UCRL-53822

Report to Congress on Stockpile Reliability, Weapon Remanufacture, and the Role of Nuclear Testing

George H. Miller
Associate Director for Defense Systems

Paul S. Brown
Assistant Associate Director for Arms Control

Carol T. Alonso
Deputy A Division Leader

October 1987

Lawrence Livermore National Laboratory

UCRL--53822
D
DE88 002479

Report to Congress on Stockpile Reliability, Weapon Remanufacture, and the Role of Nuclear Testing

George H. Miller
Associate Director for Defense Systems

Paul S. Brown
Assistant Associate Director for Arms Control

Carol T. Alonso
Deputy A Division Leader

Manuscript date: October 12, 1987

Contents

DISCLAIMER

Report to Congress on Stockpile Reliability, Weapon Remanufacture, and the Role of Nuclear Testing

Abstract

This report has been prepared in response to a request from Congressmen L. Aspin, N. D. Dicks, D. B. Fascell, E. J. Markey, and J. M. Spratt, and Senator E. M. Kennedy, to Dr. Roger Batzel, the Director of the Lawrence Livermore National Laboratory (LLNL). Dr. Batzel was asked to make Dr. Ray Kidder available to study two issues: (1) "whether past warhead reliability problems demonstrate that nuclear explosive testing is needed to identify or to correct stockpile reliability," or (2) "whether a program of stockpile inspection, nonnuclear testing, and remanufacture would be sufficient to deal with stockpile reliability problems." In his response, Dr. Batzel indicated that Dr. Kidder would be available to perform the requested study, and that materials would be made available to him for his review. Dr. Batzel also indicated that Dr. George Miller, Associate Director for Defense Systems at LLNL, would prepare a separate report analyzing the issues. This report presents the findings of Dr. Miller and his coauthors.

Chapter 1 examines the reasons for nuclear testing. Although the thrust of the request from Congressman Aspin et al., has to do with the need for nuclear testing as it relates to stockpile reliability and remanufacture, there are other very important reasons for nuclear testing. Since there has been increasing interest in the U.S. Congress for more restrictive nuclear test limits, we have addressed the overall need for nuclear testing and the potential impact of further nuclear test limitations.

Chapter 1 also summarizes the major conclusions of a recent study conducted by the Scientific and Academic Advisory Committee (SAAC) for the President of the University of California; the SAAC report is entitled, "Nuclear Weapon Tests: The Role of the University of California–Department of Energy Laboratories." The SAAC spent many days at LLNL and LANL in direct discussions with numerous experienced weapon design personnel. They received classified briefings and read classified material on the subjects of weapon reliability, the role of nuclear testing, and the measures the Laboratories have been taking to prepare for further nuclear test limitations. There was much interchange and discussion on these topics. The depth of the SAAC study far exceeds that of any other independent review of these topics.

Chapter 2 presents a brief history of stockpile problems that involved post-deployment nuclear testing for their resolution. Chapter 3 addresses the problems involved in remanufacturing nuclear weapons, and Chapter 4 discusses measures that should be taken to prepare for possible future restrictive test limits.

Executive Summary

This report was prepared in response to a request from Congressmen L. Aspin, N. D. Dicks, D. B. Fascell, E. J. Markey, and J. M. Spratt, and Senator E. M. Kennedy (see Appendices A and B). We address their questions of "whether past warhead reliability problems demonstrate that nuclear explosive testing is needed to identify or to correct stockpile reliability, or alternatively, whether a program of stockpile inspection, nonnuclear testing, and remanufacture would be sufficient to deal with stockpile reliability problems."

The answer to the first question is "yes." Past experience indicates that nuclear testing is necessary to identify and correct problems in the stockpile. Although we have learned from each case, some problems have been very recent. Therefore, we believe that for the foreseeable future, continued nuclear testing will be necessary to maintain stockpile reliability.

The answer to the second question is a qualified "yes" over the short term and a definite "no" over the longer term. Over the short term, experienced scientists and engineers would probably be able to deal with stockpile reliability concerns about as well as they do now; we currently have a high level of confidence in the stockpile, but some problems do arise. The "short term" is the time it takes for the scientific judgment and expert capabilities of weapon scientists and engineers to atrophy in the absence of nuclear test experience. This time may be as short as three to five years, as we found during the Nuclear Test Moratorium of 1958–1961 (Reference 1). Measures taken to prepare for further test restrictions can slow the erosion of capability but they cannot stop it.

Before one can assess whether further nuclear test limitations are advisable, the technical and national security issues involved must be thoroughly addressed. Only then can the risks and benefits of additional nuclear testing constraints be evaluated. In this report, we present our views on the technical issues, supported by historical and technical facts, many of which are presented for the first time in an unclassified publication.

Nuclear Testing in the Context of U.S. Policy

The debate about nuclear testing has focused mostly on the issue of stockpile reliability. The discussion should, in fact, be much broader and examine the role of nuclear testing in the context of the U.S. policy of deterrence. Current U.S. strategy is to deter nuclear and conventional war by maintaining a credible and effective retaliatory capability that can respond in a limited and proportional way to an act of aggression. Deterrence thus is a dynamic condition and, as such, must be responsive to military and technological developments.

Nuclear testing supports deterrence in four important ways. First, nuclear tests are required to maintain the proper functioning of the stockpile. Second, nuclear tests are needed to modernize the existing stockpile for enhanced safety, security, and effectiveness. The advance of Soviet technologies, most of which are nonnuclear, requires the modernization of U.S. weapon systems to ensure their survivability. Examples of such modernization needs are the mobile small ICBM (SICBM), the longer range Trident II submarine-launched ballistic missile, and the fast, low-flying B-1B bomber; nuclear testing is needed to verify the warheads for these systems. Third, nuclear tests are required to measure the effects of a nuclear weapon environment on U.S. weapon systems and on critical command, control, and communications systems. Finally, nuclear tests make it possible to identify future weapon concepts for U.S. decision-makers and to stay abreast of potential Soviet nuclear weapon developments, thus avoiding technological surprise. While these reasons for testing are all vitally important, in this report we focus on the issues related to stockpile reliability.

The Need for Nuclear Testing to Resolve Stockpile Problems

The reliability of U.S. nuclear weapons is currently very high because we have been able to sustain a balanced program of weapons physics tests, stockpile confidence tests, and production verification tests. At issue are the conditions for maintaining high confidence in this reliability. Experience has shown that testing is essential. One-third of all the weapon designs placed in the U.S. stockpile since 1958 have required and received post-deployment nuclear tests to resolve problems. In three-quarters of these cases, the problems were identified as a result of nuclear testing. The important point here is that in each case, the weapon was thought to be reliable and adequately tested when it entered the stockpile. Problems resulted from aging, from concerns about safety, from environmental effects, or from a later realization that our understanding of the weapon's physical behavior was incomplete.

Let us emphasize that although a number of weapons in the stockpile have required nuclear tests to evaluate or correct problems, *most* of the problems encountered with the stockpile have been fixed *without* nuclear tests to certify the changes. This has been possible only because the designers and engineers involved could make informed judgments about the problem—judgments that drew on years of experience in actual nuclear testing. Nuclear testing, thus, has a vital role in assuring confidence in *all* U.S. nuclear weapons.

Some have claimed that many of the stockpile problems were the result of deploying weapons that were not "thoroughly tested." There is no such thing as a "thoroughly tested" weapon. Budgetary limitations make it impossible to test nuclear weapon designs under all possible conditions (e.g., delivery environments, defensive threat levels, target requirements, storage histories, safety and security requirements). When a weapon is developed, we test it as thoroughly as we judge to be appropriate to define the boundaries of reliable operation. We conservatively balance factors affecting reliability against those affecting cost. However, not all of the important factors may be known or assessable ahead of time. We test to the level of performance required to meet the military characteristics (MCs) specified by the Department of Defense (DOD).

The military characteristics are prepared by the DOD to specify the requirements for each nuclear warhead. These requirements include, in order of priority, nuclear safety, size and weight, plutonium dispersal safety, operational reliability, yield, conservative use of nuclear materials, and operational simplicity. In the event that compliance with the MCs leads to a design conflict, priorities are to be observed in the order listed, with tradeoffs that allow high-priority MCs to be met while minimizing the degradation of the competing, lower-priority MCs. In 1982, the DOD established an unprioritized MC for stockpile endurance and replicability; these are stated to be *desirable* goals to be achieved to the extent possible while meeting the other MCs.

Claims have been made that the success with which we predict the yield of new nuclear devices in their first nuclear tests indicates the reliability and surety of weapon performance. It would, however, be misleading to judge stockpile reliability on this basis. Our success with first-time predictions is indeed high. There are reasons for this. First, the designers making the predictions either have extensive test experience themselves or their work is reviewed by senior designers with extensive experience. Second, most new designs are based on fairly conservative, previously established technology. For the first test of a variation of this technology, our designers build safe margins into the design. It is later, when the designers begin to optimize a device for its intended weapon application, to study it at environmental extremes, or to incorporate structural, safety, or security features, that margins are reduced and performance sometimes falls short of prediction.

Weapon Remanufacture and the Need for Nuclear Testing

The difficulties involved in "replica" remanufacture have been faced by all major U.S. industries—aerospace, automobile, chemical and materials, and engineering, as well as nuclear weapon design and fabrication. Experience with attempts at remanufacturing in all these industries can be summarized in three important conclusions.

First, exact replication, especially of older systems, is impossible. Material batches are never the same; some materials become unavailable; equivalent materials are never exactly equivalent; "improved" parts often have new failure modes; different people (not those who did the initial work) are involved in the remanufacturing; vendors go out of business or stop producing some products; new health and safety regulations prohibit the use of certain materials or processes.

Second, documentation has never been sufficiently exact to ensure replication. A perfect specification has never yet been written. We have never known enough about every detail to specify everything that may be important. Individuals in the production plants learn to bridge the gaps in the specifications and to make things work. Even the most complete specifications must leave some things to the individual's common knowledge; it would be an infinite task to attempt to specify all products, processes, and everything involved in their manufacture and use. Experts believe that it would be extremely difficult to improve documentation enough to ensure replication by inexperienced personnel.

Third, testing is the most important step in product certification; it provides the data for valid certification. A nuclear test provides our only data on the performance of the whole nuclear warhead package. Tests, even with the limitations of small numbers and possibly equivocal interpretation, are the final arbiters of the tradeoffs and judgments that have been made. They force people to ask the right questions.

Today, design physicists and engineers *with extensive nuclear test experience* at the relevant yield levels could undertake a weapon remanufacture with confidence that the weapon would perform about as well as the original version. However, even such a group has had difficulty predicting the behavior of some weapons recently manufactured for the stockpile—in particular the W68 Poseidon warhead and the W84 warhead for the ground-launched cruise missile. (The W68 was a remanufactured weapon.) In both cases, measured yields fell short of the predictions made by test-experienced weapon designers on the basis of production specifications. Even in retrospect and taking into account the minor changes known to exist between the development and stockpile hardware, we have not yet been able to explain the causes of these yield degradations. The nuclear tests uncovered gaps in our knowledge and revealed that important and as-yet-unidentified production details should have been specified.

The W68 and W84 are relatively recent weapons. The documentation and specifications for older weapon systems are less complete. Although documentation has improved since the MC for replicability was established in 1982, our experience with the W68 and W84 demonstrates that the specifications are still insufficiently complete to prevent subtle but apparently significant variations from taking place. Improved documentation will be helpful in remanufacturing the newer weapon systems. However, confidence in their performance would be lacking if they are placed in the stockpile without relevant nuclear testing and without certification by test-experienced physicists and engineers.

It is important to emphasize that in the manufacture of nuclear weapons, we are dealing with *practical* problems. Idealized proposals about what we should be able to do, without a proper experience base, are prescriptions for failure.

The Importance of Scientific Judgment and Continuity of Experience

Nuclear weapons are extremely complicated, and they operate at conditions that are virtually unique—at material velocities of millions of miles per hour, under temperatures and pressures that are hotter and denser than the center of the sun, in time scales as short as a few billionths of a second. Because of the complexity of nuclear weapons and the limited rate at which they are tested, nuclear weapon design is largely an empirical science. Thus assessments of weapon performance—whether for stockpile inspection, new design, or remanufacture—depend primarily on scientific judgment.

It takes years for designers to gain the experience on which they base their scientific judgment. This judgment must be continually cultivated by the application of theory and experiment to device design and refined with data from nuclear tests. We strive to maintain a continuous line of experienced designers, as senior designers pass on their knowledge to younger designers. This continuity of experience is of paramount importance.

We expect, in the event of very restrictive test limits, that in only a few years we would start to lose the test-experienced people. After a while, the people whose judgment has been honed by the realities of nuclear testing would no longer be available—they would have retired or moved on to other fields. We would then be faced with the prospect of asking scientists without nuclear testing experience to make judgments about the inevitable changes that will occur in remanufactured or stockpile weapons. This is a script for failure. If today, test-experienced personnel have difficulty explaining unexpected behaviors in the nuclear weapons they themselves have designed, how in the future will personnel without test experience be able to establish confidence in weapons designed by people long since gone?

Preparing for Further Nuclear Test Limitations

We are continually studying ways to prepare for further nuclear test limitations so that we can maximize our ability to meet our responsibilities for ensuring the reliability and effectiveness of U.S. nuclear weapons. A number of measures could help alleviate the impact of additional test limitations, if they are vigorously pursued *before* such restrictions are imposed. However, it is important to emphasize that, irrespective of any amount of preparation, further test restrictions will adversely affect confidence in the U.S. nuclear weapon stockpile. In addition, there is no way to ensure that the effect will be symmetric between the U.S. and the Soviet Union. The risk of such a loss in confidence needs to be carefully weighed against the potential political gains of new testing limitations.

Nuclear tests have played a necessary role in helping us meet our responsibilities to ensure the reliability and effectiveness of the stockpile. The need for increased nuclear testing to prepare for new test limits was most recently recognized in 1980 as part of the Augmented Test Program (ATP), planned at the request of the Office of Science and Technology Policy and in response to a memorandum from the National Security Council. The underlying purpose of the ATP was to prepare for a Comprehensive Test Ban (CTB) by placing "early emphasis on those areas of science and technology that contribute most to reliability and confidence of the stockpile."

President Carter approved the ATP in principle, but he did not submit it to Congress for explicit approval and funding. Although in the years since then, there has been some additional funding for nuclear testing, most of this increased funding at LLNL has been earmarked for nuclear-driven directed-energy programs for the Strategic Defense Initiative (SDI); we cannot simultaneously sustain high levels of research on both SDI and weapon physics with the current level of funding. We believe that it would be advisable to consider the equivalent of an ATP at this time. If such a test program is to be successful and avoid the fate of the 1980 ATP, it requires Congressional endorsement, and sustained support will be imperative.

Measures to prepare for more restrictive limits and to help mitigate the problems caused by more restrictive limits include nuclear tests to provide assurance about the reliability of the current stockpile, verify the production of new weapons, and improve our understanding of weapon physics. Expanded nonnuclear experimental facilities, such as expanded hydrodynamic capabilities and a High-Gain Test Facility for fusion research, and advanced computing and numerical modeling capabilities would provide valuable supplements to nuclear test data. Also helpful would be programs to investigate means of certifying nuclear components at reduced yields as well as nonnuclear projects that use some of the same skills as the current nuclear weapon programs. In addition, nuclear weapons might be designed to reduce the likelihood of material degradation with age or to permit modification with less uncertainty about their resulting performance. We are pursuing all of these measures to the extent that funding and the DOD's military characteristics allow.

With the optimized stockpile that we presently possess, nuclear testing has played a key role in maintaining confidence in reliability. It should be mentioned here that with direction, support, and a sustained testing and production program, the stockpile could be reconfigured to be less reliant on (but not totally free from) nuclear testing to maintain reliability. Such an effort would deal only with the testing issues associated with reliability and would not address issues of future modernization. Such a decision would have a significant impact on the cost and capability of the weapon delivery systems since the reconfigured stockpile would generally consist of larger, heavier nuclear systems.

Let us emphasize, however, that in preparing for future, more restrictive test limits, these measures have only limited value. Nonnuclear and low-yield nuclear experiments can maintain some weapon skills but they cannot be used to solve weapon problems. Computer calculations have yet to (and may never) reach the stage where they can replace nuclear tests. These measures provide little guarantee that we will be able to fix future stockpile problems or address new military requirements. They can help slow the erosion of scientific expertise and judgment. They cannot stop it.

SAAC Review of Nuclear Weapon Testing

The Scientific and Academic Advisory Committee (SAAC) advises the President and the Regents of the University of California on matters concerning the Livermore and Los Alamos National Laboratories. Earlier this year, the SAAC was asked to conduct a study on nuclear weapon tests and the role of the University of California–DOE laboratories (Reference 2). The committee spent many days at both laboratories and met with experienced weapon designers, physicists, and engineers. The SAAC came to a number of major conclusions that independently support the technical points we have made above. In particular, they confirmed the historical need for nuclear testing to maintain confidence in the reliability of the stockpile. They noted the continued occurrence of problems requiring nuclear tests to resolve, and they acknowledged the impossibility of "thoroughly testing" nuclear weapons under current test limits and funding levels. They recognized that the laboratories could develop more robust warheads if the military characteristic for warhead endurance were given a specific high priority. The SAAC acknowledged that the laboratories have been making concerted efforts to prepare for a CTB. They highlighted the serious need to maintain qualified personnel with scientific expertise during a CTB.

Conclusion

We believe that if further nuclear test limits are determined to be desirable, then a detailed study of the feasibility and impact of reducing our reliance on underground nuclear testing is needed. Such a study should be done in the context of the overall arms control environment. The study would investigate the changes in nuclear design that might have to be made and the military capabilities that might have to be relinquished in order to develop more robust warheads. These issues must be addressed to determine what could or could not be accomplished under more restrictive test limits.

We are not ready today for significantly reduced nuclear test limits. Until we can find ways to meet our responsibilities for ensuring the reliability and effectiveness of U.S. nuclear weapons and ways to prevent the erosion of nuclear weapon expertise and judgment under restrictive nuclear test limits, it would be imprudent to commit this country to a regime of further nuclear test limitations.

Chapter 1. The Need for Nuclear Testing

For such an important issue as nuclear testing, it is necessary to understand clearly the technical issues so that an appropriate evaluation of the risks and benefits of additional nuclear testing constraints can be evaluated. This report demonstrates, through multiple examples, that to guarantee excellence in our nuclear stockpile, we must maintain an expert group of test-experienced scientists and engineers, well-versed in the practical details of nuclear weapon development and testing.

The issues surrounding further restrictions on nuclear testing must be examined in the context of overall U.S. policy. The present U.S. nuclear policy is fundamentally one of deterrence. There is a lack of consensus as to the nature of deterrence; the spectrum of thought ranges from that of "minimum" deterrence, which proposes that deterrence is maintained by a few survivable nuclear weapons which threaten the opponents' population and industrial centers (Reference 3), to calculated deterrence, which deters limited and full-scale attacks by threatening counters at the appropriate level to acts of aggression (Reference 4). The strategy to implement the latter concept of deterrence is called "Countervailing Strategy," which was stated clearly by Secretary of Defense Harold Brown under President Carter (Reference 5) and later adopted by President Reagan. Deterrence is a very dynamic condition and must be flexible and responsive to nuclear and nonnuclear military and technological developments. Such developments include increased levels of air defenses and antisubmarine warfare, changing target characteristics (like hardening), and threats (like missile accuracy) to the survivability of U.S. forces.

