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Nuclear technoaesthetics:

Sensory politics from Trinity to the virtual bomb in Los Alamos

A B S T R A C T
In this article I investigate the politics of nuclear weapons production by examining how weapons scientists have experienced the exploding bomb at the level of sense perception through three experimental regimes: underground testing (1945–62), aboveground testing (1963–92), and stockpile stewardship (1995–2010). I argue that, for weapons scientists, a diminishing sensory experience of the exploding bomb has, over time, allowed nuclear weapon research to be increasingly depoliticized and normalized within the laboratory. The result is a post–Cold War nuclear project that assesses the atomic bomb not on its military potential as a weapon of mass destruction but, rather, on the aesthetic pleasure afforded by its computer simulations and material science. [*nuclear weapons, technoaesthetics, science studies, embodiment, virtual reality, U.S. militarism, New Mexico*]

A striking feature of nuclear weapons science—as a science—is that its experimental form would seem to have been most powerfully determined by nonscientists.[1] From the 1963 atmospheric test ban treaty through the 1992 underground test moratorium, the experimental regimes open to nuclear weapons scientists have been predominately defined by international treaties and U.S. nuclear policy, rather than by experts within the laboratory. In the post–Cold War period, this means that U.S. nuclear weapons scientists cannot conduct what would appear to be the most basic experiment in their profession: detonating a nuclear device.[2] Nuclear weapons science is further complicated in the United States because it is a highly classified and compartmentalized enterprise in which scientists are not able to freely engage one another on the technical nature of their work within the national laboratories. Moreover, the ultimate goal of post–Cold War nuclear weapons science is not to produce an explosive technology per se but, rather, to provide the technological infrastructure for a nuclear deterrent—a means of preventing a particular species of war. Thus, Los Alamos scientists today self-consciously devote their careers to engineering the bomb so that it will never actually be used *as a bomb*. Caught between the competing demands of a shifting experimental foundation, state secrecy, and the increasingly symbolic role nuclear weapons have come to play in (inter)national politics, the reality of the bomb as both a machine and a weapon of mass destruction has become (for all but its most direct victims) difficult to locate in the post–Cold War United States. Outside the national laboratories, U.S. nuclear weapons have come to exist primarily as political constructs and are rarely considered as technologies subject to the usual scientific challenges of what Peter Galison (1997) has called theorization, instrumentalization, and experimentation.[3]

In Los Alamos, the post–Cold War order has, consequently, presented a unique set of technoscientific challenges, requiring nothing less than a reinvention of nuclear weapons science. Because weapons scientists trained after the 1992 test moratorium may never actually conduct or

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witness a nuclear detonation, it is important to ask: What constitutes the continuing intellectual appeal of nuclear weapons science *as a science*? To answer this question, I suggest that one needs to critically engage the technoaesthetics of the bomb, by which I mean the evaluative aesthetic categories embedded in the expert practices of weapons scientists.[4] I am interested here in how weapons scientists have negotiated the bomb at the level of sensory experience since 1945, and I argue that technoaesthetics largely determine the politics of the enterprise within the epistemic cultures of the laboratory. Technoaesthetics are also important because they are the nonclassified everyday modes of interacting with nuclear technologies, forms of perception and practice that unify divergent groups of physicists, chemists, engineers, and computer specialists as nuclear weapons scientists. In Los Alamos, I would argue, it is in the realm of technoaesthetics that both the meaning of the bomb and the pleasures of conducting nuclear weapons science are constituted and expressed.[5]

Drawing on two and a half years of fieldwork in post–Cold War New Mexico, this article is part of a larger four-community study of nuclear politics and national security debates surrounding Los Alamos National Laboratory.[6] My focus here is exclusively on the internal culture of the professionals responsible for designing and maintaining the U.S. nuclear arsenal and not on the wide-ranging consequences of that nuclear project for people, the environment, or the economy (which I examine elsewhere; see Masco 1999, 2002, in press). My goal is to show how the reconfigured experimental regime of the post–Cold War period has fundamentally altered how scientists experience the bomb as a technology, thus changing the terms of our collective nuclear future. By examining the epistemic spaces where scientific bodies and nuclear devices actually interact—through pleasure—I believe one can see past the regimented statements of nuclear policy makers to engage the complicated world of nuclear weapons science as both an ideological and a technoscientific practice.[7] I argue that the shifting experimental regimes open to Los Alamos weapons scientists have, over time, worked to position the U.S. nuclear arsenal within the laboratory as an increasingly aesthetic–intellectual project, one that is both normalized and depoliticized.

My argument proceeds in three parts, each engaging a distinct experimental regime at Los Alamos: First, I examine how weapons scientists experienced the bomb—at the level of sense perception—during the era of aboveground nuclear testing (1945–62). Second, I examine how the move to underground nuclear testing (1963–92) reconfigured sensory access to the exploding bomb, both abstracting its destructive potential and encouraging an intellectual engagement with complexity. Finally, I examine how the post–Cold War experimental program known as ''Science-Based Stockpile Stewardship'' (1995–2010), which relies on an increasingly virtual bomb, systematically confuses bodies and machines in such a way as to transform the experience of nuclear science from a military reality to one of potentially infinite technoaesthetic pleasure. The structural achievement of post–Cold War nuclear science in Los Alamos, I ultimately argue, is to have reinvented the bomb—at precisely the moment when the U.S. nuclear project and the laboratory's future seemed most uncertain—as an unending technonational project that is simultaneously fragile, essential, and beautiful.

The aboveground testing regime (1945–62): On tactility and the nuclear sublime

> At the deepest level, the existence of atomic weapons has undermined the possibility of the sublime relationship to both natural and technological objects. . . . Who identifies with the bomb?
>
> —David E. Nye, *American Technological Sublime*

> I firmly believe that if every five years the world's major political leaders were required to witness the in-air detonation of a multi-megaton warhead, progress on meaningful arms control measures would be speeded up appreciably.
>
> —Harold Agnew, ''Vintage Agnew,'' *Los Alamos Science*

In his remarkable study of U.S. spectacular technologies, David Nye (1994) argues that nuclear weapons are so terrifying that they cannot be experienced through an aesthetic of the sublime. For Nye, the visual power of the Brooklyn Bridge or the Apollo 11 moon mission fuses an experience of the sublime with a national consciousness for all spectators, creating a feeling of pride in U.S. technology and a collective notion of uplift. The bomb, on the other hand, has no such positive dimension, as ''to anyone who contemplates them, nuclear weapons can only be a permanent, invisible terror that offers no moral enlightenment'' (Nye 1994:253). Los Alamos scientists, however, have banked their careers on a diametrically opposed proposition, namely, that nuclear weapons are so powerful that they fundamentally reshape human consciousness in ways that can enable global security and peace. Harold Agnew, director of Los Alamos Scientific Laboratory from 1970 to 1979, for example, has argued that the visual power of a multimegaton explosion is transformative for all viewers (1983:71). In calling for regular public demonstrations of the power of the thermonuclear bomb, Agnew explicitly deploys a notion of the ''nuclear sublime'' to foster international enlightenment in the form of disarmament. If, however, human consciousness can be so thoroughly transformed by a physical experience of the exploding bomb, as Agnew argues, then a basic cognitive problem produced by the move to underground nuclear testing during the Cold War also becomes evident. Put simply, because no American has witnessed an atomic explosion without the use of prosthetic senses (computer screens and seismic monitors) since the signing of the 1963 Atmospheric Test Ban Treaty, who now has full cognitive access to the technology? And if, as Agnew suggests, the conceptual power of a nuclear weapon is fundamentally linked to a direct human sensory experience of the explosion, how has the shifting experimental regime of nuclear weapons science transformed the meaning of the technology within the laboratory?

In the Kantian formulation, the sublime is evoked by a natural object or process whose massive form produces a combination of awe and fear. Immanuel Kant (1986) offers two species of the sublime that inform nuclear weapons science: the dynamic sublime, which is provoked by the terror of seeing a tornado or an erupting volcano from a safe distance, and the mathematical sublime, which begins with the inability to comprehend the scale and vastness of a mountain or a river. Both forms of the sublime are deeply disturbing because, in demonstrating the limits of human cognition, the confrontation with an infinitely powerful or infinitely complex form threatens to obliterate the self. As a sensory experience, the profundity of the sublime is inexpressible, placing it outside of language. The traumatized psyche recovers from this realization by naming the thing that is so disquieting, thereby containing the infinite within a conceptual category: Importantly, the sublime does not end in comprehension but, rather, in an intellectual compensation. The pleasure of the sublime, for Kant, derives not from understanding the river or mountain but from internally managing an overwhelming sensory experience; the sublime is ultimately resolved via a false sense of intellectual control.

Whereas for Kant the sublime is always tied to a natural form, the nuclear sublime is a more complex phenomenon in that the bomb is an invented technosocial form.[8] For weapons scientists, there is consequently an inherent tension between the reality of the bomb as a device built to certain specifications and detonated at precise moments (and thus under human control) and the experience of the nuclear explosion itself, which is a destructive force that is cognitively overwhelming and a direct threat to the human body. But if the conceptual force of the sublime is directly proportional to the danger involved in the experiential event, as Kant seems to argue, then nuclear weapons offer access to a uniquely powerful manifestation of sublimity. In Los Alamos, the pleasures of nuclear production—of experimental success—have always been mediated by the military context of nuclear explosions, requiring a complicated internal negotiation of the meaning of the technology. Consequently, an experience of the nuclear sublime for weapons scientists, I would argue, is always an eminently political thing. By historicizing expressions of the nuclear sublime within the Los Alamos weapons science community, one can see how the shifting experimental regimes open to weapons research since 1945 have worked to strip the exploding bomb of its visceral threat to the body of the scientist. The result has been a diminished access to the nuclear sublime, allowing the bomb to be experienced not through a circuit of terror–pleasure within the laboratory but increasingly as simply an aesthetic–intellectual form.

For the first Los Alamos scientists, however, the first nuclear detonation on July 16, 1945, was not merely an intellectual accomplishment but an overwhelming physical event (see Figure 1). I. I. Rabi, for example, recoiled from the power of the flash, describing it as "the brightest light I have ever seen or that I think anyone has every seen. It blasted; it pounced; it bored its way right through you. It was a vision which was seen with more than the eye. It was seen to last forever" (Rhodes 1986:672). Experiencing the first nuclear explosions as something that "pounced" and "bored" through the human body, Rabi found the millisecond ushering in a new world of nuclear physics terrifying. Emilio Segre was similarly moved: "We saw the whole sky flash with unbelievable brightness in spite of the very dark glasses we wore. ... I believe that for a moment I thought the explosion might set fire to the atmosphere and

Figure 1. Trinity test, July 16, 1945 (photograph courtesy of DOE Nevada).

thus finish the earth, even though I knew that this was not possible'' (Rhodes 1986:673). Here an experimental success produces a new kind of terror that proliferates in Segre's mind to encompass the entire planet, as Segre experiences a split between what he knows to be true (that the atmosphere will not ignite) and what he feels to be true (that the world is on fire). Philip Morrison, also wearing welding glasses to protect his eyes from the flash, was moved more by ''the blinding heat of a bright day on your face in the cold desert morning. It was like opening a hot oven with the sun coming out like a sunrise'' (Rhodes 1986:673). The unprecedented heat of the explosion scared Morrison with its strange form, arriving with a velocity and a temperature exceeding that of several midday suns. For Otto Frisch, it was not the light or the heat but the sound of the explosion that terrified, and decades later he claimed he could still hear it (Szasz 1984:88). In these descriptions the sight, the sound, and the heat of the first nuclear explosion—all part of the objective of the experiment—nonetheless still terrify, making the weapons scientist's body the most important register of the power of the bomb. Although observers were protected by goggles, barriers, and miles of buffer zone, the Trinity test explosion not only overwhelmed senses but also physically assaulted scientists: George Kistiakowsky was knocked off his feet by the shock wave, Enrico Fermi was so physically shaken by the Trinity test explosion that he was unable to drive his car afterward, and Robert Serber, who looked directly at the blast without eye protection, was flashblinded for 30 seconds. In this first nuclear explosion, the weapons scientist's body was the primary register of the explosion, the physicality of blast effects—light, sound, shock wave, and heat—all assaulting human senses and demonstrating the fragility of the human body when confronted by the power of the bomb.

