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## W88 Pit Certification Without Testing

Los Alamos has built the first nuclear trigger in 20 years and has demonstrated, without a nuclear test, that it will work if needed.

**Abstract:** *The United States has not been able to make nuclear triggers since Rocky Flats closed down in 1989. Los Alamos has restored that capability. It has also given unequivocal scientific proof (certified), without a full-scale nuclear test and using the tools of stockpile stewardship, that the W88 warhead with its Los Alamos-made component would work as specified if ever needed. Certification without nuclear testing has never before been done.*

**Almost everything about it is secret.**

It inspires awe, but not from its outward, unremarkable appearance.

The raw power than can be released from its compact, technologically advanced design boggles the mind of even those with detailed knowledge of its form and function.

It is the pit for the W88, the most modern nuclear warhead in the U.S. arsenal, designed by Los Alamos National Laboratory in 1988 to be placed on ballistic missiles carried by the U.S. Navy's submarine fleet.

The pit, which lies at the core of the W88's first stage (the primary), is a hollow sphere of plutonium. When the pit is squeezed into a supercritical mass, it undergoes an uncontrolled chain reaction that triggers the second stage (the secondary), culminating in release of the warhead's full power (see "How a Nuclear Weapon Works").

In June 2007, Los Alamos delivered a newly manufactured W88 pit that is interchangeable with those produced in an earlier era.

The delivery was the fulfillment of a two-part promise the Lab made in the early 1990s: (1) to recover the nation's capability, lost for nearly two decades, to fabricate a plutonium pit to W88 design specifications, and (2) to give unequivocal scientific proof (certify), without a full-scale nuclear test, that the warhead would work as specified with its new pit. Certification without nuclear testing had never before been done.