Nuclear weapon testing supports deterrence in four basic ways. First, testing is done to maintain the proper functioning of the current stockpile of weapons. Second, testing is done to modernize the existing stockpile for enhanced safety, security, or effectiveness or in response to the changing Soviet threat. Third, testing is done to measure the effects of nuclear weapons and ensure the survivability of our weapon systems and critical command, control, and communications which might be attacked by adversarial nuclear weapons. Finally, testing is done to avoid technological surprise by analyzing the feasibility of future options to the national decision-makers and to keep abreast of potential nuclear weapon developments of our adversaries.

Modern U.S. nuclear weapons are complex technological objects that have been optimized and tightly integrated into an overall weapon system. Nuclear weapons operate at conditions which are virtually unique: material speeds are millions of miles per hour, the temperatures and pressures are higher than at the center of the sun, and the time scales are billionths of a second. These conditions cannot be generated in the laboratory.

Nuclear warheads are designed to be enduring and robust; however, there is no such thing as a "thoroughly tested" nuclear weapon. Unlike the sampling program that tests thousands of transistors or the continuous exercise of aircraft, a nuclear weapon is usually nuclear tested fewer than ten times during its 20-year lifetime and hopefully is never "operated." The life history of any other piece of military hardware is filled with continual testing followed by small changes to correct deficiencies or to extend its applicability to new systems. Nuclear weapons involve technologies that are very different in character from most modern technology, and the resources have not existed to test them in all of the stressing environments to which they might have to be subjected.

Stockpile Reliability

The reliability of U.S. nuclear weapons is high compared to most high-technology systems. The issue here is "What are the necessary conditions for maintaining high confidence and reliability?"

Nuclear weapons are fabricated from chemically and radiologically active materials. Much as a piece of plastic becomes brittle when it is left in the sunlight, nuclear weapons age and their characteristics change in subtle, often unpredictable, ways. Testing is sometimes required to find problems and to assess the adequacy of the fixes that are implemented. Experience has shown that testing is essential. One-third of all the weapon designs introduced into the stockpile since 1958 have required and received post-deployment nuclear tests to resolve problems related to deterioration or aging or to correct a design that is found not to work properly under various conditions (see Chapter 2). In three-fourths of these cases, the problems were discovered only because of the ongoing nuclear testing. Because we frequently have difficulty understanding fully the effects of changes, particularly seemingly small changes, on the nuclear performance, nuclear testing has been required to maintain the proper functioning of our nation's deterrent. All systems that have been introduced into the stockpile have required experienced people to assess known or suspected problems.

A fundamental issue is the quality of our scientific judgment. Since nuclear weapon design is still largely an empirical science, a designer's competence is based on years of nuclear test experience in all categories—advanced development, weapon physics and stockpile confidence tests. Without this relevant nuclear test experience, nuclear weapon scientists will lack the necessary information to resolve many kinds of problems that might occur.

There is growing pressure in the Department of Defense (DOD) and the Congress for greater reliability testing of systems such as radar, airplanes, and rockets. At the same time, there have been proposals for much lower nuclear test yield thresholds. Such proposals are somewhat like a limit on solid rocket boosters allowing partial tests of first stages, but only one second stage test per year, and no tests of all three stages. Such a program—whether rockets or warheads—would eventually result in a loss of reliability as well as an exodus of experienced people. Even now, with our limited nuclear test schedule and natural turnover in staff, we suffer from a lack of experienced personnel.

The Need to Meet the Military Characteristics

Within the constraints of the military requirements, the weapons in the stockpile and currently under development have been conservatively designed to avoid, as best as possible, the adverse effects of aging. Correcting a problem in the stockpile is extremely expensive and time-consuming. Scientists and engineers strive to make their designs durable and robust against foreseeable conditions encountered in the course of a weapon's lifetime. However, tradeoffs must be made to meet the military requirements.

It has been argued that nuclear weapons could be designed to be more robust than they are now to the effects of aging. We have begun a program to study what more could be done. This is difficult since future problems are unknown. In specifying the requirements for new nuclear warheads, the DOD prepares a set of military characteristics (MCs) that define the requirements. These requirements include, first and foremost, nuclear safety, and then, in order of priority, size and weight, plutonium dispersal safety, operational reliability, yield, conservative use of nuclear materials, and operational simplicity. A separate, unprioritized MC for stockpile endurance and replicability was established in 1982. In the event that compliance with the MCs leads to a design conflict, the DOD requires that priorities be observed in the order listed, with considerations given to tradeoffs that allow high-priority MCs to be met while minimizing the degradation of the competing, lower-priority MCs. We have done the best job we can today to meet the MC for stockpile endurance and replicability. We go to great lengths to maximize weapon durability by means of material compatibility studies, accelerated aging tests, and conservative engineering practices. In fact, when asked, we have successfully extended the lifetimes of a number of nuclear weapon systems.

If stockpile endurance had been the highest priority or the only priority, it is likely that the designs would have been different. Changes in priorities could have led to different military systems—missiles or other platforms with different throw-weights, ranges, accuracies, and operational flexibility. The economic impact of these changes would have been substantial. However, different, more conservative designs would fail to provide absolute assurance of avoiding further nuclear testing. On the other hand, they would probably reduce the need for testing or extend the time over which our designers and political leaders retained confidence.

Modernization

The direction and emphasis of the U.S. modernization program have often been poorly understood. The primary focus of U.S. modernization is on the enhanced safety, security and survivability of our nuclear deterrent forces. Contrary to popular belief, modernization of the U.S. nuclear stockpile has led to a reduction in the numbers of nuclear weapons by nearly 25% and in the total destructive yield by 75% while simultaneously maintaining adequate security for the country. This reduction in numbers and yield, together with enchancements in safety and security, would not have been possible without nuclear testing.

It is obvious that as long as we have nuclear weapons, they must be safe and secure. Yet restrictive nuclear test limitations could preclude needed changes to the stockpile in these important areas. Although there have been no nuclear accidents involving the U.S. stockpile, there have been accidents which involved the detonation of high explosive and dispersal of radioactive plutonium. We have now developed a new high explosive, called insensitive high explosive (IHE), that would not have detonated in these accidents. The U.S. has begun to deploy IHE in stockpiled weapons, but IHE has been incorporated in only one-third of our nuclear systems. Because IHE performs much differently from past explosives, weapons being retrofitted with IHE must be completely redesigned and tested.

Modernization has also been required to develop weapon systems to counter new technological developments, mainly nonnuclear, by our adversaries. For example, Soviet advances in air defense prompted the development of the B-1B bomber, the air-launched cruise missile (ALCM), and a new version of the short-range attack missile (SRAM-II). A new laydown bomb was needed for the B-1B to enable it to drop its payload at low altitudes and high speeds and escape the resulting explosion; the B83 bomb was developed with nuclear testing to satisfy this need. The ALCM was developed to allow U.S. bombers to launch their retaliatory strike outside the perimeter of Soviet air defenses; the ALCM needed a new warhead and this required nuclear testing. The SRAM-II is needed to allow our bombers to more effectively penetrate the Soviet air defenses; its warhead is currently under development and further nuclear testing will be needed.

Soviet advances in antisubmarine warfare prompted the development of the Trident submarine, which is capable of operating in a much larger ocean area than its predecessor, the Poseidon submarine. The Trident needed a new missile, the Trident II, with a longer range commensurate with the submarine's increased operating area. In order to optimize the system, the Trident II missile needed a new warhead which was developed with nuclear testing.

Increased accuracies of Soviet ICBMs have placed our land-based missiles at risk to a Soviet first strike. This has prompted the development of the small ICBM (SICBM), which provides increased survivability through mobility. The current version of the SICBM calls for the missile to carry a single warhead, perhaps a variant of the W87 MX warhead. However, nuclear testing will be needed to certify the variations and the new production lot of the W87. If future versions of the SICBM carry more than one warhead, a new warhead will probably have to be developed to optimize the system and maximize the ground mobility of the missile. The new warhead would also have to meet the mission requirements of the new missile system, and this will require further nuclear testing.

To avoid being caught by technological surprise, we must retain the capability to develop new systems in response to new developments by our adversaries. The new systems will often require nuclear testing. Even if an existing warhead is used in a new system, a nuclear test within current yield limits is extremely important, both to ensure that revised packaging or environmental conditions do not affect warhead function and to verify the adequacy of the new production lot. Restrictive test limitations would limit the evolution of nuclear weapons, including improvements in safety, security, and survivability. We believe that weapon modernization can be stabilizing globally and can be synergistic with major arms reduction agreements.

Weapons Effects Testing

A critical part of our nuclear test program is testing the effects of nuclear weapons on a vast array of military equipment. Of particular importance are the nonnuclear components of our strategic weapon systems, warning sensors, and communications equipment that might have to work in a nuclear environment. If deterrence is to work, our forces must not present a vulnerable target to the Soviets and perhaps encourage them to take advantage of our vulnerability in a crisis. As in the testing of nuclear weapons themselves, we are frequently surprised by the results of nuclear effects testing on nonnuclear equipment that has previously been exposed to nonnuclear simulations of nuclear effects. Changes and subsequent nuclear testing are often required to certify that these important elements of our deterrent system will indeed be able to function properly. Aboveground nonnuclear simulators attempt to replicate discrete nuclear effects, they cannot replicate the nuclear environment itself. The intensities, spectrum, and the synergistic effects of the various kinds of nuclear and electromagnetic radiation (e.g., EMP) can only be produced by a nuclear explosion.

Nuclear Testing and SDI

If our deterrent strategy is to provide stability between the U.S. and the Soviet Union, we must avoid technological surprise with respect to the threat we are facing. Nuclear-driven directed-energy weapon (NDEW) research, as part of the Strategic Defense Initiative (SDI), provides insight into this issue.

An NDEW attempts to use a nuclear bomb as a power source to drive a directed-energy device, such as a laser or a particle beam. The primary focus of our current research is to determine the viability of such NDEW concepts in the hands of the Soviets to defeat or significantly alter a U.S. nonnuclear strategic defense system or to attack our strategic retaliatory forces as part of a Soviet first strike. Said another way, the research is directed toward threat definition and avoidance of technological surprise. We do not know how far the Soviet NDEW research has progressed; we need to know what is possible and how to defend against it.

The restrictive test limits that have been proposed would virtually halt progress on investigating the weapon feasibility of the most promising NDEW concepts. Some limited basic physics research would be permitted but not at the level required to evaluate a weapon.

Another important question is whether nonnuclear strategic defense systems are survivable against nuclear attack. As with nuclear effects testing, strategic defense assets will have to be tested in an actual nuclear environment. Nuclear effects testing of SDI-type components at current yield levels will be required until we develop the capabilities to perform the necessary tests at lower yields.

The Value of Nonnuclear and Very-Low-Yield Testing and Computer Simulation

It has frequently been stated that nonnuclear and very-low-yield (<1-kt) testing and computer simulation would be adequate for maintaining a viable nuclear deterrent. A recent variant of this argument asserts that while such testing and computer simulation may be insufficient for the development of new warheads, they would be adequate for indefinite maintenance of a stockpile of existing weapons. We believe that neither of these assertions can be substantiated.

A computer simulation of a nuclear explosion attempts to provide a detailed physics model for all of the tightly coupled processes that must occur for proper functioning of the device. There are three fundamental issues with computer simulations: (1) the physics is approximated to a varying degree of accuracy by numerical algorithms, (2) not all of the physical processes can be included in fine detail, and (3) experimental data that confirm the appropriateness of the physics are rarely available. Since many of the phenomena are tightly coupled, errors from the simulation of early processes propagate, making subsequent steps progressively more inaccurate. Because most of the physics processes are nonlinear, predictions of full-yield behavior that are based on very-low-yield testing are highly uncertain if not impossible.

The major problem is that a nuclear explosive includes such a wide range of processes and scales that it is impossible to include all the relevant physics and engineering in sufficient detail to provide an accurate representation of the real world. A nuclear explosive contains most of the complicated physics of a supernova explosion—a computational problem whose solution so far has eluded the academic community. It also includes the microscopic detail of engineering and materials—assembly gaps and grain structure. Modern computational facilities cannot provide for this level of simulation. Usually, although not always, the general trends are correctly predicted; sometimes, correct detail and performance can elude us completely.

We attempt to normalize our calculations to experiments to minimize potential errors. In the harsh environment of a nuclear explosion, experiments are very difficult. Much of the information from older experiments, for example, is crude integral data and is of limited use to us now. We simply cannot get the detailed information to tell what is really going on and to identify what might be wrong with our simulations. The conditions that occur in a nuclear explosive are so unique that no experimental facility other than a nuclear explosion can give us data about what actually happens in a nuclear explosion.

We do extensive nonnuclear tests on those parts of the system that are amenable to such tests. The information available from nonnuclear testing, coupled with our most sophisticated calculational procedures, cannot always be extrapolated to predict accurately the behavior of a nuclear device. Our history abounds with such examples, some of them described in this report.

The same is true for modern rockets: small-scale tests and computer simulations do not accurately predict the detailed behavior of solid rocket propellent; full-scale tests and actual rocket launches are necessary to provide assurance of proper function.

Of particular concern is the boosting process in primaries and the fact that this process is not fully understood. For boosting, we incorporate some thermonuclear fuel in the primary. When the fissile material in the primary goes critical, it rapidly heats the thermonuclear fuel, which then burns and emits copious quantities of neutrons. These neutrons, in turn, greatly increase the fission rate, thereby "boosting" the primary yield. If the boosting is less than expected, then the proper ignition and yield of the secondary is in doubt. The achievement of boosting and ignition of the thermonuclear device is all-important in certifying the proper functioning of a strategic primary and secondary. We cannot reliably extrapolate the results of a sub-kiloton test to the full performance of a primary.

A recent example illustrates these points. A final proof test at the specified low-temperature extreme of the W80 (ALCM) was done as the weapon was ready for deployment. The test results were a complete surprise. The primary gave only a small fraction of its expected yield, insufficient to ignite the secondary. The primary had been tested extensively in nonnuclear hydrodynamic tests, including at the low-temperature extreme, with no indication of trouble to the designers. Thus, on the basis of the nonnuclear testing, previous successful nuclear tests, and extensive computer modeling, the weapon designers had every reason to believe that the low-temperature proof test would produce the predicted yield. After extensive post-test analysis, the W80 design was modified and another low-temperature nuclear test was performed; this test was successful, and confidence was established that the warhead would operate properly over its entire temperature range. The production specifications were changed, and the approved warhead entered the stockpile. However, even today we cannot simulate the failure of the first low-temperature test from first principles.

Our experience with the W80 illustrates the inadequacy of nonnuclear and low-yield testing and the need for full-scale nuclear tests to judge the effects of small changes. Even though it has been argued that such a "thorough" test should have occurred earlier, the critical point is that computer simulation, nonnuclear testing, and less-than-full-scale nuclear testing are not always sufficient to assess the effects of deterioration, changes in packaging, or environmental conditions on weapon performance.

Testing of newly produced stockpiled systems has shown a continuing need for nuclear tests. Even an "identical" rebuild should be checked in a nuclear test if we are to have confidence that all the inevitable, small and subtle differences from one production run to the other have not affected the nuclear performance. (See Chapter 3 for a detailed discussion of the issue of weapon remanufacturing.) The current stockpile is extremely reliable, but only because continued nuclear testing at adequate yields has enabled us to properly assess and correct problems as they occur.

The Impact of Restrictive Test Limits on the Soviets

We do not know how further test limits may affect the Soviet Union. Since 1963, when both the Soviet Union and the United States were restricted to underground testing, we have gained little insight into the Soviet nuclear weapon program. What little we do know shows the Soviets to have an aggressive, well-funded program with impressive technical achievements. We know from their unclassified literature that they understand the physics of many advanced concepts. We know that nuclear weapon technology is not monolithic; thus the Soviet designs could be very different than ours. On the basis of the Chernobyl experience, we can speculate that the Soviets have a very different attitude toward the enhanced safety and security devices that contribute to the complexity of U.S. warheads. The Soviets could use the large throw weight of their missiles to accommodate less technologically sophisticated (and therefore larger) warheads. The technologically sophisticated approach that the U.S. has taken in virtually all of its military equipment has important benefits but it also has attendant costs, among them a greater reliance on testing to ensure proper functioning.

The impact of restrictive test limits could be less on the Soviets than on the U.S. More important, retention of their scientific base could be assured by restrictive state policies while U.S. experts would leave for other fields of endeavor. The difference in the durability of U.S. and Soviet weapons is too often oversimplified. Any differences are probably only a matter of degree. Deterioration of Soviet systems could possibly be less if they indeed do use larger, less sophisticated weapons. Their closed society could allow them to exploit shortcomings in verification and might permit them to secretly prepare for a treaty breakout.

We experienced the serious consequences of secret Soviet preparations during the Nuclear Test Moratorium of 1958–1961. After only three years of the Moratorium, we began to experience a significant loss of skilled personnel. The Soviets, on the other hand, had been preparing for the most complex series of nuclear tests ever conducted by either country. Under the very restrictive test limitations proposed today, we could again expect to see an exodus of skilled U.S. personnel, who would leave the weapon programs for various reasons including inadequate opportunities to verify theory against experiment. The consequences of a Soviet breakout from any restrictive treaty could also be compounded by asymmetries in the two countries' abilities to retain skilled manpower.

Nuclear Testing and Scientific Judgment

Ultimately, the viability of the U.S. nuclear deterrent rests on the judgments of our nuclear scientists. Weapon scientists cannot adequately address the impact of new technologies, verify that a problem has been properly fixed, or certify that a new weapon design will meet its military requirements on the basis of nonnuclear experiments alone. Neither can they model with computers all the complex physical processes and engineering detail necessary to predict warhead performance with confidence.

Assessments of weapon performance rest on scientific judgment that is based largely on nuclear test experience. This judgment takes considerable time to develop, is cultivated by the application of theory and experiment to device design, and is continually refined with data from nuclear tests. Removing the confirmation and scientific training provided by nuclear tests would result in the overextension of judgment and in the reduced certainty of this nation's deterrent. Such was indeed the case with the 1958–1961 Moratorium (see Chapter 2 for further examples).

Most problems encountered with the stockpile have not required nuclear tests to certify the fixes that were made. In those cases, the fixes were made by competent scientists and engineers who were able to make informed judgments about the problem, judgments based on years of experience in actual nuclear testing. One such problem involved the corrosive oxidation of internal weapon parts in the W58 warhead for the Polaris A3 missile. There was concern that the corrosion would reduce the yield of the device. On the basis of computer calculations and nuclear test experience with a similar situation in another weapon, the designers were able to correct the problem without an additional nuclear test.

Nuclear warheads cannot be "thoroughly" tested; the resources simply are not available. As a result, the functional capabilities of nuclear explosive cannot be fully established without a strong dependence on the scientific judgment of the weapon scientists. It is not feasible to conduct the large number of nuclear tests required to obtain statistically significant data on a given nuclear system. Thus, the variability of a system's nuclear performance with changes in production tolerances, environmental conditions (e.g., temperature extremes), hostile environments (as are encountered in antiballistic missile engagements), and aging effects must be simulated with analytical, computational, and phenomenological models. The relevance and completeness of such models are only as good as the professional judgment of scientific personnel who are involved in the actual physics, design, and analysis of nuclear warheads and who must rely on a relatively small number of tests to explore the margins of weapon operations. Our scientific judgment is broader than just the experience of each individual weapon scientist; the collective judgment of the entire weapon research infrastructure works synergistically to solve the problems we encounter.