Witnesses to the first atomic blast later evoked the sublime to capture its meaning, in many cases mediating the physical pain and intellectual pleasure of their technoscientific achievement through a deployment of religious imagery. Robert Oppenheimer described his experience of the Trinity test this way:

> We waited until the blast had passed, walked out of the shelter and then it was extremely solemn. We knew the world would not be the same. A few people laughed, a few people cried. Most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita: Vishnu is trying to persuade the prince that he should do his duty and to impress him he takes on his multiarmed form and says, ''Now I am become Death, the destroyer of worlds.'' I suppose we all thought that, one way or another. [Rhodes 1986:676]

Now I am become Death, the destroyer of worlds. Here the arrival of a new world of nuclear physics is immediately positioned alongside the end of a world—as creation and destruction are fused in a moment of borrowed religiosity. The dramatic quality of Oppenheimer's statement—its theatrical character—elevates the technical achievement of the Trinity test while mediating its proliferating form through a linguistic containment. William Laurence, the only reporter allowed to witness the Trinity test, also sought to ground the meaning of the explosion for the U.S. public in mythology:

> It was a sunrise such as the world had never seen, a great green super-sun climbing in a fraction of a second to a height of more than eight thousand feet, rising ever higher until it touched the clouds, lighting up earth and sky all around with a dazzling luminosity. Up it went, a great ball of fire about a mile in diameter, changing colors as it kept shooting upward, from deep purple to orange, expanding, growing bigger, rising as it expanded, an elemental force freed from its bonds after being chained for billions of years. For a fleeting instant the color was unearthly green, such as one sees only in the corona of the sun during a total eclipse. It was as though the earth had opened and the skies had split. One felt as though one were present at the moment of creation when God said: ''let there be light.'' ... In that infinitesimal fraction of time, inconceivable and immeasurable, during which the first atomic bomb converted a small part of its matter into the greatest burst of energy released on earth up to that time, Prometheus had broken his bonds and brought a new fire down to earth, a fire three million times more powerful than the original fire he snatched from the gods for the benefit of man some five hundred thousand years ago. [1946:10–13]

Let there be light. Evoking God, gods, and Prometheus, Laurence provides the U.S. public with an image of the bomb as transcendent form, minimizing the physical effects of the explosion in favor of the conceptual power of a ''new age.'' The terror of the nuclear sublime is subsumed here through an implicit religious discourse of manifest destiny, as Los Alamos scientists have reinvented both the physical world and international order from the deserts of central New Mexico. Laurence deploys the nuclear sublime to position the bomb as an intellectual project that stimulates the imagination, rather than one that threatens the body.

Nonetheless, the physical effects of a nuclear explosion—the flash, radiation, firestorm, blast wave, and fallout—threaten all witnesses, limiting the ability of scientists to experience the bomb as a purely aesthetic or intellectual form. From September 1945 to August 1963, U.S. weapons scientists would pursue an expansive aboveground testing program involving 210 atmospheric and five underwater detonations (turning much of the planet into a U.S. nuclear test complex and producing nuclear victims on an equally large scale). The initial test series in the Pacific were conducted as giant military campaigns, involving tens of thousands of workers, followed by the establishment of a permanent test area in Nevada in 1951. A brief glance at the test program reveals not only an expansive development in military explosives (leading to multiply redundant systems of nuclear bombs, warheads, torpedoes, artillery shells, depth charges, and tactical field weapons) but also the scope of the U.S. nuclear imagination, as nuclear detonations were performed on land, under water, and in the upper atmosphere, and weapons were placed on towers, dropped from planes, suspended from balloons, floated on barges, placed in craters, buried in shafts and tunnels, launched from submarines, shot from cannons, and loaded into increasingly powerful missiles.

As nuclear testing expanded in the 1950s, the scientific negotiation of the nuclear sublime took on a more calculated form. Consider the early 1950s career of Theodore Taylor, who was fascinated with the possible scale of nuclear explosions. At Los Alamos, Taylor would design both the smallest U.S. nuclear device of the 1950s (an atomic artillery shell) and the largest fission device ever detonated, before renouncing nuclear weapons work in the 1960s and committing himself to disarmament (Hansen 1988; McPhee 1973). Only one year after being simultaneously ‘‘thrilled’’ and ‘‘terrified’’ by witnessing his first nuclear detonation on Enewetak Atoll during Operation Greenhouse, Taylor orchestrated a new experience of the nuclear sublime at the recently created Nevada Proving Grounds. Prior to the test of his new warhead design, Taylor positioned himself so that, with the help of a parabolic mirror, the flash from the 20-kiloton nuclear detonation would light a cigarette (McPhee 1973:93–95). Here the exploding bomb was used to produce a moment of technoaesthetic reverie, in which the massive destructive power of the atomic age was marshaled to accomplish that most mundane—and purely sensual act—of smoking. Only seven years and 25 nuclear tests after the destruction of Hiroshima and Nagasaki, the technoaesthetic production of the bomb had already taken on a new form: For Taylor, the exploding bomb produced not mass destruction but, rather, a unique dual opportunity for intellectual and physical stimulation, as he converted a successful experiment into pure tactile pleasure.

Discussing his commitment to the first atomic bomb, Oppenheimer told the Personnel Security Board in 1954 that ‘‘it is my judgment in these things that when you see something that is technically sweet, you go ahead and do it and you argue about what to do about it only after you have had your technical success’’ (U.S. Atomic Energy Commission 1971:81). But if the aesthetic power of the ‘‘technically sweet’’ could overwhelm the nascent political reality of nuclear explosives in July 1945, by the 1950s, Los Alamos scientists (post-Hiroshima and post-Nagasaki and in the midst of a Cold War arms race) were directly confronted with the military implications of their experiments. Consider the Apple II shot on May 5, 1955, which was part of Operation Teapot conducted at the Nevada Test Site. For Los Alamos scientists, the primary task of the Teapot series was to work on miniaturizing nuclear warheads while simultaneously enhancing the explosive yield—to extract more destructive energy from a smaller machine. Though their research was primarily focused on how to boost the nuclear yield by introducing a mixture of deuterium–tritium gas into the hollow core of a plutonium sphere during the implosion process, the Apple II detonation was also the center of a U.S. nuclear war fighting program. It was also part of a massive civil defense exercise televised live for a national audience.

In addition to designing the Apple II nuclear device, Los Alamos scientists conducted an elaborate set of experiments to test the radiation and blast effects of the explosion on machines, on human mannequins distributed around the test area, and on animals. They deployed air force planes to collect atmospheric samples from within the mushroom cloud, track its fallout pattern over Nevada, and study how the shock wave would hit a plane in flight. Simultaneously, the U.S. military conducted Exercise Desert Rock VI. Intended to acclimatize troops to an atomic battlefield and develop nuclear war fighting tactics, the exercise involved 1,000 troops, 89 armored vehicles, and 19 helicopters and constituted an armored assault on ground zero (U.S. Department of Defense 1955). While the troops marched into the swirling radioactive dust storm created by the explosion, helicopters swooped in to evacuate soldiers that had been designated in advance as ‘‘casualties,’’ and other personnel fired cannons and machine guns loaded with blanks at this invading army to make the war game seem real.[9]

The Apple II detonation was also the centerpiece of Operation Cue, a civil defense exercise designed to measure how a ‘‘typical’’ U.S. community (rendered down to the last detail of consumer desire) would look after a nuclear attack.[10] An entire town was built on the test site, consisting of a fire station, a school, a radio station, a library, and a dozen homes in the current building styles. These buildings were carefully constructed, furnished with the latest consumer items—appliances, furniture, televisions, carpets, and linens—and stocked with food that had been specially flown in from Chicago and San Francisco. Residences were populated with mannequins dressed in brand new clothing and posed with domestic theatricality—at the dinner table, cowering in the basement, or watching television (like the national TV audience). Over 2,000 civil defense workers and media representatives participated in Operation Cue. After the

Apple II detonation, the television crews offered tips on surviving an atomic attack while the civil defense teams practiced mass feeding—cooking the food (carefully recovered from trenches, refrigerators, and pantries) that survived the explosion. As ritual sacrifice, Operation Cue made visible for a U.S. audience the terror of a nuclear assault while attempting to demonstrate the possibility of survival.

The Apple II device was, thus, at the center of a schizophrenic space, in which the same Los Alamos physics experiment was simultaneously a U.S. nuclear strike against an imagined enemy and a U.S. nuclear attack on a U.S. suburb. Los Alamos scientists were not simply attempting to perfect the bomb through new design work; they were also engaged in nuclear war fighting and civil defense all at the same moment, confusing the simulated and the real. The bullets in army machine guns may have been blanks, but the bomb detonated with a force of 29 kilotons (twice that which destroyed Hiroshima); and although mannequins were used to simulate the effects of the explosion on human beings, the troops, pilots, civilian observers, and neighboring communities were all subjects of a real radiological experiment in the form of exposure to atmospheric fallout, which was recorded as far away as Paris, Missouri (Miller 1986:237; see also Gallager 1993 and Hacker 1994:164–169). As physics experiment, nuclear attack, civil defense exercise, national spectacle, and theatrical display of resolve for the Soviets, the Apple II explosion cannot be reduced simply to the goal of producing either a nuclear deterrent or a specific nuclear device: Los Alamos technology was used here to enact a nuclear event in which Americans were conceived simultaneously as military aggressors and victims. The complexity of this kind of national spectacle grounded the experimental work of weapons scientists in both Cold War politics and nuclear fear. In other words, the aboveground testing regime was devoted not only to the basic science of producing atomic and, then, thermonuclear explosions but also to researching precisely how nuclear explosions traumatize the material structures of everyday life as well as the human body.[11]

Consequently, the dangers of the nuclear age were viscerally dramatized with each aboveground nuclear test. Critics pointed out that the 29-kiloton Apple II device was dwarfed in size by the multimegaton thermonuclear weapons—a thousand times more powerful—that both the United States and Soviet Union were stockpiling at the time. Thus, state spectacles like Operation Cue, which were staged explicitly to illustrate the possibility of survival, also worked to undermine U.S. beliefs in the possibility of civil defense from a Soviet nuclear attack. By the late 1950s, public concern about the global health effects of atmospheric fallout was directly competing with the official national security discourse supporting the bomb.[12] Nobel Prize–winning chemist Linus Pauling also won a Nobel Peace Prize for his efforts to publicize the accumulating environmental effects of atmospheric nuclear detonations. Pauling portrayed each aboveground nuclear detonation not as a sign of U.S. technological and military strength but, rather, as large-scale genetic experimentation on the human species, already involving tens of thousands of victims (Pauling 1963; see also Wang 1999). The scientific critique of atmospheric fallout expanded the definition of nuclear disaster from war—a thing that could be deferred into the future—to an everyday life already contaminated by the cumulative global effects of nuclear explosions. In response, a U.S.–Soviet test moratorium from 1958 to 1961 led to the Atmospheric Test Ban Treaty in 1963, which banned all nuclear explosions in the atmosphere, under water, and in outer space. Today, Los Alamos scientists remember the Atmospheric Test Ban Treaty—the first international effort to restrain weapons science—as both a public health measure and a means of shielding nuclear tests from Soviet observation. The move to underground testing, however, contained more than simply the nuclear device; it also redefined how Los Alamos scientists could experience the power of a nuclear explosion, fundamentally changing the technoaesthetic potential and, thus, the politics of the bomb.

