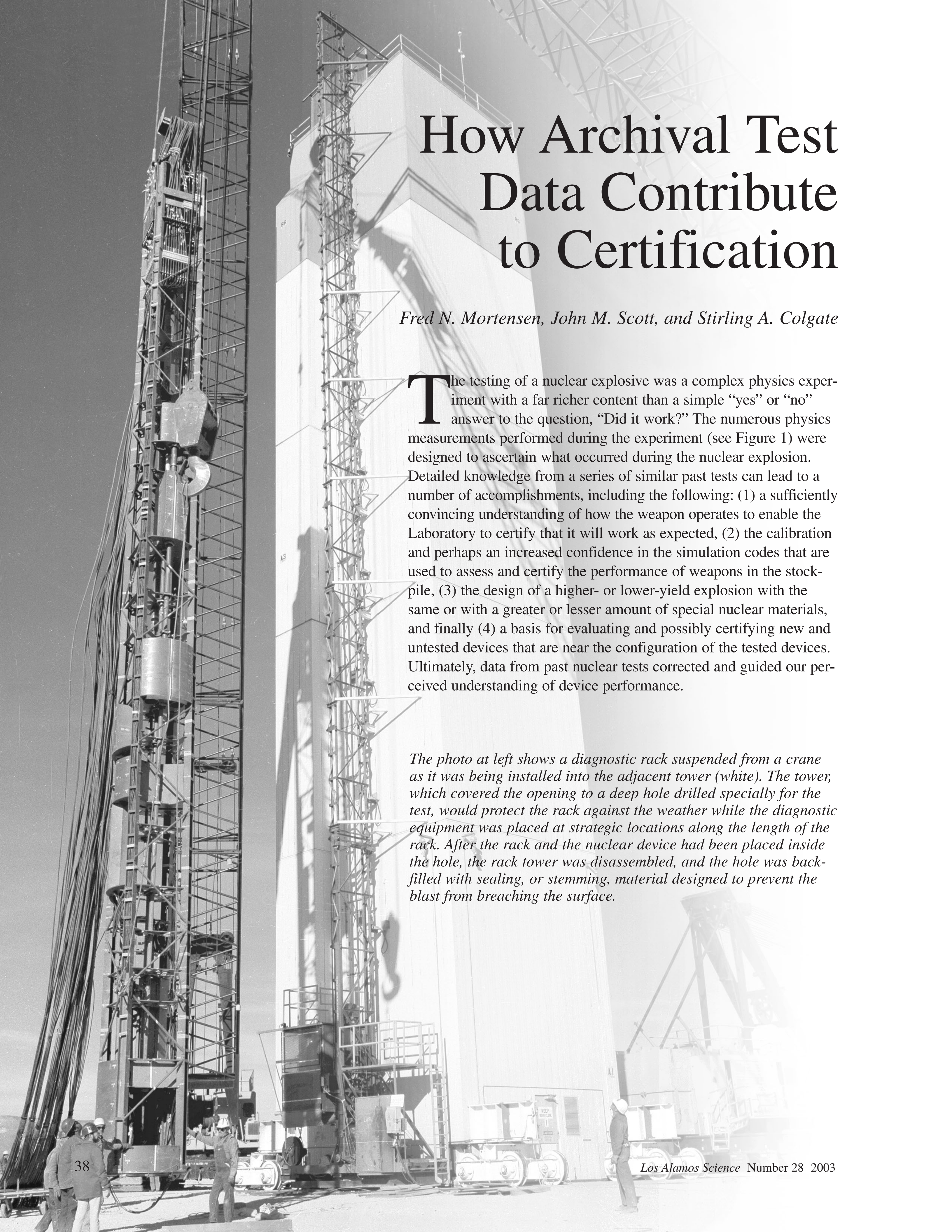


How Archival Test Data Contribute to Certification

Fred N. Mortensen, John M. Scott, and Stirling A. Colgate

The testing of a nuclear explosive was a complex physics experiment with a far richer content than a simple "yes" or "no" answer to the question, "Did it work?" The numerous physics measurements performed during the experiment (see Figure 1) were designed to ascertain what occurred during the nuclear explosion. Detailed knowledge from a series of similar past tests can lead to a number of accomplishments, including the following: (1) a sufficiently convincing understanding of how the weapon operates to enable the Laboratory to certify that it will work as expected, (2) the calibration and perhaps an increased confidence in the simulation codes that are used to assess and certify the performance of weapons in the stockpile, (3) the design of a higher- or lower-yield explosion with the same or with a greater or lesser amount of special nuclear materials, and finally (4) a basis for evaluating and possibly certifying new and untested devices that are near the configuration of the tested devices. Ultimately, data from past nuclear tests corrected and guided our perceived understanding of device performance.