Our judgment is aided and constrained by experimental data from testing actual nuclear devices and by data from physics experiments at NTS in the relevant temperature and density regimes. Significant amounts of physics data are currently derived from actual nuclear tests. Our weapon development and physics research tests constantly show us that the more we learn about the weapon physics, the more we must recognize how limited our basic understanding really is. Scientific judgment is needed to bridge the gaps in that understanding. Critical to that scientific judgment is a cadre of experienced people. With our limited test schedule, we already suffer from a lack of experienced designers, and we are most concerned that we might face a permanent loss of capability. Staff maintenance during a Comprehensive Test Ban (CTB) was one of the most important issues addressed by the SAAC report (described below).

SAAC Review of Nuclear Weapon Testing

The Scientific and Academic Advisory Committee (SAAC) is a standing committee appointed by the President of the University of California (UC) to advise him and the University Regents on matters concerning the Livermore and Los Alamos National Laboratories, which are managed by the University. The members of SAAC who conducted the study are well known in their fields; they have expertise in the sciences, mathematics, engineering, and technical management and are familiar with the nuclear weapon aspects of U.S. forces.

Earlier this year, the SAAC was asked by the President to conduct a study entitled, "Nuclear Weapon Tests: The Role of the University of California-Department of Energy Laboratories" (Reference 2). The study was a response to a number of letters to the UC President from professors expressing concern about the Laboratories' role in nuclear testing. The SAAC spent many days at LLNL and LANL in direct discussions with numerous experienced weapon design personnel. They received classified briefings and read classified material on the subjects of weapon reliability, the role of nuclear testing, and the measures the Laboratories have been taking to prepare for further nuclear test limitations. There was much interchange and discussion on these topics, and the depth of the SAAC study far exceeds that of any other independent review.

The SAAC came to a number of major conclusions that support the technical points we have made above. Some of their conclusions are summarized below:

1. The SAAC reviewed "in some detail" the stockpile problems that involved post-deployment nuclear testing for their resolution. The SAAC concurred that "confidence in reliability could not have been maintained undiminished without nuclear testing" (page 13, last paragraph).

2. The SAAC concluded that the Laboratories have improved their understanding of materials aging and degradation to greatly reduce further occurrences of such problems. "Nevertheless, in recent years sporadic problems of a more subtle nature have arisen, e.g., performance at low temperatures." The SAAC pointed out that sometimes these were recognized based on insights from other nuclear tests, including the Laboratories' weapon physics tests (page 15, last paragraph, and page 16, first paragraph).

3. The SAAC addressed the issue of whether weapons can be "thoroughly tested." The SAAC agreed that limitations on numbers and types of nuclear tests preclude testing of stockpile weapons over the full range of operational parameters. The SAAC stated, "new insight, developed by means of nuclear or laboratory tests, or by calculations, has occasionally raised retrospective questions concerning the ability of the stockpiled weapon to perform" (page 9, paragraph 4).

4. The SAAC agreed that if the military characteristic for warhead endurance were given a specific high priority, the Laboratories could develop more robust designs. This would have attendant penalties in weight, size, and yield, which would appear in increased costs (i.e., special nuclear material) in the warheads and delivery systems (page 14, paragraph 2, and page 16, paragraph 3).

5. The SAAC concluded that the Laboratories have been acting under a plan that emphasizes the necessity to be prepared for a CTB. In responding to an assertion that weapons in stockpile were deliberately designed to require continued nuclear testing to ensure their reliability, the SAAC report stated: "The SAAC concluded that this is not true" (page 2, issue 2, and page 16, issue 3).

6. The SAAC concluded that the Laboratories have designed weapons that are remarkably reliable and long-lived. The Laboratories have always given great attention to stockpile endurance (page 1, issue 1, and page 14, paragraph 2).

7. The SAAC concluded that Laboratory weapon physics programs have resulted in progress toward more enduring designs to prepare for a CTB. The SAAC encourages continuation of these programs (pages 1, 2, issue 1).

8. The SAAC regards as the most serious issue discussed with the Laboratories that of recruitment and staff maintenance during a CTB. The SAAC agrees that this would require "extraordinary" efforts. "The Committee applauds the current efforts of the Laboratories in these directions, and urges increased emphasis in the future" (page 2, issue 3, and page 16, paragraph 7).

Conclusion

Nuclear weapon research and development, supported by nuclear testing, is essential to maintain the credibility of the U.S. nuclear deterrent. Because the global strategic balance is constantly changing, new weapon systems must be developed to ensure the safety, security, survivability, and military effectiveness of our nuclear deterrent.

The DOE weapon design laboratories have the responsibility of ensuring that the weapons currently in the stockpile are safe and reliable, of developing warheads for new systems as they are needed, and of exploring what is possible in order to avoid technological surprise.

Nuclear testing is essential if the Laboratories are to meet these responsibilities successfully. Nonnuclear tests and computer simulations are very valuable tools but there is no substitute for the experimental data from nuclear tests. In many instances, weapon scientists must rely on technical judgment to make decisions regarding problems that arise in the stockpile, in recommending changes in weapon systems, and in developing new warheads—judgment that can only derive from and be refined with actual data from nuclear tests.

Without nuclear testing, deterrence would still be based on nuclear weapons. However the costs would likely be higher, the uncertainties would be greater, and our options for maintaining stability would be limited.

Chapter 2. History of Stockpile Problems and Post-Deployment Nuclear Testing

In the 26 years since testing resumed after the 1958–1961 Nuclear Test Moratorium, post-deployment nuclear testing of U.S. nuclear weapon designs has been required to assure continued confidence in the performance of the nuclear weapon stockpile. Major weapon systems (e.g., Polaris and Poseidon) have been involved in these tests. A majority of the problems would not have been discovered if the nuclear test program had been discontinued. Specifically, if the stockpile had been frozen by a test ban treaty early in this period, many of the weapon designs could have been found to be seriously deficient, had their use become necessary. Some of the problems were the consequences of the Moratorium, which was in effect a *de facto* Comprehensive Test Ban (CTB). Early problems have long since been resolved and we have learned from these experiences, but others have arisen, some very recently. One-third of all modern nuclear weapon designs in the U.S. stockpile have received post-deployment nuclear tests to resolve serious problems; in three-fourths of these cases, the problems were identified only because of the on-going nuclear testing. Many thousands of deployed weapons have been affected.

While only one-third of the deployed designs required testing to discover, evaluate, or fix problems, nuclear testing has been required to retain confidence for *all* U.S. systems. *All* systems have experienced some problems, and the assessment of these problems was made by people experienced in nuclear design and testing.

The U.S. weapon stockpile is highly reliable today. However, weapon certification by the weapon design laboratories has never been unconditional. Some conditions placed on certification are explicit: for example, limited lifetime component exchanges must be as specified, and exposures to defensive threats or adverse environments during the stockpile-to-target sequence (STS) must lie within limits specified in the military characteristics (MCs) for each weapon. Generally, these conditions are clearly stated. However, certain other conditions are less obvious, seldom clearly articulated, and equally vital; for example, there must be adequate programs for the identification, assessment, and resolution of stockpile problems. What is adequate, in turn, can only be determined by those few experts who are directly responsible for weapon certification. Experience has demonstrated that the above conditions cannot be met indefinitely without nuclear testing. Experience has also shown that while testing has been permitted, U.S. nuclear weapons have been dependable for long periods with high confidence.

Historical Background

Few problems arose in the U.S. weapon stockpile before the 1958–1961 Nuclear Test Moratorium. There were several reasons for this. First, by 1958, 11 weapon designs had been retired at an average age of less than 4.5 years; little time had passed for problems to develop or be recognized. There were 14 designs remaining that would attain slightly more than twice that average age before they, too, would be retired. The life of four weapons, in which the designs were not very complex, was to be much longer. The U.S. had a rapidly developing technology, a need to respond to a constantly changing threat from the Soviet Union, and in particular, relative simplicity in its early nuclear weapon designs. There was a rapid turnover in weapon systems. These factors, combined with less stringent safety and security requirements (by today's standards) made the development of stockpile problems very unlikely.

The first modern weapon design appeared with the first thermonuclear weapon, the Mk 14, deployed and quickly retired in 1954. More significant was the development, starting in 1955, of small and efficient "boosted" fission devices for use as single-stage weapons or as primaries (fission triggers) for thermonuclear weapons. During the late 1950s, the size of future U.S. strategic delivery systems began to be determined by attainable yield-to-weight ratios, and high ratios depended on the new boosting and thermonuclear technologies. At the same time, concerns increased regarding safety and security, and these concerns placed increasing constraints on the weapon designs.

When the United States entered the Moratorium in 1958, the first thermonuclear weapons based on the new boosted primary technology (the Mk 27 warhead for the Regulus missile and the B28 bomb) were ready to begin deployment, as a result of tests completed in 1956. In 1958, there were no recognized problems with weapons in stockpile. Concerns soon developed, however, regarding the safety of one of the new thermonuclear weapons, the B28. Although more than one-third of the tests of boosted primaries done to that date had been tests of one-point safety, it was discovered through analysis of the latest data that these had not been worst-case tests and that a significant safety problem might still remain. (In a one-point-safe design, the accidental detonation of the high explosive at a single point does not result in any significant nuclear yield.) Production and delivery of the B28 were slowed drastically. Strategic Air Command (SAC) missions in Europe were put on hold at a time of high international tension; in effect, the B28 was grounded. On the basis of data from an earlier test, weapon scientists were able to shift B28 production to a different, safer design. Without this retrofit, which would not have been possible without data from the earlier nuclear test, the deployed weapon would have had to remain subjected to onerous operational restrictions.

When the U.S. resumed testing in 1961, the situation was changing rapidly, although the implications of the changes were not yet fully recognized. Of the 18 weapon designs that had constituted the 1958 stockpile, only one had been retired. Seven new designs had entered the stockpile during the Moratorium. As a result of the stockpile surveillance program, and particularly as a result of the resumption of nuclear tests in late 1961, it was realized that four of the 24 weapon designs in the 1961 stockpile had problems that could be resolved only by additional nuclear tests.

The number of new designs in stockpile grew rapidly after 1961. Of 10 new designs deployed by 1964, half developed problems (discussed later in this chapter) that would be resolvable only by further testing. Some weapons required redesign whereas others only required assessment, through additional testing, and appropriate stockpile management.

By 1970, 10 of the 27 designs then composing the stockpile (23 from the 1964 stockpile, and four newer designs) were weapons whose continued availability had depended, or would soon depend, on post-deployment testing. By now, many earlier problems had been corrected. However, one of the two newest designs in the 1970 stockpile required further testing, as would one of the older designs. At the same time, it began to be clear that stockpile lifetimes were lengthening.

There now are 28 designs in the U.S. arsenal, 17 from the 1970 stockpile and 11 new designs. Of the 11 new designs, three (W79, W80, W84) have required additional nuclear testing, and a fourth (B61), whose reliability has not been in question, has required substantial redesign and modernization to meet current safety, security, and economy requirements.

The history presented here demonstrates the essential role of nuclear testing in preserving confidence in the reliability of U.S. deployed nuclear weapons. At no time has it been possible to dispense with the knowledge and judgment, based on current test experience, of the weapon scientists.

To understand the path that has been followed, it is useful to recall the commitments made to the nation in 1963 by President John F. Kennedy, presented as safeguards for the treaty limiting the U.S. to underground testing. The most important of these safeguards were (A) the maintenance of modern nuclear laboratory facilities and programs in theoretical and exploratory nuclear technology, to ensure continued progress in that technology, and (B) the conduct of comprehensive, aggressive, and continuing underground nuclear test programs to add to our knowledge and to improve our weapons in all areas of our military posture for the future. President Kennedy also declared (Reference 6) that "While we must all hope that at some future time a more comprehensive treaty may become possible by changes in the policies of other nations, until that time our underground testing program will continue."

Stockpile Reliability

The maintenance of confidence in the reliability of our weapon stockpile depends on the continuing stockpile surveillance program, the quality assurance and reliability testing of nonnuclear components, and the nuclear testing of warhead components and similar nuclear devices in the on-going nuclear weapon development program. The continuing nuclear test program serves to confirm, and occasionally to call into question, the design choices made in the stockpiled weapons. It trains and provides experience to new designers who will eventually be called upon to evaluate stockpile reliability problems. Identified stockpile problems have sometimes required nuclear tests to guarantee acceptable weapon performance. Had nuclear tests not been available, the stockpile problems would have forced unacceptable reductions in yield and/or reliability, unacceptable operational limitations, or replacement with a design with much greater uncertainty in performance.

Nuclear tests can be necessary to confirm the proper resolution of a stockpile problem or to determine whether the problem will adversely affect the performance of the weapon. Such tests are needed because some of the physical phenomena occurring in weapons are so complicated that it is impossible to model them completely or to evaluate them adequately with only calculations and nonnuclear tests. Nuclear tests are also necessary to verify the judgment of the weapon designer and the "realism" of models and calculations.

Our design calculations are the result of many assumptions about how materials behave at the extreme conditions of a nuclear explosion. These assumptions often are based on limited experimental data and on theoretical predictions that are difficult if not impossible to verify in sufficient detail. As a result, design calculations must be compared with actual test results; like many assumptions made in other extremely complex technologies, they sometimes are found to be incorrect, incomplete, or inadequate.

The phrase "thoroughly tested" has recently received considerable attention. It has been claimed that a large fraction of stockpile problems were the result of deploying weapons which were not "thoroughly tested." It has also been assumed by some that our new weapons are "thoroughly tested." This phrase is misleading. It is impossible, in a real world with budgetary limitations, to test nuclear weapon designs under all foreseeable STS conditions, including exposure to adverse storage or delivery environments, expected defensive threat levels, and changing target requirements. It is impossible to do a statistically meaningful number of tests. It also is impossible to know or foresee all future safety and security requirements at the time weapons enter the stockpile. Safety criteria (e.g., criteria on one-point safety, safety against accidental plutonium dispersal by high-explosive detonation, and safe levels of intrinsic radiation) and security requirements can and do change. Expected threat levels or other STS parameters change as the Soviets acquire new capabilities. The acceptability or availability of certain materials originally used in weapon fabrication may change as a result of factors entirely beyond the control of the weapon scientists. Finally, it may be discovered, sometimes in the course of subsequent testing of similar designs, that design errors were made, that basic physical data are in error, or that understanding of the physics itself has changed. The term "thoroughly tested" implies a comprehensiveness that is impossible in practice. Designer judgment, validated by ongoing testing, is vital both in determining what tests are most essential at the time of certification and in evaluating problems or changing requirements that arise later.

The bottom line is that there is no such thing as a "thoroughly tested" weapon. In developing a weapon, we test it as thoroughly as we can under a variety of conditions. In the development process, we attempt to define the boundaries of reliable operation, and we back away from these boundaries in a way that conservatively balances factors affecting reliability and factors affecting cost.

It has been noted recently that weapon designers have been quite successful in first-time predictions of the yields of new devices in nuclear tests. Claims have been made that this high rate of successful prediction is an indicator of reliability and of surety of performance if remanufacture is necessary. Evaluating stockpile reliability on the basis of such statistics is extremely misleading.

Our success rate of first-time yield predictions is high for good reasons. First, the designers making the predictions have extensive test experience themselves or their work is reviewed by senior designers who have such experience. Second, most of the designs are based on fairly conservative, well-established technology. The first time a variant of this technology is tested, our designers use their knowledge to build safe margins into the designs. Essentially, they put "fat" into the system. It is when the designers begin to fine-tune a device to optimize it for its intended weapon application, to study the device at environmental extremes, or to incorporate engineering details like structural, safety, and security features that performance margins are reduced and uncertainties creep into their predictive capabilities.

There is an important common message in the stockpile difficulties described below: the weapon was thought by the experts to be adequately tested and reliable at the time when it entered the stockpile. However, problems occurred as a result of materials aging, changes in safety concerns, environmental effects, or a later realization that our understanding of the physical performance was incomplete. Nuclear testing was done to properly identify the effects of these problems on weapon performance or to evaluate the validity of solutions to problems. It should be noted that even if an identical rebuild is chosen as the solution to a problem, a nuclear test should be done to ensure the adequacy of the production process. (See Chapter 3 for a detailed discussion of weapon remanufacturing.)

Because of budgetary and manpower constraints, a weapon in the stockpile is usually nuclear-tested fewer than ten times during its development and subsequent lifetime. Obviously, it is impossible to test every conceivable condition and eventuality. The stockpile is reliable because we test for the worst conditions that we expect, and we can fix problems if they occur or if we discover later that our expectations were wrong. In this regard, nuclear weapons are like most other modern, high-technology systems (e.g., rockets, airplanes, computers). The effects of time, environment, and chemical degradation often require testing to identify and fix sometimes subtle design and materials problems.

While not all solutions to stockpile problems require certification by full-scale nuclear tests, all rely on data obtained in nuclear tests and, most critically, on the judgment and insight that the scientists and engineers acquire on the basis of such data. If we stopped nuclear testing, such experimental data would no longer be obtained, and the pool of specialists whose judgment was validated by nuclear test experience would decline and, finally, no longer exist.

Stockpile Problems Involving Post-Deployment Nuclear Testing

In the remainder of this chapter, we give a brief unclassified description of stockpile problems that involved post-deployment nuclear testing for their identification or resolution. We address those designs developed both by LLNL and by LANL (see Table 1).

LLNL Designs

Of the 16 LLNL-developed warhead designs that entered the stockpile after 1958, several were subsequently found to have problems. For six of these (WXX, W84, W79, W68, W47, and W45), the resolution of the problems involved nuclear testing. In three of the weapons (W84, W47, W45), some problems were discovered by nuclear testing and further nuclear tests were necessary to resolve the problems. All of these problems have been corrected.

All of the designs placed in the stockpile were extensively tested beforehand. More than one-third of the weapon designs that LLNL has placed in the stockpile have experienced problems that involved nuclear testing. Some of the systems had multiple problems.

WXX. A problem recently occurred with an LLNL weapon which cannot be identified or discussed in detail on an unclassified basis. The problem involved a new concern about one-point safety of the device under certain conditions. A nuclear test was necessary to eliminate the concern.

W84. The W84 is the warhead for the ground-launched cruise missile (GLCM) and is tailored to applications in the European theater. Accordingly, it was developed to a set of stringent requirements emphasizing safety, security, and flexibility. A number of seemingly minor changes were made in the stockpile hardware as compared with the hardware used in the development tests, as is usually done for complex systems. When a stockpile confidence test was conducted on a unit that had been deployed for a year (and modified slightly to simulate certain aged conditions), a lower-than-expected yield was obtained. There was concern that the low yield was indicative of possible marginal operation of the device. Another nuclear test was necessary to evaluate the source of the yield degradation, to certify a fix to the problem, and to determine that there were indeed no problems with marginality. This stockpile confidence test is typical of the tests we now do to certify the production versions of all systems that enter the stockpile. They are dual-purpose tests in that they verify that the production process has not introduced unacceptable systematic perturbations into the weapons and they serve to determine the effects of some stockpile exposure and handling on the weapons.

W79. The W79 is the warhead for the 8-inch artillery shell. A problem was encountered in manufacturing a component needed to meet the weapon's operational requirements. The component involved a complex design, and a satisfactory design could not be achieved within the specified development time scale. Hence, the W79 was deployed with a simpler design that allowed the weapon to meet a modified operational capability. Ultimately, after the weapon was deployed, a different approach was devised to satisfy the operational requirements. This different approach required a design change that meant that the physics behavior of the device had to be altered, and a nuclear test was required to certify the design change. The W79 problem differs from the other problems described in this report in the sense that the W79 was *knowingly* placed in the stockpile with a different capability than originally required. We were unable to develop an engineering solution to solve the problem, and an

Table 1. Fifteen U.S. nuclear weapon systems have required post-deployment nuclear testing to identify or resolve problems. All the listed problems have been resolved.