The underground test regime (1963–92): Embracing complexity, fetishizing production

The consolidation of nuclear testing at the Nevada Test Site after 1963 regularized nuclear weapons science, replacing the military campaign structure of the aboveground testing regime (which required massive labor simply to equip remote test areas in the Pacific and in Nevada) with a more stable experimental form. National spectacles like Operation Cue were also eliminated by the underground test regime, which was configured to regularize nuclear production. During the underground test regime, seven formal stages in the development of a new weapon were institutionalized—conception, feasibility, design, development, manufacturing, deployment, and retirement—placing Los Alamos weapons scientists both on a carefully modulated calendar and at the center of a vast industrial machine (U.S. Department of Energy 1984). Los Alamos weapons scientists trained during the underground test regime consequently experienced the Cold War as a relentless series of nuclear warhead design and test deadlines (cf. Gusterson 1996a). It took roughly ten years to bring a new warhead or bomb from design conception to deployment. Multiple weapons systems were under production simultaneously and were designed with the understanding that they would be replaced by a next-generation system within 15–20 years. The resulting pace of U.S. nuclear weapons research was impressive: The United States conducted 1,149 nuclear detonations from

July of 1945 to September of 1992 (including the 35 detonations of the plowshares program and 24 joint U.S.–U.K. nuclear tests).[13] This averages out to roughly two nuclear tests per month over the 46 years between the first nuclear explosion, the Trinity test (July 16, 1945) and the last, Divider (September 28, 1992; National Resources Defense Council 1998).[14] Given that each nuclear test was a multimillion dollar experiment underscored by a national security imperative, the formal structures of U.S. nuclear production encouraged scientists to understand Cold War time along strictly technological terms. For Los Alamos scientists, the nuclear age remains perfectly tangible—visible in machine form—with each nuclear test part of a technological genealogy of design concepts dating back to the very first nuclear explosion in July of 1945.[15]

From a scientific point of view, the challenge of underground testing was how to both contain the explosion and make it visible to machine sensors, to safely extract technical data from an underground space in the midst of the most extreme pressures and temperatures imaginable (see U.S. Congress, Office of Technology Assessment 1989). As one Los Alamos weapons scientist trained during the underground regime described it to me:

> A weapon is at a temperature and a density, and is over so fast, that you can't really get in there and look and see how it is doing. You can only guess from the results, how it actually behaved. In that sense, it is very complex. It is possibly like astrophysics. It is in a regime that is inaccessible to you: high temperature, high density. You can't put [detectors] in the [device] because it will effect the performance. You learn something from radiochemistry because of the neutrons that come out of it; you put radiochemical detectors in the ground after the shot—and they were in where the action was—and that's the nearest you get to seeing how it actually behaves. So the difficulty [of underground testing] comes from the inaccessibility of the regime, for all those reasons.

The difficulty comes from the inaccessibility of the regime. Here one sees the change in experimental regimes registered at the level of sensory perception. For the challenge of underground testing is revealed to be not the effort to protect the human body from the effects of the explosion but, rather, making the exploding bomb visible to human senses. The "visibility" of the exploding bomb has fundamentally changed, however: No longer is a primary aspect of weapons science to investigate the effects of the bomb on everyday objects, methodically subjecting cars, houses, plants, animals, and people to the blast, thermal radiation, and electromagnetic pulse effects of a nuclear explosion—an experimental project that made each aboveground test also explicitly a nuclear war fighting exercise. Instead, underground testing as an experimental regime limited the ability to test blast and radiation effects, leaving weapons scientists to work on the internal complexities of the nuclear explosion itself; that is, Los Alamos scientists became more narrowly focused on the physics of the detonation and the robustness of the machine than on the effects of the bomb, substantially consolidating the experimental project.[16]

The shift from aboveground (1945–62) to underground testing (1963–92) not only regularized nuclear production, disciplining the bodies of weapons scientists to meet a constant series of deadlines (underscored by the Cold War state of emergency; see Gusterson 1996a), but it also fundamentally changed the technoaesthetic experience of conducting weapons science. Witnesses to a nuclear test might now feel an earthquake or see a great mass of earth heave upward at the moment of detonation (see Wolff 1984). But the most visibly dramatic aspect of the underground test came after the event itself, in the form of a large, perfectly symmetrical crater (see Figure 2). Underground testing replaced a full sensory experience of the exploding bomb (producing fear and awe in the mode of the dynamic sublime) with a more limited form, closer to what Kant (1986) called the "mathematical sublime." For Kant, the mathematical sublime involved a flooding of the senses with overwhelming scale and complexity, rather than physical fear. Underground testing rendered the exploding bomb all but invisible, also eliminating the immediate threat to the body of the scientist. Weapons science consequently became focused less on blast effects and more on the scale, temporal sequence, and nuclear progression of the event at the atomic level. In other words, when Los Alamos weapons scientists trained during the underground test regime talk about nuclear weapons,

Figure 2. Nuclear test craters at the Nevada Test Site (photograph courtesy of DOE Nevada).

they tend not to forward their own sensory experience of the explosion (as did the previous generation of weapons scientists) but, rather, the intellectual complexity of the detonation as a set of physical processes. For this generation, the intellectual pleasures of weapons science derive from investigating events that take place at millions and billions of degrees of heat and at millions of pounds of pressure and that release incredible energy in billionths of a second.

Indeed, the energy regimes at which nuclear weapons operate are unique; the closest approximation is what happens in the center of a star. Consequently, many weapons scientists have been recruited from astrophysics programs and continue to think about their weapons research in relation to stars (Los Alamos National Laboratory 1993:11–12). This tracking back and forth between macro- and microcosmic regimes of scale not only produces a proliferating sense of space (a perfect register of the mathematical sublime) but also is underscored by a unique sense of time. Nuclear explosions happen in billionths of a second, requiring weapons scientists to develop their own languages for dividing microseconds into understandable units. Since World War II, Los Alamos weapons scientists have examined nuclear explosions in units called ''shakes,'' shorthand for ''faster than the shake of a lamb's tail'': one shake equals 1/100,000,000th of a second, which is the time it takes one uranium atom to fission (Hansen 1988:11). A hydrogen bomb explosion, the most devastating military force on the planet, occurs in about one hundred shakes, or a millionth of a second. The internal complexity of a nuclear explosion can consequently be approached as a potentially endless universe of processes, interactions, pressures, and flows all happening in a split second. Put differently, if one were to add up the 2,053 nuclear detonations conducted in human history—a force thousands of times the total destructive power unleashed during World War II—collectively, these explosions would still not constitute a single second of time.[17]

To engage the scale and complexity of a nuclear explosion simply as an intellectual–aesthetic project, however, requires insulating the body from the physical and cognitive assaults of the explosion. During aboveground testing, part of the cognitive understanding of the ''test'' was the sheer visceral power of the explosion, which necessitated goggles, protective barriers, escape routes, and miles of distance to protect scientists from the results of their experiments. The restriction of weapons science to underground testing at the Nevada Test Site after 1963 allowed permanent control rooms to be established in which weapons scientists no longer watched the detonation itself but, rather, data presented on video screens and seismic monitors for confirmation of a successful test (see Figure 3). The explosion became almost totally mediated by technology. New prosthetic senses provided ever more precise and immediate information about the implosion as an experiment while insulating scientists from a direct physical perception of the blast and radiation effects. Consequently, a sensory appreciation of the power of the exploding bomb was increasingly displaced in favor of mechanical measurement. Some weapons scientists, for example, would rank their tests by comparison with recent naturally occurring earthquakes, whereas others would make a ceremonial visit to the crater produced by the exploding bomb to gain an appreciation of its scale (Bailey 1995:76; Gusterson 1996a:138). After 1963, weapons scientists would not know the yield of the explosion until days later, after radiochemical analysis of soil samples revealed the power of the event. This yield calculation was highly fetishized within the nuclear program, as the final number was important to military planners who might someday use the device. What could be appreciated at a glance, however, in the aboveground test regime (the scale of destruction) was in the underground regime a subject of retrospective analysis and reconstruction. The yield calculation might be able to produce an experience of the mathematical sublime for weapons scientists focused on the complexity of the explosion, but the answer it produced was simply a number, not a visceral understanding of the destructive power of the bomb in relation to the human body.

Figure 3. Nuclear test control room, Nevada Test Site (photograph courtesy of DOE Nevada).

Consequently, whereas an aboveground explosion was always an exciting spectacle and a marked event for weapons scientists, an underground detonation could be boring.[18] A number of scientists told me that the excitement, from their point of view, was in the build up to the experiment—the deadline-driven effort to drill the hole, build the test rack, and array it with custom-built detector equipment and coordinate the efforts of physicists, chemists, engineers, and construction workers (Los Alamos National Laboratory 1988; Wolff 1984). The intellectual excitement continued into the period after the test, when the data were in hand (sometimes days later). The sensory experience of an underground detonation (a monthly occurrence from 1963 to 1992) was the most predictable and normalized aspect of the experience. Thus, the underground test regime not only contained the radioactive effects of the bomb to the Nevada Test Site while shielding U.S. nuclear science from Soviet eyes, but it also worked overtime to make nuclear explosions routine.[19]

For Los Alamos weapons scientists, the technoaesthetic reinvention of the bomb during the underground test regime was enhanced by two factors: (1) new arms control treaties, and (2) the commitment to designing an increasingly ''safe'' nuclear arsenal. In 1970, the United States signed on to the Nuclear Nonproliferation Treaty, pledging to eliminate its nuclear arsenal at the earliest opportunity (formally designating nuclear weapons as only a temporary solution to the global crisis). Then, in 1974, the Threshold Test Ban Treaty prohibited all U.S. and Soviet nuclear tests over 150 kilotons. Neither treaty, in practice, prevented the United States from continuing to design and deploy weapons, even those with a destructive force greater than 150 kilotons. After 1974, weapons scientists simply did not detonate any nuclear devices above that limit. Instead, they devised a multiple-yield capability for nuclear weapons that could be determined prior to detonation, allowing testing at lower yields (see Garwin and Charpak 2001:65). Thus, by the mid-1970s, weapons scientists were ''perfecting'' military technologies that were never experimentally tested in the ways they would actually be used during a nuclear conflict. The last addition Los Alamos scientists made to the U.S. nuclear arsenal, for example, was the W-88 warhead. As many as 12 of these warheads, each possessing a yield of 475 kilotons (or over 30 times the size of the Hiroshima bomb; see Hansen 1988:206), can sit atop a Trident II missile.[20] As the state-of-the-art Los Alamos warhead, the W-88 is currently deployed on Trident submarines, the first leg of the always-on-alert U.S. nuclear triad. Yet the W-88 has never been tested at its full explosive power, and the United States has conducted only one full-sequence launch and detonation of a missile and nuclear warhead combination.[21] I do not mean to suggest that the W-88 is not a viable weapon or that a single Trident submarine (as of 2001, carrying 24 missiles, each armed with eight warheads, capable of simultaneously destroying 196 targets or cities) is not the most destructive military machine ever devised. What I am suggesting is that the technoscientific production of ''certainty'' that had characterized the goal of Los Alamos weapons science since the Trinity test has, over time, developed an increasingly virtual dimension: first, because after 1963 nuclear devices could not be tested in the way they would actually be used, which meant that military planners had to trust the expertise of Los Alamos scientists about how a Los Alamos–designed bomb would perform in a war; second, as Galison (1996) has shown, the increasing sophistication of computer simulation techniques encouraged theorists within the weapons program to confuse how their mathematical model of the bomb performed with the actual machine. In other words, the experimental proof of nuclear testing—the detonation that registered for a global audience the power of U.S. nuclear technology—became only a partial demonstration of that power after the mid-1970s. The shifting experimental form of Los Alamos weapons science increasingly separated scientists from a full sensory or cognitive experience of the explosive power of the bombs they designed and maintained.

The underground test regime was also devoted to making the bomb, in the language of the nuclear complex, ''safe, secure, and reliable,'' that is, making deployed nuclear weapons safe from accident and theft, as well as perfectly able to deliver a specified amount of destructive force if used in combat. Inventing a ''safe and secure'' nuclear weapon during the Cold War involved adding Permissive Action Links (which prevent unauthorized use) and Enhanced Electrical Detonation Safety Systems (which prevent a lightening strike from accidentally detonating a nuclear weapon), using Insensitive High Explosives (which are much less likely to explode in an accident), and performing ''one-point'' tests (which insure that a nuclear device would not produce a nuclear yield if just one of its explosive charges ignites; see Garwin and Charpak 2001:77). As one senior Los Alamos weapons scientist told me, this Cold War pursuit of safety now presents serious technical challenges, as the complexity of the nuclear devices could make them temperamental over time, ultimately allowing ''safety'' to undermine ''reliability'':

> The problem is we've overdesigned our weapons for safety reasons. It's part of the craziness surrounding nuclear weapons and there is a lot of that. For example, we were ordered to take beryllium out of nuclear weapons because it's a poison. Now think about it, you're worried about the health effects of a bomb that is in the megaton range! Today you could shoot a bullet through a weapon, light it on fire, drop it out of a plane, and it still won't go off or release its nuclear components. We developed a form of high explosive that will just barely go off as well. We also worried about how to prevent a weapon falling into the wrong hands—so we designed elaborate security systems and codes on each device that prevent that. Today these weapons will just barely detonate they're so complicated.

