied to meet experimental requirements. With appropriate design, the acceleration delivered by the field to the liner is nearly shockless, allowing full characterization of the liner's condition as the liner strikes the target. Furthermore, magnetically imploded liners can shocklessly pressurize a material that is the liner itself or that is initially in contact with the liner to reach off-Hugoniot states at pressures approaching 100 gigapascals—see Figure 6(c). The size of magnetically driven liners is naturally associated with centimeter-sized targets. At these scales, the target is many times the characteristic size of grains in the material of which it is made, allowing reliable probing of continuum properties. The fundamentally cylindrical geometry permits good diagnostic access both transverse to and down the cylinder's axis. Because liners can also hydrodynamically compress fluid structures, the size and geometry of the target permit studies of interface behavior and of the growth of instabilities—refer to Figure 6(d).

Future Site for Criticality Experiments

Historically, TA-18 at Los Alamos has been used for criticality and safety studies of various materials used in the weapons programs. This nuclear facility is the nation's only remaining one for general-purpose nuclear materials handling for various experiments, measurements (to determine the presence of nuclear materials), and training. Under consideration is a proposal to relocate this facility and capabilities to the NTS at the Device Assembly Facility shown in Figure 7. Integrating these capabilities with those already in place will provide more efficient use of our NTS resources as we meet the challenges of the stewardship mission.

Figure 7. The Device Assembly Facility
This aerial view shows the facility proposed to house future criticality and safety studies.

Outlook

The NTS continues to be a testbed for experiments that return unique and crucial data in support of the enduring stockpile and fundamental weapons physics. The location and geology of the site, coupled with a traditional "can-do" attitude, serve the laboratories and the nation well. Conducting subcritical experiments not only supports certification but maintains an operational test-readiness infrastructure. The transition of Atlas and of operations at TA-18 will augment the mission space in which the NTS conducts activities today. ■

Ghazar (Raffi) Papazian graduated from the University of Miami with a bachelor's degree in mechanical engineering in 1978. His career at Los Alamos began in 1984, when he started working in the Field Test Engineering Group at the NTS. In 1990, Raffi became the group's deputy leader. In 1993, after the cessation of underground nuclear testing, Raffi was transferred to New Mexico. Since then, he has been involved in the development and execution of the Subcritical Experiments Project at the test site and is a certified test director. He is now project director for NTS activities and director of the Los Alamos Test Group.

Robert (Bob) Reinovsky received a Ph.D. in electrophysics from Rensselaer Polytechnic Institute in 1973. Bob joined Los Alamos in 1986. During his tenure at the Laboratory, he led the Shock Wave Physics Group and the Athena Pulse Power Project. He was project leader and chief scientist for the High Energy Density Hydrodynamics (HEDH) Program, which sponsored the development and construction of the Atlas pulsed-power system at Los Alamos. Currently, Bob is manager of the HEDH Program.

Jerry Beatty received his M.S. in nuclear engineering from the University of New Mexico in 1970. After working in the aerospace industry, Jerry joined Los Alamos in the Test Division in 1965. He worked in designing, producing, and fielding test racks for the underground nuclear tests at the NTS. Since retirement in 1993, Jerry has been involved in the subcritical experiments conducted at the test site.