Managing the U.S. Nuclear Weapons Stockpile

A Comparison
of Five Strategies

A Report for Tri-Valley CAREs

by

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The cover photo shows the hundreds of parts that go into a typical nuclear weapon—the B61 bomb. The red arrow indicates the "core physics package," which contains the nuclear explosive components. As part of its stockpile management program, DOE disassembles eleven warheads of each design every year and examines and tests the components to determine whether they are still in working order. The only part that cannot be fully tested is the core physics package. Even that, however, can undergo detailed examination and be replaced if any degradation is observed.
Photo credit: U.S. Department of Energy.

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Tri-Valley CAREs (Communities Against a Radioactive Environment) is a Livermore, California-based 501(c)(3) nonprofit organization dedicated to increasing public knowledge of the relationship between peace, social justice and the environment, with a special focus on nuclear weapons and nuclear waste.

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Executive Summary

Introduction

Under the Nuclear Nonproliferation Treaty (NPT) the United States and the other four major nuclear powers have pledged to:

> . . . pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

Unfortunately, achieving the goal of complete disarmament does not appear imminent. The United States still maintains some 10,400 nuclear weapons in operational condition. Until all nuclear weapons can be eliminated, we must maintain the safety and security of the remaining stockpile. In addition, present policy dictates continued reliance on the nuclear stockpile to deter others from using nuclear weapons against us. Maintaining the safety, security and deterrent value of the U.S. nuclear stockpile must not, however, impede efforts to reduce or eliminate nuclear weapons. We are concerned that the current approach to managing the stockpile does just that.

The Department of Energy (DOE), manages the nuclear stockpile under a program called the Stockpile Stewardship Program. The DOE approach goes well beyond merely maintaining current nuclear weapons. DOE's Stockpile Stewardship Program is a multifaceted effort to:

- Expand the scientific knowledge and understanding of nuclear weapons physics and engineering using a host of sophisticated experimental facilities;
- Model the behavior of exploding nuclear weapons using the world's fastest computers; and
- Refurbish and modernize all the weapons in the stockpile by replacing components with updated versions and, in some cases, by designing and manufacturing completely new nuclear weapons.

The DOE approach is a massive program whose cost is approaching $5 billion per year. At the height of the Cold War, DOE spent $3.8 billion per year (in today's dollars) on nuclear weapons' design, testing, and manufacture.

This report examines other ways to ensure the safety and reliability of the stockpile, including options that are simpler, less costly, and more certain than the DOE approach, and which better match U.S. commitments to end the arms race and eliminate nuclear weapons.

We take a comprehensive look at a wide range of strategies for managing the nuclear weapons stockpile. Each option is precisely defined and the activities that would be conducted and facilities that would be needed are specified. Each option is evaluated on its ability to meet five criteria, which we believe must be satisfied to adequately maintain the nuclear weapons stockpile and achieve broad political support.

- Maintaining weapons safety and security;
- Maintaining weapons reliability and performance;
- Supporting arms control and nonproliferation;
- Controlling costs; and
- Minimizing adverse environmental impacts.

We also evaluate the options on their ability to improve and modernize nuclear weapons.

The five options are:

- The current **DOE Stockpile Stewardship Program**;
- A **Remanufacturing Option**, under which DOE would periodically replace all the components in every nuclear weapon with new ones. Nuclear components would be remanufactured as closely as possible to the original designs, but other components could be modified;
- A **Curatorship Option**, under which DOE would rely on surveillance and nonnuclear testing to determine when repairs are necessary to nuclear weapons. Only if there is compelling evidence that components have degraded or will soon degrade, and could cause a significant loss of safety, reliability, or performance, would DOE replace the affected parts with new ones. All new components would be remanufactured as closely as possible to the original designs;
- A **Passive Arms Reduction Option**, in which DOE would replenish tritium supplies and replace traditional "limited life components," such as batteries and neutron generators, but would make no other repairs to nuclear weapons; and
- A **Return to Testing Option**, under which DOE would conduct two to four underground nuclear explosive tests per year, in addition to continuing nearly all the activities of the current Stockpile Stewardship Program.

Under each of the options, the Department of Energy could adequately maintain a sizable U.S. nuclear weapons stockpile for many years.

Under each of the options, the Department of Energy could adequately maintain a sizable U.S. nuclear weapons stockpile for many years. That is not meant to imply our lack of support or interest in rapid reductions and eventual elimination of all nuclear weapons. Active steps to bring about U.S. and international arms reductions are beyond the scope of this report. Rather, this report looks solely options for managing U.S. nuclear weapons until they can all be eliminated.

Assessment of the Options for Managing the U.S. Nuclear Weapons Stockpile

Our assessment of the five options against each of six criteria is shown in Table ES-1. The assessments are summarized below. Table ES-2 shows our estimates of the likely annual costs to pursue the major elements of each option for the next five to ten years.

The Curatorship Option is the only one of the five options that we rate as superior or good on all five criteria, which we believe must be satisfied to adequately maintain the nuclear weapons stockpile and achieve broad political support. Curatorship rates superior for Maintaining Weapons Safety and Security and good for Maintaining Reliability and Performance. Those high ratings are due primarily to the strong emphasis under this option on replacing degraded components with new ones as close to the original designs as possible. DOE would not attempt to make any improvements. In general, the fewer changes one attempts to make in safe and reliable warheads, the more likely they are to remain safe and reliable. Curatorship rates good rather than superior for Maintaining Reliability and Performance, because DOE would not replace most weapons components until it observed some degradation in their condition. That would entail some risk that once degradation of a component is observed, it might already prevent the weapon from performing properly. Curatorship rates good on Supporting Arms Control and Nonproliferation, because of its policy of no improvements to nuclear weapons and because DOE would cease all research and experimentation that is not absolutely necessary to maintain the nuclear weapons stockpile. It falls short of superior, because it does not automatically reduce the number of nuclear weapons. The curtailment of most of DOE's current weapons-related research and experimentation is also the primary reason that Curatorship receives good ratings for Controlling Costs and for Minimizing Adverse Environmental Impacts. The Curatorship Option rates poor on the criterion of Improving and Modernizing Nuclear Weapons. Efforts to improve U.S. nuclear weapons can encourage other nations to develop their own nuclear weapons. Such efforts are also inconsistent with the U.S. commitments under the NPT to cease the arms race. Therefore, we view the low rating for the Curatorship Option on this criterion as further reason to favor it.

The Remanufacturing Option is the only one that we rate as superior for Maintaining Weapons Reliability and Performance. It also rates superior for Maintaining Safety and Security. Those high ratings are due to the pro-active posture of this option in replacing components on a regular basis, before degradation occurs. Nuclear components would be replaced with new units as close to the original design as possible. Changes would be allowed to nonnuclear components under this option, but since such changes can be thoroughly tested, they do not detract from the superior ratings for these criteria. On the other hand, since DOE would, under this option, continue an active weapons research and engineering program, begin remanufacturing and replacing nuclear weapons' primaries as soon as possible, and seek to make improvements in the nonnuclear components of nuclear weapons, this option rates only fair for Supporting Arms Control and Nonproliferation. In addition, the Remanufacturing Option rates poor for controlling costs and only fair for minimizing adverse environmental impact. This option gets low ratings on those

TABLE ES-1. **Assessment of Options for Managing the U.S. Nuclear Weapons Stockpile**

	DOE Stockpile Stewardship Program	Remanu-facturing	Curatorship	Passive Arms Reduction	Return to Testing
Maintaining Weapons Safety and Security	★★★	★★★★	★★★★	★★★★	★★★★
Maintaining Reliability and Performance	★★★	★★★★	★★★	★★	★★★★
Improving and Modernizing Nuclear Weapons	★★★	★★	★	0	★★★★
Supporting Arms Control and Nonproliferation	★	★★	★★★	★★★★	0
Controlling Costs	0	★	★★★	★★★★	0
Minimizing Adverse Environmental Impacts	★★	★★	★★★	★★★★	0

LEGEND: 0 = Inferior ★ = Poor ★★ = Fair ★★★ = Good ★★★★ = Superior

TABLE ES-2. **Representative Funding for Major Program by Option**[a]
(in millions of dollars annually)

Major Element	DOE Stockpile Stewardship Program	Remanu-facturing	Curatorship	Passive Arms Reduction	Return to Testing
Science and Technology	2150	1275	700	300	2200
Surveillance and Testing	725	725	730	540	750
Manufacturing	1725	1675	1050	680	1850
Other	300	250	220	180	300
TOTAL	**4900**	**3925**	**2700**	**1700**	**5100**

a. Additional details on the funding estimates for the five options appear in Table 2 in the main text and in Appendix B.

criteria because it would promptly proceed to remanufacture a considerable number of plutonium pits, absent significant arsenal reductions. Furthermore, proponents of this option assume that most of DOE's weapons related research and experimentation programs would be continued. If, however, weapons-related research activities and improvements to weapons components were constrained under the Remanufacturing Option, it would become more attractive. A hybrid option is possible that retains the pro-active stance of the Remanufacturing Option by replacing components before degradation is observed, and combines that with the restricted research and engineering and prohibition on improvements to nuclear weapons of the Curatorship Option. Such a hybrid might be attractive to those who do not support the approach of the Curatorship Option of waiting for defects to be discovered before making repairs.

The Passive Arms Reduction Option rates superior on four of the five key criteria we believe must be satisfied to adequately maintain the stockpile and achieve broad political support. However, it rates only fair on Maintaining Reliability and Performance. That low rating is due primarily to this option's approach of removing failed weapons from the stockpile, instead of fixing and replacing them. We assume that under this option DOE would conduct a thorough surveillance and testing program to identify degraded warheads and remove them from the stockpile. In that case, the remaining weapons could be as reliable as under any of the other options. The *number* of reliable warheads would decline over time, however. Eventually, one or more classes of warheads might have to be removed from the stockpile. This would reduce the flexibility in the United States response to a potential aggressor. This approach is likely to make the Passive Arms Reduction Option politically unacceptable in the current environment. However, even under the "no repairs" policy of this option, it is very unlikely, that the number of reliable nuclear weapons in the stockpile would fall precipitously for at least the next few decades. Thus, those who support a minimum core deterrence role for nuclear weapons might favor this option.

The DOE Stockpile Stewardship Program rates poor and **the Return to Testing Option** rates inferior on Support for Arms Control and Nonproliferation. In both cases, we assign those low ratings because of their broad programs in weapons research and engineering and their plans for improving nuclear weapons. Such plans are inconsistent with U.S. commitments under the NPT to cease the nuclear arms race. Those options serve to encourage further development of nuclear weapons around the world. In addition, those options are by far the most costly and least protective of the environment.

Conclusion and Recommendations

We have identified three distinctly different options that offer substantial improvements over the Stockpile Stewardship Program. They are the Curatorship Option, the Remanufacturing Option, and the Passive Arms Reduction Option. We rate all three of those options higher than the Stockpile Stewardship Program for maintaining weapons safety and security; supporting arms control and nonproliferation; controlling costs; and minimizing environmental impacts. We therefore recommend the following:

Recommendation 1. The U.S. Congress should request from the Congressional Budget Office and the General Accounting Office financial and policy analyses of the five strategies identified here for managing the U.S. nuclear weapons stockpile.

Recommendation 2. Congress should hold comprehensive oversight hearings examining DOE's Stockpile Stewardship Program in comparison to the full suite of stockpile management options.

Recommendation 3. Congress should redirect funds from DOE's efforts at expanding nuclear weapons science and engineering and improving nuclear weapons designs. Instead, some of the funds should be used to increase support for basic programs in surveillance, testing, and evaluation of existing weapons in the active stockpile.

Recommendation 4. The Department of Energy should conduct a comprehensive reevaluation of how it manages the nuclear weapons stockpile. The reevaluation should consider a range of options, such as those presented here, and evaluate the options against a set of criteria similar to those used here. The reevaluation should give special consideration to options that are more supportive of U.S. arms control and nonproliferation objectives than is Stockpile Stewardship.

Recommendation 5. Citizens groups and the general public should use the information presented in this report to advocate for changes in U.S. nuclear weapons policy that would reduce the worldwide danger from nuclear weapons.

Introduction

Today, more than ten years after the fall of the Berlin Wall, the United States maintains approximately 7,900 nuclear warheads and bombs in operational weapon systems. With the addition of spares and an "inactive reserve," some 10,400 weapons are maintained in the U.S. nuclear stockpile. About 20,000 nuclear weapons remain in the Russian stockpile, of which some 10,000 are believed to be operational.[1] These large nuclear weapons stockpiles are inherently dangerous, raise the level of international tension, and help legitimize the ownership and pursuit of nuclear weapons by other nations. Moreover, the disintegration of the Russian economy increases the threat of accidents, unauthorized launches, and seizures or thefts of weapons or weapons materials by terrorists or domestic rebels.

The prospect for substantial reductions of nuclear weapons may be higher now than anytime in the past fifty years. Nevertheless, elimination of nuclear weapons does not appear imminent. Until all nuclear weapons can be eliminated, the United States must maintain the safety and security of its nuclear weapons stockpile. Present policy dictates continued reliance on the nuclear stockpile to deter others from using their nuclear weapons against us. Maintaining the safety, security and deterrent value of the U.S. nuclear stockpile must not, however, impede efforts to reduce or eliminate nuclear weapons. We are concerned that the current approach to managing the stockpile does just that.

The Department of Energy (DOE) is the Government agency with the primary responsibility for managing the U.S. nuclear stockpile. DOE has developed a strategy to do this called the Stockpile Stewardship Program. DOE's Stockpile Stewardship Program is a multifaceted effort to:

- Expand the scientific knowledge and understanding of nuclear weapons physics and engineering using a host of sophisticated experimental facilities;
- Model the behavior of exploding nuclear weapons using the world's fastest computers; and
- Refurbish and modernize all the weapons in the stockpile by replacing components with updated versions and, in some cases, by designing and manufacturing completely new nuclear weapons.

The Stockpile Stewardship Program employs more than 25,000 people at a host of large research, experimentation, testing, and production facilities in seven states, including: Lawrence Livermore National Laboratory and Sandia Livermore Laboratory in California, Los Alamos National Laboratory and Sandia National Laboratory in New Mexico, the Nevada Test Site, the Kansas City Plant, the Pantex Plant in Texas, the Y-12 Plant in Tennessee, and the Savannah River Plant in South Carolina. DOE plans to build several expensive new facilities at these sites to expand its research, testing, computation and production capabilities. Among DOE's near term plans are:

- A multibillion dollar "National Ignition Facility" (NIF) for research on nuclear fusion via inertial confinement and on the behavior of materials at conditions approaching those of an exploding nuclear weapon;
- A $6-8 billion Advanced Strategic Computing Initiative (ASCI) to build the world's fastest computers and write software to model the behavior of nuclear weapons;
- A $400 million Microsystems Engineering and Sciences Application (MESA) facility; and
- New facilities costing from hundreds of millions to several billion dollars each for manufacturing plutonium pits, imaging surrogate imploding pits to the moment before the nuclear chain reaction begins, doing chemistry and metallurgical research, fabricating parts for nuclear secondaries, and storing high enriched uranium.

The DOE approach is a massive program whose cost is approaching $5 billion per year. That sum exceeds DOE's average yearly spending of $3.8 billion (in today's dollars) on nuclear weapons design, testing, and manufacture during the Cold War.[2] (DOE's major existing and planned facilities are briefly described in Appendix A.)

The DOE approach is a massive program whose cost is approaching $5 billion per year. That sum exceeds DOE's average yearly spending of $3.8 billion (in today's dollars) on nuclear weapons design, testing, and manufacture during the Cold War.

DOE's plans for continued improvement of nuclear weapons under its massive Stockpile Stewardship Program impede U.S. nonproliferation and arms control objectives.[3] Other ways to ensure the safety and reliability of the stockpile have been proposed that are simpler, less costly, and more certain than the DOE approach, and which better match U.S. commitments to end the arms race and eliminate nuclear weapons.[4] There has been little public discussion of these alternatives to DOE's expensive and far-flung program.

This report helps to fill that void. It takes a comprehensive look at a wide range of different strategies for managing the nuclear weapons stockpile. For the first time, stockpile maintenance strategies as divergent as passive arms reduction and a return to full-scale testing are analyzed on the same basis. In an effort to inform and broaden the debate, we have precisely defined the philosophy and approach to maintaining the stockpile of each of five strategies. We describe the types of activities that would be conducted under each option, suggest what facilities would be needed, and estimate the relative spending of the options on major activities and facilities. Each option is evaluated on its ability to meet the essential objectives of stewardship, including its ability to maintain the safety, reliability and performance of the stockpile, and on its impact on arms control, nonproliferation, and the environment.

The five options examined are:

- The current **DOE Stockpile Stewardship** Program;
- A **Remanufacturing Option**, which is based on proposals by former nuclear weapons designers Richard Garwin and Ray Kidder, under which DOE would periodically replace all of the components in every nuclear weapon with new ones. Nuclear components would be remanufactured as closely as possible to the original designs, but other components could be modified;

- A **Curatorship Option**, under which DOE would rely on surveillance and nonnuclear testing to determine when repairs are necessary to nuclear weapons. Only if there is compelling evidence that components have degraded or will soon degrade, and could cause a significant loss of safety, reliability, or performance, would DOE replace the affected parts with new ones. All new components would be remanufactured as closely as possible to the original designs;
- A **Passive Arms Reduction Option**, in which DOE would replenish tritium supplies and replace other traditional "limited life components," such as batteries and neutron generators, but would make no other repairs to nuclear weapons; and
- A **Return to Testing Option**, under which DOE would conduct two to four underground nuclear explosive tests per year, in addition to continuing nearly all the activities of the current Stockpile Stewardship Program.

Under each of the options, the Department of Energy could adequately maintain a sizable U.S. nuclear weapons stockpile for many years. That is not meant to imply our lack of support or interest in rapid reductions and eventual elimination of all nuclear weapons. Until all nuclear weapons can be eliminated, however, the United States must at least maintain the safety and security of its nuclear weapons stockpile. Active measures that might be taken to bring about U.S. and international arms reductions are beyond the scope of this report. We do, however, address the degree to which the above options are conducive to international arms control.