These weapons will just barely detonate they're so complicated. The problem now is not the exploding bomb that threatens the human body but, rather, the dud—the bomb that is too ''overdesigned'' to explode. Thus, while expanding the destructive power of the bomb and miniaturizing its form factor for missile delivery to any part of the planet in under 30 minutes, many Los Alamos scientists during the last decades of the Cold War were more self-consciously producing ''safety'' than unprecedented destructive power: safety in the form of a nuclear deterrent produced by nuclear devices that were highly optimized against accidental detonation and for military command and control. Each underground nuclear test was, thus, a highly productive event: It produced a community of expertise, as Hugh Gusterson (1996a, 1996b) has argued; it also created ''confidence'' in the viability of the U.S. arsenal, making each device a complex experimental area in which deterrence, safety, and the aesthetic beauty of a highly optimized design were realized in the same explosive act.

I have argued here that changes in the experimental regime of Cold War nuclear weapons science have produced profound changes in the epistemic culture of the laboratory, most readily visible in the technoaesthetics of weapons science. The achievement of aboveground testing was to invent the atom and hydrogen bombs and weaponize their form; it was also to dramatize the destructive power of these technologies in a way that brought their military reality home to all viewers. The achievement of the underground test regime was then to systematically eliminate those disturbing aspects of the bomb—nuclear fallout as well as blast and radiation effects—from public view, allowing the challenge of weapons science to lie in perfecting the bomb as a complex technology. The underground regime contained the bomb both physically and cognitively, allowing the process of conducting weapons research to be increasingly abstracted from the military reality of the technology. The difference between testing the explosive power of the bomb on a model U.S. community in the midst of a nuclear war fighting exercise in 1955 and engineering a ''safe and reliable'' nuclear device through underground testing in 1975 is conceptually important and reveals a deep domestication of the technology by the end of the Cold War. This cognitive shift is not readily apparent in the discourse of nuclear policy, which has always positioned the bomb as a tool of international relations, but is immediately visible in the technoaesthetic evolution of weapons science. Experienced through prosthetic senses, the bomb produced by underground testing became a philosophical project within the laboratory, increasingly linked not to mass destruction or war but to complexity, safety, and deterrence, allowing new generations of scientists increasingly to invest in nuclear weapons as a patriotic intellectual enterprise to produce machines that could only prevent conflict.

The Soviet nuclear threat provided a counter to this ideological construction of the bomb within the laboratory, threatening discourses of deterrence and pure science with the possibility of a real war. The post–Cold War period is, consequently, the only time in which Los Alamos weapons science has not been justified in relation to an arms race. As I shall show, the post–Cold War experimental regime extends the aesthetic project of nuclear weapons science in new ways, eliminating not only the human body but also the nuclear explosion from the space of the experiment. In post–Cold War Los Alamos, each nuclear device has been purified of its destructive potential, allowing weapons scientists to approach the bomb as a complex universe of material science and virtual representations that offer potentially endless technoscientific pleasure. In other words, the bomb has been reinvented in Los Alamos in ways that free its aesthetic possibility from its destructive potential, finally allowing the bomb to cease being a bomb at all.

The Science-Based Stockpile Stewardship regime (1995–2010): On virtual bombs and prosthetic senses

In Los Alamos, the post–Cold War period began not with the end of the Soviet Union but with the cessation of underground nuclear testing and nuclear weapon design work in 1992—an experimental regime and conceptual project that had defined generations of weapons scientists.[22] The Clinton administration's subsequent support for the Comprehensive Test Ban Treaty (CTBT; signed in 1996 but voted down by the Senate in 1999) committed the weapons laboratories to maintaining the existing U.S. nuclear arsenal, as well as their nuclear weapons expertise, without conducting nuclear detonations.[23] The new experimental regime devoted to this task in Los Alamos was dubbed ''Science-Based Stockpile Stewardship'' (SBSS), an effort to maintain the Cold War U.S. nuclear arsenal through a combination of subcritical and nonnuclear explosive testing, a fleet of new experimental facilities, archiving Cold War experimental data, and modeling the combined insights on state-of-the-art computer simulations.[24] SBSS was conceived in 1995 as a 15-year project with a projected cost of $4.5 billion a year—making it significantly more expensive than the Cold War project of nuclear weapons design and testing it replaced.[25] As an experimental regime, SBSS is not only an effort to maintain U.S. nuclear weapons under a test ban but also a programmatic effort to reconstitute the pleasures of conducting weapons science for nuclear experts confronting a radically changed mission. As I shall show, SBSS fundamentally alters the material form of Los Alamos weapons science, promoting a different concept of the bomb while reconfiguring sensory access to its destructive potential.

A deputy director of nuclear weapons technologies at Los Alamos offered this concise explanation of the consequences of the shift from underground nuclear testing to the ''science-based'' model for maintaining the U.S. nuclear arsenal:

> For 50 years the Nuclear Weapons Program relied on nuclear testing, complemented by large-scale production, to guarantee a safe and reliable stockpile. New weapons were designed, tested, and manufactured on a regular basis. If the surveillance program discovered a defect, its significance could be established by nuclear testing. If the defect was serious, it could be repaired by the production complex. Even if the defect was not significant, the weapon was likely to be replaced by a more modern system in only a few years. As the stockpile ages far beyond its anticipated life, we can expect a variety of defects which will break the symmetries which were used in the design process. This means that weapons gerontology is far more challenging than designing new weapons. We are sometimes accused by anti-nuclear activists of wanting [new] facilities ... in order to design new weapons. My answer is that we know how to design new weapons. But we do not know how to certify the safety, reliability and performance of weapons as they age. Thus the SBSS challenge can be stated quite simply: ''since we can't test them, we will have to understand them at a fundamental level.'' [Smith 1995:1]

Weapons gerontology is far more challenging than designing new weapons. Instead of continuing the evolution of the bomb through new warhead designs, weapons scientists have become gerontologists, involved in studying how nuclear weapons age. Whereas the Cold War experimental regime was based on the planned obsolescence of each weapon type (and an accelerated timetable of development), the SBSS program is designed to keep the current U.S. nuclear arsenal viable indefinitely. If the Cold War program speeded up time through constant production, as scientists rushed from one test to the next, the immediate post–Cold War project became to slow down time, to prevent nothing less than aging itself. The first articulations of the SBSS program seemed to hope for a kind of technological cryogenics in which both bombs and the knowledge of bomb makers could be put into a deep freeze at 1992 levels, to be thawed in case of future nuclear emergency. The inability, however, to stop time completely in Los Alamos—to keep bodies and machines safely on ice—promoted ''aging'' as the major threat to U.S. national security after the Cold War. The arms race may be on hold in post–Cold War Los Alamos, but a new race against time is at the center of the laboratory's nuclear mission, a programmatic effort to endlessly defer a future of aged, and perhaps derelict, U.S. nuclear machines.

The vulnerable body, carefully scripted out of the Cold War experimental regime of underground testing, has also returned to the discourse of Los Alamos scientists. But the body in question is not the human body threatened by the exploding bomb; it is the bomb itself as fragile body, exposed to the elements, aging, and increasingly infirm. Within this post–Cold War program of weapons gerontology, nuclear weapons have ''birth defects,'' require ''care and feeding,'' ''get sick'' and ''go to the hospital,'' get regular ''checkups,'' ''retire,'' and have ''autopsies.'' Individual weapons systems are now undergoing formal ''life extension'' projects, and new regimens of surveillance and component replacement extend the viability of the oldest weapons in the U.S. nuclear arsenal past their planned deployment. This use of productive bodily metaphors for supremely destructive technologies, which runs throughout the U.S. nuclear project, has always been part of the larger cognitive process of domesticating nuclear technology and giving machines a ''life course''—literally, translating nuclear weapon time into human time.

A strategic confusion of bodies and machines is a common technoaesthetic technique for internally controlling the meaning of laboratory work (see Knorr-Centina 1999; Traweek 1988). Within the nuclear complex, however, there is an added political consequence from confusing the animate and the inanimate and deploying highly gendered categories for massively destructive technologies.[26] Carol Cohn (1987) has demonstrated that the expert discourse of defense intellectuals grants military machines and not people agency, making it linguistically impossible to represent the victims of military technology. And Gusterson has shown in his study of Lawrence Livermore National Laboratory that, when weapons scientists use birth metaphors to describe the bomb, they use ''the connotative power of words to produce—and be produced by—a cosmological world where nuclear weapons tests symbolize not despair, destruction, and death but hope, renewal, and life'' (1996b:145). But, although a combination of technoaesthetic discourse and successful experiments is the key to producing a ''community'' of experts, it is also important to underscore what is evacuated from the project of nuclear weapons science by these techniques and to recognize the project's historical transformation in the post–Cold War period.

When Edward Teller announced the first successful detonation of a thermonuclear device in 1952 by cabling his Los Alamos colleagues ''It's a boy'' (see Ott 1999), he was not only linguistically transforming the most devastating force yet achieved into a purely productive event, but he was also deploying an image of the human body to enable the complete evacuation of people and the environment from the space of the experiment. At a yield of 10.4 megatons (500 times the bomb that destroyed Nagasaki), the ''Mike'' device vaporized the island of Elugelab, creating a fireball 3.5 miles wide and sending a radioactive cloud 20 miles into the sky, contaminating a 100-square-mile area around the Marshall Islands (see Hansen 1988:58–61; Ott 1999; Rhodes 1995). By describing a thermonuclear detonation through procreative and masculine metaphors (presumably a ''girl'' would not explode), weapons scientists were not only positively valuing their achievement as a form of creation but also working to linguistically contain the destructive reality of the event. The act of describing an exploding nuclear weapon as a biological being endows that machine and process at the level of discourse with sentient characteristics and empathic possibilities, allowing both a misrecognition of the relationship of the bomb to the human body and a powerful technoaesthetic identification with the technology. But if the Cold War discourse produced an image of the bomb as invulnerable body (the ''boy'' that can vaporize islands faster than a ''shake of a lamb's tail''), the post–Cold War discourse has reversed the conceptual circuit of this logic, offering an image of the masculine bomb–body as senior citizen, so aged and weak as to be unable to perform. No longer the ''baby boy,'' the bomb is now structurally positioned at the end of its life course, as the ''old man,'' struggling against the progression of time and failing faculties. What is important for my purposes here is not the technical accuracy or political strategy of deploying this allegorical form to communicate the challenges of SBSS within the laboratory. Rather, by attending to the technoaesthetic production of the bomb, one can see an important transformation in the everyday logics of laboratory life, as weapons scientists have become more directly concerned with protecting the vulnerable weapon of mass destruction from a catastrophic future than with protecting the human body.