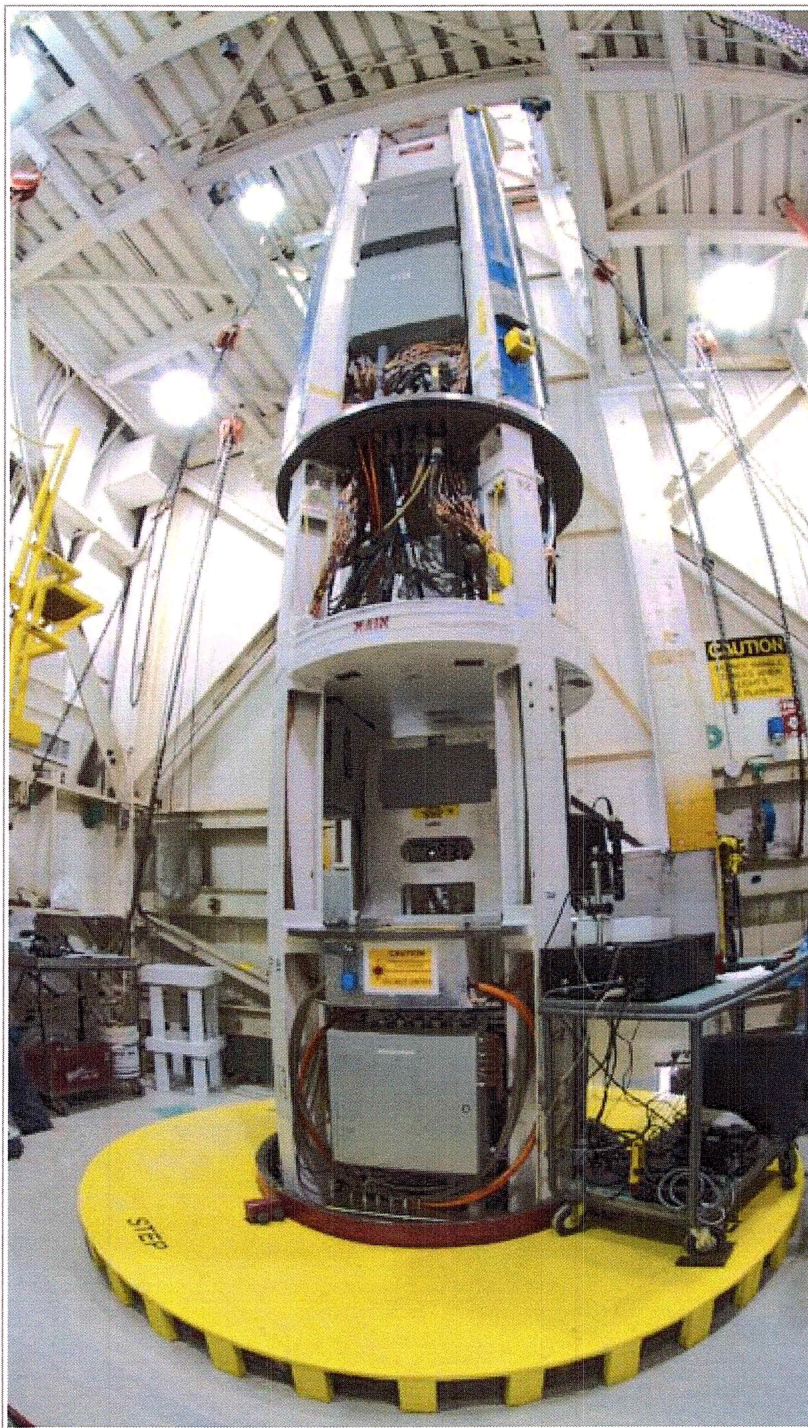
## Unprecedented Challenges

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The United States lost its pit-manufacturing capability in 1989 when the Rocky Flats production plant south of Boulder, Colorado, was shut down. The plant was closed in the middle of the production run for the W88, and the run was never





The large test rack for a subcritical underground experiment, including diagnostic detectors and the cables that send signals from the detectors to aboveground stations.

completed.

Only three years later, in 1992, the United States began a self-imposed, informal ban on nuclear testing.

Nuclear testing had always been the ultimate means of validating the technical judgment of weapons designers that a warhead would perform reliably and would be safe against accidental detonation. After 1992, validation became the province of a Department of Energy (DOE) program called Stockpile Stewardship. The program was to supply a new set of tools—a collection of experimental and computational capabilities and scientific data, including the results of past nuclear tests, that would enable weapons designers to make technically sound judgments about nuclear performance without any new nuclear tests.



One of the key elements of Stockpile Stewardship is stockpile surveillance, through which a few of each type of weapons system are examined annually to monitor how they age and to determine if there are problems that need fixing.

As part of surveillance, one W88 pit per year was being analyzed, and destroyed in the process. Eventually, the Navy, already deprived of its originally desired number of W88 pits, balked at providing more until replacements could be made.

"Because Los Alamos has the only fully functional plutonium facility in the United States, it fell to us to figure out how to make a Rocky Flats W88 pit and then guarantee it would work if needed," says Glenn Mara, principal associate director for nuclear weapons programs. "As usual, the Laboratory rose to the task, delivering both a high-quality product and a high-quality, high-efficiency process."

To carry out the work, the Lab had to develop new machining, welding, and inspection capabilities, along with processing methods that met modern regulatory standards. This development phase ended in 2003 with the delivery of "Qual 1," the first Los Alamos pit that had the right W88 material properties, size, weight, and shape and that was built using "qualified" processes and "quality" systems—ones that met DOE's quality-control standards for manufacturing and assembly.

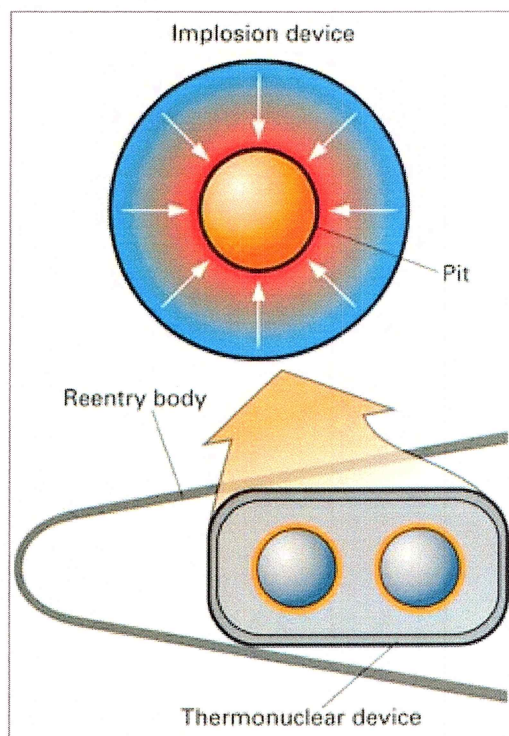
The completion of Qual 1 kicked off the next stage of operations: refinement of the manufacturing processes and certification that the new pits would work.

## More Than Just Pits

"Actually, it's not just the pit we certify, it's the warhead, with the pit as a key component," says Gary Wall, leader of the certification team, Laboratory Fellow, and stalwart member of the weapons design community. "From the physics side, we certify that it will deliver a certain yield (nuclear energy release) and, from the engineering side, that it will survive all the mechanical stresses and thermal environments it might eventually encounter."