How Challenging Is the Task?

Maintaining such complex systems is no small task, but it is one that has been routinely accomplished for more than 50 years.

Nuclear weapons are highly complex systems with thousands of components, all of which are expected to perform properly the first time they are called upon. Modern warheads begin with sophisticated arming, fusing, and firing systems that prevent accidental or unauthorized discharge. If properly initiated, those systems ignite chemical explosives that surround and compress a plutonium "pit," which is the key element of the primary or first stage of the weapon. At precisely the right moment, a neutron generator must function to initiate the nuclear chain reaction. Before that, systems for storage and transfer of tritium and deuterium (heavy isotopes of hydrogen gas) must properly insert their contents into the pit to boost the explosive yield of the primary to its design value. As the primary explodes it emits x-rays. The x-rays must be properly guided through the exploding warhead to compress and heat the "secondary." The secondary, in turn, provides most of the explosive yield through the fissioning of uranium and the fusion of hydrogen isotopes, which are created from lithium-deuterium compounds in the first moments of the explosion. Maintaining such complex systems is no small task, but it is one that has been routinely accomplished for more than 50 years.

DOE points to two changes that have occurred since the end of the Cold War to justify its massive Stockpile Stewardship Program. First, the United States has not conducted a full-scale nuclear test since 1992 and does not plan to resume testing. Second, according to DOE, the United States is not currently manufacturing completely new nuclear weapons.[5] The last plutonium pit for a new nuclear weapon left its factory in 1989. So today, the U.S. has a nuclear stockpile containing aging warheads and will no longer stage full-scale nuclear tests to analyze their performance or safety characteristics.

DOE has likened performing stockpile stewardship, without testing, to the technical challenge of putting a man on the moon. Such statements are motivated by the desire within the nuclear weapons establishment to spend ever increasing amounts of money. DOE vastly exaggerates the technical challenges posed by the loss of testing to the proper maintenance of the nuclear weapons stockpile. Throughout the history of the U.S. nuclear weapons program, nuclear testing has been used almost exclusively to broaden understanding of weapons physics and to develop and design new weapons systems. No additional nuclear tests were normally conducted to verify the performance of a new warhead after one early production version of that warhead design was proof-tested. Instead, DOE used a program of stockpile surveillance and nonnuclear testing to monitor the condition of the warheads. This program consists of annual sampling of the stockpile by taking eleven deployed warheads of each type out of the field, taking them apart, rigorously inspecting and testing their parts, and reassembling most of them. Most of the systems in a nuclear weapon can be fully tested in this manner including: guidance systems, radars, casings, altimeters, batteries, detonators, chemical explosives, neutron generators, boost-gas storage and delivery systems, parachutes, and arming, fusing, and firing systems. The only components that cannot be fully tested are the plutonium pits of the primary and the uranium, lithium-deuterium secondary. These are called collectively the core physics package. On average, the core physics package of one warhead of each type is taken apart each year for detailed examination and (nonnuclear) destructive testing. **It is this surveillance program and not nuclear testing that has identified the vast majority of problems that have occurred in nuclear weapons. It can continue to do so.**

Similarly, DOE significantly overstates the challenge presented by aging of the stockpile. Traditionally, once a warhead was certified to enter the stockpile, it was assumed to remain certified unless the surveillance and testing program found a problem. Warheads have been retired only when more modern models were developed and available to replace them. A 1993 study by Sandia National Laboratory concluded, "we can find no example of a nuclear weapon retirement where age was ever a major factor in the retirement decision."[6] Some weapons have remained in the stockpile for more than thirty years. The vast majority of problems that have occurred in the stockpile were identified in warheads less than four years old. Most of those were due to design problems. Nearly all were outside the core physics package. The average age of the current warheads in the stockpile is about fifteen years.

In the vast majority of cases, when a problem was identified it was analyzed with tools other than nuclear explosive testing. If necessary, retrofits were made. In only a handful of cases did DOE conduct nuclear explosive tests in connection with problems with warheads in the stockpile. Furthermore, most of those were confirmatory, rather than essential to determining how to proceed. The tools available to DOE today to detect, evaluate, and remedy problems have been greatly expanded and counteract the loss of nuclear explosive testing. The knowledge base of weapons physics has been enlarged by the more than 1,000 nuclear tests that have been conducted. The capabilities of computers and computer codes for weapons analysis have multiplied thousands of times. DOE now has a wide range of nonnuclear test apparatus at its disposal. Moreover, the nation's science and technology base continues to expand at a mind-boggling pace. Innumerable techniques are now available to test, analyze, and evaluate the components of nuclear weapons that were not available as recently as ten years ago.

In sum, it is a challenging task to maintain the nuclear weapons stockpile, but it is far from overwhelming. While DOE faces some new challenges, comparisons to the challenge of putting a man on the moon are considerably overblown. Maintaining nuclear weapons is an engineering and management challenge far more than a scientific one. The current stewards of the nuclear stockpile have many advantages over their counterparts who were able to meet the requirements of maintaining a safe and reliable stockpile for more than fifty years. They have benefited from experience gained in conducting more than 1,000 nuclear tests and in designing, testing, manufacturing, and eventually retiring more than 70,000 warheads of dozens of different designs. Furthermore, the reliability of U.S. nuclear weapons need not be perfect for deterrence to work. It is most unlikely that any rational adversary would feel confident enough to ignore the threat of U.S. nuclear weapons based on a belief that they would not work, unless they had solid evidence for that belief. Such evidence would be exceptionally difficult, if not impossible to obtain.

All the weapons in today's stockpile have been rigorously designed, thoroughly tested, and continually scrutinized throughout their service lives. The directors of the weapons laboratories and many independent experts have repeatedly stated that the existing arsenal meets the highest standards of safety and reliability. One recent study found that even if DOE did nothing to detect and repair problems, less than 2 percent of the warheads in the stockpile would fail to function properly in the first thirty years after they were manufactured.[7] The nuclear stockpile has historically had very few problems and has shown no signs of any increase in defects with age.

Summary of the Options for Managing the U.S. Nuclear Weapons Stockpile

Any option for managing the nuclear weapons stockpile must provide several basic functions. There must be a program of surveillance and testing of nuclear weapons components to monitor their condition and determine if there are any problems. There must be sufficient scientific and technical capabilities to perform the surveillance and testing, to understand the results, and to address problems that arise. And, there must be a system or strategy for manufacturing and replacing components that need to be replaced. The three basic functions—surveillance and testing, science and technology, and manufacturing—are all present to some extent within each of the five options. There are substantial variations, however, in how they are conducted and the relative dependance upon each.

DOE Stockpile Stewardship Program

The organizing principle for the DOE Stockpile Stewardship program is science and technology. Until recently, that emphasis was explicit in the full name of the program, which was the "Science-Based Stockpile Stewardship Program." The central approach of the DOE program is to develop new experimental and computational capabilities to provide a better understanding of the physics of nuclear explosions and the fundamental properties of plutonium, uranium, and other materials. DOE's ultimate goal is to model precisely the behavior of an exploding nuclear weapon through all its stages, from first principles, with no adjustable parameters (i.e., fudge factors). This capability goes well beyond anything envisaged during the era of nuclear testing. This approach presents an enormous scientific and technical challenge. It is questionable, however, whether pursuing that challenge is necessary, or even useful, for maintaining the safety, reliability, and performance of the nuclear stockpile.

While the DOE approach includes a robust surveillance and testing program, that program serves as a backup system for detecting defects in nuclear weapons. DOE plans instead to use its enhanced scientific and technical understanding to predict when components might no longer work properly and take action before actual problems are detected. This approach requires an enormous leap in the current understanding of the properties and behavior of hundreds of different materials as they age.

The DOE approach also includes a robust manufacturing operation. DOE is developing elaborate plans and schedules under a "Stockpile Life Extension Program

(SLEP)" to replace each of the thousands of parts in every nuclear weapon on a regular schedule, including the plutonium pits. Under the DOE approach, parts will not only be replaced as they age, but weapons systems will be refurbished and modernized with new components of new design. Current Administration policy statements explicitly call for DOE to maintain the capability to design, fabricate, and certify new warheads.[8]

Under the DOE Stockpile Stewardship approach, each year the Secretary of Energy and the Secretary of Defense, upon the advice of the directors of the nuclear weapons laboratories, must certify to the President that the stockpile remains safe and reliable. This is a relatively new requirement prompted by the weapons laboratories in 1995. Before that, it was assumed that nuclear weapons remained safe and reliable unless a problem was identified through the surveillance program or by other means. The laboratories now use the annual certification program to justify conducting extensive research on hypothetical problems, whether or not such problems have actually been observed.

New or revised requirements may come from a new or revised mission or role for one of the military services. Just as commonly, a new requirement is introduced because the DOE laboratories have developed or believe they can develop a new capability.

The DOE approach also includes an elaborate "revalidation" process under which the laboratories periodically recalibrate each weapons system against an ever changing set of military requirements. The military requirements for each weapons system are very detailed. They go well beyond specifying the explosive yield and the size and weight of the weapon. Military requirements include items such as the ability to select among multiple yields, the desired altitude of detonation, and the temperature range within which a weapon must operate. They also include detailed requirements for guidance systems, arming fusing and firing systems, and safety requirements. The setting of military requirements is an iterative process in which the DOE laboratories and ex-DOE lab employees, who now work for the Pentagon, play a major role. New or revised requirements may come from a new or revised mission or role for one of the military services. Just as commonly, a new requirement is introduced because the DOE laboratories have developed or believe they can develop a new capability.

The certification and revalidation processes will both get increasingly challenging as DOE makes more and more changes to weapons over time. DOE will have to continually enhance its scientific, technical, and computing capabilities to meet these challenges. In sum, the DOE approach to Stockpile Stewardship will remain a massive program designed and structured to pursue continual improvements to the stockpile. It will require enormous efforts in science and technology and computer modeling that will be increasingly costly.

Remanufacturing

The defining approach of this option is to remanufacture and replace weapons components, including the core physics package, before any degradation occurs that could impair performance. The key task is to assure that remanufactured physics packages conform to the original designs and fall within the range of variability in tolerances and materials of proof-tested warheads from the original manufacturing run.[9] Other components, including the arming, fusing and firing system, power supplies, and the like, may be changed, as long as they provide the correct inputs to the physics package within the originally specified tolerances. If those tasks are accomplished, then the resulting warheads will be at least as safe and reliable as the originals.

Under this option, DOE would begin replacing the nuclear explosive packages of nuclear weapons soon. It would continue to do so about every 25 or 30 years, rather than waiting for the surveillance program to detect a problem. This early remanufacture is also intended to prevent potential erosion of expertise in production technologies and gain experience in remanufacturing, before problems might arise. A comprehensive nonnuclear testing and surveillance program is also key to this option to identify potential problems in components that have not yet been replaced, and to assure that new components function properly.

Under a variation of this option, Ray Kidder proposes that DOE might modify some physics packages once, before valuable experience is lost, but only if subsequent replication by remanufacture would otherwise be impractical, and proper performance of the modified physics package were certified.[10] No further modifications to the physics package would be allowed after that.

Since changes in existing physics package designs are not called for in the standard version of this option, the science and technology program need not be as broad as under the DOE stewardship approach. Nevertheless, the most prominent proponents of the Remanufacturing Option, Richard Garwin and Ray Kidder, would have DOE conduct a robust science and technology program. Garwin and Kidder agree that much of DOE's current research and experimentation program is not strictly needed under the remanufacturing option. They favor a strong science program, nevertheless, primarily to help retain a functioning technical community that understands nuclear weapons science and engineering, and also to provide for improvements outside the physics package. Our analysis of this option assumes that most of DOE's existing research and experimentation programs would be maintained, but that the building of new facilities and the large "ASCI program" for improving computers and codes that model the performance of nuclear weapons would be slowed.

Curatorship

This option is based upon reliance on the surveillance and nonnuclear testing program to determine when repairs are necessary to nuclear weapons. Only if there is compelling evidence that components have degraded, or will soon degrade, and could cause a significant loss of safety or reliability, would DOE replace the affected parts with new ones that would be remanufactured as closely to their original design as possible. A core philosophy of this approach is that absent detectable changes, the well designed and thoroughly tested warheads in the stockpile will remain as safe and reliable as the laboratories have certified them to be today. No separate action would be taken to recertify each warhead annually. This places a heavy responsibility on the surveillance and testing program to assure timely warning of any problem that could materially impair a significant fraction of the nuclear weapons stockpile.

Under the Curatorship Option, DOE would take a very cautious approach to making any changes to the weapons in the current stockpile. The approach is like that of a museum curator, whose first priority is to preserve the pieces under his charge and only restore them if they suffer unacceptable degradation. DOE would make the minimum number of changes to warheads in the stockpile that are believed necessary to maintain current levels of safety and reliability. Nuclear explosive components would be remanufactured and replaced only when there is compelling evidence from the surveillance and testing program that they have degraded, or will soon degrade, to a degree that will cause a significant loss of performance. Then, DOE would replace such components with others as close to the originals as possible, and always meeting the specifications previously associated with adequate nuclear performance. Nonnuclear components would be replaced only when detected degradation threatens to impair safety or weapon reliability. The burden of proof would be on those in the surveillance program to demonstrate that a component must be replaced to maintain historical levels of confidence in safety and reliability. No attempts at improving performance in either of these areas would be made.

DOE would support state-of-the-art testing and engineering capabilities to examine components. It would retain sufficient scientific and computing capabilities to apply current models and normal evolutionary improvements in analytical models to appraise potential problems with weapons systems. Weapons design and development capabilities would be allowed to atrophy, however, and most of DOE's weapons-related research and experimentation programs would be suspended. Existing manufacturing capabilities would be retained and facilities would be refurbished only as needed to remanufacture components to previous designs. Changes in materials and production techniques would be limited to those dictated by environmental, health, and safety requirements, or by the unavailability at reasonable cost of products and processes used in a component's original manufacturing process. The production complex would be smaller than under the first two options, since components would be replaced less frequently. Functioning components would rarely be replaced with improved versions.

Passive Arms Reduction

This option would go further than the Curatorship Option in minimizing changes to nuclear weapons. No changes would be made, except for replenishing tritium supplies and replacing components such as batteries and neutron generators, which have traditionally been referred to as "limited-life components." Over time, other components would eventually degrade. DOE would conduct a thorough surveillance and testing program to assess the reliability of the weapons in the stockpile. If DOE lost sufficient confidence in the reliability of a class of weapons, they would be removed from the stockpile unilaterally, retained as decoys, or traded for mutual arms control reductions. Under the Passive Arms Reduction Option, DOE would retain manufacturing capability for only the traditional limited-life components and would retain scientific and technical capabilities only to conduct the surveillance and testing program and credibly assess warhead reliability.

While the performance of warhead systems would decline over time, it could be many years before the U.S. stockpile lost significant deterrent value. A recent study for DOE by the JASONs, found that even if DOE did nothing to detect and repair component defects, less than 2 percent of the warheads in the stockpile would fail to function properly in the first thirty years after they were manufactured.[11] The JASON's found no evidence to suggest that the rate of failure would increase for older weapons. The JASONs are a group of distinguished scientists, under the administration of the MITRE Corporation, who advise the Departments of Defense and Energy on national security issues.Not a single defect was found in any of the 59 weapons from the stockpile that had been examined with ages greater than 27 years.

Many experts believe that as few as 100 secure, survivable, and deliverable warheads should be adequate to preserve the core function of deterring the use of nuclear weapons against the United States or its allies.[12] The JASON's analysis suggests that it could be many years before so few warheads would remain functional, even if no action was taken to replace those with defects. In the very long-term (several decades or more), the radioactive decay of plutonium could eventually render all U.S. weapons suspect. Thus, this option would remain politically viable only if arms control agreements were to reduce significantly the number of nuclear weapons, and eventually eliminate them.

Return to Testing

Since the 1960's, underground nuclear testing has played a limited role in maintaining the safety and reliability of well-tested nuclear weapons once they have entered the stockpile. Thus, if the mission is to maintain the stockpile, without developing new classes of nuclear weapons, there is little reason to test. Nevertheless, this option assumes that the U.S. returns to full-scale nuclear testing at a rate of about two to four tests per year. This could occur for purely geopolitical reasons or because the DOE weapons laboratories persuade policy makers that they must test to resolve one or more questions about the stockpile, whether or not that is technically justified by the problem at hand. It could also result from a determination that new types of nuclear weapons are needed for future war-fighting requirements.

The overall program would look very much like the current DOE Stockpile Stewardship Program. Nuclear tests would be used primarily to further DOE's understanding of weapons physics. Some tests would probably use weapons from the stockpile and may be designed to improve understanding of an issue related to safety or nuclear explosive performance. In the latter case, the nuclear testing would be only one reference point in the overall evaluation DOE performs each year to certify weapons. Our analysis of this option assumes that DOE would continue to do nearly everything it plans to do under the current Stockpile Stewardship Program and adds the elements of the underground nuclear testing program to that.

Assessment of the Options for Managing the U.S. Nuclear Weapons Stockpile

In this section, we rate each option on how well it might accomplish the following objectives.

- Maintaining weapons safety and security;
- Maintaining weapons reliability and performance;
- Improving and modernizing nuclear weapons;
- Supporting arms control and nonproliferation;
- Controlling costs; and
- Minimizing adverse environmental impacts.

We do not believe that "Improving and modernizing nuclear weapons" is a desirable objective or one that is broadly supported. It is included on the list, however, because it is a key goal of DOE's Stockpile Stewardship Program. We believe the other five objectives must all be met for an option to achieve broad political support.

We rate the options from "inferior" to "superior" in their ability to meet each objective. The ratings are summarized in Table 1. That is followed by a discussion of each objective and an explanation of the individual ratings.

Maintaining Weapons Safety and Security

Background and Issues for Rating the Options

Nuclear weapons are inherently dangerous. Any program to manage the nuclear weapons stockpile must keep it safe from accidental nuclear detonation or dispersal of its radioactive materials and secure against theft or unauthorized use. Safety and security can be open-ended pursuits, however. Short of complete elimination of nuclear weapons, we cannot reach a state of zero risk. As a practical matter, we must set an achievable safety goal for the stewardship program other than zero risk. An important question to ask in setting that goal is how safe is the current stockpile?