The photo at left shows a diagnostic rack suspended from a crane as it was being installed into the adjacent tower (white). The tower, which covered the opening to a deep hole drilled specially for the test, would protect the rack against the weather while the diagnostic equipment was placed at strategic locations along the length of the rack. After the rack and the nuclear device had been placed inside the hole, the rack tower was disassembled, and the hole was back-filled with sealing, or stemming, material designed to prevent the blast from breaching the surface.

The complex fundamental physical laws and interrelated measurements that must be accurately interwoven to explain the performance of a weapon are awesome. The depth of understanding, gained from over a thousand past nuclear tests, is what ultimately gives conviction to the testimony of the nuclear laboratories' directors before the Congress and the nation that our nuclear stockpile is safe and reliable and that it will perform as designed. For the scientist, essential proof of that understanding is the ability to develop a numerical model that accurately reproduces the results of the diagnostic measurements. The models, which are applied to current weapons undergoing aging or manufacturing changes, can only use the nuclear test data that already exist. The ability to answer current stockpile questions is evolving as experience is gained and calculations improve. In the end, our Laboratory director relies on the peer-reviewed scientific judgment of the weapon designers to certify the stockpile.

In this article, we discuss various diagnostic measurements, how they are made, and the information they provide. These measurements were recorded and then preserved as archival data. Today, they represent a major legacy of research that must be employed in the process of certifying aging and altered devices without nuclear testing.

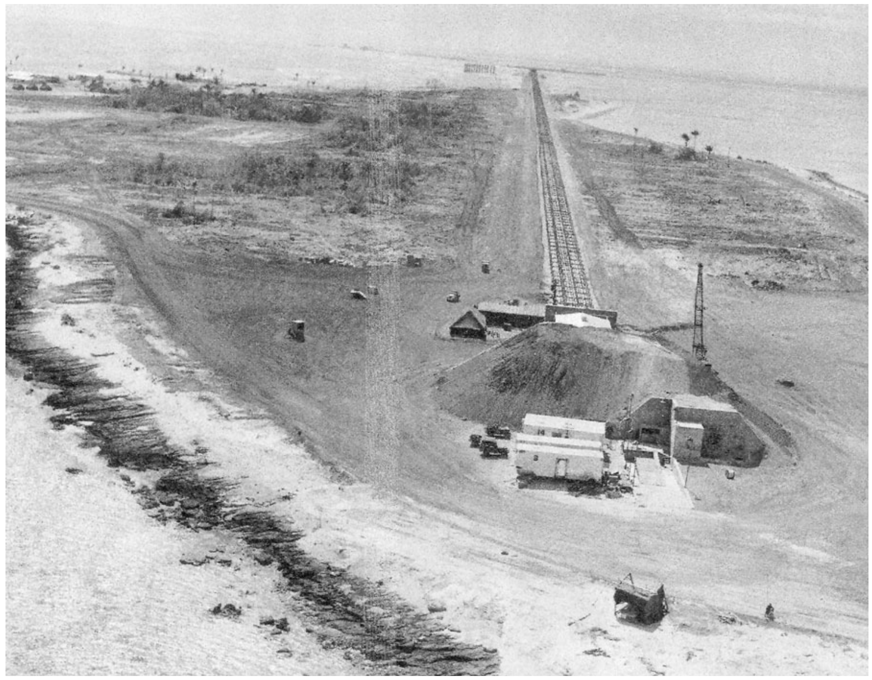


Figure 1. Line of Sight (LOS) from the Blockhouse to the Bravo Test Site
The first weaponized version of the hydrogen bomb was tested under the code name Bravo in 1954. Yielding 15 Mt, it was the largest test conducted by the Los Alamos Scientific Laboratory. The design and execution of the diagnostics were performed, however, by Lawrence Livermore Laboratory under the direction of the last author. The view shown is from the block house on Bikini Atoll (housing the detectors and recording oscilloscopes) toward the test site 4 km away. A dozen vacuum pipelines were placed level to provide an LOS between the detectors and the device. At a distance of 4 km, the curvature of the earth is sufficient to occlude the view through the pipe aperture unless the pipes are straight rather than level, a point corrected in some haste. Less obvious was a late worry that a "fireball" of energy might travel along the pipe lines and destroy the block house and recording instrumentation. Such fireballs had been observed many times traveling along the guy wires of the nuclear tests placed on towers (at the Trinity test and later at the NTS). No satisfactory explanation existed. Consequently, additional coral, 100,000 tons, is being piled on top of the block house, a fortunate last-minute correction. Later pictures showed a fireball of 1 kt equivalent energy traveling down the pipe lines to the block house. The block house, equipment, and data survived, but not until 30 years later has a possible explanation emerged: Gamma rays from the bomb, traveling at the speed of light and incident tangentially on the surface of the cable (or pipe lines), absorb and heat the surface of the cable and blow a "hole" in the atmosphere around the cable. Slightly later, a powerful radiation-driven shock wave travels in the air, along the cable and drives a widening wedge of energy into the gap in the atmosphere surrounding the cable. Ever more energy flows into the wedge, and the gap opens in the atmosphere producing a "gap shock" or fireball.