Warhead	Problem	Responsible laboratory	Identified or evaluated by nuclear testing	Resolved by nuclear testing
WXX	One-point-safety concerns	LLNL	X	
W84	Concern about marginal behavior at aged conditions	LLNL	X	X
W79	No practical manufacture of a complex part; different approach required altering the physics behavior	LLNL		X
W80	Failure at low temperature	LANL	X	X
B61	Replacement of HE with IHE for safety	LANL		X
	Concern about low-temperature performance		X	
W68	Degradation of HE	LLNL		X
W47	Corroding fissile material	LLNL	X	
	Vulnerability in simulated ABM environment		X	X
	Improvement of one-point safety			X
W45	Mechanical change of HE	LLNL		X
	Performance under aged conditions		X	X
W52	Replacement of HE because original wasn't safe enough for handling	LANL	X	X
B43	Improvement of one-point safety	LANL		X
	Performance under aged conditions		X	X
B28/W49	Performance under aged conditions	LANL	X	X
W44	Improvement of one-point saftey	LANL		X
	Performance under aged conditions		X	X
W50	Improvement of one-point safety	LANL		X
	Performance under aged conditions		X	X
B57	Performance under aged conditions	LANL	X	X
	Improvement of one-point safety			X
W59	Improvement of one-point safety	LANL		X
	Performance under aged conditions		X	X

alternate physics solution was used to allow the W79 to meet its full requirements. Continued nuclear testing was necessary to certify the solution.

W68. The W68 is the warhead for the Poseidon submarine-launched ballistic missile (SLBM). In routine stockpile surveillance, the high explosive (HE) in the W68 was found to be decomposing and the decomposition products were causing deterioration of the detonators. We judged that it was only a matter of time before the W68 weapons in stockpile would be inoperable. We could have repeatedly rebuilt the W68 warheads using the same type of HE that was decomposing, at tremendous expense and with large operational impact on the U.S. Navy. Instead, we chose a more cost-effective and technically sensible approach and rebuilt each warhead with a more chemically stable HE.

Even though a version of the W68 with the more stable HE had been tested in initial development, we judged that a nuclear test was necessary to certify the design. The production verification test was done at certain simulated extreme conditions of the STS. We were surprised when the resulting yield was degraded beyond what we expected based on the earlier test with the new HE. Besides changing the HE, there had been a number of other changes in warhead parts. For example, certain warhead materials had to be changed because the vendors of the original materials had gone out of business.

We have not yet been able to explain the cause of the observed yield degradation. Although the new HE was supposed to be the same as that tested earlier, there may have been subtle changes in its formulation. We do not know whether the degradation was caused by the new HE, the other changes, or some combination. We might even have experienced yield degradation had we rebuilt the warhead with a fresh batch of the same chemically unstable HE.

Although the yield of the W68 was considered to be acceptable, it has been necessary to emphasize certain maintenance procedures to allow the warhead to meet its intended function at certain STS extreme operational conditions. When the Navy asked if the time for doing these maintenance procedures could be relaxed because of the large impact on their operational work load and associated costs, we emphasized the importance of doing the procedures in a timely manner. Our advice to the Navy was significantly influenced by the unexpected result in the production verification test.

While some have stated that a production verification test of the rebuilt W68 was not necessary, the above results showed that the test was needed both to certify the adequacy of the production rebuild and to allow us to provide accurate advice to the Navy on required maintenance and operational restrictions. It is clear that the rebuilt version of the W68 is different in substantive ways from the original.

It is important to recognize that the HE decomposition and its effects on the detonator caused considerable concern. A test of the remanufactured warhead was necessary to restore our confidence and that of our leadership. The Poseidon warhead was too important to our national security to leave our leaders in a position of doubt.

W47. The W47 was the warhead for the Polaris SLBM. Several problems were encountered with the W47 that required post-deployment nuclear testing for their resolution. One of these problems was discovered in a nuclear test.

First, corrosion of the fissile material was observed during stockpile maintenance. A test of a unit simulating the problem defined the acceptable corrosion limits, and those weapons that exceeded these limits were removed from the stockpile.

A nuclear effects test showed that material in the W47 primary was vulnerable to effects encountered in a potential antiballistic missile environment. The design was modified to cure this deficiency, and a nuclear test was needed to insure that the modified design performed adequately.

Another problem with a safety device required the development and testing of a new primary. Before the Moratorium, we were unable to make the W47 inherently one-point safe (i.e., incapable of producing any nuclear yield in the event of accidental detonation at a single point of its HE). The Moratorium prevented us from performing the necessary tests to develop an inherently one-point safe design. Instead we incorporated a mechanical safing device in the W47 to provide the necessary one-point safety. Use of such a device was not a novel idea at the time and such devices had been successfully used in other systems and are still used in some. The designers of the W47 had every confidence that the weapon would meet its intended mission. However, chemical corrosion in the W47 eventually caused a serious reliability problem in the safing mechanism that did not lend itself to a viable engineering solution. The mechanism would not fully complete its arming operation in a large number of the sampled warheads, indicating that a large fraction of the W47 warheads would be duds and that the number of dud warheads was increasing with age. This problem was solved by replacing the primary with one known to be one-point safe, and a nuclear test was required to certify the new design.

W45. The W45 is the warhead for the Navy's Terrier missile, the now-retired medium atomic demolition munition, and the Army's now-retired Little John missile. The W45 was developed in part during the 1958–1961 Moratorium and entered the stockpile in 1962. There were two W45 reliability problems that required post-deployment nuclear testing.

One involved unexpected effects of radioactive aging of a warhead component. When the W45 entered the stockpile, our weapon scientists had no reason to believe its operability would be unacceptably affected under aged conditions. They believed the weapon had been well tested before entering the stockpile. When the weapon was tested under aged conditions, after the Moratorium, it gave only half its expected yield. To respond to this unexpected result, it was necessary to conduct a number of nuclear tests to certify all versions of the W45 in the stockpile. Five tests were required establish yield values and changes in the maintenance procedure for the weapon. The issue here is that although it was relatively simple to calculate or measure radioactive decay rates, it was much more difficult to estimate the effects of radioactive decay on the complex operation of this sensitive weapon.

The second problem, a permanent deformation of the explosive after aging, also required a nuclear test to certify a new design with a modified chemical explosive.

LANL Designs

Of 25 Los Alamos weapon designs that have been deployed since 1958, one-third have required post-deployment nuclear testing. The W80 warhead was ready for deployment when a probable flaw in the primary design was discovered. A new modification of the B61 was in production, but not yet deployed, when new nuclear safety requirements caused production to be terminated pending development, through additional tests, of an alternative safer primary design. Seven other designs (B28/W49, B43, W44, W50, W52, and W59) developed one or more problems whose recognition and resolution required further nuclear tests.

W80. The W80 is the warhead for the air-launched cruise missile (ALCM). A test at the low-temperature extreme of the temperature range of the W80's STS was done just as the weapon was ready for deployment. The test results were a complete surprise. The primary gave only a small fraction of its expected yield, insufficient to drive the secondary. The weapon had been tested extensively in nonnuclear hydrodynamic tests, even at the low-temperature extreme with no indication of trouble. Thus, on the basis of nonnuclear testing and previous successful nuclear tests, the weapon designers had every reason to believe that the low-temperature proof test would produce the predicted yield. After extensive post-test analysis, the design was modified and another low-temperature nuclear test was performed. The test of the modified design was successful, and confidence was established that the warhead would operate properly over its entire temperature range. The production specifications were changed accordingly, and the approved warhead entered the stockpile. Because of concerns about performance at extreme temperatures raised by the low-temperature test, a nuclear test at the high-temperature extreme was performed later.

This example illustrates again the inadequacy of nonnuclear testing and the need for nuclear tests. Without the disastrous result of the low-temperature nuclear test, the weapon designers would have judged, on the basis of the nonnuclear tests, that the system would perform properly. As a result of the experience with the W80, similar low-temperature nuclear tests have been done for several other weapon systems, including the B61.

B61. The B61 is a strategic bomb that entered the stockpile in 1968. By 1971, a modification to the design was required, and, more important, the safety and security features of the older design did not meet current standards. A new series of B61 designs was produced with various modifications containing improved safety and security features and, in one, insensitive high explosive (IHE). Incorporation of all modern technology except the IHE was accomplished without nuclear testing; nuclear testing was required to make the change to IHE. In the early 1980s, a nuclear test revealed that the B61 had a cold-temperature sensitivity similar to though less severe than that exhibited by the W80. Because of this, a further design change had to be implemented.

In reviewing the history of the B61, it is important to note that the original design was never judged to be unreliable; it did not meet modern performance criteria. Modern versions of the B61 incorporate IHE, permissive action links (PALs), command disablement, and other use-control features.

W52. The W52 was the nuclear warhead for the Army's now-retired Sergeant surface-to-surface missile. In 1959, the warhead was nearly ready for production when two explosive accidents occurred at Los Alamos, killing six people. The explosions were due to the unexpected susceptibility to accidental detonation of the type of high explosive used in the W52's fission trigger. Los Alamos had to change the explosive used in the W52 to a safer, less sensitive, and somewhat less energetic explosive. This decision was made during the Moratorium when the new design could not be verified in a nuclear test. The redesign was based on nonnuclear hydrodynamic tests and on computer design calculations. Because of the high confidence the Los Alamos scientists had in their redesign, they did not immediately test the W52 when the Moratorium ended in 1961. The W52 entered the stockpile in April 1962. When Los Alamos finally tested the device, the weapon gave only a fraction of its expected yield. The W52, as delivered, had too low a yield to be militarily acceptable. Los Alamos scientists made a rapid redesign, and within three months of the test failure, they successfully conducted a nuclear test of the new design, which was then incorporated into the stockpile.

The W52 dramatically illustrates the limitations of nonnuclear experiments and computer calculations to evaluate seemingly moderate changes in warhead designs. Although the problem with the W52 occurred in the early 1960s and our capabilities in computer modeling and nonnuclear experiments have improved significantly since then, experienced designers today would not undertake to change the HE in a weapon without nuclear testing. Even with modern capabilities, this is a very major change and the risks of errors are too high.

B43. The B43 is a tactical and strategic thermonuclear bomb. It experienced several post-deployment problems. In 1961, Los Alamos scientists concluded that the primary for the B43 was not one-point safe under all conditions. A long series of tests was required to develop an adequately safe version.

In a second problem, a radioactive aging problem like that noted above for LLNL's W45 was recognized in a test of the B43. To investigate whether it might be possible to extend the lifetime of the B43 weapons in the stockpile, a test of an aged B43 was fired. The test gave only half its expected yield. After further nuclear testing and increased theoretical understanding, LANL was able to establish appropriate B43 maintenance procedures for aged weapons.

The low yield was a shock, in part because its results applied not just to the B43 but to all similar weapons in the stockpile. Weapon scientists were more concerned about some systems than others, depending on application. Under a continued Moratorium, maintenance procedures might have been used that would have allowed weapons to remain in service beyond their useful lives.

B28/W49. The B28 is a tactical and strategic thermonuclear bomb. The W49 version was the warhead for the Thor and Jupiter intermediate-range ballistic missiles and the Atlas D ICBM. The B28 had a problem with warhead aging like that experienced by the B43. A nuclear test of an aged B28/W49 warhead was required to certify the existing maintenance procedures for the weapon. As the behavior of the warhead was better understood, through computer modeling and confirmed by nuclear testing, the maintenance procedure for the B28 was further modified.

W44. The W44 is the warhead for the antisubmarine rocket (ASROC) missile. The W44 had the same problems as seen with the B43 with respect to one-point safety and radioactive aging. The same solutions were employed.

W50. The W50 is the warhead for the Pershing I missile and for the now-retired Nike Zeus missile. The W50 had a one-point-safety problem and there were the same concerns about radioactive aging as with the B43. The same solutions were employed as for the B43.

B57. The B57 is a tactical and a strategic bomb. The B57 experienced the same radioactive aging problem as the B43. It was also found to have a one-point-safety problem. A nuclear test was done to certify a new version of the B57 primary that was one-point safe. The same solutions to the radioactive aging problem were used as for the B43.

W59. The W59 was a warhead for the Minuteman I missile. The W59 had a one-point-safety problem and there were the same concerns about radioactive aging as with the B43. The same solutions to these problems were used as for the B43.

General Comment

LANL's B28/W49, B43, W44, W50, W57, and W59, and LLNL's W45 were all affected by the same problem—unexpected sensitivity to the radioactive aging of the warheads. We have gained considerable experience since the 1960s and believe that such a common-mode problem is much less likely now than it was then. This particular problem has long since been solved. It has been stated that any one problem in a single system does not pose a threat to the entire nuclear stockpile, since other systems can fill the gap left by the faulty system. However, modern designs do have a great deal of commonality (e.g., high explosive, detonators, security features, etc.) and a common-mode problem could affect a large fraction of the stockpile. We must protect ourselves against such problems, and nuclear tests are of vital importance in recognizing and solving them when they occur.

Vulnerability Problems

The vulnerability of U.S. strategic nuclear weapon systems as well as nonnuclear assets like warning sensors and communications equipment to nuclear effects is a matter of extreme importance. Underground nuclear tests are used by the

Defense Nuclear Agency (DNA) to assess the vulnerability of U.S. systems. There are many uncertainties in the codes and calculations that are done to predict vulnerability to nuclear effects. These uncertainties are largely due to the difficulty in accurately modeling a complex real weapon system and the fact that one is attempting to calculate the response of materials in a very difficult regime of equation-of-state. Although aboveground testing is conducted with various accelerators and nuclear reactors, the fluences and deposition times are far removed from those in an actual nuclear explosion and there is no way to assess combinations of effects. In addition, the size of the sample that can be exposed is often limited, making it impossible to assess the vulnerability of complete systems.

Surprises have been found in the underground vulnerability testing of all U.S. strategic nuclear systems except the Minuteman II. Effects tests are vital to ensuring the survivability of nonnuclear systems, including space-based command, control, and communications assets. Effects tests will also be necessary to ensure the survivability of space-based SDI assets.

Figure 1 shows the various U.S. strategic systems and their years of testing and/or deployment. It is interesting to note the frequency with which unexpected test results occur and the number of instances where a number of tests were required to obtain satisfactory results. In some cases, system characteristics had to be altered. (The DNA should be consulted for specific information on these results.)

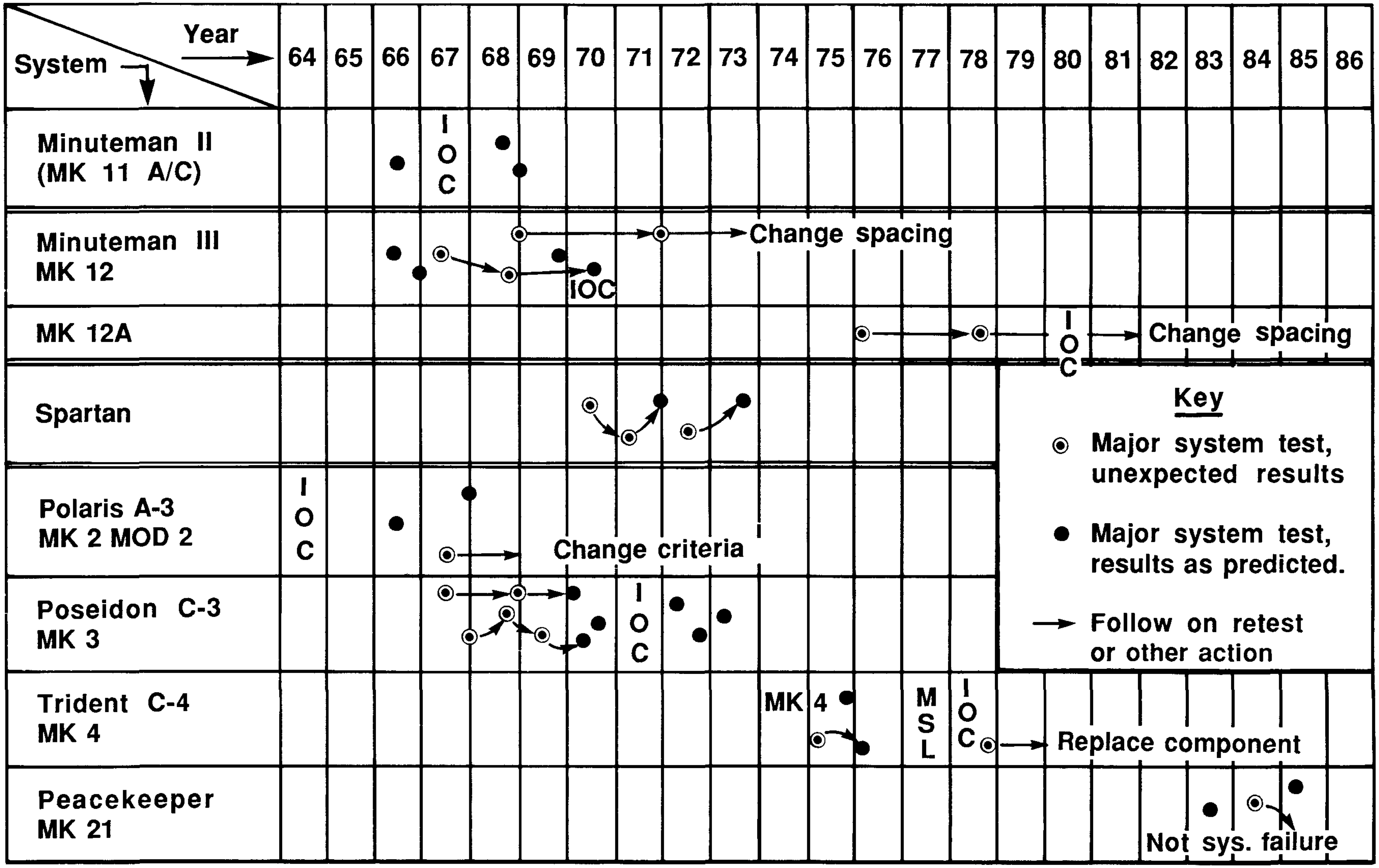

Figure 1. Results of underground nuclear tests of U.S. nuclear missile warheads. Note the number of tests in which results did not match predictions.

Chapter 3. Weapon Remanufacture

The issue of "replica" remanufacture is familiar to engineers in all major U.S. industries. Although tests of a complex system are expensive and time-consuming, one is hard-put to find an example anywhere in U.S. industry where a major production line was reopened and requalified without tests. We have discussed remanufacturing with many people experienced in materials research, aerospace, engineering, and private industry, as well as in nuclear weapon design and fabrication. The aerospace industry has many parallels to nuclear weapon development. Two particularly instructive cases are the Polaris A3 missile remanufacture and the proposed remanufacture of the Saturn V rocket. In both cases, we consulted with the responsible engineers—top people with firsthand experience and direct responsibility for remanufacturing a complex technology with hundreds of separate parts, each with its own special design and purpose. Their experiences are detailed in Appendix C.