Performance of the Rocky Flats pit, including its yield, had been measured directly in the underground testing program at the Nevada Test Site. Nuclear explosions were set off hundreds of feet underground and performance information teased out of the explosion byproducts (radiation, debris, and so on). There was visceral validation too—measured by how much the ground shook.

Without nuclear testing, performance of the Los Alamos pit had to be assessed indirectly. The pressure was on, as never



**How Nuclear Weapons Work** - Modern thermonuclear weapons have two main stages: the primary and the secondary. The primary, which resembles an old-fashioned fission bomb, delivers energy to the secondary, which uses thermonuclear fusion to release hundreds to thousands of times more energy than a fission bomb would. The nuclear core of the primary is the hollow sphere of plutonium or enriched uranium known as the pit. Chemical explosives surround the pit and, when detonated, send shock waves inward, squeezing ("implosion") the pit from a subcritical to a supercritical mass—one that will sustain an uncontrolled nuclear fission chain reaction ending in a nuclear explosion. The x-rays from this nuclear explosion trigger the secondary by compressing and igniting the thermonuclear fuel. The entire process, from detonation of the explosives in the primary to the release of fusion energy in the secondary happens in less than a thousandth of a second.





This metal sample, containing many tiny crystalline grains (colored regions), was exposed to strong shocks. The highly strained regions produced by the shocks have coalesced into tiny cracks (black).

before, to apply the scientific tools of Stockpile Stewardship.

The plan for the new W88 pit was first to measure the differences between small plutonium samples taken from the Rocky Flats and Los Alamos pits and to use the results to build accurate physics models describing the pit material's behavior. Those models would then be used in the full-system codes developed by another DOE program, the Advanced Simulation and Computing (ASC) program.

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Starting with the detonation of high explosives and ending with the final energy release of the entire warhead, those full-system codes would simulate beginning-to-end performance, including the differences between the Rocky Flats and Los Alamos pits. Then the code predictions would be assessed through comparisons with past nuclear tests. Plutonium experiments would also be used to inform and validate the computer physics models supporting W88 certification.

## Wrought versus Cast

The most glaring difference between the old and new pits? Rocky Flats pits were wrought; Los Alamos pits are cast. Rocky Flats was large enough to house the machinery used to form solid metals into the required configurations and was devoted entirely to pit production. In contrast, the Laboratory's plutonium facility at Technical Area 55 is much smaller and accommodates many other activities. It has to rely on the more-compact method of casting, in which molten plutonium is poured into molds to make rough versions that are then machined into their final shapes.

"Ninety percent of why the W88 certification process was so extensive was the change from a wrought to a cast pit," says Paul Dunn, leader of the Lab's metallurgy group. "It's a philosophical principle that if you change the processing, you change the material's performance. There would be differences between the two pits."

Wrought materials tend to be stronger than cast ones, so designers needed to develop very accurate computer models of plutonium strength from precision measurements of both kinds of pit.

Measurements and models had to describe pit responses to a millionfold range of potential "strain rates" (fractional changes in material length, area, or volume per second) that a W88 could encounter. Strain rates would be lowest during shipping and assembly, a thousand times higher during ballistic-missile liftoff, and yet another thousand times higher during pit implosion.

Responses to low strain rates were measured by "simply" squeezing, stretching, and twisting the plutonium metal, while the effects of higher strain rates were measured using a gas gun that sends a projectile into the sample at speeds of up to 18,000 miles per hour.

Finally, responses to the highest strain rates and the highest pressure and temperature changes were measured in "subcritical" (non-nuclear) experiments in deep underground laboratories at the Nevada Test Site, where high explosives delivered strong shocks to the plutonium samples.



Towers at the Nevada Test Site, where the test rack for a subcritical test was assembled before being placed downhole.

## Experiment/Computer Modeling Seesaw

The higher strain rates produce small cracks and voids, which coalesce into fractured surfaces and finally into deep cracks throughout the material. Theorist Paul Maudlin and experimentalists Rusty Gray and Rob Hixson evolved materials models

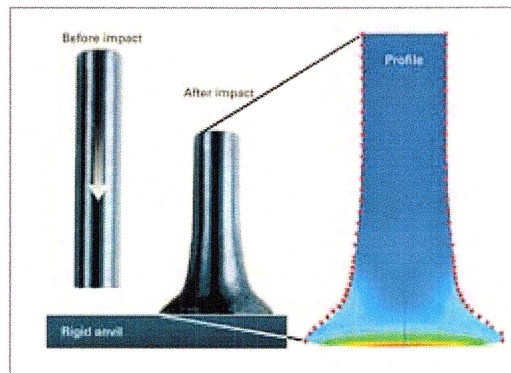


that reproduce such deformations with great fidelity. They also developed equations of state that quantify the density changes resulting from wide variations in pressure and temperature.