What Do Diagnostics Measure?

To understand what can be learned from diagnostics, one needs to know how a device operates. A modern thermonuclear weapon consists of four elements: a primary, a secondary, a separating volume, and an enclosing radiation case. Nuclear device operation begins with the initiation of the detonators for the high explosive (HE). The HE detonation assembles the nuclear materials of the primary into a supercritical configuration. Once the materials are in this configuration, neutrons introduced into the material will cause fission reactions, each of which releases 180 million electron volts (MeV) of energy and several more neutrons. In turn, these neutrons will cause more fissions and the release of more energy. As an example, if 1 kilogram of uranium-235

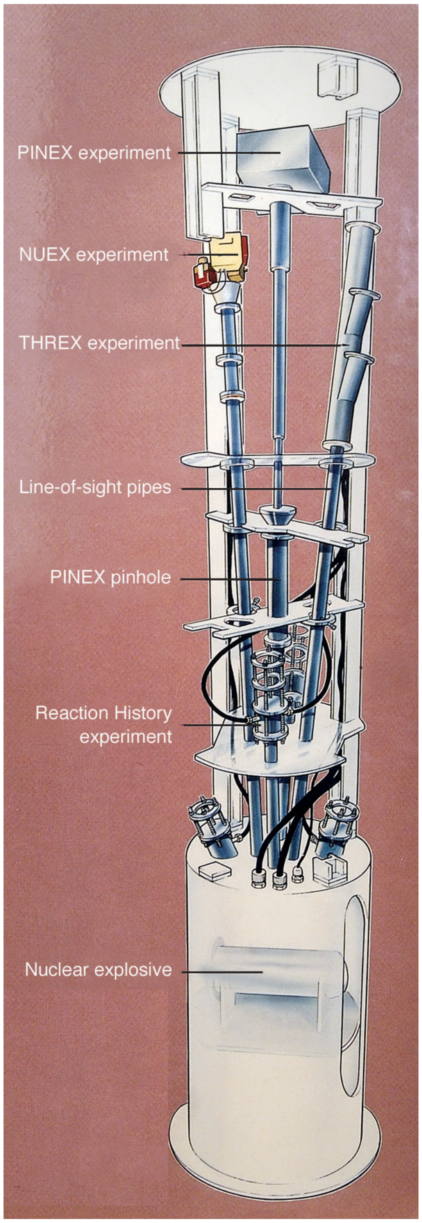


Figure 2. Diagnostic Rack Layout
This drawing of an underground test rack shows the typical positions of the nuclear explosive, timing and firing instruments, and radiation-measuring instruments. Each custom-designed rack required about 6000 h of effort to build and represented work from all the skilled crafts. Upon completion, the tensile strength of the rack and supporting hardware was tested and certified. Racks weighed up to 300,000 lb when fully loaded. Once completed and certified, the rack was trucked to the NTS on a flatbed trailer.

were to completely fission, it would liberate an amount of energy equivalent to the detonation of 17,600 tons of the explosive TNT. That amount is approximately the energy content in 600,000 gallons of gasoline. Additionally, use of deuterium-tritium (DT) fusion reactions in the primary enhances the fission energy release from the primary, a concept known as boosting.

Most of the energy released in the fission reaction is deposited within micrometers from where the fission event occurred. The release of this energy occurs in nanoseconds, heating the materials in the primary to temperatures of about 10^7 kelvins. At these high temperatures, the materials in the primary radiate a large amount of energy (mostly x-rays), similar to an electric stove element glowing red when set on high. This energy can be used for the radiation implosion of the secondary if both the primary and secondary are surrounded by a radiation case that is partially opaque to the radiative energy emitted by the primary. Because the radiative energy leaving the primary cannot quickly escape through the radiation case, it is forced to surround the secondary. As the radiation energy surrounds the secondary, enormous pressures are created, and the secondary implodes, releasing nuclear yield.