The body of opinion from these experienced people can be summarized as follows:

- *Exact replication, especially of older systems, is impossible.* Material batches are never quite the same, some materials become unavailable, and equivalent materials are never exactly equivalent. "Improved" parts often have new, unexpected failure modes. Vendors go out of business or stop producing critical products. New health and safety regulations rule out previously used materials or processes. Different people—not those who did the initial work—do the remanufacturing.
- *Documentation has never been sufficiently exact to ensure replication.* A perfect specification has never yet been written. We have never known enough about every detail to specify everything that may be important. Even "perfect" specifications are changed many times after they are formulated and certified. Individuals in the production plants learn how to bridge the gaps in the specifications and to make things work. Even the most complete specifications must leave some things to the individual's common knowledge; it would be an infinite task to attempt to specify all products, processes, and everything involved in their manufacture and use. Experts believe that it would be extremely difficult to improve documentation enough to ensure replication by inexperienced personnel.
- *The most important aspect of any product certification is testing; it provides the data for valid certification.* A nuclear test provides our only data on the nuclear performance of the whole nuclear warhead package. Tests, even with the limitations of small numbers and possibly equivocal interpretation of results, are the final arbiters of the tradeoffs and judgments that have been made. We are concerned that, if responsible engineers and scientists were to refuse to certify a remanufactured weapon, pressures could produce individuals who would. The Challenger accident resulted from such a situation and highlights an all-too-common tendency of human nature to override judgment in favor of expediency.

Weapon Remanufacture and the Need for Experienced Personnel

Remanufacture of a nuclear warhead is often asserted to be a straightforward exercise in engineering and material science, and simply involves following well-established specifications to make identical copies. In the real world, however, there are many examples where weapon parts cannot be duplicated because of outmoded technologies, health hazards, unprofitable operations, out-of-business vendors, irreproducible materials, lack of documentation, and myriad other reasons. Every time we encounter such a problem in duplication, we have to rely on the experience of our weapon engineers, material scientists, and design physicists to carefully analyze and approve any deviations from the specifications.

When we find that a weapon cannot be manufactured precisely to its original specifications, someone has to determine "Does it really matter?" Only weapon designers, engineers, and material scientists *with nuclear test experience* are qualified to answer this question with any degree of confidence. Most of the changes made during remanufacture do not need to be certified in a nuclear test. It is usually sufficient to rely on nonnuclear tests and computer simulations, together with the judgments made by experienced scientists and engineers, to determine whether or not a change is acceptable. In some cases, nuclear tests have been required to certify a change, and most of these tests have been successful, determining that a change was satisfactory or revealing the need for further modifications. Hindsight shows that we could have avoided those nuclear tests that were successful, because they were successful. However, without these tests, we would not have had the confidence that the change was satisfactory and would not affect the performance of the remanufactured device.

Today, design physicists and engineers *with extensive nuclear test experience* at the relevant yield levels could undertake a weapon remanufacture with confidence that the weapon would perform about as well as the original version. However, even such a group has had difficulty in predicting the behavior of some weapons recently remanufactured for the stockpile. Not only must remanufacturing attempt to replicate the construction of the original weapon, it must also duplicate the performance of the original weapon.

Two aspects of our current weapon design process are primarily responsible for the success with which our designers are able to predict the performance of nuclear weapon designs, under the range of yields that are within our predictive capabilities. Both rely on experience. The first is the actual nuclear test experience of our present staff of designers, physicists, and engineers. The second is the critical review to which each new design or modification is subjected.

Because of the complexity of nuclear weapons and the limited rate at which they are tested, nuclear weapon design is largely an empirical science. Assessments of weapon performance—whether for stockpile inspection or remanufacture—depend on scientific judgment, and it takes years for designers to acquire the experience on which they base their scientific judgments. New designers must gather their knowledge and experience directly from nuclear tests and indirectly from the senior designers.

Currently, our nuclear test schedule is very limited, and it is taking longer for the newer designers to develop test-based experience. Thus the indirect route to experience is more important than ever, as younger designers take the output from their computer simulations and their interpretations of experimental results to test-seasoned senior designers for review and confirmation. This *continuity of experience* is indispensible.

Today, the first tests of a new design (most frequently a variation on a previously tested and certified design) are usually successful because our designers have the necessary experience to be able to build safe margins into the nuclear tests. It is when they incorporate engineering details or test at environmental extremes—necessary steps in turning a "device" into a weapon—that actual performance can fall short of predictions. If today, test-experienced personnel sometimes have difficulty predicting device performance or explaining unexpected behavior, how could a designer without actual nuclear test experience and without experienced coworkers to consult be able to design or modify a weapon with success or confidence?

We expect that, in the event of very restrictive test limits, in only a few years, we would start to lose our test-experienced people. They would leave to work on other, less restrictive, more productive projects. After a while, the people whose judgment had been honed by the realities of nuclear testing would no longer be available. We would then be faced with the prospect of asking scientists without nuclear testing experience to make judgments about the inevitable changes that will occur in remanufactured or stockpiled weapons.

Examples of the Need for Nuclear Testing in Remanufacture

When faced with the inevitable changes encountered in weapon remanufacture, the crucial question is "Will this change affect the weapon's performance?" A "yes" answer means that we must then determine how to fix the problem and if a nuclear test is needed to certify the fix. Experience plays a crucial role in these decisions. Here, we give a number of examples where changes did matter and where nuclear tests were needed. Some of these are actual weapon remanufactures, and others involve situations almost identical to what we might encounter in weapon remanufacture. Most of these examples involved stockpile problems and have been discussed in that light in Chapter 2.

Remanufacture of the W68 Poseidon Warhead

Routine stockpile surveillance revealed that the high explosive (HE) in the W68 was decomposing and the decomposition products were causing deterioration of the detonators. We judged that it was only a matter of time before the weapons would be inoperable. One "solution" would have been to rebuild the W68 warheads every five years, using the same type of HE that was decomposing. This would have been extremely costly and would have had a large operational impact on the U.S. Navy. Instead, we chose the more cost-effective and technically sound solution of replacing the deteriorating HE with a more chemically stable formulation; this HE had, in fact, already been tested in the W68 development program. This fix entailed a remanufacture of the W68.

The W68 was a critical part of the U.S. deterrent forces and the DOD was quite sensitive to the urgency of the changeout. Thus we judged that a nuclear test—a production verification test under simulated aged conditions—was necessary to certify the modified design to the Navy. We were surprised when the resulting yield was degraded beyond what we expected on the basis of the earlier test with the new HE. We knew that in addition to changing the HE, a number of other changes in warhead parts had been made during this remanufacture. For example, certain warhead materials had to be changed because the vendors of the originals had gone out of business. However, none of these other changes had been thought to be significant.

It is often argued that replacement materials can be stockpiled. One of the W68 materials that was no longer available was an organic material that had to be formulated at the time of use (much as epoxy cement available at any hardware store is formulated by mixing the contents from two different tubes). The raw materials used to make the final material for the W68 began to show significant changes after only two years of storage, even when refrigerated.

We have not yet been able to explain the cause of the yield degradation. Although the new HE was supposed to be the same as the material tested in the original W68 development program, there may have been subtle changes in its formulation. We do not know whether the yield degradation was caused by the new HE, by other part changes, or by some combination of changes. It is entirely possible that we might even have experienced yield degradation had we simply replicated the warhead with a fresh batch of the same chemically unstable HE. As discussed in Appendix D, we have experienced a number of problems in replicating HE.

Although the degraded yield of the W68 with the new HE was considered to be acceptable, it was necessary to modify the maintenance procedures and some conditions of the warhead's stockpile-to-target sequence. When the Navy asked for a relaxation of these procedures because of the large impact on their operations and associated costs, we emphasized the importance of following the procedures as specified. Our advice was significantly influenced by the unexpected result in the production verification test.

It is clear that the rebuilt W68 is different in substantial ways from the original. While some have stated that a production verification test of the rebuilt W68 was not necessary, we believe that the results show that the test was indeed necessary, both to certify the adequacy of the production rebuild and to enable us to provide accurate advice to the Navy on maintenance and operational procedures. The W68 production verification test is a definite example of the need for nuclear tests when remanufacturing a warhead.

Development vs Stockpile Versions of the W84 GLCM Warhead

The W84 experience illustrates the impact of seemingly small and insignificant changes that occurred as the development warhead was turned into the stockpile weapon. The types of changes are virtually idential to those that would be encountered in remanufacturing a warhead.

During the engineering of the W84 warhead, a number of small changes were made between the final development hardware and the production hardware. At the time they were made, each of these changes was judged to have no impact on warhead performance. When a stockpile confidence test was conducted on a unit that had been deployed for a year and modified slightly to simulate certain aged conditions, a lower-than-expected yield was obtained. We were concerned that this low yield was indicative of possible marginal operation of the device. Another nuclear test was necessary to evaluate the source of the yield degradation, to certify a fix to the problem, and to determine that there were indeed no problems with marginal operation.

Although the problem we experienced with the W84 has since been resolved, the experience we gained is directly relevant to remanufacturing a warhead. None of the seemingly minor changes made between the final development version and the production version, taken singly or together, can account for the observed yield degradation. Since we can account for the known changes in the specifications between the development and production versions, we conclude that we lack the necessary knowledge about what other things should have been specified. Evidently, we did not specify and control all the factors that mattered.

Only three years elapsed from the final yield certification test of the final development version of the W84 to the test of the production version (and less than two years from the tests of the development hardware at the high- and low-temperature extremes). Knowing that something significant changed in the fabrication process in this short time, we must wonder what sorts of changes might take place between now and some future time when a decision might be made to remanufacture the warhead. Until we learn the answer to this question, we believe that production verification nuclear tests will be needed to certify remanufactured warheads. In fact, if the production of a warhead extends over very many years, more than one production verification test may be advisable.

Sensitivity of Primary Performance to IHE Properties

The safety features of insensitive high explosive (IHE) are very important for the peacetime storage and transport of U.S. nuclear weapons. While IHE weapons are virtually impervious to accidental HE detonation under extreme conditions of shock, impact, and fire, there are manufacturing problems associated with this material that make it difficult to replicate from batch to batch.

In the early 1980s, an in-production warhead was fired in a nuclear test to determine the sensitivity of its IHE primary to certain environmental conditions. The effects of environmental conditions on IHE are of concern since the same properties that make IHE safe to accidental detonation also make it difficult to initiate detonation in actual use. In this nuclear test, the measured primary yield was 25% lower than expected. Extensive post-test analysis of the experiment revealed a number of possible causes of the primary yield reduction.

One possible cause involved the particle-size distribution of the specific IHE lot used to manufacture the weapon; some particle-size distributions make the IHE more difficult to initiate. A research program was begun to study the sensitivity of IHE initiation to various factors, including particle-size distribution. As a result of this research, the production specifications of the IHE were changed to ensure consistent detonation performance under all expected conditions. Had it not been for the nuclear test, the production specifications might have gone unchanged, with possible serious consequences for future weapon builds. It should be noted that the IHE batch used in the nuclear test had a particle-size distribution that was worse than in any of the units that had already been deployed; thus the already produced units were judged to be acceptable. The fact remains, however, that it was only in the nuclear test that the extent of the IHE's sensitivity to particle-size distribution was discovered, and only then could the necessary particle-size distribution specifications be implemented.

This example illustrates the variabilities possible in HE manufacture. Even with detailed specifications, it may be extremely difficult to produce consistent and reproducible batches of HE since many aspects of HE manufacture are as much an art as a science. Just as important, while we believe we know today what to specify, there may be some unspecified but important characteristic that we know nothing about.

In a future remanufacture, we would extensively check the HE components in nonnuclear experiments. We would estimate the effects on nuclear performance of any differences that might arise in behavior between the new and original systems. However, without a nuclear test to verify the magnitude of these effects, considerable uncertainty in performance could result.

New High Explosive for the W52 Sergeant Warhead

The redesign of the W52 warhead was a remanufacturing-like situation required for reasons of safety. In 1959, the W52 warhead was nearly ready for production when two explosive accidents occurred at LANL, killing six people. The explosions were due to the unexpected susceptibility to accidental detonation of the HE used in the W52 primary. Los Alamos scientists had to change the explosive used in the warhead to a safer and less sensitive explosive, which was also somewhat less energetic. This decision was made during the Nuclear Test Moratorium of 1958–1961, when the new design could not be verified in a nuclear test. The redesign was based on nonnuclear hydrodynamic tests and computer design calculations. Because of the high confidence that LANL scientists had in their redesign, they did not immediately test the W52 when the Moratorium ended in 1961. The W52 entered the stockpile in April 1962. When the device was finally tested, it gave only a fraction of its expected yield. The W52, as delivered, was militarily unacceptable. Los Alamos scientists made a rapid redesign; within three months of the test failure, they conducted a successful nuclear test of the new design, which was subsequently incorporated into the stockpile.

The W52 is an example of a weapon design that *had* to be changed because of safety reasons. Nonnuclear experiments and computer calculations were inadequate, and nuclear testing was essential to verify the design. Although this was not literally a weapon "remanufacture," it might well have been if the fatal accidents had occurred *after* deployment of the original W52. The W52 case also illustrates how pressures in the system can contribute to recertification, even though there should be reservations about doing so.

Problems with the W47 Polaris Warhead

Three problems were identified with the W47 warhead: corroding fissile material, vulnerability of a material to an ABM environment, and a defect in a mechanical safing device. Remanufacturing issues were associated with the second and third problems, and nuclear testing played a necessary role in correcting them.

A modified design was needed to correct the ABM vulnerability problem. The extent of the design modification was large enough to require a nuclear test to certify the change, and weapons were rebuilt with the modification.

A mechanical safing device was used in the W47 warhead to make it safe to one-point detonation. However, chemical corrosion in the W47 caused a serious reliability problem in the safing mechanism that did not lend itself to a viable engineering solution. In a large fraction of the sampled warheads, the mechanism would not fully complete its arming operation; this indicated that a large fraction of the W47 warheads would be duds, and the number of duds was increasing with age. Rather than remanufacture the warheads with rebuilt safing mechanisms that would fail again, we solved the problem by replacing the primary with one known to be inherently one-point safe. A nuclear test was required to certify this new design. All W47 warheads in the stockpile were retrofitted with the new primary.

Although these problems with the W47 did not involve exact replication of the warhead, they all involved dismantling warheads and rebuilding them with improvements. Each of the improvements was necessitated by serious unforeseen changes in vulnerability or reliability. The W47 illustrates that in order to maintain the capability of a weapon, exact replication may not be desirable or even possible.

Repackaging Warheads

It has been suggested that, in the event of future restrictive test limitations that preclude the design of new warheads, it would be possible to repackage existing warheads in new delivery systems. Note that repackaging is considerably different than remanufacturing. Repackaging would involve taking a warhead designed for one application (i.e., delivery vehicle and mission) and, without redesigning it, adapt it for another use.

U.S. warheads and delivery vehicles are tightly integrated into weapon systems; each warhead is optimized for its specific missile and each missile is optimized for its warhead. The warhead is designed to withstand conditions unique to the mission of the delivery vehicle, and thus is designed to meet specific targeting requirements, transportation environments, hostile (e.g., ABM intercept) environments, etc. It would be extremely imprudent to adapt an existing warhead to a new application without nuclear testing if the conditions of the new application are much different from the "as designed" environments.

If we cease nuclear testing, we would have to freeze certain aspects of the packaging system and significantly limit warhead options for new delivery systems. Such a limitation on future defense systems could prove to be extremely costly and inhibitive since changes in the warhead could cause major changes in the whole system. The overall effect would likely be one of increasing the effective warhead mass and volume. For example, we would need a stay-out zone between the warhead and certain missile components; we would not be able to qualify a new weapon electrical system (WES); we would have to freeze the electromagnetic pulse (EMP) specifications; and generally we would require more volume to repackage.

Historically, warheads and missiles have been designed as an integrated system, with features in one affecting or dictating features in the other. For example, in order to increase range and decrease cost, we have often designed our warheads on the margin in terms of the yield-to-weight ratio or other especially important military requirements. Our designers have worked to reduce the system weight (often by reducing the warhead dimensions) while maintaining warhead yield. This approach is very cost-effective in terms of delivery systems, enabling aircraft and submarines to carry more missiles. On the other hand, it has meant that our warheads are more complex and thus more dependent on nuclear testing. We have paid for this system integration and efficiency with a warhead complexity that has increased our reliance on nuclear tests for certification.

The priorities among competing military characteristics are not carved in stone; they change as new contingencies arise. For example, in recent years we have accepted a less-than-optimum yield-to-weight ratio in order to install

IHE and to reduce oralloy usage. Similar changes in priorities will certainly occur in the future; for example, successful development of a directed-energy weapon (DEW) by an adversary would force us to give high priority to a requirement for DEW-vulnerability protection.

It may indeed be possible to design a more "robust" nuclear warhead, as is discussed in Chapter 4. Such a device could be based on very conservative design practices and probably would be heavier and larger than its optimized modern counterpart. It would probably have a decreased yield-to-weight ratio; it would also have to provide for the required stay-out zones for electronics. Before these warheads could be incorporated into existing delivery systems, many of the systems would have to be redesigned and retrofitted—a time-consuming and extremely expensive undertaking.

Thus a freeze in packaging options, due to restrictive nuclear limitations, or a decrease in the yield-to-weight ratio, due to extremely conservative warhead designs, would lead to a need to reconfigure existing delivery systems to accept larger diameter warheads (assuming this would be possible; for many systems it is not), a probable increase in the total number of delivery systems, and possibly the development and production of new delivery systems. This situation calls to mind comments from Lockheed engineers about remanufacturing a rocket motor in the absence of testing—they might have been able to do it with a very conservative design, but the end product would not have fit into the existing submarine launch tubes!

The strategic balance often depends on our ability to make critical changes in missile configurations. Testing gives us the ability to certify efficient warheads in new configurations. Without testing, we foreclose on our options to make those changes.

Conclusion

When we examine the issue of remanufacture, our most important conclusion is that *test experience is vital.* Even with the limited nuclear testing permitted today (limited both in yield and in number of tests), the day-to-day decisions that must be made in the weapon production process can be handled, in large part, using the judgment of test-experienced scientists and engineers. This brings us face to face with a major concern when we consider remanufacturing nuclear warheads without testing. The experience base essential for making these decisions will deteriorate without testing, and yet, without testing, there will be an even greater need for these judgments. The end result will be a product—a nuclear weapon—with reduced credibility. The uncertainty in the warhead's performance (difficult or impossible to quantify without knowing the detailed nature of a possible problem) might become great enough that its deterrent value would be significantly reduced.

Our *current* test-experienced engineers and scientists could undertake a remanufacture with confidence that the weapon would perform about as well as the original weapon. However, experience has shown that, even now, we might have difficulty in matching earlier performance. It is difficult to be quantitative about how close we can come to exact replication since we cannot know the nature of future problems. Without nuclear certification tests of remanufactured weapons, there will undoubtedly be greater uncertainties. Perhaps, the uncertainties can be mitigated by more conservative designs or by more conservative operational limitations on the deployed weapons. Whether the resulting uncertainties in deterrent value are acceptable is a question for the policy-makers.

A major problem in remanufacturing a weapon is the available documentation. The documentation for older weapon systems is inadequate and many of the specifications are unknown. Documentation has improved since the military characteristic for replicability was established in 1982, and we now have significantly improved specifications for the more recent weapon systems. However, as we learned from the W68 and W84, the specifications for even these recent systems may be incomplete and we lack the knowledge to make them complete. While, in the future, it should be more feasible to remanufacture these modern weapon systems than the older systems, the uncertainties in performance of the remanufactured weapons could be significantly greater without nuclear certification tests and in the absence of design physicists and engineers with test experience.

It is important to emphasize that in weapon remanufacture we are dealing with a *practical* problem. Idealized proposals and statements that we "should be able to remanufacture without testing because expertise is not essential" are a prescription for failure.