Indeed, under SBSS, a sensory engagement with the bomb produces not fear of the explosion but, rather, an increasing concern about the viability of the machine as an embodied aesthetic form. The cornerstone of SBSS is a surveillance regime devoted to identifying how time and the elements are influencing each device in the U.S. nuclear arsenal. Every year, 11 warheads from each of the nine deployed U.S. weapons systems are pulled from submarines, missile silos, bombers, and weapons storage and subjected to component-by-component inspection and testing (U.S. Department of Energy 1998, 1999). Nuclear weapons have between 6,000 and 7,000 parts, and under SBSS each part of each weapon has a specific inspection program devoted to it (Medalia 1994, 1998). Here, for example, is how one weapon scientist describes the post–Cold War project of ''detonator surveillance'':

> First we do a visual inspection to see how the detonators fared in the stockpile. Then we check the circuit resistance of each detonator cable assembly and compare that to the resistance measures when the detonator was first manufactured (yes, each one—and there are a lot of detonators). We x-ray all detonator cable assemblies in three views to check for voids, inclusions, cracks, or any other anomalies. We disassemble some of the detonators so we can visually inspect the subassemblies. We do chemical tests on the powders and perform scanning electron microscope and x-ray fluorescence spectroscopy inspections of the inner parts. Some of the detonators are recertified and sent to the Weapons Evaluation Test Laboratory at Sandia/Pantex. There the detonators are test fired in conjunction with a real weapons fireset, simulating a full-up firing system test. The rest of the detonators are test fired here at our war reserve facility. We use a rotating mirror camera to record when the outbreak of light from each detonator occurs and compare that time to the start time of the firing pulse. This measurement, called transit time, must meet strict specifications. We also measure the simultaneity of the breakout of light from the detonators. The collected data are compiled and given to the design agency, which then compares the present condition and behavior of the detonators to those as-built and tracks any trends in the data (or changes due to aging). The design agency then issues a report that ultimately contributes to the weapons system certification. [Los Alamos National Laboratory 2000:4–5]

The production of scientific rigor here, in the recitation of inspection regimes, achieves fetishistic status, as scientists search for signs of aging in Cold War technology and wonder about how minute changes (cracks and abrasions) in individual components might affect the performance of each U.S. nuclear device during a war. Although this inspection regime prioritizes surveillance, the problem of maintaining the U.S. arsenal has been reduced in some cases to the availability of specific components and materials. For example, after Dow Corning stopped making its Silastic S-5370 RTV Foam and its 281 Adhesive, weapons scientists devoted years to studying how a change in either the foam or adhesive used in a nuclear device might affect its performance (Los Alamos National Laboratory 1996:2). Figure 4, from the *1998 Stockpile Stewardship Plan* (U.S. Department of Energy 1998), displays how this program of surveillance is designed to produce, out of the material analysis of component parts (depicted here as jigsaw puzzle pieces), an ''integrated bomb''; however, the integrated bomb produced by SBSS is not one that explodes but one that can be identified as ''safe and reliable.'' Thus, the Cold War world of weapons science, which was energized by regular nuclear detonations and the arms race, has been reduced for some weapons scientists to a long-term analysis of the compressibility of pieces of foam over time and an unending

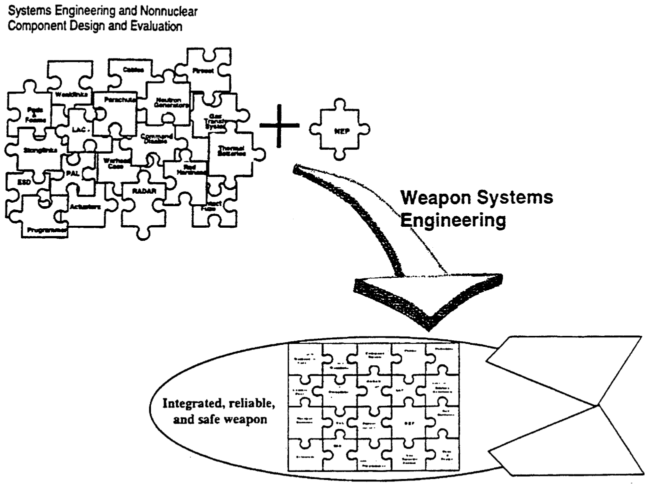

Figure 4. Integrated bomb (from the 1998 Stockpile Stewardship Plan).

surveillance of aging machines. Although this might seem a simple progression from the nuclear sublime to the nuclear banal, the logics behind the SBSS program are more complicated than they first appear.

If the Cold War project was simply to get new nuclear weapons to function as expected (i.e., to explode on time and with the expected scale and not to explode at any other time), SBSS has promoted the question of aging in weapons as an opportunity for new kinds of basic scientific research. Rather than designing new nuclear devices to fit new military specifications, as they did for nearly a half century, weapons scientists are now working to model all of the complex nanosecond processes that occur within a nuclear detonation. The formal goal of SBSS is to understand how aging effects on any single component might alter safety and performance over decades of storage.[27] But, given the extreme pressures, velocities, and temperatures operating within a nuclear implosion–explosion, this effort to model the bomb also promises a new and more nuanced understanding of how a variety of materials behave in extreme conditions. The SBSS program promises weapons scientists the opportunity to replace nuclear production with what a former head of the Los Alamos weapons program has called the ''holy grail of nuclear weapons theory'' (Hopkins 2000); namely, a ''first-principles'' understanding of nuclear processes. As an experimental regime, the intellectual appeal of SBSS is that weapons scientists can pursue the kinds of questions that would allow a totally scalable understanding of what happens inside a thermonuclear blast, a generalized model applicable to all weapons systems. Because a first-principles understanding of nuclear weapons is not necessary for producing a nuclear arsenal (as the Cold War arms race demonstrated), the decision to pursue the ''equations of state'' for U.S. nuclear weapons is an explicit effort to make nuclear weapons science compelling to scientists, to reenergize their nuclear imaginary in the absence of nuclear detonations and the arms race.

This focus on the component-by-component status of the U.S. nuclear arsenal has transformed the bomb from a device that explodes into one that provokes a vast array of scientific questions about the behavior of plastics, metals, and nuclear materials over time. Uncertainty about the aging bomb–body has been mobilized, in other words, to turn each U.S. nuclear weapon into a potentially endless universe of basic questions about material science. I asked one weapons scientist if the known aging problems in the U.S. arsenal would simply reduce the yield or if they could actually stop a nuclear device from detonating. He responded:

> It is the latter case. Because of the specific details of how the weapon functions, and this energy amplification, this is not a gradual reduction in yield. If the primary doesn't achieve sufficient energy output, it will not light the secondary. So we're talking about cliffs here not gradual slopes. That's an important point—any further detail needs to get into weapons design and function [and is classified]. By the way, that's a terrible limitation to a discussion in an open society. I read things in the newspaper: The activists say, ''We know everything we need to know about weapons''; I've seen members of the Senate stand up and say, ''We can just model it on the computer''—and I just want to tear my hair out. No! It's just factually wrong. We don't understand everything there is to know about basic properties. This is a good example: how does plutonium experience a known aging effect—that is, the growth of helium into the material from the radioactive decay—which could potentially change its property. Now what stockpile stewardship is having us do is take old plutonium and measure the compressibility, and then compare it with plutonium that is not aged. And then by knowing the physics, we put it in computer code (using the Accelerated Strategic Computing Initiative), and calculate just how old the plutonium can get before it unacceptably degrades the performance. So that, in a nutshell, is how stewardship works—but we had to invent the tools to measure all that compressibility. What I've just described to you explains why we are doing all these experiments in Nevada. You've heard of subcritical experiments at the UA1 facility? That's exactly what we are doing in Nevada—measuring the compressibility of plutonium.

We don't understand everything about basic properties. As I have argued, each new experimental regime in Los Alamos has produced not only new kinds of knowledge but also a new concept of the bomb. In this presentation the definition of an exploding bomb is one that reaches its assigned, militarily valued yield. A device that only ignites its ''primary''—the atomic bomb used to trigger a thermonuclear reaction, which might easily produce a yield similar to the Hiroshima bomb—is a total failure.[28] Moreover, a first-principles understanding of nuclear technology produces not a bomb that actually explodes but, rather, a deep understanding of how plutonium behaves over time and under extreme conditions. There is no need to worry about the human body in this experimental regime, as there are only nonnuclear detonations occurring in Nevada, which are constituted as basic experiments in exotic material science. The nuclear weapon produced by SBSS is one that primarily exists in component parts, each framed by a discourse of uncertainty about aging, and the military value of each nuclear device is produced not by an explosion but through a high-tech inspection.

During the Cold War, Los Alamos scientists talked on occasion of designing what they called a ''wooden bomb,'' a simplified and superrobust nuclear device that could be left on the shelf for many decades with no threat to its performance as a weapon (Hansen 1988). These experiments were consistently put off in favor of experiments exploring state-of-the-art concepts and exotic (and thus more volatile) materials, as Los Alamos scientists assumed that nuclear testing would not end. Weapons scientists were consequently caught off guard by the test moratorium of 1992, which left one Los Alamos test tower half completed in the Nevada desert. Weapons scientists also worked at such a pace during the Cold War that they did not maintain detailed records about their experimental successes and failures in Nevada. As a result, one of the first SBSS projects was an effort simply to archive the knowledge that was produced by the Cold War nuclear complex, to record for posterity how to conduct underground nuclear detonations and build a highly optimized nuclear arsenal. By interviewing Cold War weapons scientists and following the existing paper trail about U.S. nuclear weapons through office safes and file cabinets scattered throughout the laboratory, the Los Alamos Nuclear Weapons Archiving Project is the first effort to formally document the explicit as well as the tacit knowledge about how to produce the bomb.[29] This historical assessment, as well as the new experimental knowledge produced by SBSS, will be consolidated in a new computer archive, which represents the first centralized database for the U.S. nuclear weapons program (see Stober 1999). The archiving project underscores that, from 1945 to 1992, confidence in the nuclear arsenal (for officials in Los Alamos; Washington, D.C.; and internationally) was produced by the regular detonation of nuclear devices, not simply by the existence of nuclear experts. In the post–Cold War period, however, certainty comes not from an explosion but from a process of certification—a yearly report from the directors of the national laboratories stating that they see no reason why the U.S. nuclear arsenal would not function as planned during a nuclear war. Although experimental ''certainty'' and ''certification'' may be different experimental and political concepts, one should remember that through the second half of the Cold War the United States was routinely deploying weapons that had not been tested in the ways in which they would actually be used in a nuclear war, and the nuclear device that destroyed the city of Hiroshima in 1945 was never tested prior to its military use. Thus, the current pursuit of a first-principles understanding of nuclear weapons, although promising a host of new insights into how materials behave at extreme temperatures, pressures, and velocities, marks a significant change in the technoaesthetic construction of the bomb. Put simply, within the post–Cold War order, the bomb is being evaluated not on its ability to be perfectly destructive but, rather, on the perfectibility of its form.

Nuclear weapons science has always been a compartmentalized experimental project in the United States, in which the rules of state secrecy as well as the division of expertise among theorists, physicists, chemists, and engineers have divided the bomb into a series of discrete experimental projects. The detonation of a nuclear device during the Cold War thus involved coordination of a vast array of scientific experiments distributed throughout the laboratory, which together constituted the technology as both a military machine and the material form of mutual assured destruction. Under SBSS, the bomb is equally compartmentalized, but there is no unifying moment in which the destructive power of the bomb is visible, in either an explosion or aftereffects, such as a desert valley pitted with test craters. In the absence of the arms race, as well as any material trace of the destructive power of the bomb, the SBSS focus on first principles fragments the bomb into a series of basic science questions that have no direct connection to the military reality of nuclear weapons. In post–Cold War Los Alamos, the bomb is, consequently, many things but rarely a weapon of mass destruction. Consider, for example, how weapons scientists describe the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT), a key tool in the SBSS regime for studying the effects of aging on the U.S. stockpile. When completed, DARHT will focus 40 billion watts of power in a 60-billionth-of-a-second (or 60-shake) burst to produce a three-dimensional x-ray image of a mock nuclear weapon primary during the implosion process (Los Alamos National Laboratory 2001:9). In the mid-1990s, project managers explained the need for DARHT through a variety of medical analogies, most prominently describing the explosives test facility as a ''hospital for sick bombs.'' A former director of the Los Alamos nuclear weapons program suggested in a public hearing that the United States needed DARHT to allow ''an assessment of the weapons we have before they get older—kind of like a CAT-scan baseline before someone develops heart disease—as [in the future] we might have to give these weapons a new heart'' (author's field notes). Mapping contemporary nuclear weapons science alongside modern heart transplant surgery, the bomb gains not only an organic form in this discourse but also an explicitly fragile (rather than a destructive) body. In post–Cold War Los Alamos, nuclear weapons are also frequently compared to a garaged automobile, often an ambulance that might not be able to start if one needed to race to the hospital in ten or 20 years. And, as Jo Ann Shroyer learned from one weapons scientist, a nuclear weapon under stockpile stewardship is also like a fire extinguisher before an emergency: ''There's a fire and you have twenty fire extinguishers sitting there. You have a pretty good chance of finding one that works and you're going to put out the flames. But if you have only one fire extinguisher, you're going to want to test that thing, understand how it works, and make sure it's recharged'' (1998:25). This analogy, although focusing on the problem of knowing how and when a machine will work, also does the technoaesthetic work of transforming a nuclear weapon—whose central effect is the production of an explosion and massive fireball—into its opposite: a fire extinguisher.