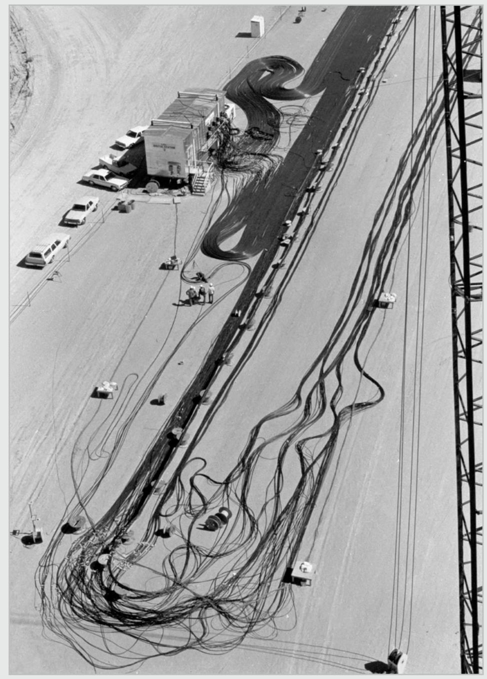
Diagnostics play an important role even before a nuclear test occurs. They record the results of hydrodynamic experiments (hydrotests) that aid in the modeling of primary performance. These nonnuclear (or noncritical) experiments examine the implosion of the primary using surrogate nonfissile materials. In other words, hydrotests have the proper geometry of a real device but do not use special nuclear material. In one type of diagnostic, devices called pin domes measure the time of arrival of primary materials at certain locations during the implosion. Because the implosion is spherical, a pin dome uses a set of wires mounted in the shape of a dome. During the implosion, the electrified wires are short-circuited when the imploding metal contacts the wire. The recording of this signal indicates when material has arrived at the location of the wire and results in a series of measurements that give position versus time. In another diagnostic, pulses of high-energy photons, timed to pass through the primary near maximum implosion, record x-ray-like images of the configuration. Together, the measurements of the HE detonation velocity, the timing of material motions, and the surrogate material positions are a confirmation that the actual primary design produces the calculated supercritical geometric configuration. Those types of data also provide a means to validate the models used for simulating the primary implosion. Because those data are so useful, a significant effort is being put forth to determine the potential of proton radiography for even more precise imaging of hydrodynamic experiments.

Hundreds to thousands of HE experiments and hydrotests have been done and are continuing to be done. The results of those nonnuclear tests are extremely important to certification. They are the cornerstones of primary design because they provide evidence that the assembly of the primary materials into a supercritical configuration proceeds as planned, albeit, using surrogate materials. Of course, age and environmental factors such as temperature can degrade the HE. Given that degradation occurs, the hydrotest becomes a measurement of the robustness of the bomb design in the face of the degraded HE.

In the past, when results of hydrodynamic experiments gave enough confidence in a particular primary design, a nuclear test was used to confirm that the primary worked as models indicated. The high-energy, high-intensity emissions from a device

Getting Out the Signal in a High-Radiation Environment

How far must a detector be from a nuclear device to deliver a clean signal to the recording instruments? Many detectors are typically made of scintillator material. The incident flux of neutrons or gamma rays causes ionization in the scintillator, which converts part of that ionization energy to light. A photomultiplier, or photodiode, converts the light into current, and the current pulse is transmitted through coaxial (coax) cables, like a television signal, to recording electronics, oscilloscopes, or digital recorders protected in a trailer aboveground or a "block house" for atmospheric testing.



View of the coax cables looking down from the rack tower.

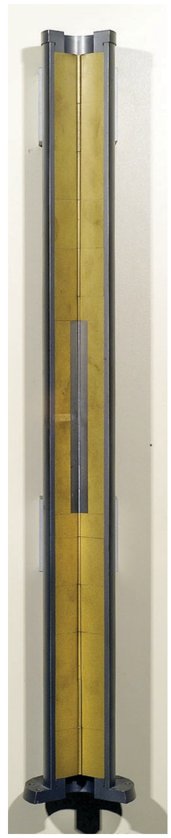
Surprisingly, the coax cable itself is the cause of the most stringent restrictions on the distance between detector and device. The reason is that the incident flux of gamma rays can Compton scatter from electrons of the central conductor and produce a spurious signal called the Compton recoil current. That recoil current per centimeter of cable length, must not give rise to a voltage pulse in the cable that is even a small fraction of the signal to be recorded—typically 50 volts, or 1 ampere in 50 ohms of cable.

Let's first estimate the distance D at which the radiation from a typical aboveground fission explosion with a 15-kiloton yield would induce a spurious signal level of 1 ampere in a coax cable 1 centimeter in length whose radius is also 1 centimeter. To estimate the flux, or number of particles per second, emitted from that canonical source, let's assume that one gamma survives from each fission and that the fission rate is one mole per shake (10^{-8} second), or a 4-kiloton equivalent yield of gammas every 10^{-8} second. That gamma flux is Avogadro's number (6×10^{23}) in 10^{-8} second, or 6×10^{31} gammas per second, or about 10^{13} amperes equivalent flux of charged particles (1 ampere = 6×10^{18} electrons per second). Distance, attenuation, and efficiency for converting gamma rays to a Compton current must all contribute to reducing this flux by a factor of 10^{13}. When these factors are used judiciously, the distances required become kilometers for aboveground testing and meters for underground testing, in which high-density stemming materials are used. However, for safety and signal-to-noise margin, underground dimensions are up to tens of meters (see Figures 1 and 4 in the text).