The virtually unanimous answer to that question by all experts is that the stockpile is very safe and secure.[13] DOE made major improvements to the safety and security of nuclear weapons over the past two decades. For example, it added permissive action links (PALs) to all U.S. weapons to better prevent unauthorized use and added

TABLE 1. **Assessment of Options for Managing the U.S. Nuclear Weapons Stockpile**

	DOE Stockpile Stewardship Program	Remanu-facturing	Curatorship	Passive Arms Reduction	Return to Testing
Maintaining Weapons Safety and Security	★★★	★★★★	★★★★	★★★★	★★★★
Maintaining Reliability and Performance	★★★	★★★★	★★★	★★	★★★★
Improving and Modernizing Nuclear Weapons	★★★	★★	★	0	★★★★
Supporting Arms Control and Nonproliferation	★	★★	★★★	★★★★	0
Controlling Costs	0	★	★★★	★★★★	0
Minimizing Adverse Environmental Impacts	★★	★★	★★★	★★★★	0

LEGEND: 0 = Inferior ★ = Poor ★★ = Fair ★★★ = Good ★★★★ = Superior

Enhanced Nuclear Detonation Safety (ENDS), which make it extremely unlikely that stray electrical signals can initiate the detonators. It also replaced the high explosive in all weapons (except submarine-launched, long-range missiles) with a variety that is remarkably resistant to accidental detonation. Operational changes were also made that greatly reduced the risk of nuclear accidents or thefts. In 1991, President Bush ordered all nuclear weapons removed from naval surface vessels and tactical aircraft and placed in secure bunkers. He also ordered all warheads removed from U.S. strategic aircraft, ending the practice of keeping bombers on "strip alert," where they were vulnerable to collisions with other aircraft. Because of these and other measures, the U.S. stockpile is unquestionably safer today than it has been any time over the past thirty years.[14]

Since the existing level of safety and security is widely judged to be superior, there is no need to seek additional safety improvements. Efforts to improve the safety of existing nuclear weapons further are wasteful and could be counterproductive. Design changes that are made without the benefit of full scale nuclear tests have as much or more potential to reduce safety as they do to improve it. That is because design changes often require that tradeoffs be made between safety, reliability, performance, cost, and other factors.

Since very few safety problems are expected to occur with age, maintaining the safety of the stockpiles is relatively easy if major changes are not made from existing designs.

DOE justifies its massive scientific and technical effort to improve the understanding of nuclear weapons as necessary to analyze questions of warhead safety and reliability as they age. DOE is wrong in lumping safety with reliability in this regard. Virtually any conceivable aging problem, such as corrosion of metals and organic materials, cracking of parts, or degradation of adhesives, will make it less likely that a warhead will explode and will improve, rather than degrade, safety. Explosives may become less powerful as they age, reducing the warhead's reliability, but DOE has found no evidence that aging will make the explosive more sensitive to accidental detonation.[15] Rather, at least one high explosive that DOE uses in weapons becomes more stable as it ages.[16] Indeed, since very few safety problems are expected to occur with age, maintaining the safety of the stockpiles is relatively easy if major changes are not made from existing designs. We rate all of the options either good or superior in their ability to maintain weapons' safety and security

Explanation of the Ratings for Maintaining Safety and Security for the Five Options

DOE is devoting substantial resources and attention to maintaining safety and security. We downgraded the **DOE Stockpile Stewardship Option (★★★)** from superior to good, however, because of DOE's extensive plans to use the Stewardship Program to refurbish, modernize, and improve nuclear weapons. Under that program, DOE might attempt to address new military requirements with entirely new weapons designs that it cannot test adequately enough to be certain that there are no nuclear detonation safety problems.[17] We considered giving this option only two stars for safety, because of the extensiveness of DOE's plans to modify weapons. That was balanced, however, by the potential for DOE to gain some new information through its science program that could improve safety. We also assume that DOE's increased knowledge will help inform its judgement in making performance improvements that might reduce safety.

We rated the **Remanufacturing Option (★★★★)** superior for safety. There would be far fewer changes to nuclear weapons under this option than under the Stockpile Stewardship Option and no changes to the core physics package. Nonnuclear components can be thoroughly tested, so new nonnuclear components are unlikely to introduce safety problems. We have concern regarding a variant of the Remanufacturing Option in which pits would be modified once to make them more robust. Making any design changes to pits without nuclear testing is risky. We have not reduced this option's score for safety on that account, however, because that variation is not central to the Remanufacturing Option. We would downgrade a Remanufacturing Option that includes changes to pit designs by at least one star in this category, depending upon the extent of the changes.

The **Curatorship Option (★★★★)** also earns a superior rating for safety. DOE is even less likely to introduce new safety problems under this option than under the previous option. Since safety problems are unlikely to result from aging of components, the fewer changes made to an already safe weapon, the safer it will remain. There would be an explicit prohibition against making changes to the weapons in the current stockpile, unless the surveillance and testing of a weapons system showed convincingly that a change was necessary to maintain safety.

The **Passive Arms Reduction Option (★★★★)** also earns a superior rating for safety. Under this option, a thorough surveillance program would be maintained. If there were any uncertainties about a warhead's safety, it would be removed from the stockpile and, if necessary, dismantled so as to present no continuing danger. Under this option, no effort to improve warheads would be made that might introduce new or unknown safety problems. Finally, since the continued safety of each remaining warhead would be a criterion for retention in the stockpile, the overall safety of the stockpile would improve under this option as the overall size of the stockpile declines and problem warheads are continually weeded out.

DOE would likely introduce new weapon designs under the **Return to Testing Option (★★★★)**, which could be less safe than existing weapons. We rate this option superior for safety, nevertheless, because we assume that with nuclear testing DOE could assure that new weapons would be as safe as weapons in the existing stockpile.

Maintaining Weapons Reliability and Performance

Background and Issues for Rating the Options

As with safety, there is broad agreement among experts that the current stockpile meets a very high standard of reliability and performance. Thus, maintaining (not improving) weapons' reliability and performance is sufficient. Issues regarding the programs and capabilities that are necessary and sufficient to maintain the reliability of the nuclear weapons stockpile, without nuclear testing, were a key element in the debate over the Comprehensive Test Ban Treaty (CTBT). It may be the most controversial issue regarding how to manage the stockpile. Three multi-part questions bear on this issue.

- How serious are the problems of aging and can they be detected?
- Can DOE confidently maintain the reliability of nuclear weapons and components by remanufacturing them to previous specifications? and
- How good are DOE's current tools for analyzing age-related changes to stockpile reliability and how much help would additional capabilities be?

Question 1: How serious are the problems of aging and can they be detected?

Age-related problems that could significantly affect the reliability or performance of nuclear weapons have occurred and will continue to occur. DOE is confident, however, that it has detected and corrected all such problems in the current stockpile. Analysis of past problems strongly indicates that a surveillance and testing program similar to the one that DOE has traditionally conducted will, with high confidence, detect all problems that might have any material impact on weapons reliability or performance.

In 1996, Sandia National Laboratory published the results of a study done by the three DOE weapons laboratories (called the "Tri-Lab Study") analyzing all the issues raised about weapons in the stockpile since 1958.[18] Of the 70,000 warheads that had passed through the stockpile during that time, more than 13,800 had been randomly sampled and tested for defects. During that time, 800 distinct "findings" were made, where a finding is any issue requiring further study. That set included about 400 "actionable" findings. The later term is misleading, since less than one-third of the actionable findings resulted in any changes to the weapons. The Tri-Lab Study did not characterize how the reliability of the stockpile might have been affected should those actionable findings have gone unnoticed or untreated. However, an earlier study by Sandia Laboratory, called the "Stockpile Life Study," found that only 4 percent of actionable findings would have reduced the reliability of a single system by as much as 10 percent, if no action at all were taken.[19]

More than 75 percent of all the findings in those studies were discovered through DOE's stockpile surveillance program. Most of the others were reported by DOD or were discovered while weapons were still in production or undergoing repair or replacement of parts. The Stockpile Life Study reported that not even one actionable findings was discovered through nuclear testing. The revised, Tri-Lab Study in 1996 reported that three underground tests "revealed or confirmed a problem that required corrective action." These were later revealed to be design and manufacturing problems and not aging-related reliability problems.

More than 75 percent of all actionable findings were discovered within the first eight years of a weapon entering the stockpile and were not related to aging. All current U.S. weapons have been in the stockpile for ten or more years. After the first eight years, aging problems continue to occur at a rate of less than one every ten years per weapon system. Even if that rate should double, and the rate at which actionable findings threaten to reduce reliability by as much as 10 percent should also double, DOE would encounter a problem that threatens to reduce the reliability of even one of the ten nuclear weapons systems in the U.S. stockpile by 10 percent only once every six years. Thus, there is ample reason to conclude that a surveillance and testing program, similar to the one DOE has traditionally conducted, will, with high confidence, detect all problems well before they have a significant impact on the reliability or performance or the stockpile. That conclusion is supported further by the results of a model derived by the JASONs, which predicts the rate at which weapons in the stockpile would fail if their parts were not replaced. The Jason's model uses similar data to the two Sandia studies. It predicts that, even if DOE did nothing to replace aged components, or detect and repair component defects, less than 2 percent of the warheads in the stockpile would fail to function properly in the first thirty years after they were manufactured.[20] The JASON's found no evidence to suggest that the rate of failure would increase for older weapons. Not one defect was found in any of the 59 weapons from the stockpile that had been examined with ages greater than 27 years.

Even if DOE did nothing to replace aged components, or detect and repair component defects, less than 2 percent of the warheads in the stockpile would fail to function properly in the first thirty years after they were manufactured.

Over the very long-term (several decades or more), the radioactive decay of plutonium will eventually cause all nuclear weapons to fail if corrective measures are not taken. Neither plutonium aging nor any other mechanism has been identified, however, that is expected to cause significant numbers of weapons in the current stockpile to function improperly for at least the next several decades.

Question 2: Can DOE confidently maintain the reliability of nuclear weapons and components by remanufacturing them to previous specifications?

The most straightforward way to fix an age-related problem is to replace the affected part with a new one that meets the specifications of the original. Some have questioned whether DOE could do this over long times, since key parts and materials may not remain available.

The question of remanufacture can be broken into two parts — remanufacture of nonnuclear components and remanufacture of the primary and secondary core physics packages. There is no doubt that nonnuclear components can be remanufactured and tested to assure that they conform to previous performance specifications. While materials and parts may not be available, the continual advance of technology assures that new materials and parts can produce the same results. There is no buggy whip industry in the United States, and some fine leathers used in the past to make buggy whips may not be available, but there should be little doubt that modern materials can be found to match the performance specifications of a buggy whip precisely. Nonnuclear components can be fully tested and their performance to previous specifications can be certified with assurance.

Since the nuclear components of remanufactured primaries and secondaries cannot be fully tested, DOE might lack total assurance that they would perform as intended. It is possible to make that lack of assurance exceedingly small, however, by coming as close as possible to the original design specifications. Manufactured parts inevitably differ in small ways from their design, but DOE should be able to match the original design specifications to within very close tolerances. In the days of full weapons production and testing, DOE would generally test an early unit of a new weapon that came off the production line in a final production verification test. In no case did a new primary fail the final verification test because of problems introduced during the manufacturing process, despite many changes in tolerances and materials. Today, we can meet much more stringent manufacturing tolerances than in the past. Furthermore, we have extensive documentation of the details of the actual manufacturing processes used for all of the weapons in the stockpile. This documentation makes it far easier for production personnel to remanufacture pits or secondaries within the tolerances of the warheads that have been in the stockpile than it was for personnel who had to conform the first production units to design specifications.

The impressive record of manufactured pits performing as predicted extends beyond just the final production verification test. Ray Kidder reviewed the results of the initial tests of a large number of new weapons primaries. He found excellent agreement between the predicted yields and the observed yields for: all first-time tests of new primaries from 1977–1986; tests of weapons withdrawn from the deployed stockpile from 1979–1986; and all nuclear tests with explosive yields exceeding 1 kiloton from 1980–1984. He concluded, "Clearly, this impressive record would not have been possible if U.S. nuclear weapons were not comfortably tolerant of the small variations in materials and manufacturing that accompany any practical production process."[21] This conclusion is reinforced by an experiment at Los Alamos in which an intentionally off specification pit was made and successfully tested. Additional support is provided by the lack of statistically significant differences between the nuclear explosive performance of plutonium pits produced by casting near final shapes and by rolling and machining techniques.

Thus, there is every reason to believe that components, including the core physics package, can be remanufactured to previous specifications with sufficient precision to provide high confidence that the remanufactured components and the complete weapons system in which they are placed will function as they were initially designed. The only question remaining about remanufacture is not **if** the U.S. can confidently remanufacture its nuclear weapons, but **when**, and **how closely to the originals** do we want to do so.

Question 3: How good are DOE's current tools for analyzing age-related changes to stockpile reliability and how much help would additional capabilities be?

The United States has an unparalleled capability for analyzing nuclear weapons designs and related problems. DOE has the experience of more than 1,000 nuclear tests and fifty years of other experiments conducted by thousands of scientists. DOE has a host of highly specialized test facilities (see Appendix A) for investigating particular issues. It has developed incredibly detailed computer codes that run on the fastest computers in history to model the behavior of nuclear weapons. DOE was able to design and build all of the weapons systems in the enduring stockpile with the knowledge and tools available before 1990. Since then, it has significantly expanded its understanding of weapons physics and acquired new tools for examining weapons issues. A 1999 review of the Stockpile Stewardship Program, led by DOE Under Secretary Moniz, lists thirty recent accomplishments that have improved DOE's ability to predict and detect problems with nuclear weapons and to analyze and evaluate them.[22]

Those tools are proven and available today for maintaining the stockpile. The "Foster Panel," established pursuant to the 1999 Defense Authorization Act, to assess DOE's Stockpile Stewardship Program recently expressed its confidence in DOE's existing ability to review problems in the stockpile without nuclear tests. They found:

> . . . concerns have already arisen and actions have been taken to change the design of weapons in the stockpile. If there were not a moratorium, nuclear tests would have been performed to confirm the validity of these actions. After careful review, the risks of making these changes without requiring a nuclear test were judged to be acceptable.[23]

The former Director of Los Alamos Laboratory, Sig Hecker, has also noted how existing tools have been used to analyze and solve real weapons problems. In reply to a question from Senator Jon Kyl, Hecker wrote:

> Yes, there have been several instances since the cessation of nuclear testing in September 1992, where we have found problems, either age related or otherwise, for which in the past we would have turned to a nuclear test in the kiloton range to resolve. In the absence of testing, we have used the methodology of [Stockpile Stewardship] to evaluate the problem and suggest fixes if required. This has included more extensive calculation, nonnuclear laboratory experiments, comparison to previous nuclear test data, and extensive experience of our designers and engineers . . . . If our confidence in the fixes were not sufficiently high, we would not certify the stockpile. Our experience to date in resolving suspected problems has increased our confidence in [Stockpile Stewardship] and in the process of annual certification.[24]

These quotations clearly suggest that DOE's current tools are sufficient for analyzing problems that occur. There has not been a single question about the weapons stockpile since the moratorium on nuclear testing began in September 1992 that DOE could not sufficiently address with its current capabilities. If such a problem should occur, it is extremely unlikely it would rapidly reduce the overall reliability and performance of the stockpile significantly. DOE would have ample opportunity to correct the problem by remanufacturing and replacing the component(s) involved. Thus, there is little need for DOE to continue to expand its scientific and technical study of nuclear weapons and to build new and improved experimental and diagnostic facilities to maintain the reliability of the stockpile.

Explanation of the Ratings for Maintaining Weapons Reliability and Performance for the Five Options

Before rating the options on this objective, it is useful to consider one more question. That is, "How reliable must U.S. nuclear weapons be to perform their only potentially legitimate role in U.S. defense policy, which is to deter nuclear attack, or coercion by threat of nuclear attack, against the United States or its allies?" The answer is that the U.S. stockpile must be sufficiently reliable for the nuclear threat to remain credible. The credibility of the U.S. nuclear threat, in turn, hinges on the perceptions of a potential aggressor. An adversary's perception of the performance of U.S. nuclear weapons is related to the objective evidence for the reliability of the stockpile, but many subjective factors also come into play. Chief among those is a potential adversary's subjective evaluation of the conditions under which the United States would actually use its nuclear weapons. Given the potentially large uncertainty regarding their use, there are those who believe that nuclear weapons might be a sufficient deterrent if an aggressor believed only that U.S. weapons *might* meet their performance expectations when called upon. Others believe that sufficient deterrence can be obtained solely with precision-guided, conventional explosive weapons.[25]

A full treatment of deterrence is beyond the scope of this paper. We, however, share the belief that deterrence does not require the large numbers and near-perfect performance expectations of the current nuclear weapons stockpile. Notwithstanding that belief, the ratings below are based solely on our judgement of the options' abilities to maintain the *current* level of reliability and performance of the nuclear weapons stockpile from a technical standpoint.

The **DOE Stockpile Stewardship Program (★★★)** includes an extensive "Enhanced Surveillance" program under which it is applying its substantial knowledge base of nuclear weapons technology to predict when components might degrade before actual failures could affect the reliability of the stockpile. This is backed up by a continuation of DOE's traditional surveillance and testing program to detect potential problems. If DOE were to rely on the results of these programs to identify suspect components, and replace them with freshly produced ones that meet or exceed the previous performance specifications, we might rate the Stockpile Stewardship Option superior (four stars) for maintaining reliability and performance. Unfortunately, DOE plans to make extensive additional modifications to the warheads in the stockpile, including modifications to nuclear explosive packages. We believe that making such modifications, without full nuclear testing, reduces confidence in the reliability of the stockpile. We, therefore, give the Stockpile Stewardship Program only three stars for its ability to maintain the reliability and performance of the stockpile.