Chapter 4. Preparing for Further Nuclear Test Limitations

It is difficult to predict when, if, or in what form we will see further limitations on nuclear testing. In the face of more restrictive test limits, the weapon laboratories would still be responsible for ensuring the reliability and effectiveness of U.S. nuclear weapons. Thus it behooves us to take the necessary steps now to prepare for such a situation. The technical impacts would be less severe if the limitations took effect gradually, in phase with other arms limitations and technology controls. The President has proposed such an approach to the Soviets. He has called for step-by-step progress toward further test limitations in parallel with major arms reductions, with the ultimate goal of a complete cessation of nuclear testing.

Since the 1958–1961 Nuclear Test Moratorium, we have been acutely aware of the potential impact of a Comprehensive Test Ban (CTB). On many occasions, the Laboratory has been requested by the U.S. government to assess the consequences of more restrictive test limits or a CTB.

What will be our ability to carry out our responsibilities if testing is severely limited? At the very least, these responsibilities would include ensuring the reliability of the existing stockpile, assessing changes in weapons caused by stockpile aging, overseeing corrections to potential problems, and evaluating the inclusion of previously designed weapons into new delivery systems. It appears likely that under restrictive test limits, many of these responsibilities could not be met with today's level of confidence. Upgrades and improvements, however minor or reasonable, would have to be carefully examined to ensure that they would not introduce unacceptable uncertainties.

In the earlier chapters of this report, we have discussed how changes in weapon design are dictated by safety and security considerations, use of new materials, new configurations, or new military requirements. Although not all of these changes must be certified in full-scale nuclear tests, they all rely on data obtained in nuclear tests and, most critically, on the judgment and insight that scientists and engineers acquire on the basis of such data. Depending on the specific test limits, experimental data from testing could be very limited or nonexistent. Thus the pool of experienced specialists would decline and the skills of those that remain would diminish.

Although we see no satisfactory way to solve the problems involved in meeting our responsibilities under a regime of very restrictive nuclear test limitations (e.g., a CTB or a very low yield threshold), we have identified several measures by which they may be mitigated. Measures we could employ *before* new test limitations go into effect include stockpile confidence tests of existing warheads, production verification tests of new weapons, developing backup warheads for various weapon systems, improving our understanding of weapon physics by nuclear and nonnuclear tests, finding ways to certify thermonuclear components at reduced yields, and designing weapons less likely to suffer material degradation or more suited to modification than current designs.

Other measures could continue *after* test limitations have gone into effect. These include acquiring more extensive nonnuclear experimental facilities, developing advanced supercomputers and numerical modeling capabilities, pursuing nonnuclear programs (e.g., advanced conventional munitions) that use many of the same skills as the current nuclear weapon program, and taking deliberate steps to maintain the capability to produce existing weapon designs.

We are pursuing all of these measures to the extent that funding and the military characteristics (MCs) allow. Our efforts in this area were recently attested to by the University of California Scientific and Academic Advisory Committee (SAAC); the findings of the committee are reported in Reference 2 and are summarized in Chapter 1.

The Augmented Nuclear Test Program

Laboratory programs in support of these measures were mapped out, more than five years ago, at the time of the Augmented Nuclear Test Program. In 1980, at the request of President Carter's Office of Science and Technology Policy and in response to a memorandum from the National Security Council, the Departments of Energy and Defense developed a plan for an Augmented Test Program (ATP) for underground nuclear testing. The ATP called for a 50% increase in the number of nuclear tests for the first two years, followed by an additional 25% increase in succeeding years. The purpose of the ATP was to "place the U.S. in a more sound national security posture." In addition, the ATP report stated that:

"The program places early emphasis on those areas of science and technology that contribute most to reliability and confidence of the stockpile.

In this regard, the program supports as a first priority CTB readiness objectives in the short term while continuing to provide for orderly reestablishment in the longer term of the nuclear science and technology base which is the bedrock of the U.S. nuclear deterrent."

The ATP set a high priority on the nuclear tests required to complete the current and projected military requirements. Plans were made for other nuclear tests to address the issues of alternative warheads, longevity, assessability, and reliability. Research was to continue on improving the safety and security of the stockpile and on assuring the survivability of U.S. systems exposed to nuclear weapon effects. In addition, a large fraction of the tests were to be devoted to enhancing our fundamental knowledge of nuclear weapon design physics.

The Office of Science and Technology Policy convened a panel (Solomon Buchsbaum, Harold Agnew, John Foster, Gerald Johnson, Carson Mark, Ernest Martinelli, and Wolfgang Panofsky) to review and provide input to the ATP plans. The Panel made the following observations:

"In general, the Panel is favorably impressed by most parts of the Program, in particular those parts that address fundamental nuclear design questions. It is important to remove the physics uncertainties in device designs, which are now compensated for empirically, so that designers can predict performance from first principles.

"In the absence of ability to test, confidence in the reliability of the stockpile ultimately rests on availability of people who are intimately knowledgable of the design of the warheads in the stockpile and who, on examining a particular warhead, can judge its capability to perform according to its design. A key objective of any expanded program should be to help retain a cadre of such people and attract new ones.

"The Panel agrees that the ATP as proposed would make an important contribution to increased confidence in the reliability of the U.S. nuclear weapon stockpile under a CTB. The ATP cannot, however, eliminate all concerns about stockpile reliability especially under a protracted CTB."

The Panel recommended a number of changes that were incorporated in the ATP plans. These included provisions to allow for more stockpile confidence tests of key systems, development of alternative warheads for important strategic systems, and a recommendation to improve our understanding of the performance of primaries. Accordingly, the ATP called for a series of boost physics experiments. Regarding alternative warheads, the ATP intended that alternative designs would be developed and placed "on the shelf" to provide backups to systems then under development. Such backups could be used if an unresolvable problem arose with the preferred warhead. In particular, the panel recommended the development of conventional high-explosive backups to primaries using insensitive high explosive (IHE), owing to the newness of IHE designs at that time.

What was the outcome of the ATP? President Carter approved the ATP in principle. Although he did not submit the ATP to Congress for their explicit approval, he requested and obtained additional funding for nuclear testing. President Reagan has continued to seek more funds for testing in his budget requests.

At the time the ATP was planned, we had already started to work on many of its suggested measures. Beginning in 1980, the weapon laboratories began to do more stockpile confidence tests. One such test that is now done regularly on new stockpile systems is a production verification test; in this test, a unit is brought back for a proof test after it has been exposed to field conditions for a short time. We have also tested a number of older systems. We recognized that more nuclear tests were needed for weapon physics research (described below). In addition, we instituted a boost physics research program, one of the specific ATP goals. Although we have fallen short of the goal of developing alternative or backup warheads for all important systems, some alternatives are available if an unresolvable problem arises with a particular warhead. For example, the Mk 12A/W78 conventional HE warhead could be used in place of the Mk 21/W87 IHE warhead for the Peacekeeper (MX) missile. The GLCM (W84), ALCM (W80), and Pershing II (W85) warheads might also be adapted to other systems if needed, although penalties in operational capability and military performance would probably be incurred.

Our weapon physics research and stockpile confidence tests are continuing, but not under the name of the ATP. The redirection of effort to nuclear-driven directed-energy weapon (NDEW) programs for the Strategic Defense Initiative (SDI) has absorbed most of our additional nuclear testing resources for the last seven years. We cannot simultaneously sustain high levels of research on SDI and on weapon physics with the current funding levels. Although we have accomplished much, because of limited funding, only a fraction of the goals set by the ATP in 1980 have been met.

It would be advisable to institute an ATP. As part of our five-year planning of nuclear test activity, we have detailed additional testing along these lines, including several tests relevant to stockpile confidence at lower yield thresholds. If a new ATP is to be successful and avoid the fate of its predecessor, a future ATP will require Congressional endorsement and adequate sustained support will be imperative.

Laboratory Efforts to Prepare for Further Test Limitations

We are already taking steps to prepare for future limits on nuclear testing and have identified a number of ways in which these measures could be enhanced.

Weapon Physics Experiments

We regularly conduct weapon physics experiments as part of nuclear tests fielded for other purposes. Since 1981, one or two additional nuclear tests have been dedicated specifically to weapon physics research under the heading of "fundamentals of reliability." The knowledge gained from these tests has already been used to develop more conservative and more reliable designs. We have improved our understanding of the boosting process, reduced the uncertainties involved in thermonuclear energy production, and enlarged our knowledge of aspects of radiation hydrodynamics. However, we still have a long way to go before our understanding of these complex physics processes is complete enough to substantially reduce our dependence on nuclear testing. In recent years, as a result of programmatic requirements for NDEW research, we have had to scale back on the number of dedicated weapon physics tests. There is also a limit to how rapidly the results of weapon physics experiments can be interpreted and computational models developed or modified as theory and experiment are integrated.

Weapon physics experiments are also done at our nonnuclear and high-explosives experimental facilities. With the Nova laser, we have measured the x-ray opacity in materials, providing the first laboratory-gathered data crucial to thermonuclear design. With the Flash X-Ray facility, we are exploiting recent advances in radiography and ultrafast (10-nanosecond) photography to take pictures of spallation from explosively driven metal shells characteristic of fission triggers. We are also constructing the High-Explosives Applications Facility (HEAF), with which we will investigate the nonideal properties of insensitive high explosives and to characterize more completely the safety of "ideal" (but sensitive) explosives.

An important commentary on our weapon physics research was provided by the SAAC as they examined the role of these tests in the resolution of problems encountered with stockpile weapons:

> "It is evident from the results of these physics tests that they have contributed to a better general understanding of this technology. ... the increased number of weapons physics tests since 1981 has both helped to identify these problems and has contributed to an understanding that will be instrumental in reducing their number in the future."

With continued research in weapon physics, we should be able to improve our understanding even further. This would allow us to place less reliance on nuclear testing for the identification, evaluation, and resolution of physics problems. Recently, however, the DOE has submitted budgets to Congress with *decreased* funding for "core" testing (i.e., tests other than for NDEW research). This will seriously reduce the level of our research effort into the "fundamentals of reliability."

Advanced Nonnuclear Experimental Facilities

We are continually searching for nonnuclear experimental facilities that could come close to duplicating the conditions created in a nuclear test. The various existing nonnuclear experimental facilities and the facilities envisioned for the future do not come close enough to simulating the conditions in a nuclear explosion and thus could not take the place of nuclear testing. They can, however, provide valuable weapon physics data, help experimenters maintain some level of relevant skills, and provide a test bed for designers to verify some theoretical aspects of weapon physics. This might enable us to maintain a certain level of nuclear weapon expertise, but such facilities might also have a lulling effect on our capabilities. Focusing attention on areas only partially relevant to nuclear weapons could lead to errors in judgment about actual nuclear design matters.

Major extensions of existing nonnuclear facilities would be required to enhance our capabilities in nonnuclear testing. For example, a High-Gain Test Facility (HGTF), using a multimegajoule laser for research on inertial confinement fusion (ICF), would provide more intense conditions than are available with the Nova facility. The HGTF would allow us to make studies on 1000-MJ ICF capsules.

The conditions produced at such yields would be relevant to some aspects of nuclear weapons design and diagnostics and would provide a source for some tests on military vulnerability, lethality, and exposure. However, many aspects of the physical performance of nuclear weapons (e.g., the behavior of fission primaries) could not be addressed by the HGTF.

Enhancements in the capabilities of the above-mentioned FXR facility at Site 300 would be valuable. Advances in accelerator technology leading to higher x-ray intensities would provide the improved resolution needed to explore the late-time implosion behavior of primaries. Progress in acquiring such improved or new facilities is very much limited by available funding.

Low-Yield Fission Explosions

A CTB might be configured to allow very-low-yield fission explosions, below the verification threshold. These explosions would have some value for maintaining minimal experience with fission weapons but they would be of little help in resolving stockpile problems.

We have conducted a preliminary study of the role of low-yield nuclear tests (under 100 tons total yield) in maintaining a nuclear design capability. We attempted to identify what nuclear explosives technologies could be maintained under such a highly restrictive limit and what weapon physics experiments could be performed that would contribute to our understanding of higher-yield weapons. The report of the results of this study is classified; an unclassified version is available, although it lacks much of the technical reasoning and detail presented in the full report.

We reached several conclusions about the impact of a very-low-yield nuclear test threshold. We concluded that tests at low yields add little or nothing at all to our confidence in the performance of nuclear weapons systems. Neither do they contribute significantly to the maintenance of the essential, critical design skills relevant to today's stockpile. The reason for this is that stockpile devices use a number of different physical processes to achieve their yield, and some of these processes cannot be simulated at very low yields. We did identify several weapon physics experiments that would add to our technology base for understanding the general operation of nuclear explosives and could be conducted at low yields.

One of the most critical aspects of a low-yield test limit or a CTB would be the difficulty in training new weapon designers and engineering personnel and in maintaining the competence of the existing staff in technologies relevant to the existing stockpile. During an extended absence from nuclear testing at relevant yields, we would expect an inexorable deterioration of our understanding of the nuclear weapon stockpile.

Advanced Computational Capability

The Laboratory continues to acquire the most advanced supercomputers available. The Livermore Computer Center currently has two CDC 7600 computers, four Cray-1 computers, a Cray-XMP/48, and a Cray-XMP/416. We devote much research to developing improved computational methods to take full advantage of the advanced computer architectures and to improve the accuracy of the physics models in our weapon design codes. We have made large gains over the years in our ability to model nuclear explosions, but we are still far from being able to give up our reliance on nuclear tests. In fact, historically, computational modeling has been intended to supplement nuclear tests, not eliminate them.

The cost of modern computers is high enough that equipment funding of the national laboratories limits the acquisition of a new mainframe replacement to one every two years. This is not rapid enough to enable us to make the potential gains inherent in advanced computational capability.

Certifying Nuclear Components at Reduced Yields

We have been studying the possibility of certifying the full-scale yield of weapons at test yields below 150 kt. The fundamental issues are whether devices with large quantities of inert materials will produce diagnostic data that are representative of the full-yield device, and whether we can extrapolate, with confidence, the full-scale yields from small fractional yields. Computational studies indicate that often-suggested thresholds below 15 kt are inadequate for full certification. We are investigating the adequacy of thresholds at and above 15 kt. Preliminary analytical results, yet to be confirmed by experiments, indicate that yields beyond 15 kt are needed to provide definitive data from largely inert secondaries. Our research to date indicates that it would not be possible to certify new-type, high-yield thermonuclear devices at any of these reduced test yields. Also, these levels would not enable us to determine full yields to the accuracy now available.

We are investigating what can be learned about the boosting process at low test yields. Our experimental data in this area are extremely limited. More nuclear tests are needed before we can determine the value of low-yield testing to studies of the very complex boosting processes present in current primaries.

Reduced-yield studies are vitally important, and we are planning several nuclear tests as part of this research. The rate at which we do these experiments is limited by the funding available for our core programs.

Nonnuclear Weapon Programs

During a CTB, work on advanced conventional munitions would help to maintain some of the skills relevant to primaries. These munitions use many of the same technologies—in particular, hydrodynamics, materials science, high-explosive chemistry, and high-speed diagnostics—that are required in the development of the fission triggers for nuclear weapons. We have sought a stable, block-funded program in conventional munitions and, most recently, a joint DOE-DOD-funded Energetic Materials Center (for the study of explosives and rocket propellants). DOD funding cutbacks in the 6.2 category have limited the former program and precluded the latter.

The ICF program uses skills relevant to the physics of secondaries. When ICF capsules are imploded, much of the same physics is involved as in secondaries (e.g., radiation hydrodynamics, thermonuclear reactions, radiation opacities, and hydrodynamic instabilities), albeit on a much smaller scale. While physics skills may be exercised in such ICF studies, the development of nuclear weapons and the solution of stockpile reliability problems require full-scale nuclear tests. Although ICF capsules involve much of the physics of secondaries, an examination of the prospects for achieving ICF has forced us to conclude that even though ICF is both technically interesting and challenging, it does not address many critical issues of weapons design and thus would not be adequate to enable us to maintain a competent nuclear design capability during a protracted nuclear test ban.

There are some nonnuclear programs that exercise skills relevant to NDEW research. The ICF facilities can be used in such research. In fact, the Nova laser is currently being used in the laboratory x-ray laser program. Some laboratory research is also possible on microwave weapons.

We must emphasize that the role of these nonnuclear programs is quite limited. They can be used to help maintain some relevant physics skills but they cannot be used to solve weapon problems. They can help to slow the erosion of capability but they cannot stop it. Unless these programs have an important national mission, they will not attract the top people. Even with very limited nuclear testing and with generous funding for nonnuclear facilities, it will be hard to get and keep top people. Expertise on real weapon problems will decline, and depending on the allowed level of testing, personnel knowledgable about nuclear test operations and diagnostics will leave.

Another major concern is that weapon physics draws heavily on such basic scientific disciplines as atomic physics and the theory of hot dense plasmas. The research base in the U.S. in these area is almost nonexistent. In contrast, these subjects are strongly emphasized in foreign countries, especially the in Soviet Union. For example, there are no Assistant Professors of Atomic Physics Theory in the U.S. It will take many years and tens of millions of dollars for university research facilities to redress this problem. Since the Mansfield amendment disallowed DOD's application of 6.1 funds, atomic physics has not had a principal sponsor among the federal agencies. We suggest that the DOE establish a Division of Atomic and Dense Plasma Physics to parallel the Division of Nuclear and Particle Physics.

"More Robust" Weapons

We could design and manufacture weapons that are less likely to suffer degradation with time. However, because of the configuration of the present stockpile and delivery systems and because we cannot anticipate what problems will develop, this would be an expensive and difficult undertaking. For example, larger primaries containing more nuclear material are seen by some as less demanding and more robust. Since we often cannot judge ahead of time which components will degrade, we still could not make absolute guarantees about the longevity or durability of these "more robust" weapons. The addition of 10% more high explosive or more fissionable material might provide some assurance against the effects of minor deterioration in the future; however, this would not have prevented some of the problems encountered in the past.

For any of these changes to be incorporated in U.S. nuclear weapons, the MCs would have to be changed. If they are changed, we might be forced to give up improvements in weapon technology that provide increased safety, security, survivability, and military effectiveness. Without carefully studying each proposed new weapon system, we could not know what specific technological improvements would have to be sacrificed in any one system. For example, while unlikely, we might forego the use of IHE in favor of conventional high explosive, since IHE is more difficult to initiate and thus potentially more sensitive to some stockpile aging effects.

The size and weight of the warheads might also be increased. We have learned from experience that larger systems are less sensitive to small design changes and, for this reason, would be expected to be less prone to some effects of stockpile aging. The increased size and weight of the warhead could also generate the need for larger missile systems. Adapting DOD delivery systems to the available DOE warheads, rather than optimizing the warheads for the delivery systems, is likely to increase overall weapon systems costs substantially.

Similarly, the more nuclear material, such as plutonium and tritium, that a weapon contains, the more robust it normally is to parametric changes and consequently to some of the effects of stockpile aging. A thorough study would be required to account for the increased nuclear material needs of more robust designs and to determine whether the production reactors can meet these needs in a timely manner.

Other improvements that might be relinquished in an attempt to make weapons more robust include certain built-in security features and structural features required for specialized missions. For example, the construction features that allow earth penetrator weapons, artillery shells, and laydown bombs to withstand extremely high accelerations and decelerations can affect the operation of the nuclear warhead and could be the source of uncertainty in the event of a stockpile aging problem. Thus we might have to forego the development and deployment of systems that depend on these features for their effectiveness.

