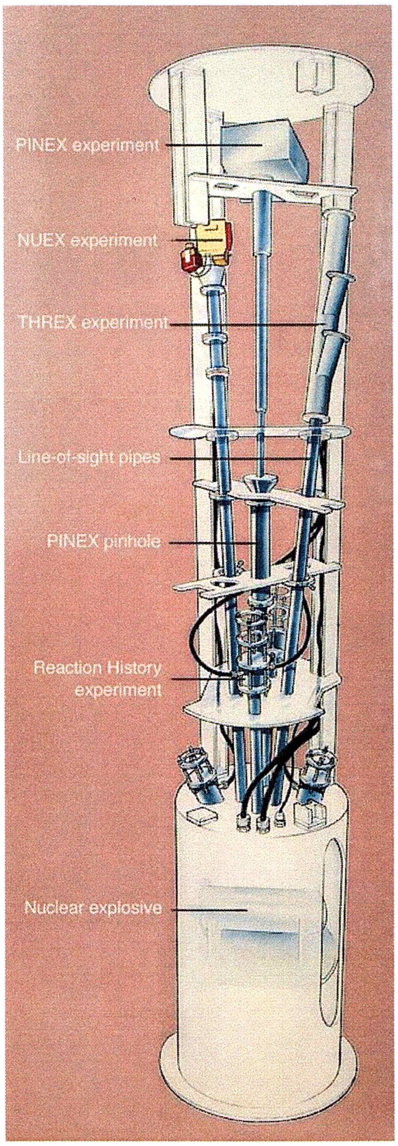

Figure 2. Diagnostic Rack Layout
This drawing of an underground test rack shows the typical positions of the nuclear explosive, timing and firing instruments, and radiation-measuring instruments. Each custom-designed rack required about 6000 h of effort to build and represented work from all the skilled 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

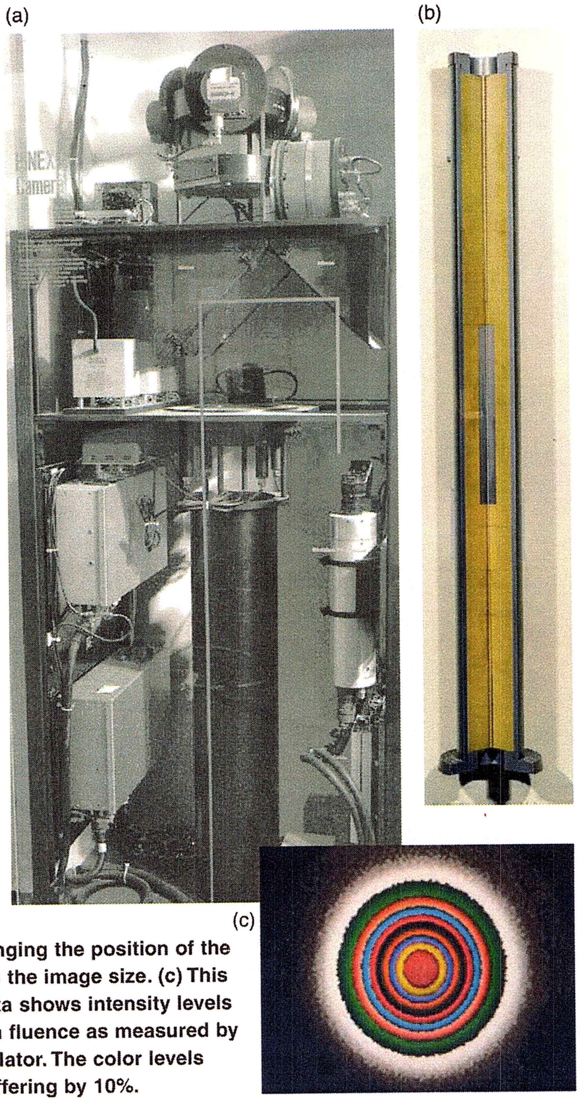

Figure 3. PINEX Measurements
(a) The PINEX camera includes a pinhole assembly (b) that focuses neutrons from a nuclear explosion onto a piece of fluorescent plastic. The plastic produces fluorescent light in proportion to the neutron fluence striking it. Modified TV cameras view the pattern of light 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 14-MeV neutrons,