The **Remanufacturing Option (★★★★)** earns a superior rating for its ability to maintain the reliability and performance of the stockpile. The guiding philosophy of this option is to remanufacture the physics package of nuclear weapons to original specifications at regular intervals of about 25 to 30 years. In addition, remanufacturing would begin soon, before production expertise is lost. Those factors are very strong for maintaining reliability. We have concern regarding a variant of the Remanufacturing Option in which pits would be modified once to make them more robust. Making any design changes to pits without nuclear testing is risky. We have not reduced this option's score for reliability on that account, however, because that variation is not central to the Remanufacturing Option. We would downgrade a Remanufacturing Option that includes changes to pit designs by at least one star in this category, depending upon the extent of the changes.

The **Curatorship Option (★★★)** rates three stars for its ability to maintain the reliability and performance of the stockpile. This option is the most strict in its commitment to replace degraded parts with those that are as close as possible to the original specifications and in its restraint in making any changes to nuclear weapons. Under this option, DOE would generally not replace parts until it observed some degradation in their condition. This would minimize the risk that unnecessary changes might introduce reliability problems. On the other hand, there would be some risk that once degradation of a component is observed, that degradation might already prevent the weapon from performing properly. In a worst case, weapons of a particular design may have to be removed from the active stockpile more quickly than it takes to address the problem. It is extremely unlikely, however, that a large percentage of the stockpile would be affected at one time. We cannot rate this option superior for reliability, because of the risk that actual weapons in the stockpile may have to be removed for a time to fix problems. We, however, rate it good, because it is unlikely that the deterrent value of the stockpile would be reduced in a meaningful way.

Under the **Passive Arms Reduction Option (★★)** DOE would continue its current surveillance and testing program to identify problems with weapons in the stockpile, but would not fix or replace long-lived components, such as pits and high explosive assemblies, as they undergo changes that might degrade their performance. Rather, weapons that DOE believed to be unreliable would be removed from the stockpile. If the surveillance and testing program is adequate, the weapons remaining in the active stockpile would be as reliable as under any of the other options. The *number* of reliable warheads would decline over time, however. Eventually, one or more classes of warheads might have to be removed from the stockpile. This would reduce the flexibility in the United States response to a potential aggressor, which would represent a significant reduction in performance of the stockpile.

It is very unlikely that a potential adversary would perceive an exploitable weakness in the United States deterrent for the foreseeable future. Many experts believe that as few as 100 secure, survivable, and deliverable warheads should be adequate to preserve the core function of deterring the use of nuclear weapons against the United States or its allies.[26] As noted above, studies have found no increase in the rate of occurrence of defects in the oldest weapons, and no mechanisms have been identified that might cause the majority of the weapons in the stockpile to fail for at least the next few decades. Nevertheless, this option is rated only fair under this category, because of the potential loss of flexibility in the U.S. response should one or more weapons systems be eliminated from the stockpile because they were no longer reliable.

There is no reason to question that DOE could and would maintain the reliability and performance of the stockpile if it were allowed to perform nuclear tests. Thus, the **Return to Testing Option (★★★★)** rates four stars for its ability to meet this objective. However, if DOE should choose to introduce one or more new weapons types under a limited return to testing, they might be tempted to place the new warheads in the stockpile without adequate testing. Under such a scenario, the rating for this option for maintaining reliability and performance would fall to three or perhaps even two stars.

Improving and Modernizing Nuclear Weapons

Background and Issues for Rating the Options

Current U.S. policy clearly calls for improving and modernizing the nuclear weapons stockpile, despite statements from President Clinton that might be interpreted otherwise. In his address to the United Nations on September 24, 1996, after he became the first head of State to sign the CTBT, President Clinton stated, "This Comprehensive Test Ban Treaty will help to prevent the nuclear powers from developing more advanced and more dangerous weapons." Several times since then, the President has spoken of DOE's mission to maintain the safety and reliability of the United States nuclear stockpile, without ever referring to potential improvements. From the inception of the Stockpile Stewardship Program, however, DOE and DOD have sought a capability to improve and modernize nuclear weapons. Recently, DOE documents have begun to list improvements it has already made to the nuclear stockpile and to describe plans for further weapons modernization. DOE has been helped by the Department of Defense and the Congress in making the conceptual shift from maintaining the stockpile without testing to improving and modernizing it.

As early as the 1994 Nuclear Posture Review, DOD called for DOE to maintain the capability to design, fabricate, and certify new warheads. The word "new" in this context could be interpreted to mean merely new copies of existing designs. However, both DOD and DOE have interpreted it to mean "new and improved" designs. Congress supported making improvements in the Fiscal Year 2000 Defense Authorization Act (P.L. 106-65). That Act requires DOE to prepare a plan "for the remanufacture, refurbishment, and modernization of each weapons design designated by the Secretary [of Energy] for inclusion in the enduring nuclear weapons stockpile." The Senate version of the 2001 Defense Authorization Bill (sec. 1018 of S. 2549) explicitly directs DOE to begin design studies for a new low-yield nuclear weapon that could destroy hardened and deeply buried targets by penetrating far into the ground before exploding.

DOE provided a wealth of information on its modernization plans in the November 1999, 30-Day Review. The Review suggests that DOE plans to upgrade all ten weapons systems remaining in the active stockpile and perform extensive refurbishment and modernization on the W80, W76, and B61 systems within the next ten years. It describes an elaborate process for establishing new military requirements for nuclear weapons coordinated through the joint DOD/DOE Nuclear Weapons Council. It also sets forth a six-stage process for managing weapons refurbishments consisting of:

- Concept Assessment
- Feasibility Study and Option Downselect
- Design Definition and Cost Study
- Development Engineering
- First Production, and
- Full-scale Refurbishment

That process is identical to the six stage process that DOE used for 30 years for designing, developing, and acquiring entirely new classes of nuclear weapons during the Cold War.

Whether or not one supports improvements to nuclear weapons, knowing what capabilities are necessary and sufficient to certify improvements, without underground nuclear testing, is useful. All improvements are not the same, however. The answer will depend on how extensively the weapon is modified, and particularly whether and to what degree the core physics package is modified.

If only components outside the core physics package are changed, it would be possible to certify such changes with capabilities similar to those used to test and examine existing weapons components in the surveillance and testing program. Changes to the arming, fusing, and firing chain, such as installation of longer lived batteries, and changes to guidance systems and other electronic components could easily be made in this manner. More complex changes that do not directly modify the physics package, but could affect the overall performance of the weapons, would require additional computational, analytical and test capabilities. DOE has already made changes that fall in this latter category since it ceased nuclear testing. For example, DOE modified the casings and other parts of B61 bombs, which have been in the stockpile for many years, to allow them to function in an earth penetrating mode. Earth penetration transfers more of the blast to the ground and threatens hardened underground command bunkers.

DOE has also made significant changes to the W87 in its "Stockpile Life Extension Program" (SLEP) and certified and began inserting into several systems a new neutron generator, designed and built at Sandia National Laboratory, which replaces entirely different types of neutron generators that were designed and made at DOE facilities that have since been closed.

DOE has high confidence in the reliability of weapons that have undergone these modifications, but says it could not have certified them without the new computational capabilities and test facilities it has recently developed under its Stockpile Stewardship Program. For example, the new casing and earth overburden involved in earth penetration changes the reflected neutron environment of the weapon system, which could affect the course of the nuclear detonation, and therefore, had to be analyzed through computational modeling and experimentation.

The upgrades that DOE has performed so far are modest ones that could be confidently modeled because they were incremental changes to well-tested nuclear explosive package designs.[27] More extensive changes will require considerably more capabilities. The 30-Day Review describes the capabilities that DOE believes are necessary to certify such changes:

> . . . [Certification of significant changes] requires that computational facilities be available to simulate weapon performance with full-fidelity physics in three dimensions. Also required are facilities to conduct subcritical experiments to verify dynamic properties of nuclear weapons materials. Additional radiographic facilities, both x-ray and proton, are required along with facilities for developing microsystem-based surety options.[28]

DOE's ultimate goal is to model nuclear weapons behavior accurately and completely with fully integrated three-dimensional codes that are based on fundamental physics and properties of materials without any empirically derived calibration factors.

DOE's ultimate goal is to model nuclear weapons behavior accurately and completely with fully integrated three-dimensional codes that are based on fundamental physics and properties of materials without any empirically derived calibration factors. This is a task without foreseeable limits. If DOE could achieve this ability to model full scale systems in an integrated fashion, it would provide a capability vastly superior to underground nuclear testing. Nuclear testing requires long preparation times and considerable expense for a single shot. A fully integrated model could be run repeatedly to investigate entirely new weapons concepts and more rapidly design new generations of nuclear weapons.

A problem with the DOE approach is that absent empirical confirmation of the nuclear explosive performance of the final product, one can never be sure how closely the analytical predictions match reality. Weapons designers will endlessly push for higher and higher spending to improve their understanding of nuclear weapons phenomena further. This approach could also lead to at least two situations that could engender calls for a return to testing. Weapons designers could overestimate their ability to model weapons performance and introduce changes into weapons that will not function as intended. This happened following the 1958–1961 moratorium on nuclear weapons testing, when weapons introduced into the stockpile, without production certification tests, were later found to have fundamental problems. Another possibility is that political or military leaders could lose confidence in changes to weapons that the designers have made and insist on a return to nuclear testing.

Explanation of the Ratings for Improving and Modernizing Nuclear Weapons for the Five Options

Any program for managing the nuclear weapons stockpile that seeks to significantly improve and modernize nuclear weapons under the present test moratorium or a CTBT will be extremely expensive and risky. It will also conflict with U.S. objectives for arms control and nonproliferation. While, we give high ratings in this category to the options that have the best technical ability to improve and modernize nuclear weapons, we do not believe that improving weapons is a desirable objective. That belief is reflected in the ratings for support for arms control and nonproliferation that follow.

Options that score well under this category will score poorly under the following one.

The **DOE Stockpile Stewardship Option (★★★)** scores three stars for its ability to improve and modernize nuclear weapons. DOE is putting tremendous effort and expense into being able to do this without nuclear testing. There is a broad consensus, however, that no matter how much money DOE spends it cannot develop and design new weapons as well without nuclear testing as it could with a return to testing.

The **Remanufacturing Option (★★)** scores two stars for its ability to improve and modernize nuclear weapons. Under this option, much of DOE's planned scientific program would be continued and could be applied to improving the nonnuclear components of nuclear weapons. This option would not allow making performance improvements to the physics package of nuclear weapons, which would limit its ability to make significant overall improvements to nuclear warheads. On the other hand, weapons delivery systems could be modernized and improved. Significant modifications to the nonnuclear portions of nuclear warheads would likely be needed to match them to new delivery systems.

Under the **Curatorship Option (★)**, the declared policy would be not to make any improvements to nuclear weapons. Capabilities to repair damaged components would be retained, however, as would some scientific and technical expertise in weapons design. Using these capabilities to make some modifications and improvements to nonnuclear components, if necessary, would be possible. Therefore, this option is given one star for its ability to improve and modernize nuclear weapons.

Under the **Passive Arms Reduction Option (0)**, there would be no capability to make new weapons components, other than to replace traditional limited-life components. DOE would have no ability to improve and modernize nuclear weapons. This option rates no stars for its ability to improve and modernize nuclear weapons.

There would be no limits on DOE's ability to improve and modernize nuclear weapons under the **Return to Testing Option (★★★★).** It therefore, rates four stars in this category.

Supporting Arms Control and Nonproliferation

Background and Issues for Rating the Options

Supporting arms control and nonproliferation should be a major objective of any program to manage the nuclear weapons stockpile. The United States is legally committed to pursuing nuclear disarmament under the Treaty on the NonProliferation of Nuclear Weapons (NPT). Article VI of the NPT states:

> Each of the Parties to the Treaty undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a treaty on general and complete disarmament under strict and effective international control.

The commitment by the nuclear weapons states to Article VI is the quid pro quo for which more than 180 Nations foreswear seeking to acquire nuclear weapons. The perception—by now well established—that the United States is not fully committed to Article VI of the NPT continues to weaken the entire nonproliferation regime. Over time, lack of progress on Article VI cold lead to the ultimate undoing of the NPT. At the very least, perceptions of an insincere U.S. commitment to its NPT obligations make it much harder to achieve improvements in the nonproliferation regime.

It is also the intent of the parties to the CTBT for that Treaty to constrain the development and improvement of nuclear weapons and foster disarmament. The Preamble to the CTBT states:

> The States Party to this Treaty . . . .
>
> Convinced that the present international situation provides an opportunity to take further effective measures towards nuclear disarmament and against the proliferation of nuclear weapons in all its aspects, and declaring their intention to take such measures, . . .
>
> Recognizing that the cessation of all nuclear weapons test explosions and all other nuclear explosions, by constraining the development and qualitative improvement of nuclear weapons and ending the development of advanced new types of nuclear weapons, constitutes an effective measure of nuclear disarmament and nonproliferation in all its aspects, . . .
>
> Have agreed as follows: . . . not to carry out any nuclear weapon test explosion or any other nuclear explosion . . .

Continuing to develop and improve nuclear weapons, even without nuclear testing, runs counter to both the NPT and the CTBT. Developing new nuclear weapons continues the arms race, which the United States is committed to end in the NPT. It significantly undercuts that Treaty. It is unrealistic for the United States to expect other nations to forego the development of nuclear weapons forever, if this Nation continues to design, develop, and produce new and improved nuclear weapons. Continuing to develop and improve nuclear weapons is also clearly counter to the spirit of the CTBT, since that Treaty's declared purpose is to constrain such development and improvement.

A broad program to improve U.S. nuclear weapons is an impediment to progress on bilateral arms control with Russia. It also encourages Russia, China, and other nations that possess nuclear weapons to continue and expand their nuclear weapons development activities. While the Russian Duma finally ratified the START II Treaty in April 2000, the Treaty will not enter into force until the U.S. Senate agrees to certain protocols. It is unlikely that the protocols will be brought up for a vote in the Senate this year. Prospects for their approval beyond that are uncertain. There is still widespread mistrust between the United States and Russia over ballistic missile defense systems and other strategic nuclear weapons issues. The prospects for further arms reductions are uncertain. In December 1999, the Associated Press reported that Russian Defense Minister Igor Sergeyev called for the development of "weapons based on new physical principles" to offset what he described as a growing U.S. military edge. Sergeyev stated, "Any further postponement of a full-scale modernization of Russian weapons systems may lead to a rapid lag behind the West in the military-technical field."[29] By not significantly constraining nuclear weapons development and not pursuing bilateral reductions in nuclear weapons more aggressively, the United States is missing a golden opportunity to lock in permanent reductions in nuclear weapons.

Explanation of the Ratings for Supporting Arms Control and Nonproliferation for the Five Options

In general, the greater that DOE's ability and intent to improve nuclear weapons would be under an option for managing the nuclear weapons stockpile, the lower we rate that option's support for arms control and nonproliferation.

DOE's broad experimental program in nuclear weapons technology, which includes secret underground explosions; its determined efforts to advance its understanding of nuclear weapons technology; and its plans to improve and modernize every U.S. weapons system, encourages, rather than deters, the development and maintenance of nuclear weapons around the world.

The **DOE Stockpile Stewardship Option (⋆)** rates poor (one star) for supporting arms control and nonproliferation. DOE's broad experimental program in nuclear weapons technology, which includes secret underground explosions; its determined efforts to advance its understanding of nuclear weapons technology; and its plans to improve and modernize every U.S. weapons system, encourages, rather than deters, the development and maintenance of nuclear weapons around the world. DOE's program to refurbish and modernize the stockpile is inconsistent with U.S. commitments under the NPT to cease the nuclear arms race. It is also counter to the purpose of the CTBT.

The conduct of subcritical tests underground at the Nevada Test Site makes it difficult for other nations to verify that the United States is not conducting explosive nuclear tests. These deep underground tests foster suspicion and mistrust of U.S. actions, which hinders progress on arms control and encourages secret nuclear weapons development in other nations. Furthermore, the extent of DOE's multifaceted Stockpile Stewardship effort (including new testing facilities such as NIF and DARHT and the ASCI program) also fosters other nation's fears that the United States is putting in place the ability to make qualitative improvements to nuclear weapons. The U.S. Senate's instructions to DOE in the 2001 Defense Authorization Bill to begin design studies for a new low yield earth penetrating nuclear weapon can only exacerbate this problem.

Finally, the vast expansion of the knowledge base of nuclear weapons phenomena and improvements in nuclear weapons codes that DOE seeks under the Stockpile Stewardship Program is a proliferation threat in and of itself. History has shown that such knowledge will eventually spread around the world. This could occur covertly, as is alleged in recent charges that China has illegally obtained extremely sensitive information about U.S. nuclear weapons. It could also proceed by the slow diffusion of knowledge related to nuclear weaponry that may or may not be classified.[30]

The **Remanufacturing Option (⋆⋆)** rates fair for supporting arms control and nonproliferation. As defined here, the Remanufacturing Option would continue much of the development of weapons science and technology that DOE plans for Stockpile Stewardship and would also allow for modernization of the nonnuclear components of nuclear weapons. Both those practices run counter to full support for Arms Control and Nonproliferation. This option would be less harmful to arms control efforts than the DOE Stockpile Stewardship Program, because weapons development would be constrained. Subcritical explosions would continue under this option, but they would be conducted at or near the surface rather than deep underground, providing far more transparency to potential international monitors than under DOE's current approach. On the other hand, any further research on nuclear weapons science and technology and improvements to U.S. nuclear weapons could provide some excuse for other nations to develop nuclear weapons. Those aspects need not be a part of a more minimalist remanufacturing program. Such a minimalist remanufacturing program would have much in common with the Curatorship Option.

The **Curatorship Option (★★★)** earns a good rating for supporting arms control and nonproliferation. Curatorship would be fully consistent with existing arms control commitments. Improvements to U.S. nuclear weapons or new developments in weapons science would be strongly discouraged. Thus, activities under this option would provide little excuse for other nations to develop their nuclear weapons. We give this option only a good rating, however, because it does not provide as much impetus for further arms control as the Passive Arms Reduction Option.

The **Passive Arms Reduction Option (★★★★)** rates superior for supporting arms control and nonproliferation. This approach would lead naturally to reductions in U.S. nuclear weapons, which would provide a positive impetus for further international arms control. There would be no U.S. nuclear weapons research or development activities for existing or potential new entrants into the nuclear weapons club to point to as justification for their own nuclear weapons programs.