An SBSS exhibit in the Bradbury Science Museum, which is the primary public space at Los Alamos National Laboratory, pushes this technoaesthetic project further, suggesting that a nuclear weapon is like a 911 emergency call (see Figure 5). The exhibit asks visitors to: ''Pretend that this phone is going to be used by your local 911-emergency operator. Can you test it and verify that it will work whenever it is needed? There is one important rule. You are not allowed to make or receive a call to test it.''

The exhibit, then, invites visitors to check the dial tone, to press the keys and listen to the key tones, as well as to test the ringer. It then asks, ''Are you confident that this phone will work if needed for an emergency?'' and gives visitors a chance to vote on whether the phone could successfully complete a 911 call or not. Dramatizing the technical problem of how to maintain nuclear weapons without actually detonating them, the exhibit attempts to normalize the destructive power of the U.S. nuclear arsenal not as the instrument that threatens the human body but, rather, as an institutional emergency response that attends to physical trauma—as ambulance, fire truck, or police action. Unlike the 1950s experimental regime, in which the exploding bomb was tested on ambulances, fire trucks, police cars, and living beings to understand the physical effects of a nuclear attack, the bomb produced by SBSS can only be conceptualized as the institutional response to violence, not as a means of enacting it. Weapons gerontology thus promotes an image of the aging bomb as body to mobilize a new kind of nuclear fear: fear not of the bomb that explodes but of the bomb that cannot.

Figure 5. Science Based Stockpile Stewardship exhibit, Bradbury Science Museum (photograph by Joseph Masco).

This effort to underscore the fragility of nuclear weapons alongside the vast opportunities for basic research in the materials science through SBSS is, in part, tactical; for, despite the rhetorical and technoscientific attention to aging weapons, the most profound question of aging at Los Alamos pertains to weapons scientists themselves. By the mid-1990s, the average age of Los Alamos weapon scientists in X Division, which is responsible for nuclear weapons design work, was over 50 years old.[30] Thus, just about the time when the last weapon in the current U.S. stockpile is going to exceed its planned design life in 2010, the last remaining weapons scientists with underground test experience are likely to be retiring. The SBSS program is consequently orchestrated around that 2010 date, when a whole generation of bombs and expert bodies are scheduled to simultaneously retire. As a result, the weapons laboratories have started a graduate program for new recruits who enter the weapons program knowing they are unlikely to ever conduct a nuclear detonation. A new academic program at Los Alamos—the Theoretical Institute for Thermonuclear and Nuclear Studies (or TITANS)—provides postdoctoral training in weapons physics for Los Alamos recruits who in previous experimental regimes would have undergone a multiyear apprenticeship with senior weapons scientists (Los Alamos National Laboratory 1997:3; see Gusterson 1996a). The more immediate question, however, is not how do you train the bodies once you have them in the program, but how do you get bodies into the program in the first place? After all, without an active nuclear weapons design project, it is difficult to sell a career in nuclear weapons physics–gerontology to new Ph.D.s, who are now more familiar with post–Cold War security scandals at Los Alamos than with the pleasures of conducting nuclear weapons science.[31]

One of the immediate goals of the SBSS program is, therefore, to build a state-of-the-art infrastructure of experimental laboratories at Los Alamos and Lawrence Livermore National Laboratories that will be enticing to a new generation of scientists and counter the banality of yearly surveillance reports with cutting-edge science. If the Cold War nuclear project was devoted to producing new generations of bombs, the post–Cold War project is to produce a new generation of nuclear weapons scientists capable of tending to those bombs. To this end, the Department of Energy has committed to maintaining the fastest supercomputers in the world at the national laboratories through 2010.[32] The Accelerated Strategic Computing Initiative (ASCI) is intended to be a key tool not only for studying aging effects in nuclear weapons and pursuing a first-principles understanding of nuclear processes but also for recruiting scientists into the weapons programs.[33] In 1999, Los Alamos maintained a supercomputer running at 1 teraOPS (i.e., capable of running one trillion operations per second), a 30-teraOPS system was under construction in 2001, and a 100-teraOPS computer was already on the drawing board. The goal of the ASCI program is to give weapons scientists over 10,000 times the computing power used to design the U.S. nuclear arsenal in the first place (U.S. Government Accounting Office 1999). Here the Cold War commitment to speed of nuclear production has been transformed into a post–Cold War pursuit of computational speed, manifested in the ability to render three-dimensional simulations of nuclear explosions in ever greater degrees of (temporal and spatial) resolution. The programmatic commitment to the ASCI program is not without controversy in Los Alamos; as one veteran of the underground test regime put it, the problem with simulation-based nuclear weapons research is:

> Truth. You can't test it. It might be highly precise but very inaccurate. Well, you can make a measurement very precise to four or five significant figures and because of something in your experiment it can be dead wrong. So your precision is very high, and your accuracy is very bad. So answers to questions are going to become more and more computational and hypothetical. Now there is nothing inherently wrong with that. We were getting more and more involved in simulating experiments before we would try them. The problem is that you lose sight of the fact that they are computational and not reality. So you start believing them. It becomes reality instead of being a virtual experiment.

It becomes reality instead of being a virtual experiment. The problem for post–Cold War weapons scientists is how to evaluate the meaning of the data produced by their various SBSS projects in relation to a military nuclear explosion. Without the ''truth test'' of the nuclear detonation to evaluate theoretical results, some senior Los Alamos scientists do not believe that future weapons scientists will have the right experimental expertise to properly evaluate U.S. nuclear weapons. Hardly a stable form, SBSS is simultaneously portrayed in Los Alamos as either a highly challenging means of perfecting nuclear technology or simply an economy of appearances, a discrepancy that could be mobilized as a rationale for a return to U.S. underground nuclear testing in the near future.

It is important to recognize, however, that the theory, the instrumentation, and the experimental method of Los Alamos weapons science have changed in the post–Cold War era (see Galison 1997). SBSS assumes that one can test the components and processes in a nuclear weapon separately and assemble a picture of the military performance of the device from the collected data. The Cold War program was focused on the detonation of the actual weapons system, with success judged by how accurately weapons scientists were able to predict and reproduce the explosive yield. The instrumentation of nuclear weapons science is no longer a combination of the nuclear device, test sensors, and radiochemistry but is, rather, a series of discrete hydrodynamic test facilities, nonnuclear material science studies, and computer simulations. And, finally, the experiment is no longer an earthshaking rumble in the Nevada desert registered on seismographs around the world but is now a virtual nuclear explosion simulated on the world's fastest computers located in air-conditioned buildings at Los Alamos, Lawrence Livermore, and Sandia National Laboratories. Gusterson (2001) has argued that the knowledge produced by a more virtual weapons program is currently ''hyperconstructible'' because it remains an uncertain experiment, currently producing three competing scenarios about the future of the U.S. nuclear program: (1) that new design work will continue and be enhanced by a state-of-the-art nuclear complex, which would allow the United States to break out of the test ban treaty with maximal nuclear superiority at some date in the future; (2) that a new ''virtual arms race'' could take place in which nation-states stockpile advanced simulation facilities and new weapon designs rather than actual bombs; or (3) that a ''virtual disarmament'' could inadvertently occur, as U.S. weapons scientists over decades lose key areas of ''tacit'' knowledge about how to build and maintain nuclear weapons. The range of possibilities here—from new forms of the arms race to the ''uninvention'' of nuclear weapons through atrophied expertise—is a register of the long-term uncertainty surrounding SBSS as an experimental enterprise and underscores the profound nuclear policy implications of the program (see MacKenzie and Spinardi 1995). There is, however, a potentially more foundational structural effect of SBSS over time, namely, that the professionals most immediately responsible for the U.S. nuclear arsenal will embrace the aesthetic appeal of SBSS so completely as to lose cognitive access to the terror of the exploding bomb.

In Los Alamos, the pleasures of nuclear science have always been at odds with the destructive potential of the military machine, requiring a conceptual mediation of the project to transform a weapon of mass destruction into a purely productive scientific enterprise. The experimental trajectory of Cold War weapons science, as I have shown, diminished sensory access to the destructive power of the bomb with the move to underground testing, which encouraged a technoscientific focus on the internal characteristics of the explosion, rather than on its material effects. The post–Cold War regime of SBSS has taken this conceptual mediation of the enterprise one step further by eliminating nuclear detonations altogether while reinvesting in weapons science on a new scale. One can begin to assess the cognitive effects of this transformation in one of the major achievements of post–Cold War weapons science: the completion in 2001 of the first three-dimensional computer simulation of a thermonuclear detonation. The simulation was jointly conducted on Lawrence Livermore National Laboratory's 12.3-teraOPS ASCI White and Los Alamos National Laboratory's 3.1-teraOPS Blue Mountain supercomputers. Using a new secured network connecting the weapons laboratories, Los Alamos scientists engaged the Livermore system from their home laboratory in New Mexico. The simulation ran for 122.5 days and involved 35 times the total information contained in the Library of Congress. According to the Los Alamos press release, it would take a state-of-the-art home computer 750 years to complete the calculation (see National Nuclear Security Administration 2002).

Although the scale and sophistication of this simulation constitute a remarkable achievement in computer science, what is more important for my purposes is how weapons scientists tactilely experience the experimental results (see Lawrence Livermore National Laboratory 2000). The three-dimensional simulation of the thermonuclear explosion is presented in the form of a movie, which is displayed in state-of-the-art ''visualization centers'' in Los Alamos. In these new SBSS facilities, scientists are positioned at the center of an ''immersive theater'' and oriented toward the Power Wall, which is the largest and most detailed projection screen on the planet. Standing in front of the 16-by-8-foot Power Wall, scientists are physically dwarfed by the microscopic processes that make up a simulated nuclear explosion, which are projected on a massive scale and in full color (see Figure 6). Some interfaces allow scientists to manipulate the simulation through use of a virtual-reality glove, and the national laboratories are all exploring ways of rendering nuclear simulations in ever greater temporal and spatial detail, as well as with more interactive possibilities. The goal of this project in Los Alamos is to provide a ''shake-by-shake'' portrait of the densities, pressures, velocities, and turbulence that make up a nuclear implosion–explosion and to be able to track all of these processes in three dimensions with perfect resolution. The first major achievement of the post–Cold War virtual laboratory is, thus, to have repositioned a nuclear explosion at the center of Los Alamos weapons science. This nuclear detonation, however, is experienced not through vulnerable human senses that need to be protected from the blast but, rather, through prosthetic devices that enable the body to interact with the simulated explosion within the safety of a secured room. The half-century progression from protective goggles (necessary to prevent flashblindness during an aboveground event) to virtual-reality gloves and goggles (needed to interact with the nuclear simulation) is the most significant evolution in the material form of Los Alamos weapons science, as this new experimental regime evacuates the destructive bomb entirely through a compelling new form of virtual embodiment.

SBSS ultimately promotes the possibility of a new kind of intimacy between scientists and the exploding bomb, allowing one to chart a logical conclusion to the multigenerational ''bomb-as-body'' concept in Los Alamos. Looking past 2010, if the 15-year project of SBSS is successful, Los Alamos weapons scientists will be able to evaluate and account for the significant gerontological issues in the nuclear stockpile as well as design new weapons in virtual reality with confidence that the systems would work if actually built and detonated. Thus, the last generation of Cold War weapons scientists will be retiring with most, if not all, of the fundamental questions about nuclear weapons answered. The technical knowledge drawn from a half century of U.S. nuclear testing, as well as the advanced material science and computational achievements of SBSS, will be archived in permanent form—securing the technoscientific legacy of the Manhattan Project. Moreover, the next-generation supercomputers, in combination with next-generation three-dimensional virtual-reality technologies, will complete the ongoing revolution in the body–bomb relationship for weapons scientists. Future weapons scientists will no longer interact with their experimental data via computer screens, which maintain a separation between the physical body of the scientist and the bomb as technoscientific project. Instead, the next-generation visualization center will fulfill what is clearly the conceptual goal of the current system, which places scientists at the center of a highly sophisticated virtual space. In the near future, Los Alamos scientists will track specific particles, velocities, pressures, and flows through new, technologically mediated, but nonetheless felt senses, and they will do so not from office chairs and via computer screens but from *inside* the nuclear explosion.