during a nuclear test, including gamma rays, neutrons, and x-rays, present a different measurement problem than the signals in a hydrotest. The radiation flux from a nuclear explosion is so large that, even before reaching its peak, the flux would destroy any detector placed close to the explosion. That destructive potential has led to the complicated geometry of the diagnostic racks (Figure 2) of test equipment. These racks are lowered to the bottom of a hole, typically a few thousand feet deep. Detectors for recording peak signals are placed at the top of the rack, each with a view of the device through a long line-of-sight (LOS) pipe. Many neutrons and gamma rays from the nuclear explosion scatter within the rack, thereby producing additional particles that can interfere with the collection of the desired data. Shielding materials placed in the rack to protect the diagnostic experiments are designed to attenuate these extraneous fluxes of gamma rays, the slower neutrons, and delayed x-rays, allowing the desired signals from both the primary and secondary to get to the detectors without contamination. Atmospheric testing from the 1940s to the 1960s required longer LOS. In the Bravo-Shrimp test, the nation's and Los Alamos' largest thermonuclear test (15-megaton yield), vacuum pipe lines (long pipe lines from which the air had been removed) 4 kilometers long were used to give a highly colli-

(a)

(b)



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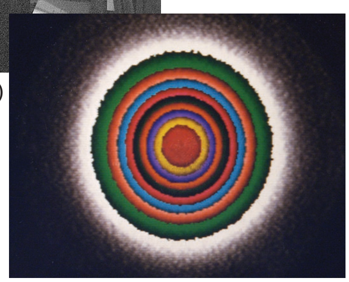


Figure 3. PINEX Measurements
(a) The PINEX camera includes a pinhole assembly (b) that focuses neutrons from a nuclear explosion onto a piece of fluorescent plastic. The plastic produces fluorescent light in proportion to the neutron fluence striking it. Modified TV cameras view the pattern of light through reflecting mirrors and record the image. Before the TV cameras are destroyed by the shock of the explosion, the PINEX image, which is usually only one frame, is relayed to recording instruments aboveground. (b) This PINEX "lens," or pinhole assembly, is made of tungsten, a metal that shields unwanted neutrons. The size of the hole regulates the number of neutrons passing through it. Changing the position of the pinhole assembly varies the image size. (c) This calculation of PINEX data shows intensity levels (by color) of the neutron fluence as measured by the light from the scintillator. The color levels show intensity levels differing by 10%.

mated view of the nuclear reactions. At that distance, the signal-recording detectors escaped most of the damaging radiation (Figure 1). In addition to measuring gamma rays, neutrons, and x-rays emitted by the device, diagnostics can measure the effect of a device. For example, measuring the ground shock of an underground test allows one to infer the device yield.

During a nuclear test, the start of criticality is observed as the exponential growth of either neutrons or gamma rays from the nuclear core. The neutrons result from fission, and the gamma rays result from fission or the interaction of fission neutrons with other elements. A diagnostic known as a reaction history measures the gamma-ray flux with good time resolution. Because the flux varies over many orders of magnitude, measuring its time history is quite a feat. Those data provide a time history of the criticality of the device, a quantity known as alpha. The prediction of alpha is one of the most exotic calculations in all of physics—it requires simultaneously modeling the hydrodynamics and the transport, absorption, and multiplication of the neutrons by fission and fusion burn. Thus, the measurement of alpha at various points in time during the exponential growth of neutrons from fission and fusion becomes a critical diagnostic of the implosion and explosion. The measurement indicates how the fissile material becomes supercritical and explodes. Usually, separate LOS on the diagnostic rack are used to measure the reaction histories of the primary and secondary. This measurement is considered so important that it has been taken on every nuclear test event since Trinity. The interval time, roughly the time between primary and secondary operation, can be assessed from reaction history measurements of the primary and secondary.

A NUEX (for neutron experiment) measures neutron output versus time. That measurement has lower time resolution than a reaction history measurement because the time of flight of neutrons from their point of emission to the detector is longer than the time during which they are produced. Because a neutron's velocity is proportional to the square root of its energy, NUEX is a measure of the time-integrated neutron energy spectrum from the device.

PINEX, for pinhole camera experiment, uses a pinhole camera to image neutrons (or sometimes gamma rays) from a device (Figure 3). The experiment can image all neutrons over time or may be gated in time to measure only the 14-MeV fusion component of the neutron spectrum. (Time gating is possible because, again, the velocity of a neutron scales with the square root of its energy.) PINEX gives a time-integrated but spatially resolved image, indicating where neutrons are being emitted from a device. Essentially, it can give the shape of the regions in a device where neutrons are being produced. If PINEX is gated to measure only the l4-MeV neutrons, the result of the measurement will indicate where DT fusion reactions are occurring.

A THREX (for threshold experiment) measures neutron output versus time from DT reactions. As a material containing both deuterium and tritium becomes very hot (about 10^7 kelvins), fusion reactions will begin to occur, which will produce 14-MeV neutrons. Some of these neutrons will escape the device and can be detected. Since the rate at which DT fusion occurs increases dramatically as temperatures rise above 10^7 kelvins, the rates at which neutrons are produced, escape, and are detected are also very sensitive to the temperature at the location where the detected neutrons were produced. Consequently, from measurement of the escaping DT neutrons, a temperature can be inferred.