A **Return to Testing (0)** by the United States would reverse years of progress in limiting nations' abilities to develop nuclear weapons. It would signal to all nations (including nonnuclear weapons states) that pursuing nuclear weapons development is legitimate. It would also create an environment of distrust that would take years to overcome before serious arms control efforts could resume. This option, therefore, rates inferior (no stars) for supporting arms control and nonproliferation.

Controlling Costs

Background and Issues for Rating the Options

We estimate the likely annual costs to pursue the options in this paper over the next five to ten years as follows:

Stockpile Stewardship	$4.9 billion per year
Remanufacturing	$3.9 billion per year
Curatorship	$2.7 billion per year
Passive Arms Reduction	$1.7 billion per year
Return to Testing	$5.1 billion per year

Details of the cost estimates are summarized in Table 2 and further specified in Appendix B.

The estimates in Table 2 are the **likely spending levels** under each option. They are **not the minimum amounts** that we believe are necessary to maintain the safety, reliability, and performance of the stockpile in all cases. In particular, we believe that the stockpile could be adequately maintained under the approaches outlined for the Stockpile Stewardship and Remanufacturing Options with much less spending. The costs shown for Stockpile Stewardship reflect our estimate of what DOE is likely to spend annually over the next five to ten years, not what we would recommend as necessary to pursue the Stockpile Stewardship Option. Similarly, the costs shown for the Remanufacturing Option are based on statements by prominent proponents of that option, Richard Garwin and Ray Kidder, that much of the science and technology that DOE is conducting should be continued. Most of that science and technology is not necessary for an option that truly relies upon remanufacturing as the basis for ensuring the safety and reliability of the stockpile. We believe that the Remanufacturing Option could be successful with a spending level on science and technology that is similar to our estimate for the Curatorship Option ($0.7 billion). Table 2, however, shows our estimate of what spending on science and technology would be if Kidder and Garwin were to shape the program, which is nearly $1.3 billion.

The figures in Table 2 represent average funding levels over the next five to ten years, rather than a snapshot of funding in a specific year. The estimates for the Stockpile Stewardship Option are derived from DOE's Fiscal Year 2001 Budget Request. The categories in Table 2 do not, however, correspond to the categories in the DOE Budget. We have used a functional, performance-based presentation that aligns the spending with the outputs of the program. DOE's Fiscal Year 2001 Budget Request is not organized by output function. Rather, more than half the operating budget is attributed to "Readiness in Technical Base and Facilities," which is primarily the cost of operating facilities. The Budget does not relate those costs to the missions those facilities perform. The structure of the 2001 Budget provides the Congress little information regarding how spending relates to the activities that are necessary to maintain the safety and reliability of the stockpile.

While the estimates for the Stockpile Stewardship Option are derived from DOE's 2001 Budget request, they do not correspond exactly to that request. First, the 2001 DOE Budget does not contain sufficient detail to allow us to place all the spending in the proper category with assurance. Thus, we used information from the 2000 Budget and other sources in estimating the spending for each category. In addition, since our estimate represents an average spending figure for the next five to ten years, we made several adjustments, including:

- Added approximately $300 million per year for a next generation of science facilities that DOE plans to build, but has not yet fully funded;[31]
- Subtracted approximately $200 million per year from computing activities for an anticipated reduction as some goals of ASCI are met;
- Added approximately $100 million for basic and applied research and development activities to replace ASCI-related research and validation;
- Added approximately $150 million for increased activities related to future production of pits and other components; and

TABLE 2. **Representative Funding for Major Programs and Facilities by Option** (in millions of dollars)

Programs and Facilities	DOE Stockpile Stewardship Program	Remanu-facturing	Curatorship	Passive Arms Reduction	Return to Testing
SCIENCE AND TECHNOLOGY					
Basic and applied nuclear weapons research	225	150	75	50	275
Development and engineering of new and modified weapons and components	175	100	50	0	275
Computing, code development, and computer hardware	600	300	150	100	400
Nevada Test Site facilities and operation, including subcritical experiments	200	125	75	50	300
Inertial Confinement Fusion (ICF) research and operations	300	200	100	0	300
Other science facilities and infrastructure	250	200	150	100	250
Next generation science facilities (including NIF, MESA, CMR Upgrade, and AHF)	400	200	100	0	400
SUBTOTAL Science and Technology	**2150**	**1275**	**700**	**300**	**2200**
SURVEILLANCE AND TESTING					
Surveillance, testing, data archiving, and evaluation of the existing stockpile and remanufactured components	300	350	400	300	300
Testing and certification of new or modified components	175	125	50	0	200
Dismantlement and associated examination and evaluation	150	150	180	200	150
Research and development to predict failures and to improve surveillance and testing	100	100	100	40	100
SUBTOTAL Surveillance and Testing	**725**	**725**	**730**	**540**	**750**
MANUFACTURING					
Pit and secondary production and associated materials processing	350	450	150	0	400
Tritium production, extraction, recycling, and reservoir filling	200	200	200	150	200
Production of limited life components, test equipment, and replacement components of existing design	300	300	250	200	300
Engineering and production of new and modified components and equipment	300	200	50	0	350
Storage, transportation and waste disposal	300	325	250	280	325
Development and improvements to manufacturing processes and infrastructure, including ADAPT	275	200	150	50	275
SUBTOTAL Manufacturing	**1725**	**1675**	**1050**	**680**	**1850**
Other (Program direction, education, and mission support)	300	250	220	180	300
TOTAL	**4900**	**3925**	**2700**	**1700**	**5100**

- Subtracted about $50 million from tritium production, as the design of the backup linear accelerator for tritium production and the design and construction of the Tritium Extraction Facility (TEF) will be completed.

Thus, our total estimate for the Stockpile Stewardship Option is $4.9 billion, compared to DOE's 2001 request of $4.6 billion.

For the other options, we estimate how spending on each category in Table 2 might differ from the Stockpile Stewardship Option. Our assumptions in preparing the estimates in Table 2 are detailed in Appendix B. **The estimates in Table 2 should not be viewed as precise budget estimates, but as indications of the relative emphasis that would be placed on the various activities under each option. The *differences* in programs and facilities that would be conducted under each option (detailed in Appendix B) are more important than the absolute spending estimates for any of the options.** The cost of closing out existing programs and remediating any environmental impacts are not included. In the long term, the options with more extensive program activities (i.e., Stockpile Stewardship and Return to Testing) will have higher costs for environmental remediation. In the short term, however, shutdown and remediation costs could significantly increase spending on the lower cost options.

Explanation of the Ratings for Controlling Costs for the Five Options

The ratings in this category are directly aligned with the cost estimates in Table 2. The **DOE Stockpile Stewardship Option (0)** and the **Return to Testing Option (0)** both rate inferior for controlling costs. They are estimated to cost $4.9 billion and $5.1 billion per year respectively. That is much more than the average annual spending for comparable activities during the Cold War, which was $3.8 billion in today's dollars.[32]

The **Remanufacturing Option (⋆)** is the most difficult option for estimating costs, since large variations in spending on science and technology could be consistent with this option. Major proponents of the Remanufacturing Option, including Ray Kidder and Richard Garwin, favor continuing much of the science and technology that DOE plans under the Stockpile Stewardship Option. They acknowledge that some facilities planned for Stockpile Stewardship, including National Ignition Facility (NIF), and much of the Advanced Strategic Computing Initiative (ASCI) program, are not *necessary* to maintain the stockpile by remanufacturing. They would continue these programs, however, for their general scientific utility and to assure that competent scientists are attracted to the weapons laboratories, and would be available to assist the weapons program, if they were needed. The figures shown on Table 2 are somewhat of a compromise. We have assumed that NIF and ASCI would proceed, but at a slower pace than under the DOE Stockpile Stewardship Option. We assume that DOE would cease performing subcritical experiments deep underground in Nevada, and that the level of readiness at the Nevada Test Site would be reduced. DOE would, however, conduct some subcritical experiments above ground or near the surface. Most other existing DOE science and technology programs would continue operating similarly to DOE's current plans. Fewer new, advanced facilities would be built. With those assumptions, this option would cost about $3.9 billion/year, which is slightly higher than the average annual Cold War spending level. Under those assumptions, we rate this option poor (one star) for controlling costs. If, however, this option were revised so that only the science and technology that is strictly necessary to maintain the stockpile using the remanufacturing approach is conducted, its total cost could be reduced by $500 million per year or more. In that case, it would earn two stars in this category.

We estimate that the Curatorship Option would save more than $2 billion per year compared with Stockpile Stewardship.

We estimate that the **Curatorship Option (★★★)** would save more than $2 billion per year compared with Stockpile Stewardship. This earns it a three star rating for controlling costs. Most of the savings come from reducing spending on science and technology by two-thirds. Funding for surveillance and testing would be about the same as under the Stockpile Stewardship Option, but more funds would be directed toward surveillance of the existing stockpile and less to testing of new and modified components. Manufacturing costs would be reduced by one-third, which is about the portion that DOE spends making improvements to existing parts and procedures under the Stockpile Stewardship Program.

The **Passive Arms Reduction Option (★★★★)** would be the least costly of all. It earns a superior rating (four stars) for controlling costs. This option would save more than $3 billion per year compared with Stockpile Stewardship.

Minimizing Adverse Environmental Impacts

Background and Issues for Rating the Options

Managing thousands of nuclear weapons presents an enormous environmental challenge. It requires the proper handling of huge quantities of hazardous and radioactive materials, much of which must eventually be discarded as waste. In addition, large tracts of land surrounding hazardous nuclear facilities are typically dedicated to exclusion zones, preventing their use for other purposes.

The programs and activities conducted under any of the options for managing the nuclear weapons stockpile would have to meet all environmental protection requirements. Thus, in principle, no activities would be conducted unless their environmental impacts were judged to be acceptable. In the real world, however, DOE has had a shoddy record of environmental protection that has resulted in contamination at every site in the weapons complex. DOE's latest estimate is that it will cost between $168 and $212 billion, beyond the $35 billion that has already been spent, to clean up contamination from past activities at the nuclear weapons complex.[33] Future maintenance of the stockpile is certain to produce additional contamination that will require large sums of money to clean up. Our ratings of the options in the category are roughly in line with our expectations for the cost of cleaning up the contamination that they will produce in the future.

Explanation of the Ratings for Minimizing Adverse Environmental Impacts for the Five Options

The ratings in this category track closely with the overall extent of the activities that would be conducted under each option. The smaller the program, the better chance it has to minimize adverse environmental impacts. The **Return to Testing Option (0)** stands out as the worst option in this category. It would renew the practice of contaminating large tracts of the subsurface environment in Nevada with radioactivity in a manner that is beyond any hope of remediation for thousands of years.

We rate the **DOE Stockpile Stewardship Option (★★)** two stars. DOE plans to conduct extensive production activities and experimental programs under this option. New facilities would be built and operated that use large amounts of hazardous and radioactive materials in new processes. The potential for accidents or other environmental breaches is large.

We also give the **Remanufacturing Option (★★)** only two stars for Minimizing Adverse Environmental Impacts. Under this option, DOE would seek to manufacture about 300 plutonium pits per year, as soon as possible. Pit manufacture would create large amounts of long-lived (transuranic and mixed) radioactive waste.

The **Curatorship Option (★★★)** would require a much smaller overall program than stewardship or remanufacturing. In addition, most of the program would continue activities that have been conducted safely in the past. It therefore rates three stars.

The **Passive Arms Reduction Option (★★★★)** would be the smallest, least invasive program of all. Over time, the number of nuclear weapons would be gradually reduced, with a corresponding reduction in the potential for environmental harm. Thus, we give this option a superior rating (four stars) for minimizing adverse environmental impacts.

Conclusion and Recommendations

All of the options rate good or superior on maintaining weapons safety and security, which must be a first priority in dealing with inherently dangerous nuclear weapons. There are substantial differences among the options on all the other criteria. At least one option rates superior and one or more options rate fair or below for each of the other five criteria that we examined. These differences provide ample opportunity for observers to choose an option that satisfies the objectives they value most highly.

The Curatorship Option is the only one of the five options that we rate as superior or good on all five criteria, which we believe must be satisfied to adequately maintain the nuclear weapons stockpile and achieve broad political support.

- Maintaining weapons safety and security;
- Maintaining weapons reliability and performance;
- Supporting arms control and nonproliferation;
- Controlling costs, and
- Minimizing adverse environmental impacts

The Curatorship Option rates a "poor" on the sixth criterion—Improving and modernizing nuclear weapons. We believe that improvements to nuclear weapons are not needed. Moreover, the ability to improve nuclear weapons is counterproductive. Efforts to improve U.S. nuclear weapons are detrimental to arms control and nonproliferation, since they encourage other nations to develop their own nuclear weapons. We, therefore view the low rating for the Curatorship Option on this criterion as further reason to favor it. In our view, the strongest features in favor of the Curatorship Option are its policy of making no improvements to nuclear weapons; its strategy of bolstering and using the surveillance and testing program to identify defects before making any repairs to nuclear weapons; and its discontinuation of all research and experimentation that is not necessary to maintain the safety, security, reliability, or performance of the nuclear weapons stockpile.

The Remanufacturing Option is the only one of the five that we rate as superior for maintaining weapons reliability and performance. It also rates superior for maintaining safety and security. On the other hand, under this option, DOE would continue an active weapons research and engineering program, even though the main purpose of it may be only to retain talented scientists and engineers at the weapons laboratories. DOE would also begin remanufacturing and replacing nuclear weapons primaries as soon as possible (albeit with near exact replicas of those already in the weapons), and would seek to make continual improvements in the nonnuclear components of nuclear weapons. Taken together, those activities could provide justification for other nations to continue or expand their nuclear weapons development programs. This option, therefore, rates only fair for supporting arms control and nonproliferation. Furthermore, the Remanufacturing Option rates poor for controlling costs and only fair for minimizing adverse environmental impacts. If weapons-related research activities and improvements to weapons components were both significantly restricted under the Remanufacturing Option, it would become much more attractive. A hybrid option is possible that retains the pro-active stance of the Remanufacturing Option in replacing components (including nuclear weapons primaries) before any degradation is observed, and combines that with the restricted research and engineering and prohibition on improvements to nuclear weapons of the Curatorship Option. Such a hybrid might be attractive to those who do not support the approach of the Curatorship Option of waiting for defects to be discovered before making repairs.

The Passive Arms Reduction Option rates superior on four of the five key criteria we believe must be satisfied to adequately maintain the stockpile and achieve broad political support. It is the only option to receive more than two such ratings. However, it rates only fair on maintaining reliability and performance. This option's approach of removing failed weapons from the stockpile, rather than replacing them, is likely to make it politically unacceptable in the current environment. Few in the current Congress would allow the possibility for unplanned and somewhat random degradation of the stockpile to control reductions in U.S. nuclear weapons. Such reductions could potentially complicate planned reductions and/or negotiated arms control, if the first systems to encounter problems were not the same ones that policy makers would choose to eliminate first. On the other hand, many experts believe that as few as 100 secure, survivable, and deliverable warheads would be adequate to preserve the core function of deterring the use of nuclear weapons against the United States or its allies. It is very unlikely that, even under the "no repairs" policy of this option, the number of reliable nuclear weapons in the stockpile would fall to anywhere near that level for at least the next few decades. Thus, those who support a minimum core deterrence role for nuclear weapons might favor this option.

The DOE Stockpile Stewardship Option rates poor and the Return to Testing Option rates inferior on support for arms control and nonproliferation. In both cases, we assign those low ratings because of the broad programs in weapons research and engineering and the continued improvement and modernization of all aspects of nuclear weapons (including the nuclear explosive portions) called for under those options. The modernization of the stockpile that would occur under those options is inconsistent with U.S. commitments under the NPT to cease the nuclear arms race. The DOE Stockpile Stewardship Option and the Return to Testing Option also fly in the face of the CTBT. Those options encourage the further development and continued legitimacy of possessing nuclear weapons around the world. In addition, those options are by far the most costly and least protective of the environment. In short, there is little to recommend either the DOE Stockpile Stewardship Option or the Return to Testing Option.

In conclusion, there are significant deficiencies in the Department of Energy's Stockpile Stewardship Program for managing nuclear weapons. We have identified three distinctly different options that offer substantial improvements over Stockpile Stewardship. They are the Curatorship Option, the Remanufacturing Option, and the Passive Arms Reduction Option. There are also variations on these options that would meet the mission of adequately maintaining the nuclear weapons stockpile at least as well as Stockpile Stewardship, without impeding U.S. goals and treaty obligations for reducing the worldwide danger from nuclear weapons. We therefore recommend the following:

We have identified three distinctly different options that offer substantial improvements over Stockpile Stewardship. They are the Curatorship Option, the Remanufacturing Option, and the Passive Arms Reduction Option.

Recommendation 1. The U.S. Congress should request from the Congressional Budget Office and the General Accounting Office financial and policy analyses of the five strategies identified here for managing the U.S. nuclear weapons stockpile.

Recommendation 2. Congress should hold comprehensive oversight hearings examining DOE's Stockpile Stewardship Program in comparison to the full suite of stockpile management options. Witnesses should be drawn from Government agencies, academic institutions, and non-governmental organizations, who would bring different perspectives and expertise to bear on this issue. Witnesses should include experts in quality assurance, arms control and nonproliferation, and organizational dynamics, as well as nuclear weapons science and engineering.

Recommendation 3. Congress should redirect funds from DOE's efforts at expanding nuclear weapons science and engineering and improving nuclear weapons designs. Instead, some of the funds should be used to increase support for basic programs in surveillance, testing, and evaluation of existing weapons in the active stockpile.

Recommendation 4. In preparation for the next Presidential Administration, the Department of Energy should conduct a comprehensive reevaluation of how it manages the nuclear weapons stockpile. The reevaluation should consider a range of options, such as those presented here, and evaluate the options against a set of criteria similar to those used here. The reevaluation should give special consideration to options that are more supportive of U.S. arms control and nonproliferation objectives than is Stockpile Stewardship. The reevaluation team should include representatives from DOE, DOD, the Executive Office of the President, State, the weapons laboratories, and outside experts.