A more detailed description of the nuclear design changes that might be involved and the military capabilities that might have to be relinquished in order to develop more robust warheads has been requested by the Senate Armed Services Committee (SASC) in the FY 1988 Defense Authorization Bill. This study would direct the DOE to examine the feasibility of reduced reliance on underground nuclear testing (Appendix E). If it is decided that further nuclear test limits are a desirable goal, we believe that the approach suggested in the SASC language is the correct one. Rather than making assertions about what can be accomplished under more restrictive test limits, the SASC language poses questions that must be answered before agreeing to additional testing limits. We certainly are not ready today for significantly reduced limits, and a thorough preparation and investigation, including nuclear tests, is needed before this country commits to a new regime of greatly increased test restrictions.

Enhancing Our Ability to Remanufacture Weapons

We are placing major emphasis on 25-year objectives, materials compatibility, and engineering durability in order to maintain the capability to remanufacture weapons. At the government's request, we have already judged it acceptable to extend the lifetimes of a number of systems in the stockpile. Although we rigidly document production procedures and materials, there is no guarantee that remanufacturing will be easy; indeed, there is ample evidence to the contrary (see Chapter 3 and Appendix D).

Continued Production at Low Rates

Production of weapons could be continued at low rates. It would be quite expensive to do this, since we would have to maintain a complete manufacturing infrastructure for each weapon (of which there are currently 28 types), even though the build rates would be small. A very high premium might have to be paid to keep small vendors involved in the process. Tremendous loads would be placed on existing production facilities, and extra facilities might have to be built.

It is also not clear that continuing production will indeed maintain capabilities. Consider, for example, the W68 Poseidon warhead. During the very early production of the W68 at the Burlington AEC (Atomic Energy Commission) plant the quality of the product was very high. As the build rate increased and new assembly people were brought into the program, the quality dropped to an unacceptably low level. To correct this problem, production had to be stopped and the new operators educated in both procedure and design intent (i.e., operation of the warhead) by the experienced engineering team responsible for overseeing the production.

Maintaining Critical Processes

It has been suggested that we maintain certain critical processes, manufacturing technologies, and production plants on a stand-by status in the event that remanufacturing becomes a necessity. This might be accomplished for a few high-priority systems and selected technologies. The risk is that we will preserve unneeded technologies and ignore the critical ones. We would have to deal with the problems of maintaining a highly trained, knowledgable cadre who would not be doing anything "productive." In addition, the processes and technologies would have to be continuously monitored to make sure that they did not change with time, either through lack of attention from a potentially bored staff or, conversely, through their creative efforts to "improve" the processes and product.

Improved Documentation

A major problem in remanufacturing a weapon is the documentation. The documentation of older weapon systems is inadequate, and many of the specifications are unknown. Documentation has improved since 1982 when the DOD added an MC for warhead endurance and replicability, in which these features are stated to be *desirable* goals consistent with meeting the other MCs:

"It is desired that the warhead have an inherent endurance obtained as a result of design considerations that address: a maximum warhead lifetime, maximizing the ability to replicate the warhead at a future date, and maximizing the ability to incorporate this warhead in other weapon delivery systems. Therefore, the design, development, and production of the warhead must be well documented and involve processes that to the extent possible allow replication at a future date."

Since then, we have significantly improved the documentation and specifications for the more recent systems that have gone into the stockpile. However, as experience with the W68 and W84 revealed (see Chapter 3), the specifications for even the more recent systems may be incomplete and we lack the knowledge to make them complete. While the improved documentation should make it more feasible to remanufacture modern weapon systems in the future, the uncertainties in performance of the remanufactured weapons could be great in the absence of nuclear certification tests and without test-experienced design physicists and engineers.

Today, we are providing adequate documentation for our current job-shop methods of weapon development, production, and stockpile surveillance. Current and past documentation is not and never was intended to cover the possibility of *inexperienced* personnel attempting a weapon remanufacture. We could prepare still more detailed specifications and documentation, given substantially increased resources. However, the experts with practical remanufacturing experience in both the weapons complex and private industry warn that there is a practical limit to the level of detail that can be included in production specifications.

Stockpiling Materials

It has been suggested that weapon materials be stockpiled for possible future rebuilds. Indeed, this can be and is being done for some materials. Appendix D gives examples of the problems we have already faced with replicating batches of high explosive, procuring metals with the right mechanical or chemical property, locating a source of a material with the required uniformity and strength, and discovering that materials have become obsolete for reasons of economy or because of new health and safety standards. Many of the materials used in *existing* weapons—materials that are critical to the correct functioning of the weapons—would take much effort and expense (and testing) to replicate, and we would have to solve the problems of replicating the material before it could be stockpiled.

Stockpiling large amounts of weapon materials would be expensive and, in some cases, would require special handling of hazardous materials. The availability of safe and secure storage space is already limited, as are the funds required to operate the production plants. Even assuming that we can stockpile a given material to replace identical material that has aged in a weapon, there is no guarantee that the stored material will be in better shape than the aged material in the weapon. Therefore, although stockpiling materials may seem to be an ideal solution to the problem of remanufacturing a weapon, it may actually be more practical and effective to remake the material or to find a suitable substitute at the time we need it. This will of course require testing, possibly even a nuclear test. In fact, a substitute material that will age well is likely to be preferred over a material that has aged badly if, through proper testing, we can demonstrate that the substitute is satisfactory.

Conclusion

The Laboratory is committed to fully meeting its responsibilities for ensuring the reliability and effectiveness of U.S. nuclear weapons both today and in the event of future, more restrictive limitations on nuclear testing. We have identified and are already taking a number of steps to prepare for more restrictive test limitations. We are continually seeking new and better ways to preserve the nuclear weapon expertise and judgment so critical to meeting our responsibilities. Until we accomplish this, it would be imprudent to agree to further limitations and restrictions on nuclear testing.

Acknowledgments

Many expert scientists and engineers were consulted in the preparation of this report. Certain sections of the report were written by Herman Leider and Charles Wraith of Lawrence Livermore National Laboratory (LLNL). Particularly valuable input came from John Immele, Eugene Burke, William Zagotta, Steve Younger, Bill Inouye, and Warren Heckrotte of LLNL, and David Watkins, Don Westervelt, Delmar Bergen, and Robert Osborne of Los Alamos National Laboratory (LANL). Some sections of the report were adapted from draft material written by Don Westervelt of LANL. We thank the Strategic Systems Program Office of the U.S. Navy for allowing us to include the information on the experience of the Lockheed Missiles and Space Company on the remanufacture of the Polaris A3 missile. We also thank the many weapon designers, engineers, physicists, materials scientists, and technical managers at LLNL and LANL who provided their expert opinions in numerous discussions and manuscript reviews. We particularly want to thank Lauren de Vore for her expert editing and for providing valuable suggestions for this manuscript.

References

1. R. D. Woodruff, Testimony Before the Subcommittee on Arms Control and Disarmament, Armed Services Committee, U.S. House of Representatives (September 20, 1985); also, R. N. Thorn, testimony on same date.
2. The Scientific and Academic Advisory Committee; Lew Allen, E. L. Goldwasser, A. J. Goodpaster, A. K. Kerman, M. B. Maple, K. McKay, W. G. McMillan, F. Reines, H. F. York, and R. E. Vogt, *Nuclear Weapons Tests: The Role of the University of California-Department of Energy Laboratories, A Report to the President and the Regents of the University of California* (July 1987).
3. Robert S. McNamara, *Blundering into Disaster, Surviving the First Century of the Nuclear Age* (Pantheon Books, New York, 1986).
4. See for example, Secretary of Defense Harold Brown's Posture Statements, *Department of Defense Annual Report, FY 1979 and FY 1980.*
5. Harold Brown, *Report of the Secretary of Defense to the Congress on the FY 1982 Budget* (January 19, 1981).
6. State Department Special Report regarding U.S. Policy Regarding Limitations in Nuclear Testing (August 1986).

Appendix A. Letter from Congressmen L. Aspin, N. D. Dicks, D. B. Fascell, E. J. Markey, J. M. Spratt, and Senator E. M. Kennedy to Director Roger Batzel, dated March 30, 1987.

This page intentionally left blank

Congreſs of the United States
Washington, DC 20515

March 30, 1987

Dr. Roger Batzel
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94500

Dear Dr. Batzel:

As you are aware, in recent months Administration officials have argued that the United States should not negotiate a Comprehensive Test Ban Treaty with the Soviet Union because such an agreement would prevent us from conducting explosive reliability or "proof" tests of existing nuclear warheads.

One of the key technical questions that has to be answered in assessing the validity of this argument is whether it is possible to assure the reliability of the existing nuclear stockpile through non-nuclear explosive testing and remanufacture of new warheads using the original design and product specifications of existing, thoroughly tested warheads.

It has been argued that previous examples of problems with stockpile reliability indicate that nuclear explosive testing will continue to be necessary in order to identify and correct stockpile problems. Examples of such stockpile problems have been cited in a number of unclassified and classified documents, as follows:

1. Jack W. Rosengren, <u>Some Little-Publicized Difficulties with a Nuclear Freeze,</u> R&D Associates. Report RDA-TR-122116-001, October, 1983. (Unclassified)

2. Jack W. Rosengren, <u>Reliability of the Nuclear Stockpile under a CTB.</u> R&D Associates. RDA-TR-122100-001-Rev. 1, December 1982. (Secret/Restricted Data)

3. Jack W. Rosengren, <u>Stockpile Reliability and Nuclear Test Bans: A Reply to a Critic's Comments.</u> R&D Associates. Report RDA-TR-138522-001, November, 1986 (Unclassified)

3. Dr. Roger Batzel, <u>Classified Addendum</u>. Submitted into record of the September 18, 1985 Hearing of the Special Panel on Arms Control and Disarmament of the Procurement and Nuclear Systems Subcommittee of the House Armed Services Committee. (Secret/Restricted Data)

4. Admiral Sylvester R. Foley, Jr. Assistant Secretary for Defense Programs, Department of Energy. Answers to questions asked in Congressman Edward J. Markey's letter of April 17, 1986. (Secret/Restricted Data)

As we will be considering nuclear testing legislation this session, we wish to have an independent and comprehensive technical review of the information that has been made available to the Congress on the reliability issue. We wish Dr. Ray Kidder of the

Lawrence Livermore National Laboratory to prepare such a technical review.

While our request may on the surface appear somewhat unusual, in the past Congress has often relied on the special technical and scientific expertise of employees of the national laboratories to provide advice on nuclear weapons issues. The House Armed Services Committee, for example, has made special note of this fact on a number of occasions. In its report on the FY86 DOE Authorization Bill, the Committee noted that it did not want the Congress to be "isolate(d)...from the technical and scientific advice of experts employed by contractors carrying out DOE defense programs." In its report on the FY87 DOD Authorization, the Committee indicated that it had never been the "intention of the Congress that the employees of the Department of Energy national laboratories should be discouraged from responding to oral or written inquries from Members of Congress or the chairman, the ranking minority member, or a member of the staff of the appropriate committees."

It is our understanding that Dr. Kidder has been involved in the preparation of classified technical reviews of a number of on-going nuclear weapons programs. We also understand that Dr. Kidder has previously prepared short analyses of both the unclassified Rosengren Report (UCID-20804) and the Classified Addendum you submitted to the House Armed Services Committee. But these analyses do not cover all of the examples (or all of the issues) that have been raised in the other documents we have mentioned. For this reason, we would like Dr. Kidder to carefully review all of the aforementioned documents and prepare for us a comprehensive report (in both classified and unclassified form) which addresses the issue of whether past warhead reliability problems demonstrate that nuclear explosive testing is needed to identify or to correct stockpile reliability, or alternatively, whether a program of stockpile inspection, non-nuclear testing, and remanufacture would be sufficient to deal with stockpile reliability problems.

We would therefore appreciate your cooperation in making the above-mentioned materials available to Dr. Kidder and making arrangements for the prompt transmittal of his analysis to us upon its completion.

With best wishes,

Sincerely,

Edward J. Markey

Edward J. Markey, M.C.

Les Aspin

Les Aspin, M.C.

Norm Dicks

Norman D. Dicks, M.C.

Ted Kennedy

Edward M. Kennedy, U.S.S.

John Spratt

John M. Spratt, M.C.

Dante Fascell

Dante B. Fascell, M.C.

Appendix B. Letter from Director Roger Batzel to Congressman L. Aspin, dated April 17, 1987.

This page intentionally left blank

April 17, 1987

The Honorable Les Aspin
U.S. House of Representatives
1118 Longworth House Office Building
Washington, D.C. 20515

Dear Congressman Aspin:

You have asked that the Laboratory make available Dr. Ray Kidder to prepare a comprehensive report which addresses the issue of whether past warhead reliability problems demonstrate that nuclear explosive testing is needed to identify or to correct stockpile reliability, or alternatively, whether a program of stockpile inspection, non-nuclear testing, and remanufacture would be sufficient to deal with stockpile reliability problems. While it is indeed unusual that we are asked to make available a particular Laboratory staff member for a particular, independent study, we will honor your request if he wishes to perform this review. Of course, stockpile reliability is only one of many reasons why nuclear testing is necessary.

Dr. Ray Kidder has available to him the technical information he should need to analyze this question and has been encouraged by Laboratory staff members to become informed, as this subject is not one on which Dr. Kidder has had extensive experience. The Laboratory will cooperate in making materials available to him for the review you have requested. With respect to Reference 4 in your letter of March 30, 1987, that is material which was provided to the House Armed Services Committee in response to Mr. Markey's questions by Admiral Foley, and Dr. Kidder will need to obtain that from him. He is, of course, free to reply to your inquiry both in classified and unclassified form, and may submit his findings to you at any time that he feels he has finished his analysis.

Dr. Kidder is a respected theoretical physicist at the Laboratory with considerable experience in several of the Laboratory's programs. However, he has not had recent, direct responsibility or experience as a nuclear weapons designer, nor experience in the weaponization of nuclear weapon systems, nor responsibility for evaluating the reliability of stockpiled nuclear systems or the problems that can arise therein.

In order to provide the Congress with the technical information it should have, I have asked Dr. George H. Miller, Associate Director for Defense Systems, to provide you with a separate analysis of the issues which you have raised. In his position at the Laboratory, Dr. Miller has direct responsibility for all nuclear weapons activities, including stockpile reliability, maintenance and manufacturing issues which arise in the DOE production complex. Dr. Miller and his staff have the experience base to make the necessary judgements and can provide you with background and details on all of the many aspects of this important question.

By identical copy of this letter, I am responding to Senator Kennedy and the other Members of Congress who were cosigners with you of your letter.

Sincerely,

Roger Batzel

Roger E. Batzel
Director

Appendix C. The Polaris A3 and the Saturn V Remanufacture Experiences

The difficulties involved in "replica" remanufacture have been faced by all major U.S. industries—aerospace, automobile, chemical and materials, and engineering, as well as nuclear weapons. The aerospace industry has many parallels with nuclear weapon development and production. The Polaris A3 missile remanufacture and the proposed remanufacture of the Saturn V rocket illustrate the difficulties encountered when attempting to remanufacture technologically complex systems.

The U.S. Navy Polaris A3 Experience

In 1982, the U.S. Navy's Strategic Systems Program Office (SSPO) contracted with Lockheed, on behalf of the United Kingdom, to do a "replica" rebuild of the Polaris A3 first- and second-stage rocket motors. These motors were designed and built in the 1960s for the U.S. and U.K. programs by Aerojet and Hercules, respectively; production of these motors ceased 19 years ago. To minimize technical risks, the U.K. requested the rebuild to be as close a replica of the first build as possible. The intent was to maximize assurance that the same reliability and performance of the original motors would be achieved, and at the same time provide the most expedient means of providing replacement motors. Time was critical; the U.K. needed more assets on a short time scale, and wanted to maintain their deterrence credibility throughout. The U.K. Polaris SLBMs are scheduled to remain deployed until the late 1990s.

Recently, we visited Lockheed, the prime contractor for the rebuild program, to learn more about this remanufacturing effort, and talked with personnel who had been involved with the A3 moror remanufacture program. Some of their observations and commentaries are described below.

The motor rebuilds were successfully accomplished by Aerojet and Hercules, but only with an extensive test program. It was found that true replication is impossible to achieve, because (a) "same" materials are frequently not the same, sometimes in unknown ways, (b) "equivalent" materials seldom are equivalent, sometimes in unknown ways, (c) "better" parts often introduce new failure modes, sometimes undetected, and (d) documentation, however rigorous, sometimes is not adequate to reproduce actual on-the-job operations. Because of these problems with replication, a successful rebuild of the A3 motors required extensive testing, including full-scale motor tests at NWC/China Lake and flight demonstration tests on the Eastern Test Range.

This was a true replication attempt. One of the precepts was not to change the original design unless it was absolutely necessary and the change could be shown to have no adverse influences on the performance of the new motors. The motor subcontractors tried to exactly duplicate the history of the original build, including all the documented design alterations approved since completion of the original build program.

In an effort of this magnitude and complexity, a great deal of lower level testing can be performed to determine material properties and to approximate performance characteristics. However, it is not until full-scale tests of the complete rocket motors are performed that an evaluation of the "all-up" configuration is possible. Specific points to illustrate this follow.

Material Replication

Original supplier unavailability required qualifying an alternate source. There were some surprises, however. A case in point was the first-stage rocket motor chamber insulator material. Material from the original source was no longer available and a material from an alternate source was selected. This material met the original specification requirements, but when it was used in a full-scale motor, a significantly different (more rapid) erosion rate occurred. A design change was required (increased insulator thickness) to achieve acceptable motor chamber insulation. This is perhaps the best example to illustrate the need for full-scale testing of the remanufactured motors. Had this not been discovered following the rocket motor test firing, it could have resulted in motors being produced with a performance weakness that could have manifested itself in a similar manner to the problem experienced in the aged motors being replaced.

One of the aluminum forgings used was Alcoa 7075-T6. It was the "same" alloy as used in the original manufacture according to Alcoa. In the interim, however, due to Alcoa facility changes and process improvements, the time from forging to quench had changed significantly. This resulted in forgings with higher internal stress characteristics, causing cracks in the forgings and subsequent rejections when the forgings were machined into adapters. Although this problem was identified and corrected at the component level, it illustrates the type of problem that can occur in a replica program from a subtle process change.

Documentation

The problem with materials specifications was that, in some cases, the engineers needed a parametric performance specification as well, and this is usually not available. A full parametric evaluation of specification allowables is needed for a fully adequate "how to" specification. This would have to be achieved from numerous and expensive tests. Simply tightening tolerances does not control the product sufficiently, and makes processing more difficult.

Procedures

Management's major concerns were the following: documentation, tooling and facilities, materials, suppliers, safety requirements, reacquiring experienced personnel, and adverse effects of changes, both direct and synergistic, immediate and long range. Procedurally, a review board was set up to pass on any changes. It was composed of U.S. government, Lockheed, and vendor representatives. The board's charter was to fully scrutinize any proposed changes and only pass those that were mandated by safety, tooling or facility changes, or material unavailability. Still, some propsed changes that were approved had to eventually be revised as a result of subsequent processing and testing experiences.

Testing

Each approved change required some level of testing/evaluation. One cannot look only at what has been changed; the whole system must be retested because of synergism. Full-up flight tests were needed to determine if the design and performance requirements were met. There is a difference between what can be learned from static tests and what can be learned from flight tests. They needed them both. Most experienced and knowledgable engineers would refuse to certify without testing. They view flight-test data as necessarily representative to provide true replica certification; the test program provides the major indicators for areas of concern.

In addition to the full-scale motor firings of units selected at regular intervals from the production sequence, assessment of motor performance is made from nondestructive tests (radiographic) and static test firings of motors retained in an aging program. Nondestructive tests are also periodically performed on motors returned to field facilities from operational tactical submarine deployment. Complete weapon-system level tests, i.e., flight tests, are periodically conducted by the U.K. at the U.S. Eastern Test Range. In the aggregate, the information obtained from these various test programs is used to assess system reliability and to monitor aging characteristics. Data is compared to manufacturing baseline and original motor experience.