Radiochemistry is a diagnostic technique that employs the effects of the neutrons emitted from the device. Small amounts of material (radiochemical tracers) that readily transform to different isotopes when exposed to a flux of neutrons are positioned in various places throughout the device. These isotopes subsequently decay radioactively, but the decay time is long compared with the time required to recover material from the explosion. The relative abundances of the products after the nuclear explosion compared with the initial amount of material are a measure of the time-integrated neutron flux at the position of the radiochemical tracer. Another important measurement provided by radiochemists is known as ΔP and does not rely on additional radiochemical tracer materials. It measures the change in the ratio of plutonium isotopes. That change is a sensitive measure for the number of fissions that occurred in the plutonium. Knowing the number of fissions allows one to calculate the fission yield from the plutonium. Radiochemical samples were recovered from an underground test through a process known as drillback. That is, core samples were drilled from the bomb residue left after the explosion and the collapse of the cavern. The samples were then chemically separated and radiologically counted to measure the relative abundance of all the material isotopes from the device. Tracers of different materials were used to prevent cross contamination from tracers in different regions of the device. The radioactive decay products and beta or gamma energies, are a unique signature of the specific isotope of an element. These types of data are generally referred to as integral measurements.

One cannot emphasize strongly enough that simulations cannot be undertaken with meaningful expectations unless the diagnosis of the physics that occurred in the device and the modeling of the physics are both understood in great depth.

Many more diagnostic techniques were used to assess how a device operates, but those described above are generally emphasized in present-day comparisons of simulations with archival test data. Ultimately, all diagnostic results from a nuclear test contribute to our understanding of a particular device. The acid test of this understanding is whether our numerical simulation agrees with the experimental signals or data. We must understand whatever differences exist between the simulation and the experiment if we are to gain confidence in our ability to predict device performance. One cannot emphasize strongly enough that simulations cannot be undertaken with meaningful expectations unless the diagnosis of the physics that occurred in the device and the modeling of the physics are understood in great depth.

Getting to the Nuclear Test

Placing a test on the nuclear test schedule was a complex process not always governed by a quantifiable set of reasoned criteria. We were always facing a limited budget to address a seemingly limitless set of questions. Therefore, placing a test on the testing schedule was a balancing act between the slate of questions and our priorities. What diagnostics will be needed to obtain the data necessary to answer the question? How much volumetric real estate in the rack will the necessary diagnostics take and not interfere with other diagnostics? How much of the test budget can we spend on this shot and still do the other necessary nuclear events? To explain how a proponent for a test worked through all the politics in the above set of questions is worth a paper in its own right. For this article, we will assume that a test (consisting of a nuclear device with both a primary and a secondary) is on the schedule and then sort the remaining questions by considering the physical and technical needs required to obtain the necessary data.

In general, after a nuclear test had been officially placed on the testing schedule, a nuclear test team would be set up. This team would consist of personnel from the design division (for design), physics division (for development and deployment of diagnostics), engineering division (responsible for providing actual bomb parts and the assembly of the parts into a usable test object), and testing division (the people responsible for overseeing anything happening at the test site and supplying Nevada Test Site (NTS) support people such as crafts people, crane operators, and stemming teams). Interactions among all these organizations were necessary to ensure that a successful and safe test would take place. This team would develop a test plan addressing what could be done within the allowed budget and time constraints.

The design division team would generally consist of a primary designer, a secondary designer, a diagnostician, and any additional team members needed to support this group. This team was responsible for developing the total nuclear design of the device to be used for the test. Members would work closely with the engineering and physics team. The engineering team would generally consist of a primary engineer, secondary engineer, and an assembly engineer, as well as an assembly team. The primary engineer was responsible for producing the necessary primary parts, just as the secondary engineer was responsible for the secondary parts. The assembly engineer was charged with building the whole collection into a working nuclear device with the help of the assembly team. The physics team would generally consist of a diagnostic physicist for each required diagnostic experiment fielded on the nuclear test and any additional experimenters needed to support that work. The physics team worked very closely with the testing division to ensure everything came together correctly at the NTS.

Staff of the design and engineering divisions would get together to determine what the nuclear device would be and the features or properties that would be needed to address the goals for the test. Then staff from the design and physics divisions would determine the best diagnostic experiments required to obtain the necessary data for addressing those goals. These people would also define the size of the nuclear test rack necessary to hold the test device and the accompanying diagnostics.

Figure 4. Tower and Cables before Lowering the Rack
This aerial photograph shows a diagnostic rack tower in the distance. Next to the tower is the crane that would lower the rack into the hole drilled for the event. Cables from the rack were snaking a long distance to a trailer park, which contained the instruments recording the information from the diagnostics. Once the diagnostic rack had been fully prepared, miles of cables, literally, were used to connect the downhole diagnostics to the recording trailers aboveground.