Recommendation 5. Citizens groups and the general public should use the information presented in this report to advocate for changes in U.S. nuclear weapons policy that would reduce the worldwide danger from nuclear weapons. Nuclear weapons issues have all but fallen off the political agenda, yet substantial danger remains from existing nuclear weapons and the potential expansion of nuclear weapons technology to new nations. A concerned and vocal citizenry is needed to bring about change in this area.

Endnotes

1 U.S. and Russian stockpile estimates from Natural Resources Defense Council. Nuclear Program.

2 Schwartz, S.I., *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons Since 1940*. Brookings Institution Press, 1998.

3 Paine, C.E. and M.G. McKinzie, Does the U.S. Science-Based Stockpile Stewardship Program Pose a Proliferation Threat? *Science and Global Security,* 1998, vol. 7, pp. 151–193.

Lichterman, A. and J. Cabasso, *A Faustian Bargain: Why 'Stockpile Stewardship' is Fundamentally Incompatible with the Process of Nuclear disarmament*. Western States Legal Foundation, Oakland, CA, April 1998, 39 p.

4 Kidder, R.E., Problems with stockpile stewardship. *Nature,* April 17, 1997, pp. 645–647.

Garwin, R.L., The Future of nuclear weapons without nuclear testing. *Arms Control Today,* Nov/Dec 1997.

Mello, G., A. Lichterman, and W Weida, The Stockpile Stewardship Charade. *Issues in Science and Technology*, Spring 1999. (http://remus.nap.edu/issues/15.3/mello.htm)

5 DOE is replacing many of the components in existing weapons with upgraded components. In one case, the B61-11, it modified an existing bomb to give it the capability to penetrate into the earth before exploding. This is a new capability that no previous U.S. nuclear weapon possessed. Thus, DOE's claim that it is not manufacturing new nuclear weapons is arguable.

6 Unclassified view graphs supplied by Sandia National Laboratory from a classified study referred to as the "*SNL Stockpile Life Study*," 1993.

7 *Remanufacture*. MITRE Corporation, JASON Program Office. Study leaders S. Drell and R. Jeanloz. JSR-99-300. p. 21.

8 This policy was first enunciated in 1994 in the Department of Defense's Nuclear Posture Review and was revalidated in May 1997 in the DoD Quadrennial Review.

9 Garwin, R.L., The Future of nuclear weapons without nuclear testing, op. cit.

10 Kidder, R.E., Problems with stockpile stewardship, op. cit.

11 *Remanufacture,* op. cit. p. 21.

12 National Academy of Sciences. Committee on International Security and Arms Control. *The Future of U.S. Nuclear Weapons Policy*. National Academy Press, Washington, D.C. 1997. 110p.

13 For a review of this issue see: Mello, G. *Nuclear Weapons Safety: No Design Changes are Warranted.* A review for Tri-Valley CAREs. July 1, 1995.

Experts in and out the Administration have continued to testify before Congress that the stockpile remains safe and secure. For the past four years, the Secretaries of Defense and Energy, on the advice of the directors of the weapons laboratories, have certified to the President that the nation's nuclear stockpile is safe and reliable. The most recent certification was sent to President Clinton on April 14, 2000.

14 This conclusion refers only to issues of safety and security as they pertain to DOE responsibilities for managing the nuclear weapons stockpile. There is currently a debate over whether the DOD should maintain the nation's deployed nuclear weapons on alert status. Removing weapons from alert status would reduce the potential for accidents or unauthorized launch. This is a fundamental issue affecting safety and security, but it is beyond the scope of this paper.

15 Mello, G. *Nuclear Weapons Safety,* op. cit.

16 Statement of Brigadier General Thomas F. Gioconda, Acting Deputy Administrator for Defense Programs, National Nuclear Security Administration, U.S. Department of Energy, for FY 2001 Appropriation Hearings. p. 9.

17 For example, DOE could add plutonium to a design, in an effort to ensure nuclear detonation in the presence of impurities or small irregularities in the crystal structure of plutonium made by a new process. Such a change might increase the probability that the weapon would detonate if ignited at only one point. Without testing, it could be difficult to assure that there is less than one chance in one million of a nuclear explosion with a yield of four pounds or more occurring from a detonation initiated at one point. All existing weapons in the stockpile have been well tested to assure they meet this goal.

18 Johnson, K., et al, *Stockpile Surveillance: Past and Future.* Sandia Report SAND95-2751. January 1996, 35 p.

19 Unclassified view graphs from the *SNL Stockpile Life Study*, op. cit.

20 *Remanufacture*, op. cit., p. 21.

21 Kidder, R., *Maintaining the U.S. Stockpile of Nuclear Weapons During a Test Ban.* Presented at the International Scientific Symposium on a Nuclear Test Ban January 15–16, 1988. Las Vegas, Nevada. UCRL-97877. p. 14.

22 U.S. Department of Energy. *Stockpile Stewardship Program: 30-day Review.* Nov. 23, 1999.

23 *FY 1999 Report of the Panel to Assess the Reliability, Safety, and Security of the United States Nuclear Stockpile*. John S. Foster, Chairman. November 8, 1999. p. 14.

24 Enclosure 1 to letter to the Honorable Jon Kyl, United States Senate, from S.S. Hecker, Director, Los Alamos National Laboratory, September 24, 1997, response to Question 7. Obtained by the Los Alamos Study Group under the Freedom of Information Act.

25 National Academy of Sciences. Commission on Physical Sciences, Mathematics, and Applications. *Post-Cold War Conflict Deterrence.* National Academy Press, Washington, D.C. 1997. 227 p.

26 *The Future of U.S. Nuclear Weapons Policy*, op. cit.

27 The modification to the B61 was physically only an incremental change to an existing warhead. It should, however, be considered a new warhead, since it provides a new military capability for U.S. nuclear planners.

28 *Stockpile Stewardship Program: 30-day Review,* op. cit., p. 6–3.

29 Isachenkov, V., Russian Minister: New Weapons Needed, Associated Press, Dec. 9, 1999.

30 Paine, C.E. and M.G. McKinzie, op. cit.

31 These include the National Ignition Facility (NIF), a Microsystems and Engineering Sciences Applications (MESA) facility, an Advanced Hydrotest Facility (AHF), and a new Chemistry and Metallurgy Research (CMR) building. (See Appendix A)

32 Schwartz, S.I., *Atomic Audit*, op. cit.

33 U.S. Department of Energy. *Status Report on Paths to Closure.* April 2000, p. 3.

APPENDIX A

Overview of DOE Facilities for Stockpile Stewardship

This appendix presents an overview of major existing and planned facilities that are part of the Department of Energy's (DOE) Stockpile Stewardship Program. The pure number of facilities that support the program is staggering. The Department of Energy states that the numerous facilities are complementary. We believe that this large variety of similar facilities is unnecessary for merely maintaining the nuclear weapons stockpile. The redundancy in facilities that support the Stockpile Stewardship Program is a result of the competition and political demands that come from having multiple laboratories and production sites with similar missions. This massive infrastructure can be used productively at a level approaching its full capacity only if the intent is to continually improve and expand nuclear weapons science and engineering and weapons manufacturing capabilities.

We have attempted to include all major facilities for both science and technology and manufacturing. We have not used a rigorous definition of "major facility," but a reasonable guideline for inclusion is that a facility cost about $50 million or more to build or that its operation has substantial policy implications. Existing and planned facilities with similar capabilities are grouped together.

The total estimated cost for all the facilities under construction, proposed, or planned, which are listed below, is between $8 and 14 billion. Completing all these facilities over the next ten to fifteen years would require a significant increase over the average spending rate on construction projects for Stockpile Stewardship, which was less than $0.5 billion per year from 1999 through the 2001 Budget request.

Science and Technology Facilities

Hydrodynamic and High Explosive Test Facilities

These facilities are used to study high explosives and the behavior of plutonium and other materials under the pressure of high explosives. A key use is to examine how the primary stage of a nuclear warhead implodes (compresses) under the pressure of its detonating high explosive. Replicas of nuclear weapons primaries can be tested with the plutonium replaced by less fissile material so a nuclear explosion does not occur. The implosion can be studied just up to the point when significant fissioning would occur and can be compared with predictions from computer models. Test diagnostics include high energy x-rays that can penetrate deep inside an imploding primary and produce images of what is happening. Electrical and optical measurements can also be made. The term "hydrodynamic" is used because solid materials flow like liquids under the high pressures produced in these experiments.

Existing Facilities

Pulsed High-Energy Radiographic Machine Emitting X-Rays (PHERMEX) at Los Alamos National Laboratory. Hydrodynamic experiments are conducted in the open-air or in steel vessels that can contain up to 20 kg of high explosives. It has the highest available x-ray energies, allowing it to see deeper and later into imploding primaries than any other facility.

Dual-Axis Radiographic Hydrodynamic Test Facility (DARHT) at Los Alamos National Laboratory. When completed (see below) DARHT is expected to provide stereoscopic images of imploding primaries, with separate beam lines that take pictures from two directions. The first beam line began operation in 1999 with imaging capabilities comparable to that of PHERMEX. Tests can be conducted in steel vessels at DARHT with up to 27 kg of high explosive.

Contained Firing Facility (CFF) in Site 300 at Lawrence Livermore National Laboratory, about 12 miles from the main Livermore Lab site. Scheduled to begin operations in 2000, CFF is an upgrade to the **Flash X-ray Facility (FXR)** that has been Livermore's premier hydrodynamic facility for many years. Experiments at FXR had been conducted in the open-air. CFF includes the upgraded FXR machine and a reinforced firing chamber for containment of debris. CFF can conduct contained tests with up to 60 kg of high explosives.

Big Explosives Experimental Facility (BEEF) at the Nevada Test Site in Area 4, about 95 miles northwest of Las Vegas. It began operation in 1996. It is used for large high explosive tests (up to 35 tons of high-explosive equivalent) that cannot be conducted at the other sites. Experiments can be conducted above or below ground. Such high explosive tests are used to study basic physical properties of materials relevant to nuclear weapons, rather than to simulate actual weapons designs.

High-Explosives Applications Facility (HEAF) is a contained hydrodynamic test facility at the LLNL main site. Completed in 1991 it is a smaller scale facility than the others and is used to test new high explosives and explosive behavior.

Explosive Components Facility (ECF) at Sandia National Lab began operation in 1997. It has a contained test fire chamber with a limit of 1 kg of explosive charge. Activities at this facility include research, testing, development, and quality control activities for neutron generators, explosives, chemicals, and batteries. Operations can support up to 900 explosive tests, 500 neutron generator tests, 1,250 chemical analyses, and 100 battery tests annually.

Facilities under Construction, Proposed, or Planned

Phase II of DARHT at Los Alamos would add a second viewing axis to this hydrodynamic test facility that began operating in 1999 (see above). The second axis will provide for stereoscopic viewing (3-D) of imploding pits. It will also be able to provide four images of the imploding pit over a period of four microseconds, with the quality of each image comparable to those obtained from the imaging system on the first viewing axis. DOE spent $106 million on the first phase of DAHRT. The second phase is scheduled for completion in 2002 and will bring the total cost to $260 million.

Advanced Hydrotest Facility (AHF) is being considered by DOE as a possible follow-on to the DARHT. It would be built at either Los Alamos or the Nevada Test Site. It would use a new technology (proton radiography) for imaging that might penetrate deeper (later) into imploding pits. DOE is considering designs with as many as four axes to provide 3-D images from multiple directions. Each axis might be capable of producing as many as twenty images in rapid succession. Los Alamos has begun preconceptual design on a 50-giga-electron-volt proton hydrotest facility that would use the existing LANSCE linac (see below) as an injector and could begin limited operations as soon as 2005. A facility that would include all the capabilities being discussed could cost two to four billion dollars.

Pulsed-Power and Electron Accelerator Facilities

These facilities direct short intense bursts of electrical energy onto targets to produce extremely high temperatures and/or pressures that approach the conditions found in a nuclear explosion. Temperatures measured in the millions of degrees and pressures many times atmospheric pressure can be produced. These conditions are produced on much smaller scales than in nuclear weapons and the experiments are used to study the basic physics of matter at high energy density rather than to model specific weapons configurations. This information is used both to improve and to test the computer codes that model weapons behavior. It is most relevant to the late stages of the primary explosion and to secondary explosions. The facilities are also used to produce X-rays and gamma rays to test the effects of these types of radiation on components of nuclear weapons and other defense systems.

Existing Facilities

Pegasus II, at Los Alamos, is a capacitor-bank, pulsed-power generator. Large capacitors are charged with up to 4.3 megajoules of electrical energy, which is then rapidly discharged into a one cubic centimeter target to produce the high temperature and pressure conditions. The targets may emit X-rays that can be directed onto other targets to study their behavior under intense radiation.

Procyon at Los Alamos is a pulsed-power facility that uses up to 15 megajoules of energy from high-explosives to compress targets and amplify the electrical energy that is simultaneously applied to them. Procyon produces higher energy bursts than Pegasus II, but since the energy cannot be focused on as small a volume and mass, it cannot reach the highest temperatures and pressures that are possible in Pegasus II.

Z-Machine at Sandia National Laboratory produces the highest power densities of all the DOE pulsed-power facilities. As a result, it can produce the highest temperatures and pressures. High electrical currents (mega amps) are passed through a large number of thin wires arranged in a cylindrical array. The currents produce a magnetic field that accelerates the wires toward the center of the cylinder, where they compress and heat material placed inside. Experiments in basic nuclear weapons physics, inertial confinement fusion, and radiation effects are conduced at the Z-Facility.

Saturn is a large pulsed-power facility at Sandia that is primarily used to produce X-rays for weapons effects studies. It discharges four megajoules from a capacitor bank, of which 600 kilojoules can be absorbed in targets to produce an intense X-ray source. It can produce up to 500 shots per year.

High-Energy Radiation Megavolt Electron Source III (Hermes-III) is a pulsed-power facility at Sandia that produces gamma rays for simulating the effects of prompt radiation from a nuclear burst on electronics and other military systems. It provides high-fidelity simulations of near nuclear-explosion environments over relatively large areas. It can produce up to 1,450 shots per year.

Sandia Accelerator and Beam Research Experiment (SABRE) is a medium sized facility at Sandia that provides X-ray and gamma ray effects testing capabilities. It can produce 400 shots per year.

Short-Pulse High Intensity Nanosecond X-Radiator (SPHINX), at Sandia, is a high-voltage, high-shot-rate electron accelerator used to measure X-ray induced currents in integrated circuits and detect the response of materials. It is capable of up to 6,000 shots per year.

Facilities under Construction, Proposed, or Planned

X-1 Machine, would be a follow on to the Z-Machine at Sandia. Proponents believe that X-1 could produce X-ray temperatures of more than three million degrees Kelvin and enough X-ray energy and power to implode fusion capsules of deuterium and tritium to achieve high-yield fusion gains. The gains could be similar to levels that might be reached by the National Ignition Facility (NIF) which is under construction at Livermore Lab. DOE has not yet requested funds for a conceptual design for the X-1, but proponents at Sandia believe it could be built for less than $1 billion. If funded and successful, the X-1 could reach initial operating capability by about 2007 and high-yield fusion by about 2010.

Large and High Power Laser Facilities

DOE has a major program to study and produce laser-powered, inertial confinement fusion (ICF). In ICF, multiple intense laser beams focus on targets containing deuterium and tritium and heat and compress those elements sufficiently for them to fuse and produce a significant amount of energy. Existing facilities can produce some fusion, but fall short of "ignition" which would produce much larger energy releases. Ignition is a goal of the National Ignition Facility, which is currently under construction. Short of ignition, DOE can still do weapons-related research on the properties of hot, dense, plasmas that can be created at its laser facilities.

Existing Facilities

Omega glass laser at the University of Rochester produces the highest energy of DOE's lasers currently in operation. It has 60 beams and a total energy of 45 kilojoules. Its primary mission is research on ICF, but experiments are also performed on the basic properties of nuclear weapons' materials at high temperatures and pressures.

Nike laser at the Naval Research Laboratory, near Washington, D.C., is the largest gas laser supported by DOE. Nike is a 4-kilojoule krypton fluoride (KrF) gas laser used primarily for examining beam smoothness requirements for direct drive laser fusion ignition and design issues for KrF lasers.

Trident is a medium-sized glass laser at Los Alamos designed to deliver two simultaneous short pulses of energy to a target to study shockwave characteristics when the pulses collide. The pulses can deliver 100 joules of energy in 100 picoseconds (10^{-10} seconds). Pressures of several megabars (millions of times atmospheric pressure) can be produced in the shock waves. Trident is also used for developing and testing diagnostic equipment for the ICF program.

Bright Source II glass laser at Los Alamos can focus its short pulses of laser energy on smaller targets than Trident and thus produce higher temperatures and more intense x-rays. It can be used to study how matter behaves at conditions closer to what is found in a nuclear explosion.

Ultra-Short Pulse (USP) glass laser at Livermore. This laser machine focuses extremely short (10^{-14} sec) pulses on very small areas. It can produce extremely high temperatures and densities over regions of only thousands of atoms. It is used to study the behavior of the highly charged gases (plasmas) that are created and the effect of ultra short laser pulses on bulk materials.

Facilities under Construction, Proposed, or Planned

National Ignition Facility (NIF), which is under construction at Lawrence Livermore National Laboratory, will be the world's most energetic laser. It is designed to achieve laser-induced fusion reactions between deuterium and tritium. The initial estimate of its construction cost was $1.2 billion, but the project has had technical difficulties and substantial cost overruns. DOE is currently rebaselining the project. The leading option would increase NIF's construction cost by about $2 billion. The lifetime cost of operating NIF for thirty years, including disassembly and cleanup, could approach $10 billion.

Underground Testings and Associated Support Facilities

The U.S. has declared a moratorium on full-scale explosive nuclear tests and has signed, but not ratified, the Comprehensive Test Ban Treaty (CTBT), which would ban such tests. DOE, however, maintains the ability to resume full-scale underground nuclear explosive testing at the Nevada Test Site (NTS), which is about 100 miles northwest of Las Vegas, NV. In addition, DOE continues to perform "subcritical experiments" underground at NTS. Subcritical experiments are explosive investigations of weapons material (primarily plutonium-239), fabricated into shapes or otherwise modified to prevent the release of fission energy above a de minimus level (equivalent to a fraction of a gram of high explosive). The experiments use high explosives to compress or shock plutonium to observe its behavior, but stop short of sustaining nuclear reactions, or criticality. Subcritical experiments are mostly used to investigate the physical properties of plutonium to incorporate that into computer calculations of nuclear weapons performance. Current efforts focus on the properties of aged plutonium and the differences between cast plutonium and plutonium formed by rolling and machining.