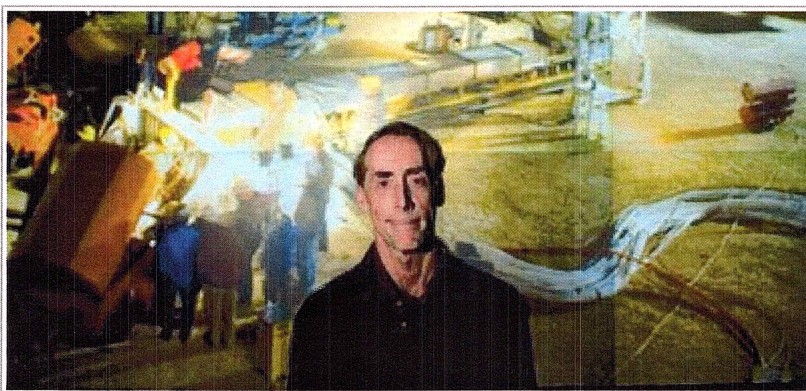
Such analysis is difficult enough with normal metals, but plutonium sends the difficulty through the roof. This most complex of all chemical elements is always changing. Small increases in temperature or pressure dramatically alter its density and its atoms' crystalline arrangement. It reacts chemically with most other elements, and it accumulates internal damage through its own radioactivity.

Gary Wall explains, "We needed to control how the plutonium samples were produced and handled so any measured differences between Rocky Flats and Los Alamos samples were not artifacts of our fabrication and testing procedures but were instead real differences derived from the two manufacturing processes."

Some experiments were laid out in the initial certification plan, but as the physics models evolved, new experiments were needed to improve or validate the models. "Experiments drove model development, and then models drove new experiments," notes Wall.



When a cylindrical sample hits a rigid anvil at high velocity, it deforms. Computer simulations using the new materials-strength models can predict the final shape after deformation. Compare the colored region (predicted) with the experimental shape (outlined by red dots). Color variations represent the predicted variation of internal strain.



Gary Wall, leader of the W88 certification team. The backdrop shows test preparations.

The final physics models for materials in the Rocky Flats and Los Alamos pits were put into the full-system ASC codes to predict whether each primary and the full system would deliver a yield in the desired range.

"We got slightly different performance results for the two types of pit. But the point was not to determine the differences but to show that the performance with the new pit was indeed within the range of yields specified by the National Nuclear Security Administration (NNSA) and the military," explains Wall.

## Simulations Confirmed

To confirm the positive results of the full-system simulations, Wall and his colleagues designed experiments that examined the behavior of plutonium as it is strongly shocked by forces produced by high explosives. All the measurements—the performance of the high explosives, the velocities at which the plutonium surfaces moved, and the properties of the materials released (the ejecta)—confirmed the results of the simulations.

From the beginning, the scientists knew that the new physics models would need to be validated by comparison with experiments and that uncertainties in the model predictions would need to be determined through statistical sampling of both experimental and computational results—all before the physics models were added to the ASC codes.

The pieces came together at the right time. The scientists used the ASC codes, the new materials models, and the results of experiments to make quantitative predictions of system performance and associated uncertainties. Together, those results were used to back up the statement, "If the warhead were taken out of the stockpile and tested, we are 95 percent confident that it would perform within this predicted range."

Los Alamos science-based certification of the W88 tells the Navy unequivocally, "You can safely place the new warheads aboard your submarines and trust that they will perform as specified if needed."

## Delivering the Product

With the physics goal achieved, the manufacturing team now has to deliver the pits the Navy needs.



"We have already delivered 15 Qual pits as part of the certification process, and our goal is always repeatability—to make the same pit, with the same strict specifications, every time so the product meets extremely high standards," says Bob Putnam of the Laboratory's Pit Manufacturing Program Office.

This past year, processes were streamlined, in part by removing hazardous and environmentally unfriendly steps. Paradoxically, some rather small changes resulted in momentous improvements in quality, productivity, and worker safety.

"We've tripled the number of pits we can make in a given time while our budget has remained the same," says Putnam.

Los Alamos delivered the first pit to the NNSA for its quality review on May 2, 2007, and in June the NNSA accepted it, giving it the so-called "Diamond Stamp" of approval, meaning it's accepted for insertion into the U.S. stockpile. That first diamond-stamped pit has been delivered to the Pantex Plant near Amarillo, Texas, for assembly into a W88 warhead. The rest will follow on schedule.

As Putnam aptly notes, "It's no secret that this is the best team Los Alamos could have put together. It would not have been possible without the great scientific and technical expertise of the whole Laboratory."