In designing the total experiment, one had to decide which detectors, instruments, and recording devices should be up close and which ones should be far away. How close, how far away, and how to connect the two determined the geometry of the experiment. The diagnostics for the HE do not raise this question because the detectors must be adjacent or buried in the HE, and fortunately the signals can be transmitted in ordinary coax cable (like TV cable) or fiber-optic cable to oscilloscopes or digital recorders in a bunker or trailer that can be far away—in some cases, miles away. This signal (current versus time) travels at two-thirds the speed of light in coax cable. With a typical time of about 100 microseconds between the HE detonation and the nuclear yield, there was plenty of time for the HE signals to escape the radiation from the bomb and safely reach the recording bunker. The cables carrying later signals must be shielded against the radiation from the explosion (see the box "Getting Out the Signals in a High-Radiation Environment" on page 41). The attenuation in the ground for underground tests or in air for the atmospheric tests also helps shield the signal cables. All these factors determined the geometry or distance and LOS for the detectors in the racks underground (or in the air, for aboveground testing).

To prevent further pollution of the environment by atmospheric tests, nuclear testing was finally confined to the underground at the various test sites around the world. At the NTS, a hole, similar to a large-diameter oil well, was drilled into the alluvial sediments, and its depth depended on yield. The device was placed in a rack and lowered to the bottom of the hole. The many signal cables from the rack led to trailers of recording instruments. These trailers were located far away from the hole to prevent their falling, with recorded data and all, into the large crater that sank into the earth after an explosion. That subsidence crater marks the collapse of the underground cavity created by the explosion. Figure 4 shows the trailers of equipment and the many signal cables snaking around on the surface. The cables were fed downhole as the rack, with its detectors and bomb, was being lowered into the ground.

The diameter of the hole was generally determined by the type and number of diagnostics and their individual complexity, as well as by how difficult it would be to isolate (shield) the individual diagnostics from the other diagnostics within the rack. The diameter of the hole could vary from 4 feet (for a relatively simple shot) to 12 feet. The depth of the hole was a function of the predicted total device yield. When a nuclear device exploded in an NTS rack, many neutrons and gammas that escaped the device were examined by diagnostic experiments. Generally, diagnostics have collimated LOS pipes looking from the experiment position to a particular device position (Figure 2). The particular particle or ray being investigated comes up the LOS. However, there are many neutrons and gammas scattering within the rack, producing additional particles that can interfere with the collection of the desired data. Isolating or shielding the individual experiments from the crosstalk induced by original bomb neutrons and gamma or secondary particles induced by scatter within the rack was therefore of major importance. The design division's diagnosticians would also play a big part in these decisions by calculating the crosstalk between the proposed diagnostic LOS. Once a rack had been lowered into a hole (Figure 5), the hole would be stemmed to contain the exploded bomb debris after the shot was fired. This stemming consisted of layers of magnetite, sand, concrete, and epoxy. The exact stemming process was experimentally determined from a large number of NTS shots and was dependent on the location of the hole within the NTS.

Figure 5. Lowering the Rack
The rack and a large number of extremely long cables were carefully lowered downhole from the surface. During the rack's emplacement, care had to be exercised to ensure that the cables maintained connection between the downhole equipment on the rack and the recording instruments in the trailer park. The cylinders on the cables are gas blocks that would prevent the flow of downhole gases through the cables into the atmosphere.

What Is Done with These Measurements?

The analysis of the numerous measurements collected results in a deep understanding of how the device operated. Typical questions that test diagnostics answer and that can later be compared with simulation results are the following: Did the multiple detonation points of the HE initiate a correct detonation wave? Is the arrival time of the first neutrons or the time from HE initiation to the time that the fissile material reaches criticality correct? What is the multiplication rate α of the fission criticality? What is the peak of the alpha curve before boost? When does boost occur? What is the boosted yield of the primary? What is the time between primary and secondary operation? What are the temperatures measured in the device? What is the multiplication rate α in the secondary? What is the total yield measurement from ground shock? Does the radiochemistry indicate the same yield? Does the radiochemistry indicate the predicted distribution of neutron fluxes?

Many other measurements contribute to the understanding of a device. The total number of measurements for each test, when combined with the possible judgments regarding each of these measurements, yields an astronomical number of permutations. Designers must be aware and able to speak to all the realistic possibilities, using their informed judgment. For certification of a device, designers will choose to simulate a suite of nuclear tests that encompass the body of relevant data associated with the device. Ideally, simulations are generated that reproduce the diagnostic measurements for each nuclear test. In practice, this may not always be true, and subjective judgments are made regarding the validity of calculations that may not fully reproduce the experimental data. However, when designers believe that a set of satisfactory calculations exists for the suite of tests, a certification judgment of the device is made. This process generally takes years and undergoes peer review. The peer review process assesses whether designers may have made obviously incorrect assumptions about the physics intricacies associated with the device. Designers must convince a peer group that the device operates as they understand it does. Although the focus of attention is on the responsible designer, it takes a cast of many from groups across the Laboratory to certify a device for the stockpile. Their work, in addition to that of the designers, ultimately leads to the Laboratory director's signature on a weapon certification statement.