Existing Facilities

U1a Complex, at the Nevada Test Site, is the current DOE facility for conducting subcritical tests. It consists of a series of tunnels about 1,000 feet underground. U1a was formerly called the **Lyner** facility, for "Low Yield Nuclear Explosive Research," since a low-yield nuclear test (below 20 kilotons yield) was conducted there. More were planned. DOE also planned to conduct hydronuclear tests in the Lyner complex, with nuclear yields equivalent to as much as hundreds of grams of high explosive, before such tests were excluded under the CTBT. Up to 500 pounds of high explosive may be used in a single test at U1a, but most tests use less explosive. DOE conducts about four subcritical experiments per year there. The incremental cost of each test is about $10 million in addition to the cost of maintaining the facility.

Device Assembly Facility (DAF) was completed at the NTS, at a cost exceeding $100 million, shortly after the U.S. declared a moratorium on full scale underground explosive tests. It has capabilities to assemble and disassemble some tens of nuclear warheads or test devices per year, but it has not been put into full operation. DOE is using a part of this facility to assemble subcritical experiments and is maintaining the rest of the facility for an undetermined potential future mission.

Nuclear Testing Infrastructure at NTS. DOE maintains more than 1,100 support buildings and laboratories at NTS, dozens of previously drilled holes for nuclear tests, and extensive equipment and personnel that could be used to rapidly resume full scale underground testing. As part of this maintenance effort, DOE is currently renovating 37 miles of roads at NTS and replacing an electrical supply substation and other electric supply facilities.

Reactors, Accelerators, and Other Nuclear Facilities

Existing Facilities

Los Alamos Neutron Science Center (LANSCE), at Los Alamos National Laboratory, is a high- powered proton accelerator. Many accelerators exceed the 800 million electron volt (Mev) energy of LANSCE protons, but its beam current (100 milliamps) is the highest at comparable energies in the United States. This allows it to produce copious quantities of protons or neutrons for study of materials. LANSCE is particularly suitable for imaging of dense materials using proton radiography, performing experiments on effects of high powered beams on material properties, studies of atomic structures of materials, production of rare isotopes, and other research in condensed matter science. It is also used to nondestructively image nuclear weapons from the stockpile, as part of the surveillance and testing program, to determine whether there have been any changes that might affect their performance.

Annular Core Research Reactor (ACRR) is a pool-type reactor located at Sandia National Laboratory. It is a general purpose research reactor for testing materials and producing isotopes. It can also be used as a neutron and gamma-ray source to simulate weapons effects and to certify components.

Sandia Pulsed Reactor (SPR) is a fast burst reactor at Sandia that uses high enriched uranium (HEU) fuel. It produces neutrons with a spectrum near that produced in fusion reactions. It can produce more intense beams of neutrons and gamma-rays than the ACRR, for shorter times and over smaller volumes. It is used for high-dose testing of electronic devices.

Gamma Irradiation Facility (GIF) and New Gamma Irradiation Facility, also at Sandia, use Cobalt-60 sources to produce neutrons and gamma-rays for testing and certification of weapons components and for studies of radiation damage to materials.

Los Alamos Critical Experiments Facility (LACEF), also known as **Technical Area 18 (TA-18)** or the **Pajarito Site**, is a general purpose nuclear experiments facility. It has several areas for manipulating, controlling and experimenting on nuclear materials near or above criticality, where self sustaining nuclear fission occurs. About 80 full-time employees work at TA-18 on projects funded by the Stockpile Stewardship Program and other DOE Program Offices. In April 2000, Secretary Richardson announced that TA-18 would be closed by the end of 2004 and its capabilities moved to a different site, most likely within Los Alamos Laboratory.

Facilities under Construction, Proposed, or Planned

Joint Actinide Shock Physics Experimental Research (JASPER), is a two-stage gas gun that is under construction at the Nevada Test Site. Jasper is designed to shoot projectiles at velocities of up to eight kilometers/sec (18,000 MPH) initially, and up to 15 kilometers/sec with future modifications. It will be used for examining the properties of plutonium, uranium and other materials at high pressures, temperatures, and strain rates by hitting small samples with projectiles traveling at high velocity. JASPER will be operated by Livermore Laboratory. It will complement a single-stage gas gun located in TA-55 at Los Alamos, which can accelerate projectiles to speeds of only two kilometers/sec, and a two-stage gas gun at Livermore Laboratory's site 300.

Accelerated Strategic Computing Initiative (ASCI)

The Accelerated Strategic Computing Initiative (ASCI) is a massive undertaking to purchase and develop computers with speed and memory capacities many times those currently available, and to develop and run complex weapons codes on these computers. DOE's ultimate goal for its codes is to model precisely the behavior of an exploding nuclear weapon through all its stages, from first principles, with no adjustable parameters (i.e., fudge factors). DOE would use this capability for virtual testing of weapons to support weapons design, production analysis, accident analysis, and certification. It would also use virtual prototyping of manufacturing techniques as an alternative to traditional approaches used for the design and manufacture of nuclear weapons. DOE is using many of the facilities described above to provide physics data for the new codes and to validate the performance of the codes in matching the results of experiments.

Existing Facilities

ASCI Red Terascale Computer at Sandia National Lab was the first ASCI computer. It began operating in 1997 at a speed of 1.8 teraflops (1.8 trillion operations per second), which is about 5,000 to 10,000 times the speed of a modern desktop computer. In 1999 ASCI Red was upgraded with faster processors and more memory. It is now operating in a production mode with a peak speed of more than 3 teraflops.

ASCI Blue Mountain Computer at Los Alamos. It began operation in 1999 and can perform 3.1 teraflops. It consists of 6,144 Silicon Graphics R10000 processors, each capable of more than 500 million floating point operations per second.

ASCI Blue Pacific Computer at Lawrence Livermore Lab was developed by IBM. It also began operation in 1999 and can perform 3.8 teraflops, which is 15,000 times faster than the average personal desktop computer. It also has roughly 80,000 times the memory of the average personal computer.

Facilities under Construction, Proposed, or Planned

Joint Computational Engineering Laboratory (JCEL at SNL), Distributed Information Systems Laboratory (DISL at SNL), Strategic Computing Complex (SCC at LANL), and Terascale Simulation Facility (TSF at LLNL) are separate projects to house new computers and associated workers in the ASCI program at each of the weapons laboratories. All but the DISL received initial funding in FY 2000. The DISL is in DOE's 2001 request. The total cost for the four facilities is more than $250 million and does not include the cost of the computers that they will house.

ASCI Option White 12 Teraops Computer is being assembled jointly by IBM and Lawrence Livermore Lab at a cost of $110 million. It is scheduled to begin operation at Livermore in 2000. This scalable parallel system will consist of 512 powerful, multi-processor "nodes." Just one 32-node RS6000 scalable parallel system named "Deep Blue" defeated the world's leading human chess master in a highly publicized series of games in 1997. When it is completed, ASCI White will be the world's fastest, most powerful computer.

A 30-TeraOPS Computer is currently being procured for Los Alamos and is projected to become operational in 2001.

A 100-TeraOPS Computer is the last in the ASCI series of supercomputers. It was scheduled for operation at Livermore Laboratory in 2004, but may be delayed.

Other R & D and Test Facilities

Existing Facilities

Weapons Engineering Tritium Facility (WETF), at Los Alamos, began operation in 1989. It is a multifaceted facility for processing tritium and developing techniques and procedures for tritium handling. It includes a Neutron Tube Target Loading (NTTL) building that will begin operation in 2000. That facility is a production facility that will load tritium into the neutron generators that must be periodically replaced in nuclear weapons in the stockpile.

Sigma Complex at Los Alamos has been used for a variety of nuclear materials missions including processing of uranium and hazardous materials, such as beryllium. Today, it is primarily used for synthesizing materials and for processing, characterizing, and fabricating metallic and ceramic items for R & D purposes.

TA-55 Plutonium Facility at Los Alamos is a multifunction facility in which most of Los Alamos' plutonium handling activities take place. Originally this was primarily an R&D facility, but it has become more production oriented since the Rocky Flats Plant was closed. Substantial R & D in plutonium chemistry and handling technologies and nuclear materials accounting continues, however. More information about this facility and planned upgrades to it appears in the Manufacturing Section below.

Superblock at Livermore Laboratory is that lab's facility for special nuclear materials research and engineering. Most of the work there involves the chemistry, processing, and handling of plutonium.

Microelectronics Development Laboratory (MDL), at Sandia supports R&D and production of silicon-based microelectronics devices. It is being expanded to produce up to 7,500 wafers per year.

Advanced Manufacturing Processes Laboratory, at Sandia supports development of manufacturing techniques including hardware manufacturing, emergency and prototype manufacturing, development of manufacturing processes, and design and fabrication of production equipment. Operations at this facility can support up to 175 full time workers.

Integrated Materials Research Laboratory, at Sandia, supports research on materials and advanced components. Activities include basic research in chemistry and physics. Operations at this facility can support up to 200 full time workers.

Tonopah Test Range occupies 625 square miles on the north end of Nellis Air Force Base in Nevada. It is operated by Sandia National Laboratory for flight testing of nuclear weapons systems.

Aerial Cable Facility, at Sandia, conducts impact tests involving weapons systems. Capabilities include free fall and rocket propelled tests. Test articles can contain up to 120 pounds of enriched uranium and 104 pounds of high explosive.

Facilities under Construction, Proposed, or Planned

Chemistry and Metallurgy Research Building (CMR) project at Los Alamos is an upgrade to an existing building of the same name. It would provide new facilities for research and experimentation in analytical chemistry, plutonium and uranium chemistry, and metallurgy. The facility would also include hotcell facilities and gloveboxes for material-related research, including fabrication and metallography and destructive and nondestructive analysis of plutonium and uranium components. DOE spent $100 million on the first phase of upgrades to this facility. It is currently performing a conceptual design for a more extensive renovation. There is no firm cost estimate for the overhaul, but it is expected to cost more than $1 billion.

Microsystems & Engineering Sciences Applications (MESA), at Sandia, is a proposed new, complex that will provide for the design, integration, prototyping and fabrication and qualification of microsystems into weapon components, subsystems, and systems within the stockpile. These systems would represent next generation upgrades to components in existing weapons systems. DOE's 2001 budget requests initial design funds for this facility, which is estimated to cost $350 to $400 million.

Manufacturing Facilities

Existing Facilities

Kansas City Plant (KCP) is a general purpose nonnuclear manufacturing plant that occupies approximately three million square feet in a single massive building in Kansas City, Missouri. In this single facility, DOE maintains capabilities to manufacture most of the thousands of components that are in the nuclear weapons in the stockpile and the equipment needed for servicing, testing and transporting nuclear weapons. KCP produces thousands of replacement parts and parts for modifications and upgrades to weapons systems and test apparatuses annually. KCP employs about 3,300 people. DOE also uses the KCP for testing and analysis of weapons' components and for development and engineering of new manufacturing technologies.

Y-12 Plant, in Oak Ridge, Tennessee, is the site of diverse facilities in support of manufacture, maintenance and repair, dismantlement, and storage of nuclear weapons secondaries (canned subassemblies), and associated materials. Separate buildings house facilities for assembly/disassembly operations; quality evaluations/ surveillance; enriched uranium operations; depleted uranium operations; lithium operations; beryllium research and development; enriched uranium machining, rolling, and forming; and storage of canned subassemblies, enriched uranium, and other materials. Y-12 employs about 4,000 people in the weapons program.

Pantex Plant is located in the Texas Panhandle. Its mission includes weapons assembly, disassembly, testing, quality assurance, repair, retirement, and disposal. The bulk of the operations are carried out in three zones. Zone 4 is used primarily for the storage of about twelve thousand plutonium pits and an additional number of nuclear weapons. The major structures in facilities in Zone 4 are earth-covered "igloos" where the pits and weapons are stored. Zone 11 is used primarily for activities supporting chemical explosives fabrication, including synthesis, forming, explosive and nonexplosive testing, and analysis. Zone 12 primarily houses the nuclear weapons assembly/disassembly operations. The assembly/disassembly cells are heavily reinforced structures designed to disperse the energy of a potential chemical explosion of a nuclear weapon, while isolating the plutonium and uranium from the outside environment. Pantex employs about 2,800 people.

Buildings 232, 233, 234, and 238 at the Savannah River Plant (SRP) in Aiken, South Carolina are the main facilities that support DOE's tritium operations. Building 232 is where tritium and other gases are extracted and recovered from reservoirs returned from nuclear weapons. Building 233 is where tritium is processed for recycling and loaded into reservoirs for reuse. Reservoir surveillance is also conducted in Building 233. Building 234 is used for shipping and receiving in support of tritium operations, for storage of tritium, and for loading of nontritium gases. Building 238 is used primarily for reclaiming reservoirs and for testing of reservoirs under high pressure. These facilities are undergoing renovations that will be completed in 2002 for a total cost of about $100 million.

TA-55 Plutonium Facility at Los Alamos is a multifunction facility in which most of Los Alamos' plutonium handling activities take place. Originally this was primarily an R&D facility, but it has become more production oriented since the Rocky Flats Plant was closed. Within TA-55, Los Alamos conducts the pit surveillance program and can fabricate several pits per year. TA-55 has chemical and metallurgical processes for recovering, purifying, and converting plutonium and other actinides. Pit fabrication capabilities include numerous processes that are used to fabricate new pits, modify internal features of existing pits, and certify pits for reuse. The facility also has capabilities for treating, packaging, storing, and transporting radioactive waste.

Nonnuclear Manufacturing Facilities at Los Alamos. Facilities to fabricate several nonnuclear parts were transferred to Los Alamos as part of a reconfiguration of the weapons complex beginning in 1991. Los Alamos now has facilities to manufacture parts including detonators, detonator simulators, beryllium parts, calorimeters, and pit mockups. It also has a production mission to load tritium into neutron generators.

Neutron Generator Facility (NGF) is located in Building 870 at Sandia. It is used for most of the processing and assembly operations associated with Sandia National Laboratory's major manufacturing activity, which is the production of neutron generators. Neutron generators are limited-life components, which must be periodically replaced in all weapons in the stockpile. DOE is upgrading the capacity of the NGF to produce 2,000 neutron generators and associated neutron and switch tubes per year.

Facilities under Construction, Proposed, or Planned

Tritium Extraction Facility (TEF) is under construction at the Savannah River Plant to provide capability to extract tritium from the targets that are to be loaded into commercial reactors for irradiation and production of tritium. It will also include upgraded facilities for recycling tritium and for purification of gases containing tritium. The total estimated cost of the TEF is $318 million.

High Enriched Uranium (HEU) Storage Facility is a projected new start in DOE's 2001 Budget Request. It is intended to consolidate storage of enriched uranium and other materials from several buildings at Y-12 and improve the ability to inventory and monitor the material. The design requirement calls for a capacity to store 14,000 cans and 14,000 55-gallon drums. The facility is scheduled to be completed in 2005 for a total estimated cost of $120 million.

Enriched Uranium Manufacturing Facility is part of DOE's long-range plan for modernizing the Y-12 Site. Construction of this facility might be phased to begin when the above storage facility is completed. Its mission would be to replace existing facilities for production and recovery operations for enriched uranium. DOE estimates it would cost about $1 billion to build. It is projected to begin operating around 2015, but has not yet been formally proposed.

Special Materials Complex is also part of DOE's long-range plan for modernizing the Y-12 Site. Its mission would be the production of special materials used in nuclear weapons that are difficult or hazardous to produce, including beryllium. It too would replace existing capabilities at Y-12. DOE projects that this facility will cost $325 million and it will begin operating in 2005

Kansas City Plant Infrastructure Projects. Four separate projects are currently underway to upgrade the infrastructure and equipment at the Kansas City Plant and to reduce the overall size of the facility. The size of the facility will be reduced by 20 percent and new equipment will be installed in a shift from a product-based approach to manufacturing to a process-based approach. The total cost of the four projects at Kansas City is nearly $200 million.

TA-55 Facility Upgrade to Produce 20 Pits/year. DOE plans to upgrade the pit production facilities at TA-55 at Los Alamos to be able to produce about 20 plutonium pits per year by 2007. There has been no specific request for the upgrade, which is expected to cost about $300 million.

Large-Scale Pit Production Facility. DOE's plans call for building a larger pit production facility either at Los Alamos or a more remote site, depending on the number of pits than might have to be produced per year. The capacity of that plant may depend on the progress of arms control and on the results of a DOE effort to determine the maximum life of plutonium pits. DOE projects that such a facility will be needed around 2015 and would cost from $600 million to more than $3 billion depending upon its size and location. The Senate Armed Services Committee added $10 million to DOE's 2001 budget request "to begin conceptual design activities for a pit production facility adequate to meet future national security needs."

APPENDIX B

Explanation of Cost Estimates

Table 2, in the main body of this report, summarizes our estimates of the likely spending levels under each of the five options analyzed for managing the nuclear weapons stockpile. The estimates for the Stockpile Stewardship Option are derived from DOE's Fiscal Year 2001 Budget Request. The categories in Table 2 do not, however, correspond to the categories in the DOE Budget. We have used a functional presentation that aligns the spending to the outputs of the program, which we believe is more useful for making comparisons between the options.

While the estimates for the Stockpile Stewardship Option are derived from DOE's 2001 Budget request, they do not correspond exactly to that request. First, since the 2001 DOE Budget does not contain sufficient detail to allow us to place all the spending in the proper category with assurance, we supplemented it with information from the FY 2000 Budget and other sources. In addition, since our estimate represents an average spending figure for the next five to ten years, we made several adjustments, including:

- Added approximately $300 million per year for a next generation of science facilities that DOE plans to build, but has not yet fully funded;
- Subtracted approximately $200 million per year from computing activities for an anticipated reduction as some of the goals of ASCI are met;
- Added approximately $100 million for basic and applied research and development activities to replace ASCI-related research and validation;
- Added approximately $150 million for increased activities related to future production of pits and other components; and
- Subtracted about $50 million from tritium production, as the design of the backup linear accelerator for tritium production and the design and construction of the Tritium Extraction Facility (TEF) will be completed.