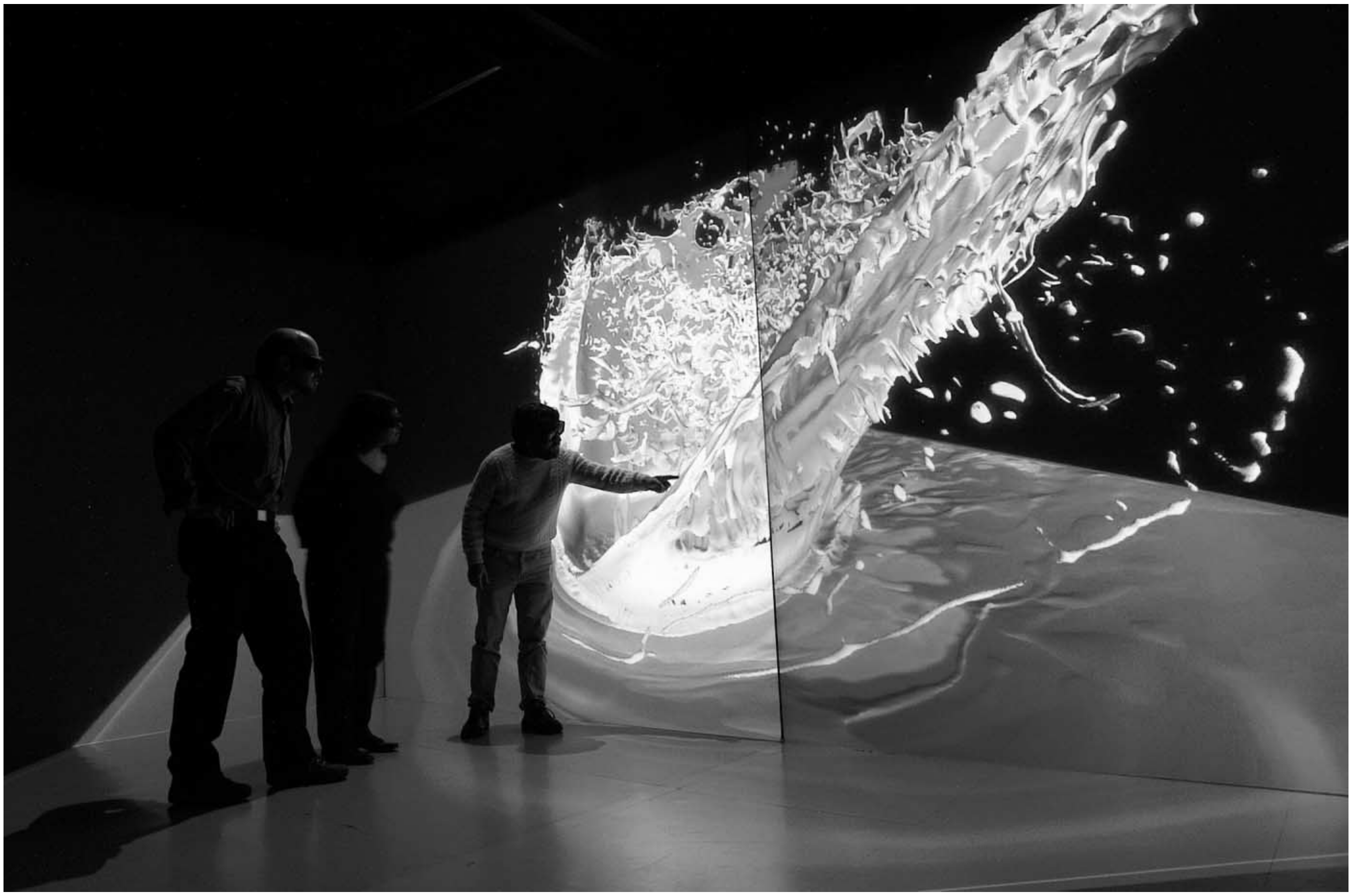

Figure 6. Power Wall three-dimensional computer simulation of meteor impact (photograph courtesy of Los Alamos National Laboratory).

The weapons laboratory of the early 21st century will ultimately allow weapons scientists to walk inside a virtual hydrogen bomb and experience the most extremely destructive force imaginable through physical senses that are not vaporized by the assault of the explosion but, rather, are tuned to the aesthetic properties of the simulation. The promise of SBSS is, thus, not only to perfect and indefinitely maintain nuclear weapons technologies through nonnuclear testing but also to resolve the multigenerational technoaesthetic confusion of bodies and machines in Los Alamos by creating a conceptual space in which weapons scientists and weapons of mass destruction can comfortably coexist—at the very moment of detonation. The bomb's new body is increasingly that of the weapons scientists themselves, as the intellectual pleasure of nuclear weapons science and a tactile sensory experience of the exploding bomb are being merged through a massively engineered technoaesthetic spectacle in virtual reality. The intimacy of this conceptual project—the desire to physically interact with a thermonuclear explosion in all its nanosecond and atomic detail—eliminates fear of the exploding bomb altogether in favor of a phantasmagoria. This flooding of the senses with virtual images of a detonating nuclear device reinvents the bomb as a purely creative project—more visible in its details, more compelling in its sensory form, and more attractive in its technoaesthetic performance than anything possible during the Cold War testing regimes. Purified of its military reality and its environmental effects in the virtual laboratory, the bomb that will ultimately be produced by SBSS will no longer be geriatric or living on borrowed time: It will have an expanding future horizon, making weapons science no longer a temporary political solution to the global crisis but an aesthetic project capable of existing finally on its own terms. To this end, the bomb as aesthetic project is already a highly developed discourse in the laboratory; consider, for example, how two successful implosion studies were recently described in the Los Alamos laboratory's publication *Dateline: Los Alamos*:

> Two explosions rock two mesas at Los Alamos. Separated by a couple of chilly fall days and 10

> miles, both experiments capture images of exploding objects very much like the primaries of nuclear weapons, absent the nuclear materials that produce criticality.
>
> Both are milestones in Los Alamos' efforts to focus the most sophisticated technology available onto its mission of maintaining the safety and reliability of an aging nuclear stockpile. And both experiments were looking for symmetry. Symmetry is beauty. Psychologists have found that the human eye judges a person attractive when it perceives symmetry in facial features. Los Alamos scientists and engineers also think symmetry is beautiful. Because without symmetry, nuclear weapons don't work. [2001:8]

Symmetry : implosion = beauty : human face. The pleasures of nuclear weapons science are being reinvented in post–Cold War Los Alamos through new experimental facilities that promise to free nuclear science from the politics of the bomb. This is a high-tech mystification, however, as the destructive reality of nuclear arsenals persists, despite and, in the future, because of this aestheticization of laboratory science.

Conclusion

The question SBSS ultimately poses, I would argue, is not how to maintain nuclear weapons as a technology—as machines—but how to maintain a conceptual understanding of what it means to detonate a nuclear device.[34] Through the shifting experimental regimes of Los Alamos weapons science, even those most directly responsible for building the bomb have mediated their access to the reality of massively explosive technologies in profound ways, transforming weapons of mass destruction into purely productive forms. In another decade, when the bomb is closer to a perfected technoaesthetic form—lovingly rendered in virtual reality by scientists who are generations removed from those who last experienced the heat, shock wave, and atmospheric effects of a nuclear detonation—Los Alamos scientists will certainly know much more about how a thermonuclear device operates than they did during the 1950s-era of nuclear testing in the Pacific. But who can argue that a computer simulation will offer the same level of conceptual understanding as did those aboveground detonations, in which the destructive power of nuclear explosions was experienced not only as intellectually powerful but also as brutally, terrifyingly destructive? This slippage between the virtual and the real, which started in Los Alamos with the first efforts to mathematically model nuclear explosions immediately after World War II and continued through the Cold War testing regimes (Galison 1996), threatens now to become the ascendant aspect of weapons science in the 21st century and the ultimate institutional compensation for the terror of the nuclear sublime.

This is not to suggest that U.S. nuclear devices capable of exploding with massive destructive force will not be deployed around the globe or to argue for a return to underground nuclear testing; it is, rather, to point out that the expertise necessary to maintain those machines is in danger of being separated from an understanding of the consequences of using the technology. What, in other words, will make a nuclear device *the bomb,* if its primarily evaluative sphere is not informed by a need to protect the human body from the explosion but, instead, by the aesthetic merits of a massively engineered three-dimensional simulation experienced from the comfort of a virtual space? An experience of the nuclear sublime provoked by an aboveground nuclear detonation involved a moment of terror that was ultimately resolved for scientists through an intellectual compensation, allowing the project of nuclear weapons science to continue. The need to manage terror at the center of the enterprise, however mediated, gave scientists momentary access to the possible real-world effects of their technoscientific work. SBSS, as an experimental regime, blocks access to any visceral understanding of the power of the U.S. nuclear arsenal, replacing it with sophisticated material science questions and a virtual spectacle, which together offer only complexity and aesthetic pleasure. The beauty of nuclear weapons science in Los Alamos has always been one of its most dangerous elements, allowing an aestheticization of scientific knowledge to circumvent the political import of engineering weapons of mass destruction. In his 1936 critique of the Italian Futurists' beautification of war and the machine body, Walter Benjamin argued that the movement revealed a ''sense perception that has been changed by technology'' and a European society on the eve of World War II whose ''self-alienation has reached such a degree that it can experience its own destruction as an aesthetic pleasure of the first order'' (1969:242). The atomic bomb is the U.S. response to forces unleashed at that moment of world crisis, and the current transformation of each U.S. nuclear device from a weapon of mass destruction into an opportunity for exotic material science and cutting-edge computer simulation advances the aestheticization of politics through a reconfigured sense perception to a new order for a new century. It is vital to recover the politics that SBSS works to erase, even as the future of the bomb in Los Alamos becomes no longer that of a bomb but, rather, of the United States' technoaesthetic spectacle *par excellence*.

Notes

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1. This is not to say that weapons scientists have not actively participated in U.S. nuclear policy debates; see Herken 1992, York 1995, and Broad 1992. Weapons scientists have also been instrumental in designing technologies for verifying nuclear treaties and for improving the command and control of nuclear weapons for safety purposes.

2. In Los Alamos, the post–Cold War period began on September 30, 1992, with the implementation of the Hatfield–Exon Amendment, which initiated a nine-month moratorium on U.S. underground nuclear testing (signed by President George H. Bush and then extended by President Bill Clinton).

3. Galison (1997) argues that laboratory knowledge is produced from the intersection of conceptual theories and questions, specific machines and instrumentation, and experiment designs. Each of these aspects of laboratory practice has a historical and ethnographic reality that can be studied as part of the expert process of producing scientific knowledge.

4. My argument builds on Susan Buck-Morss's (1992) suggestive rereading of Walter Benjamin's (1969) analysis of the cultural effects of mechanical reproduction. Buck-Morss argues that, although technology can extend human senses in radical new ways, it also opens the human sensorium up to new kinds of trauma. Industrial modernity, in her view, demands, therefore, not only a constant production of new technological forms but also a constant reconfiguration of human sensory experience to negotiate the shock of a technologically mediated world. In my reading of the Los Alamos nuclear program, *technoaesthetics* are aesthetics delivered through machines, constituting a specific fusion of appearance and utility.

5. See Traweek 1988 for an important discussion of the role of corridor talk in the professional development of high-energy physicists, and Gusterson 1996a and 1996b for ethnographic analysis of the training program and acculturation of a new recruit into the world of Cold War weapons science at Lawrence Livermore National Laboratory.