Today, without nuclear testing, we rely increasingly on simulation tools to provide the necessary answers to maintain a safe and reliable stockpile. Advanced Simulation and Computing (ASCI) is developing state-of-the-art computing facilities and a new generation of simulation tools to mitigate the effects from the moratorium on nuclear testing. Although currently less mature in capability and usage than the suite of tools (legacy codes) that gained general acceptance up to the end of nuclear testing, the new codes have contributed to some significant accomplishments. The various ASCI codes have demonstrated capabilities beyond those of the legacy codes in various milestone calculations. They have been and continue to be used as a tool in the resolution of current stockpile issues. Ultimately, the success and acceptance of these new codes will depend on their ability to match the diagnostic information from previous nuclear tests, as well as experimental data from today's ongoing experiments. As these new tools gain widespread use and are tested on more complex and challenging problems, their relative importance will evolve. Weapon designers will continue to use the legacy codes to solve current and future stockpile problems. The newer ASCI codes will supplement the legacy codes until the ASCI codes are validated. The validation will be done against past NTS data as well as newer data from ongoing experiments. Without new nuclear tests, the most difficult problem will be to develop, using available experimental facilities, the physical models that describe behavior consistent with the conditions found in a nuclear device. As part of the model development process, designers will draw on valuable diagnostic information from nuclear test data to help confirm a model's validity.

The purpose of the diagnostic measurements is to develop an understanding of all the physical processes that conspire to make a nuclear explosion possible and reliable, including processes that make a device safe. These very complicated measurements were performed many times in the past. Archived data from them have been the basis for the development of the most sophisticated, lightweight, high-yield devices currently imaginable.

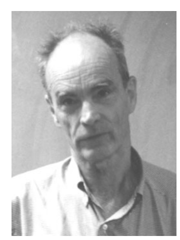
In summary, data of many types taken on over a thousand U.S. nuclear tests are essential to the understanding of how nuclear weapons work. The physics taking place within a thermonuclear weapon during its implosion and explosion is an extensive, highly nonlinear, closely coupled set of processes. Understanding these processes by numerical modeling requires that the modeling be able to reproduce the measured data.

We have discussed how certain types of data are used in the attempt to understand the workings of weapons (currently in the stockpile). Acquiring additional data from small-scale experiments and nonnuclear integral tests is currently the only way to answer some questions for which no specific NTS data exist. Confirming that those new data are accurate and applicable to weapon issues is a very difficult procedure. The Laboratory is applying that procedure today. Accurate and complete archiving of those data (old and new) is vital to the continuing effort to maintain a safe and reliable stockpile in which we have confidence. Those data are the cornerstones of the calculational effort needed to continue certification into the near future.

The Laboratory has taken on the challenge to maintain and continue to certify the U.S. nuclear stockpile, and the Laboratory staff works daily toward that goal. Without nuclear testing, however, weapons performance cannot be demonstrated as in the past. ■

Fred Mortensen received his Ph.D. in numerical fluid mechanics from the University of New Mexico. Fred has been a technical staff member in the Thermonuclear Applications Group of the Applied Physics Division at Los Alamos for the past several years. He became a Laboratory fellow in 1992. Fred has been intimately involved in the design and certification of three of the current U.S. nuclear stockpile weapons. He has served as team leader for several of these same weapons and has been involved in the design of other weapons, which did not become part of the U.S. stockpile.

John Scott received his Ph.D. in nuclear engineering from the University of California at Berkeley in 1998. Shortly thereafter, he accepted a postdoctoral associate position in the Thermonuclear Applications Group at Los Alamos. Since 2000, John has been a technical staff member at the Laboratory.



Stirling Colgate received his Ph.D. from Cornell University in 1952. He was a staff physicist at Lawrence Livermore Laboratory for twelve years after its inception and president of the New Mexico Institute of Mining and Technology (1964 to 1974) before joining Los Alamos in 1976. In 1980, Stirling became leader of the Theoretical Astrophysics Group. He is a senior fellow at the Laboratory and a member of the National Academy of Sciences. From 1952 to 1955, he was responsible for the fast diagnostics during the Castle operation of the Livermore tests and for the Los Alamos Bravo test. He served as technical advisor to the U.S. State Department for the negotiations of the Limited Test Ban Treaty in Geneva in 1959. He led an experimental program in magnetic fusion and initiated the laser, magnetic, and HE inertial fusion programs at Livermore. He continued his inertial fusion work at Los Alamos, where he has also been working in astrophysics.