Thus, our total estimate for the Stockpile Stewardship Option is $4.9 billion, compared to DOE's 2001 request of $4.6 billion. For the other options, we estimate how spending on each category in Table 2 might differ from the Stockpile Stewardship Option. The bases for estimating those differences are detailed below, following Table 2, which is reproduced here for ease of reference.

TABLE 2. **Representative Funding for Major Programs and Facilities by Option** (in millions of dollars)

Programs and Facilities	DOE Stockpile Stewardship Program	Remanu-facturing	Curatorship	Passive Arms Reduction	Return to Testing
SCIENCE AND TECHNOLOGY					
Basic and applied nuclear weapons research	225	150	75	50	275
Development and engineering of new and modified weapons and components	175	100	50	0	275
Computing, code development, and computer hardware	600	300	150	100	400
Nevada Test Site facilities and operation, including subcritical experiments	200	125	75	50	300
Inertial Confinement Fusion (ICF) research and operations	300	200	100	0	300
Other science facilities and infrastructure	250	200	150	100	250
Next generation science facilities (including NIF, MESA, CMR Upgrade, and AHF)	400	200	100	0	400
SUBTOTAL Science and Technology	**2150**	**1275**	**700**	**300**	**2200**
SURVEILLANCE AND TESTING					
Surveillance, testing, data archiving, and evaluation of the existing stockpile and remanufactured components	300	350	400	300	300
Testing and certification of new or modified components	175	125	50	0	200
Dismantlement and associated examination and evaluation	150	150	180	200	150
Research and development to predict failures and to improve surveillance and testing	100	100	100	40	100
SUBTOTAL Surveillance and Testing	**725**	**725**	**730**	**540**	**750**
MANUFACTURING					
Pit and secondary production and associated materials processing	350	450	150	0	400
Tritium production, extraction, recycling, and reservoir filling	200	200	200	150	200
Production of limited life components, test equipment, and replacement components of existing design	300	300	250	200	300
Engineering and production of new and modified components and equipment	300	200	50	0	350
Storage, transportation and waste disposal	300	325	250	280	325
Development and improvements to manufacturing processes and infrastructure, including ADAPT	275	200	150	50	275
SUBTOTAL Manufacturing	**1725**	**1675**	**1050**	**680**	**1850**
Other (Program direction, education, and mission support)	300	250	220	180	300
TOTAL	**4900**	**3925**	**2700**	**1700**	**5100**

TABLE 3. **Assumptions for Cost Estimates for Alternatives to DOE's Stockpile Stewardship Program**

Programs and Facilities	Remanufacturing	Curatorship	Passive Arms Reduction	Return to Testing
SCIENCE AND TECHNOLOGY				
Basic and applied nuclear weapons research	Reduce research in basic physics and materials properties. Reduce pace of validating new codes and using them to model primary and secondary behavior. No subcritical experiments for basic R&D. Perform fewer hydrodynamic experiments. No work on EMP.	Limited research in basic physics and materials properties. Minimal modeling of primary and secondary behavior using existing codes and modeling only existing weapons designs. Cease all subcritical experiments. Limited program of hydrodynamic experiments using only the DARHT facility. No work on EMP or other weapons outputs. Expand R&D on nondestructive testing to support surveillance.	Continue R & D only in support of the surveillance and testing program, such as baselining of existing design and test data with existing codes and development of nondestructive test methods and equipment.	Expand efforts in primary and secondary modeling, and dynamic materials properties through use of underground nuclear tests.
Development and engineering of new and modified weapons and components	Limit subcritical experiments to Pu aging and certifying casting for pit fabrication. No development requiring change to core physics packages. Less rapid development of new nonnuclear components.	No subcritical experiments. No development requiring change to core physics packages. Minimal development of nonnuclear components for improved safety and security only.	No development or engineering of new and modified weapons and components.	Increase development of new pit and secondary designs as part of underground test program.
Computing, code development, and computer hardware	Slower development of new primary and secondary codes and inclusion of new physics and materials properties in codes. Stretch out hardware acquisition. Expand analysis of existing test data.	Minimal development of new codes. Incrementally improve and revalidate existing codes using available physics and test data only. Limited hardware acquisition after 10 TeraOps procurement.	No new code development. Maintain, but don't improve existing codes. Suspend procurement of new hardware.	Slower development of new codes and procurement of computing hardware. Validating codes with data from new underground tests replaces some validation using above ground experiments.
Nevada Test Site facilities and operation, including subcritical experiments	Subcritical tests performed at or near the surface only. No deep underground tests for any purpose. Key facilities for UGTs preserved; all other facilities closed. Caretaker staff retained.	No subcritical, hydrodynamic, explosive testing, or any other test and experimentation programs at NTS. Key facilities for UGTs preserved; all other facilities closed. Caretaker staff retained.	All weapons program facilities at NTS closed, with no provision for future restart. Caretaker staff retained for security and environmental monitoring only.	Perform two to four underground tests per year, with nuclear yield and full suites of diagnostic equipment. Perform fewer subcritical experiments.
Inertial Confinement Fusion (ICF) research and operations	Redirect the ICF program to focus on scientific research, study of ICF and IFE, and performing effects testing. NIF is not needed to adequately maintain the stockpile under this option, but is completed to support the above missions and to attract talented scientists to Livermore Lab.	Reduced program continues at existing facilities only. Focus on scientific research, study of ICF and IFE, and performing effects testing. NIF is canceled, unless most of the program funding is provided by the Office of Energy Research.	No support for ICF from the weapons program. Some program elements might continue with support from the Office of Energy Research.	Same as under Stockpile Stewardship Program.

Programs and Facilities	Remanufacturing	Curatorship	Passive Arms Reduction	Return to Testing
Other science facilities and infrastructure	All major existing science facilities continue to operate, but with activities reduced 10-25 percent. Additional infrastructure savings come from modest reduction to overall science and technology program.	Hydrotesting, plutonium handling, and explosive facilities at LLNL closed. DARHT, Saturn, LANSCE and selected smaller science facilities continue operation, but with significantly reduced programs.	Most weapons program R&D facilities closed. LANSCE retained for nondestructive testing and parts of TA-55 retained to support dismantlement activities.	Same as under Stockpile Stewardship Program.
Next generation science facilities (including NIF, MESA, CMR Upgrade, and AHF)	NIF continued, but limited to 600-800 kilojoules to reduce cost. CMR upgrade and MESA projects proceed with reduced scope and slower pace. AHF research suspended.	NIF canceled. AHF research suspended. CMR upgrade greatly reduced in scope. MESA project replaced with modest renovation of existing electronics facilities at Sandia.	NIF canceled. No R & D or new starts for next generation experimental facilities.	$2 billion in project-related spending over five years for NIF, MESA, CMR upgrade, and AHF. This is the same as our assumption for Stockpile Stewardship, but it is not fully reflected in the DOE Budget.
SURVEILLANCE AND TESTING				
Surveillance, testing, data archiving, and evaluation of the existing stockpile and remanufactured components	Continue current practices for surveillance and testing. Funding increases over time for testing and certification of remanufactured pits.	All current activities continue. Expand baselining activities and archiving of technical data. Increase number of weapons dismantled and reassembled after examination and testing. Increase destructive testing for systems with replacements available from the inactive stockpile.	Continue current level of support for surveillance and testing. Use savings from reduced need to certify remanufactured components to expand examination and testing of existing weapons and components.	Same as under Stockpile Stewardship Program.
Testing and certification of new or modified components	Cost of certifying remanufactured pits is included above, vice cost for certifying new pits reflected here under Stockpile Stewardship. Small savings from reduction in new non-nuclear components to test and certify.	Suspend pit recertification activities, since no new pits are anticipated for many years. Limited new non-nuclear components to test and certify.	No new pits, secondaries or non-nuclear components to test and certify.	Increased certification of new and modified components, as testing facilitates changes to weapons design.
Dismantlement and associated examination and evaluation	Same as under Stockpile Stewardship Program.	Increase examination and testing of components from dismantled warheads.	Increase pace of weapons dismantlement and associated examination and testing of components from dismantled warheads. More warheads are removed from the stockpile and dismantled under this option.	Same as under Stockpile Stewardship Program.
Research and development to predict failures and to improve surveillance and testing	Same as under Stockpile Stewardship Program.	Same as under Stockpile Stewardship Program.	Suspend most enhanced surveillance activities.	Same as under Stockpile Stewardship Program.

Programs and Facilities	Remanufacturing	Curatorship	Passive Arms Reduction	Return to Testing
MANUFACTURING				
Pit and secondary production and associated materials processing	Accelerate work to certify pit production capability at Los Alamos. Design, build, and operate facility to manufacture 300 pits per year as soon as possible. Maintain capabilities for secondary production and repair at Y-12.	Continue work to certify pit production capability at Los Alamos at reduced pace. Defer indefinitely plans to expand pit production. Maintain some capabilities for secondary repair at Y-12.	Close all pit and secondary production facilities. Suspend all work on certifying pit production capability and plans for future production facilities.	Accelerate work to certify pit production capability at Los Alamos. Design and build facility to manufacture 150-300 pits per year when needed. Maintain capabilities for secondary production and repair at Y-12.
Tritium production, extraction, recycling, and reservoir filling	No immediate change from Stockpile Stewardship Program. Possible savings of $100 million per year under START III.	No immediate change from Stockpile Stewardship Program. Possible savings of $100 million per year under START III.	Some savings from reduced need for tritium for shrinking stockpile with or without START III. Additional savings possible under START III.	Same as under Stockpile Stewardship Program.
Production of limited life components, test equipment, and replacement components of existing design	Same as under Stockpile Stewardship Program.	Components will be replaced only when necessary, not as part of planned refurbishment for modernization or improvement.	Only traditional limited life components will be replaced.	Same as under Stockpile Stewardship Program.
Engineering and production of new and modified components and equipment	No modifications to pits or secondaries. Fewer modifications to non-nuclear components.	No modifications to pits or secondaries. Limited modifications to non-nuclear components only to improve safety and security.	No production of new or modified components.	Increased production of new and modified components, as testing facilitates changes to weapons design.
Storage, transportation and waste disposal	No immediate change from Stockpile Stewardship Program. Eventual increase in transportation and waste disposal costs resulting from accelerated pit production and replacement.	Savings in transportation and waste disposal from reduced level of refurbishments and lower production levels.	Savings from reduced production activities partially offset by increased pace of dismantlements.	No immediate change from Stockpile Stewardship Program. Eventual increase in transportation and waste disposal costs resulting from increase in pit production and replacement.
Development and improvements to manufacturing processes and infrastructure, including ADAPT	ADAPT reduced by 25-50 percent. Slower pace of other improvements to manufacturing infrastructure.	Cancel ADAPT program. Slower pace of other improvements to manufacturing infrastructure.	Cancel ADAPT program. Minimal maintenance to manufacturing infrastructure.	Same as under Stockpile Stewardship Program.
OTHER				
Program direction, education, and mission support	Program direction costs reduced in proportion to the size of the overall program.	Program direction costs reduced in proportion to the size of the overall program.	Program direction costs reduced in proportion to the size of the overall program.	Same as under Stockpile Stewardship Program.

APPENDIX C

GLossary of Terms

Active stockpile U.S. nuclear warheads that are maintained in full operational status. This currently includes about 7,900 warheads deployed with operational delivery systems and 500 spares.

Canned subassembly See "Secondary, nuclear weapon's."

Core physics package Collective term for the primary, secondary, and radiation case of a nuclear weapon. Also referred to as the nuclear components, the nuclear explosive package, or the physics package.

Delivery system The military vehicle (e.g. ballistic or cruise missile, artillery shell, airplane, or submarine) by which a nuclear weapon could be delivered to a target.

Deterrence To deter is to discourage others from some action by making the consequences of their action appear too frightening or making the action's expected benefit unattainable. The arms control literature includes several variations on the use of nuclear weapons for deterrence. There are policy variations regarding the types of actions that nuclear weapons might be used to deter (e.g. attack by nuclear, chemical, biological, or even conventional weapons) and variations in the level of response to these actions (e.g. massive nuclear retaliation, or limited nuclear strikes).

Deuterium A nonradioactive isotope of hydrogen, with one neutron and one proton.

Enduring stockpile The anticipated nuclear weapons stockpile after reductions under START II have been made. Current plans call for some 10,000 nuclear warheads of eight or nine different types to be maintained in the active and inactive stockpiles.

High-explosive Chemical compound or mixture that, when activated, undergoes rapid chemical change producing large volumes of hot gases, which exert pressure capable of imploding the hollow pit of a nuclear weapon's primary.

Hydrodynamic test Nonnuclear experiment to investigate the behavior of a surrogate nuclear weapon's primary up to the mid to late stages of pit implosion. The term "hydrodynamic" refers to the fact that all materials flow like fluids at the temperatures and pressures of these experiments.

Hydronuclear test The term generally refers to a very low yield nuclear explosive test to assess the safety and/or performance of a nuclear weapon's primary. The nuclear energy released is less than that of a few pounds of chemical high-explosive. The term hydronuclear can also be used to describe a so-called "zero yield" test, which involves fissile material and high explosives, but stops short of a self-sustaining nuclear chain reaction. See also, subcritical experiments.

Ignition Self-sustained fusion of light nuclei (usually tritium and deuterium) that releases substantially more energy than used to begin the reaction.

Implosion	The sudden inward compression and reduction in volume of the pit of a nuclear weapon's primary under the pressure produced by detonation of the surrounding high-explosive.
Inactive stockpile	U.S. warheads that are maintained in working condition, except that they are not individually loaded with tritium gas. About 2,000 warheads are currently maintained in the inactive stockpile. They are being held as spares to replace potentially defective warheads and to serve as a "hedge" should Russia attempt to break out of the obligations of the START I or START II Treaties.
Inertial confinement fusion (ICF)	Nuclear fusion initiated by high pressures and temperatures induced in small quantities of deuterium and tritium by an external driver, such as a high intensity laser. The inertia of the material contains it long enough for significant fusion to take place before the hot gases fly apart.
Military requirements	A detailed set of performance requirements that a nuclear weapon or weapons system is designed to meet. Requirements are specified for a range of conditions and include one or more explosive yields; range; accuracy; radiation spectrum; size, shape, and weight; altitude of detonation; required operating ranges for temperature, pressure, and external radiation environments; safety requirements; reliability, and numerous other specifications. Military requirements are established through an iterative process involving DOD and DOE that is coordinated by the Nuclear Weapons Council.
Nonnuclear component	Any one of thousands of parts in a nuclear weapons that do not contain radioactive or fissile material. Alternatively, any part of a nuclear weapon outside of the "core physics package." The later definition may include neutron generators, tritium and deuterium gas bottles, and bomb casings that can have radioactive materials.
Nuclear components	See "Core physics package."
Nuclear explosive package	See "Core physics package."
Performance	The manner in which a nuclear weapon or weapons system functions or is expected to function as specified by a detailed set of military requirements.
Pit	An assembly at the central core of a nuclear device containing plutonium and/or highly enriched uranium (HEU) and perhaps several other materials arrayed in concentric shells. The term "pit" refers to the fact that it sits inside the weapon the way a seed or pit sits inside a fruit.
Primary, nuclear weapon's	The first explosive stage of a thermonuclear weapon, consisting of the pit, the surrounding high explosive, and associated systems. The primary is the crucial system for weapons reliability, performance, and safety. If the primary functions properly, there is a very high probability that the secondary will also function properly.
Radiation case	Nuclear weapon's component that channels and focuses x-ray energy from the weapon's primary to the secondary. The x-ray energy from the exploding primary compresses and heats the secondary, causing it to ignite.
Reliability	The probability that a nuclear weapon's component, a warhead, or a complete weapon system will function sufficiently well to meets its intended function. Alternatively, that it will fully meet all of its detailed military requirements.

Safety Freedom from danger or risk of injury; or relative degree of freedom from danger or risk of injury. The safety threats of most concern with nuclear weapons are the possibility of dispersal of plutonium or release of a measurable nuclear yield should there be an accident. All U.S. nuclear weapons have been designed to have less than a one in a million chance of a nuclear yield exceeding the energy of four pounds of chemical explosive if their high explosive is detonated at a single point during an accident.

Secondary, nuclear weapon's Also called "canned subassembly." The second explosive stage of a thermonuclear weapon. It is set off by the explosion of the primary. The secondary provides most of the explosive energy. It contain uranium and/or plutonium that provide energy from nuclear fission; lithium-deuteride that supplies deuterium and tritium which combine and release fusion energy; and other materials.

Security Freedom from unauthorized access to or loss of custody of a nuclear weapon or weapon system; or relative degree of freedom from such unauthorized access or loss of custody.

Strategic nuclear weapons Nuclear weapons for long-range delivery systems, including intercontinental ballistic missiles and bombs and cruise missiles carried by long-range bombers. The START I and II Treaties limit the number and carrying ability of strategic weapons' delivery systems, but they do not limit the number of warheads that can be maintained for use with strategic systems.

Subcritical experiments Experiments that use high-explosives to compress or shock plutonium or uranium to observe its behavior. Some nuclear reactions may occur, but there is no self-sustaining nuclear chain reaction and the nuclear energy released is no more than that released by burning a small fraction of a gram of high-explosive.

Tactical nuclear weapons Relatively small nuclear weapons for short-range delivery systems that are generally intended for use in contact with the enemy. Historically, U.S. tactical nuclear weapons included artillery shells, mines, rockets, torpedoes, depth charges, backpack bombs, and short range missiles. The only tactical nuclear weapons remaining in the active stockpile are bombs that can be carried by short-range aircraft. Tactical nuclear weapons are not limited under the START I or START II Treaties, or by any other treaty.

Tritium A radioactive isotope of hydrogen, with two neutrons and one proton.

Warhead Collective term for the nuclear explosive package and thermonuclear components that can be mated with a delivery vehicle or carrier to produce a deliverable nuclear weapon.

Yield The energy released by a nuclear explosion.