6. Conducting ethnographic research on issues classified under U.S. national security protocols presents certain challenges. I began this work in 1994, however, at the start of the first vibrant public debate in northern New Mexico over the historical effects and future mission of Los Alamos National Laboratory. At a time of post–Cold War uncertainty about the U.S. nuclear project, laboratory personnel were invested in presenting their views on the institution and its contributions to national security and the world. Simultaneously, via public hearings, through lawsuits, and by public protests, neighboring communities in New Mexico began challenging the laboratory over hiring, environmental cleanup, cultural impacts, and health concerns. By 2000, spy allegations and corruption charges at the laboratory had raised the stakes of public discourse within the laboratory, at which time I conducted interviews with key personnel under more formal arrangements with the laboratory. The material presented in this article is drawn from archival and museum-based research as well as extensive interviews with weapons scientists, laboratory staff, and federal officials over a six-year period.

7. For classic theoretical discussions of knowledge production within the cultural spaces of nonmilitary laboratory work, see Knorr-Centina 1999, Galison 1997, Galison and Hevly 1992, Latour 1987, Nader 1996, and Pickering 1992. For discussions of Cold War military science, see MacKenzie 1990, Edwards 1996, and Gusterson 1996a.

8. On the concept of the sublime, see Kant 1986 as well as Burke's 1993 rather different formation; for critical analysis of technologies and the sublime, see Nye 1994 and Klein 1993; for discussions of a ''nuclear sublime'' see Gusterson 1999, Ferguson 1984, and Wilson 1991; see also Canaday 2000 for a discussion of religious imagery during the era of the Manhattan Project.

9. For historical analysis of radiation exposures to U.S. military personnel during aboveground nuclear testing, see Ball 1986, Miller 1986, and Hacker 1994. For broader discussions of the health effects of nuclear testing see Gallager 1993, Kuletz 1998, Advisory Committee on Human Radiation Experiments 1996, Makhijani et al. 1995, and Makhijani and Schwartz 1998.

10. See Federal Civil Defense Administration 1955 and U.S. Department of Defense 1955; see also McEnaney (2000:54), who argues that Operation Cue was a ''public relations morality play'' designed to shift responsibility from the nuclear state to the individual citizen for civil defense. See also Ott 1999 and Oakes 1994 for discussion of civil defense during the 1950s.

11. The nonclassified record of this experimental project is *The Effects of Nuclear Weapons,* edited by Samuel Glasstone and Philip Dolan (1977), first published in 1950, with major revisions in 1957, 1962, and 1977. It documents how nuclear explosions conducted at high altitude, in the air, on land, and under water will affect buildings, equipment, machines, plant, animals, and people.

12. For critical analysis of U.S. popular culture during the era of aboveground nuclear testing (1945–63), see Boyer 1994, Franklin 1988, Henriksen 1997, Evans 1998, Weart 1988, and Shapiro 2002. For analysis of the antinuclear movement during this period, see Wittner's three-volume history (1993, 1997, and 2003), as well as Titus 1986 and Wang 1999.

13. From 1945 to 1952, Los Alamos scientists conducted all U.S. nuclear test detonations. After the creation of Lawrence Livermore Laboratory in 1952, tests were eventually divided evenly between the two weapons programs, which were fierce competitors throughout the Cold War; see Gusterson 1996a:24.

14. The United States did not conduct nuclear detonations in 1947, 1949, 1950, or during the test moratorium of October 1959 to September 1961. Outside of these periods, the U.S. test program was active from 1945 to 1992, conducting as few as one experimental test in 1945 (Trinity test) and as many as 96 in 1962. During the 348-month period of the underground testing regime (October 1963–September 1992) the United States conducted 717 detonations (695 U.S. plus 22 joint U.S.–U.K. tests) for an average of two tests per month. By the last decade of the Cold War, the United States was conducting between 11 and 18 tests per year; see U.S. Department of Energy 2000.

15. The 40-year progression from the Fat Man implosion device, which weighed 10,000 pounds and detonated with a force of 15 kilotons, to the Los Alamos state-of-the-art W-88 warhead, which weighs about 450 pounds and can produce a 475-kiloton explosion, is a significant engineering accomplishment. The W-88 is less than 1/22 the size of Fat Man but more than 30 times as powerful.

16. Effects tests continued throughout the underground test regime but were limited in scale and were devoted mostly to ''hardening'' parts from other military machines (such as nose cones, satellite parts, or communication systems) against blast and radiation effects; see U.S. Congress, Office of Technology Assessment 1989.

17. The number of detonations includes 2,051 nuclear tests (see National Resources Defense Council 1998) and the Hiroshima and Nagasaki bombings. Most estimates of the total explosive power detonated during World War II place it in the neighborhood of three megatons. If accurate, this means that just one of the larger U.S. thermonuclear devices carries as much destructive power as used during the entirety of World War II.

18. Gusterson quotes a Livermore weapons scientist, who said of underground testing: ''It's not like you're watching the old atmospheric test. I mean it's pretty benign really. You can see a shock wave ripple through the earth. It's a couple thousand feet under the ground. Nevertheless you see a ripple, and under the ground there's still a fireball and that material gets molten'' (1996a:138). Although the sensory experience of the underground test might not be very dramatic, the effort to understand the detonation itself focuses scientists on some of the most complicated physical processes achievable.

19. Underground testing did not achieve a total containment of the bomb, however, as nuclear tests vented radioactivity into the atmosphere on a number of occasions, creating fallout clouds that threatened test site workers and neighboring communities. Because of work at the Nevada Test Site, the United States is the most nuclear-bombed country on earth. See Gallager 1993 and Kuletz 1998 for analysis of the effects of testing on the environment and on neighboring communities.

20. President Nixon signed the Threshold Test Ban Treaty in 1974. The Senate, however, did not ratify it until 1990, as it was formally linked to other arms-control agreements negotiated during the 1980s. The United States and the Soviet Union, however, did not test over 150 kilotons after the mid-1970s; see U.S. Department of Energy 2000.

21. In May 1962, a Polaris A-1 missile was launched from the USS *Ethan Allan* in the Pacific as part of Operation Dominic; see Commission on Maintaining United States Nuclear Weapons Expertise 1999. See also MacKenzie 1990:342–345 for a discussion of the technological and political assumptions informing intercontinental missile targeting accuracy; MacKenzie points out that, despite never having undertaken a full-scale test during the Cold War (as to do so could have been interpreted as an act of war), the United States assumed its intercontinental missiles were accurate to within a few yards of their target. This assumption allowed ''counterforce'' targeting, in which U.S. weapons were targeted on Soviet weapons, enabling a major escalation in the arms race.

22. There is a debate in the United States over what constitutes a ''new'' nuclear design. Within the national laboratories, a new nuclear design is one that involves a new physics package and that has entered into the seven-step production cycle for military deployment. Critics of the nuclear program tend to define a new nuclear weapon as any change in the military use of a nuclear device. In the 1990s, for example, Los Alamos scientists changed the casing of the B-61 bomb to give it a greater ''earth-penetrating'' ability. For weapons scientists, this change did not constitute a new design, but for many in the disarmament movement, this modification demonstrated that even under a CTBT, the United States is committed to finding new uses for nuclear weapons; see Mello 1997 as well as Paine and McKinzie 1998b.

23. President Bill Clinton signed the CTBT in 1996. The U.S. Senate voted down the treaty in 1999, although the terms of the treaty remain in effect. The directors of the Los Alamos and Lawrence Livermore National Laboratories can challenge the test ban at any time Science-Based Stockpile Stewardship (SBSS) produces uncertainty in their minds about the military performance of the U.S. nuclear arsenal. In addition to the question of reliability of the nuclear arsenal, the CTBT debate in the Senate focused on the verification of foreign nuclear tests and raised a series of questions about whether on not the United States could detect deeply buried low-yield explosions. The National Academy of Sciences (2002) investigated these concerns and concluded that a CTBT could be verified. The CTBT remains at the controversial center of alternative policy views about the role of nuclear weapons in constituting U.S. military power.

24. The Stockpile Stewardship and Management Program consists for four major projects: (1) the Dual Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory, which produces three-dimensional x-ray images of imploding primaries; (2) the National Ignition Facility at Lawrence Livermore National Laboratory, which will be the world's most powerful laser research center, able to simulate the energy regimes of an exploding thermonuclear weapon; (3) Subcritical Testing at the Nevada Test Site, explosive testing on plutonium and uranium that does not produce a nuclear yield; and (4) the Accelerated Strategic Computing Initiative (ASCI), a major investment in supercomputing, designed to model the results of SBSS and previous nuclear test data; see U.S. Department of Energy 1998, 1999 for a program overview. For assessments of the stockpile stewardship program, see Gusterson 2001, Lichterman and Cabasso 1998, Zerriffi and Makhijani 1996 as well as Paine and McKinzie 1998a, 1998b.

25. During the Cold War, the U.S. national laboratories averaged $3.7 billion per year for the design and testing program. The first budgets for SBSS totaled $4.5 billion per year, and by 2003 had risen to $6.5 billion a year. Thus, the 15-year project of SBSS is likely to cost well over $70 billion. See Schwartz 1998 for an accounting of the entire U.S. nuclear project from 1940 to 1996; Schwartz estimates that the United States spent $5.8 trillion on the nuclear production complex, weapons delivery systems, and environmental management.

26. For analysis of bodily metaphors within weapons science, see Cohn 1987; Gusterson 1991, 1996a:101–130; Chaloupka 1992; Keller 1992; Scarry 1985; and Easlea 1983.

27. From 1945 to 1992, the United States built 70,000 nuclear weapons, relying on new design work to maintain the viability of the stockpile. ''Aging'' has thus not been a major concern of the U.S. nuclear planners until the post–Cold War era. Some nuclear components change over time—tritium has a half-life of 12.5 years, and plutonium decay produces a helium element that could potentially change the symmetry of a nuclear weapon trigger over many decades of storage. Other changes, such as cracks and distortions, can occur in nonnuclear components over time. How these aging issues change the ability of any specific nuclear device to produce a nuclear explosion remains controversial; see Johnson et al. 1995 as well as Zerriffi and Makhijani 1996.

28. Indeed, the multiple-yield function of a modern Los Alamos weapon allows for at least three modes of detonation involving (1) just the primary, (2) a boosted primary for greater yield, or (3) the coupled primary and secondary for a thermonuclear explosion; see Garwin and Charpak 2001:62–65.

29. See McNamara 2001 for a nuanced ethnographic discussion of the Los Alamos National Laboratory archiving project.

30. Between 1993 and 1996, Los Alamos National Laboratory hired 115 scientists into the weapons programs while losing over 400; see Commission on Maintaining United States Nuclear Expertise 1999:8; see also Medalia 1994:27.

31. In 1999, a Los Alamos weapons scientist named Wen Ho Lee was charged with mishandling classified information and was implicitly accused of nuclear espionage (see Masco 2002). In the midst of the national furor over potential nuclear espionage at Los Alamos, a computer hard drive from the Nuclear Emergency Response Team at Los Alamos was discovered to be missing, only to reappear months later stuck behind a photocopy machine.

32. The effort to construct a mathematical model of a nuclear weapon has been a core project at Los Alamos since the early Manhattan Project. The first ''computers'' were, in fact, rooms filled with the wives of Los Alamos scientists, who did the mammoth calculations for the first atomic bombs by hand. The U.S. nuclear weapons program subsequently drove the development of supercomputing throughout the Cold War, also relying on state-of-the-art supercomputing to recruit scientists to the national laboratories; see MacKenzie 1996 and Galison 1996.

33. The ASCI has formal alliances with five universities: the California Institute of Technology, Stanford University, the University of Chicago, the University of Illinois at Urbana–Champaign, and the University of Utah. For a programmatic overview of the Academic Strategic Alliance program, see www.llnl.gov/asci/alliances/. See also McKinzie et al. 1998.

34. Mackenzie and Spinardi (1995) have argued that, over time, the tacit knowledge inherent in the Cold War nuclear production complex could be forgotten, allowing the ''uninvention'' of nuclear weapons. Certainly the ability to reproduce highly miniaturized nuclear weapons, optimized with multiple-yield capabilities and loaded with safety and security measures, presents a substantial engineering challenge, and elements of this production cycle represent a kind of folk culture. SBSS is directly aimed at capturing and preserving that folk culture, and a recent article by weapons scientist Stephen Younger (2000) argues that the United States could deploy new nuclear weapons based on the bomb design used over Hiroshima without nuclear testing. Thus, the long-term absence of underground nuclear testing will more likely influence the complexity of future nuclear weapon designs than the ability to create a nuclear explosion.

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