Experience

The first-stage motor is a more complex design, and therefore more difficult to replicate; the second-stage motor is a simpler design, but replication was process-dependent, thereby requiring involvement of some of the original experienced people. If Lockheed and Hercules hadn't had the Poseidon Program, which maintained the experience base for the "equivalent" second-stage propellant, there would have been significantly more difficulties. Their decisions were based heavily on the judgments of experienced people, and were influenced by what they did before and the knowledge that extensive tests were going to be conducted.

Motors/missiles are rarely fired to demonstrate a failure; they are normally fired to confirm expected performance characteristics. Tests are needed for the user's confidence in the performance and reliability of the product. The technical management team on this rebuild program believes that they would never have done this rebuild successfully without full-scale testing.

The U.S. Navy's SSPO, its prime missile subsystem contractor, Lockheed, and the Lockheed motor subcontractor suppliers, Aerojet and Hercules, with the support of many other material suppliers and test agencies, did an admirably thorough and professional job of carrying out this successful rebuild. It is clear that they encountered many problems, even with extensive testing. There are close parallels between the problems they encountered and the problems our engineers and scientists predict would occur with the remanufacture of older stockpiled nuclear weapons, even with testing.

Similarities between the Polaris A3 Rebuild and Nuclear Weapon Remanufacture

Material replication problems are very similar; there is even some direct overlap in material usage (for example, Alcoa 7075-T6 is used in some weapon parts). Just as Lockheed worries about the shelf life of consumable materials, so do we—especially radioactive materials like tritium, complex explosives and rubbers, and electronics components. General remanufacturing experience, illustrated by Lockheed's experience above, has shown that exact replication of complex materials usually is not possible (see also Appendix D). Thus, the purpose of testing is to verify that the necessary changes are acceptable.

Inadequate specifications will always be a problem, and part fabrication problems are essentially the same whether one is building rocket motors, nuclear warheads, or automobiles. With foresight, some of these problems can be avoided by keeping plants open, retaining tools, stockpiling parts, etc. Other problems, like material aging, safety issues, and the retirement of experienced people, probably cannot be avoided.

Electronics parts represent a deep worry. They are not easily replicated, and even when they are stockpiled, the aging characteristics of electronics are largely unknown. In addition, the electronics packages for nuclear warheads must survive the high electromagnetic pulse (EMP) environment of neighboring warheads (fratricide) and unfriendly warheads.

Computer modeling has the same goals and problems for rocket motors as for warhead designs. In both cases, the physical process is a rapid, destructive, and dynamic fuel burn. In both cases, the computer codes are scaled to match the results of tests. In both cases, some of the physics must be approximated, and the codes are not accurate or complete enough to make correct first-principles predictions. We also lack the extensive set of measurements that would allow confident scaling over a wide region of the warhead or rocket motor parameter space.

Time frames were a worry for Lockheed, and would be a similar worry for the U.S. nuclear stockpile. Remanufacture takes many years. Unanticipated common-mode problems are unacceptable for warheads and missile motors alike.

Documentation problems are the same for nuclear warheads and rocket motors. The problem has to do with human nature and imperfect knowledge. Only by carrying out an unrealistically large number of tests could a full parametric specification become possible.

Certification, of course, is different. Lockheed was able to do extensive full-up testing of the rebuilt rocket motors, but we cannot do "full-up" testing of nuclear weapons. For rebuilt nuclear warheads, we would of course do extensive nonnuclear tests of the components. Lockheed's flight tests are the equivalent of the production verification tests currently done for nuclear weapons. Just as Lockheed identified several problems during full-up flight tests, so might we need full nuclear tests to find possible problems. We could "certify" a rebuilt warhead without nuclear testing but with significantly reduced confidence.

Experience is a major concern in both cases. No matter what the product, remanufacture requires decisions based on the judgment of test-experienced people. At both Lockheed and the weapon laboratories, there is a consensus that test experience is absolutely necessary.

Testing is essential in almost all remanufacture efforts of complex technologies. With nuclear weapons, we must make a distinction between nonnuclear and nuclear tests. One can question whether the full-up flight tests of the rebuilt rocket motors were required. Lockheed's engineers believed they were necessary because of the synergistic effects that can show up only in flight tests. With a robust motor design, relaxed performance requirements, separate component tests, and new launch tubes in the submarines, Lockheed might have produced a successful motor without full-up flight tests. Similarly, if warhead yield certification requirements were reduced, we could probably rebuild some nuclear warheads without testing, at least while test-experienced designers are available. However, we would pay a price in terms of greater uncertainty about warhead performance.

(Note: The May 28, 1987, edition of *Aerospace Daily* published an article on the launch trials for the U.K. Polaris SLBMs from Royal Navy submarines. Of 12 launch trials, three resulted in failures. In the most recent trial, a missile launched from the U.K. submarine Repulse off Cape Canaveral veered off course and had to be destroyed. *Aerospace Daily* reported that "the ejection and first-stage firing modes were satisfactory. The fault was attributed to the motor despite a recent update program, costing around $610 million or more, to improve the propulsion system.")

The Saturn V Rocket Experience

Recently, because of the Challenger Space Shuttle disaster, American companies proposed to rebuild several Saturn V rockets to fill the gap (Reference A1); the Saturn V is capable of launching a 100,000-pound payload, compared to 65,000 pounds for the Space Shuttle. In particular, they wished to rebuild the Saturn F-1 engines, each of which has one million pounds of thrust. Five of these engines make up the Saturn V first stage. Seven F-1 engines were located, and plans were made to refurbish them.

Fifteen Saturn V rockets were built in the 1960s, and all but two had been fired into space by 1980. The remaining two are on display at NASA's space museums at the Kennedy Space Center and the Johnson Space Center.

Hughes Aircraft and Boeing Aerospace recently considered collaborating on a rocket using two F-1 engines that could deploy 85,000 pounds into a low orbit. Upon investigation, they found that the infrastructure no longer existed. The tools, dies, and jigs had been sold for scrap metal as a part of a regular government disposal program. Many of the vendors no longer existed, most of the F-1 experts were gone, and many drawings and documents were scattered or lost. In their opinion, it was too risky to try to rebuild the F-1 engine and they abandoned the project.

Rockwell International, the company that originally built the F-1 engines, has assessed the F-1 documentation. They believe that most of it exists in boxes stored at a depository in Atlanta, Georgia, but acknowledge that some of the blueprints are undoubtedly missing or inaccurate. As with other U.S. industries, it would be difficult at this late date to certify most of the specifications.

Hughes considered having designers draw up new plans from the existing F-1 engines. They concluded that it would be highly impractical to have engineers attempt to measure all the pieces with micrometer calipers; none of their engineers would certify this as a reasonable process.

Dr. J. R. Thompson, the director of Marshall Space Flight Center, recently told a meeting of the American Institute of Aeronautics and Astronautics that, assuming all the documentation could be found, it would take four to six years to rebuild the F-1 engineers and another four years to test to assure reliability. No one in the system was considering remanufacturing the F-1 without flight testing.

Reference

A1. W. J. Broad, "Hunt is on for Scattered Blueprints of Powerful Saturn Moon Rocket," *New York Times* (July 15, 1987).

Appendix D. Materials Science and Engineering Considerations in Weapon Manufacture

The particular problems in this section are typical of the type of materials science and engineering problems that can arise in the manufacture of nuclear weapons. All of these problems were solved by experienced materials scientists and engineers, either through consultation with the design physicists or through their own knowledge about the operational requirements of the weapon. Most materials science and engineering problems can be fixed without a nuclear test. Those cases where nuclear testing has been necessary are discussed in Chapters 2 and 3.

The general nature of the problems, not the specific details, is important, since similar problems could occur in the future. It is important to note that when such problems arise today, they are resolved by engineers and scientists with nuclear test experience.

Materials Science Considerations

Circumstances affecting materials science can arise and significantly interfere with the manufacture, remanufacture, or renovation of a nuclear weapon. By "significant" we mean that delays of more than a year between the decision to build is made and the time actual production can take place.

New Regulations

New governmental regulations (OSHA, EPA, NRC, FDA, etc.) have been enacted that interfere with nuclear weapon manufacture. In these instances, it is not simply a question of getting a waiver of the rules. Once materials have been determined to be dangerous, the plants refuse to work with them, and rightly so.

For example, in 1973, OSHA determined that the crosslinking agent (the amine "MOCA") in Adiprene/MOCA was carcinogenic. Adiprene/MOCA was an almost universal adhesive used in the assembly of nuclear weapons at that time. Thus the OSHA ruling required that either the entire DOE complex provide acceptable protective handling capabilities for this material or that an adequate substitute be found and qualified. Both options were estimated to require several years to implement, and it was deciced to develop a substitute material. A development effort was begun at LLNL, and after several years the Halthane adhesives were introduced into the production process at Pantex, Y-12, and Bendix.

Discontinued Speciality Materials

The weapons complex is often the major or sole user of specialty materials. Production of these substances is not profitable, and an industry may do so only because they have been defined as critical defense materials. However, the DOE has limited economic leverage as a customer. Materials that we have widely used have been discontinued by the manufacturer,forcing us to obtain the needed technology and transfer it to another vendor.

A good example is the discontinued manufacture of a basic silicone gum used to make stress cushions for several weapons. Union Carbide was the original manufacturer, but they discontinued the material. A French company made the "same" gum, but it proved to be highly variable and the products made with it had a very large rejection rate. General Electric made a similar gum with different mechanical properties, which we used as a stop gap. In the meantime, we obtained the rights for the original silicone gum from Union Carbide and transferred the technology to a smaller company, McGhann-Nusil, our present supplier. Presently, Bendix manufactures the stress cushions and oversees this material. Because they had to understand the technology involved, they first set up a pilot plant, and this took the better part of four years. Extensive product testing was involved, and the new product was included in nuclear tests.

In another case, Dow Corning stopped manufacturing a silicone addition potting compound in 1977. This material was also widely used in weapons. At the time, Pantex was planning the W68 retrofit and the W79 production. They were able to purchase and stockpile enough material from Dow Corning to finish the W79 production, but new materials had to be qualified for the W68 retrofit. Pantex also had to obtain and learn the process for the future. This took about three years, even with LLNL help.

Material Variability

Another issue is the variability of certain materials. We experienced this with the use of Kevlar, a high-performance polyaramid fiber, in nuclear weapons. Kevlar yarn was chosen for making a part in a nuclear artillery shell. This DuPont material had been used for automobile tires as Kevlar-29. A LLNL study on fiber composites led to the recommendation that the somewhat stronger material, Kevlar-49, be used for the weapon. Since the material obtained from DuPont was found to have statistically significant batch-to-batch variations, we decided to obtain enough Kevlar-49 from a single batch to complete the build. However, even with this single-batch material, the spool-to-spool variation in properties was troubling with regard to weapon lifetime predictions.

DuPont considered their Kevlar production details to be proprietary, but they shared some of them with us. It turns out that the order in which the polymer is put together (the so-called block copolymer arrangement) affects its engineering properties. Since our business was minor compared to the industrial market, it was uneconomical for DuPont to develop the specifications that would be needed for weapon remanufacture. Thus it may prove to be impossible to make new Kevlar parts years from now. We have Kevlar stored in the dark, but we don't know its storage-life characteristics; thus stockpiling of this material may or may not be effective.

Foreign Sources

A particularly disturbing situation weapon rebuilds is that some necessary materials have been available only from foreign sources. In fact, we do not always know the country of origin of some materials we procure. Clearly, we cannot face a rebuild in the future without the necessary manufacturing capabilities in the U.S.

High Explosives

High explosives (HE) are of particular concern for weapon remanufacture. HE technology is as much an art as a science. We have experienced a number of problems with explosives over the years. Recently, we have introduced insensitive high explosive (IHE) into the U.S. inventory. A major component of IHE is TATB (triamino-trinitrobenzene). TATB's safety advantages are very important for the peacetime storage and transportation of U.S. nuclear weapons. TATB weapons will not accidentally detonate even under extreme conditions of impact, shock, and fire. There is no other material of this type known. However, TATB has posed a number of manufacturing problems.

For example, wet- and dry-aminated TATB batches have different mechanical properties, with batch-to-batch variations. The manufacturers and the designers decided to change the process from a so-called "dry" amination to "wet" amination. The addition of water was beneficial, raising the energy of the explosive and eliminating a potentially corrosive chlorine ion. But recent lots of wet-aminated TATB have shown higher growth of one of the components, higher initial density, and reduced mechanical properties; these factors may adversely affect the performance of a weapon.

The dependence of the performance of primaries on the manufacture of such explosives mandates that a remanufactured design receive a nuclear test. There is no way to test the nuclear processes in a nonnuclear facility. We have developed confidence in the new manufacturing techniques only as a result of nuclear tests. Tests of a new explosive need not be stockpile confidence tests—we can test the performance of the explosive in development tests of other weapons.

In another example, we designed the W87 warhead to use an ultrafine TATB booster to ignite the main HE charge. We attempted to match the same TATB that had been used in the W84, produced only a few years earlier. The blender batches for the W87, however, were put together with different starting materials. Initial attempts at process verification lots of material failed to reproduce the W84 material. It became clear that we would not be able to duplicate the W84 material, and we had to find an acceptable substitute. A total of 97 process verification lots of ultrafine TATB were produced. Variables examined in these lots included TATB residence time in the grinder, mass flow rate through the grinder, amount of material stabilizer, time the stabilizer was added, washing process, and drying process. We even found that a new pump (a seemingly minor change) affected the mixing of the material and the resulting grain size enough to alter the burn properties of the material. From these 97 lots, we were able to select a process for producing the W87 ultrafine TATB. Each step of this process required extensive testing, including determination of particle-size distributions, surface area analysis, and test firings of standardized pellets for detonation divergence studies. The W87 TATB batch, as produced, demonstrated different yet acceptable detonation characteristics when compared to the W84 material. The new material was included in a nuclear test to verify its acceptability. Future attempts to duplicate either the W84 or W87 TATB material will probably encounter similar difficulties. We probably would again require a full process development of verification lots, subbatches, blending, and all associated testing to obtain a new "master" batch of ultrafine TATB.

Engineering Considerations

Warhead production is not an assembly-line or production-line procedure; it is more a job-shop process. Currently we accept materials and piece part deviations on the basis of experience and judgment. In the real world, we have rarely done a nuclear test or built a weapon that rigidly met our nominal specifications. Our engineers frequently make cost-effective decisions about parts that are outside the specifications. Without the experience of testing, the engineers probably would no longer be able to accept such parts. As a result, the production criteria would probably become very exacting and more expensive.

Documentation

The present quality of our specifications is about the same as in an industrial job shop. As in any such industry, a "perfect" specification manual does not exist. Even after the specifications have been carefully formulated and certified, they are changed many times to reflect the lessons learned during actual production. In the real production world, individual operators learn how to make things work "regardless of what the instructions say."

The issue of remanufacturing weapons is difficult to address generically. Rather, we must consider specific weapon systems at specific points in time. The time since last manufacture often sets the criteria for the availability of documentation, critical processes and materials, and knowledgable personnel.

A necessary requirement for the restart of manufacturing is the completeness of the documentation: specifications, drawings, manufacturing steps, assembly procedures, inspection procedures, quality assurance requirements, sampling plans, and—possibly the most important—identification of critical engineering and physics requirements. Historical documentation, in the detail required to enable relatively unknowledgable and untrained personnel fabricate an existing warhead, is a monumental task, and will probably never be adequate.

Modern MCs contain a request for adequate documentation for a future rebuild, within the tradeoff limits of higher priority MCs and available resources. In the real world, even with documentation (including specifications, drawings, historical records, etc.) in sufficient detail to allow restart of manufacturing, we would still require significant "reinventing" of processes and materials. This would take years to accomplish, assuming it is possible at all. We could do more from the beginning of an original build to aid the rebuild process. Early in the design process, additional team members could become documentarians to record the significant design features and the reasons why they were so designed. They could also document, summarize, and make clear the results of the test program that selected each material or design feature and carefully record what was known and not known. We do much of this documentation today, and we could do more. With such data in hand, we could then go to the production agencies with the details of each process and procedure documented in a way to facilitate future implementation. Whether such a procedure would work for nuclear weapons is unknown. It does not seem to have worked well in other industries.

Today, manufacturing procedures rely on a large number of commonly accepted standards. In addition, documentation may refer to existing equipment and current materials, which may or may not be available in the future. Some procedures are considered to be common knowledge are not documented. Documentation must address the desired end result or product, not just the procedures. Jargon must be avoided. When a manufacturer's proprietary material is specified, the desired properties of that material should also be documented. The manufacture may no longer be producing that material when we want it in the future, or he may have "improved it." Obviously, it will take considerable foresight to anticipate future questions, ambiguities, and problems to the degree needed to produce the proper documentation for a future weapon rebuild.

Continuity of Experience

Plant operators and design engineers and scientists interact almost daily about part tolerances, material properties, and assessments of minor deviations from specifications. Product experience is crucial because the performance of a weapon is sensitive to subtle details and interrelated effects. However, even today, many of our most experienced designers and engineers have already retired or moved on to other fields. Also, the rate of nuclear testing has dropped steadily over the years. This deterioration of our experience base is a concern, even at the current level of nuclear testing.

In our current production approach, a small design team is formed at the onset of potential production (Phase 3). Ideally, this team stays with the design until production is well under way. The team performs research and development, does production design, works with the plants to get the design into production, and troubleshoots the design during initial production. Once the weapon is in production, engineers trained by the design team follow the weapon until production is complete. These people provide a foundation for the future as they conduct the stockpile surveillance and material compatibility tests. Thus, the system establishes that people knowledgable in that particular weapon will follow it throughout its life, assuming they remain with the program. While there is substantial documentation in this process, it was never intended to enable relatively unknowledgable and untrained personnel to fabricate the warhead.

Actual Experiences

Impact of Inexperienced Personnel. During the very early production of the W68 at the Burlington AEC plant, the product quality was very high. However, as the production rate increased and new assembly people were brought into the program, the quality dropped to an unacceptably low level. To correct this situation, production had to be stopped and the new operators educated in both procedure and design intent (i.e., operation of the warhead).

Need for Personal Interactions. Personal interactions between design engineers and the production engineers are necessary for developing fabrication and acceptance procedures. Of key importance here is that the production engineer is knowledgable about the function of the components from both an engineering and a physics view and he can consult with test-experienced design physicists when necessary.

For example, Rocky Flats wanted Y-12 (at Oak Ridge) to machine a B83 oralloy part on the negative side of the allowed tolerances to facilitate its fit with another part. However, when this is done, the oralloy parts tended to be low in mass, which would affect the physics performance of the device. LLNL design engineers were called on to provide guidance on this subject.

Another example from the B83 build involved the laydown design of the bomb. The impact load from laydown travels through the outer mitigator; the load is partially transmitted to the internal components at very specific locations by slight variations in the way the mating parts interact. It would take a very detailed study of these mating parts to understand how this design works. LLNL engineers understand how the design works; they know that certain types of machining errors, although acceptable in one region, are unacceptable in others because they might adversely affect the load path.

Materials Selection. In many cases, weapon manufacture is driven by physics or engineering requirements synthesized, but not necessarily understood, from years of nuclear test experience. This can produce specifications for which detailed justifications do not exist, other than the observed fact that such details lead to successful tests. This commonly occurs in the selection of materials for a particular application.

For example, welding of thin stainless steel is necessary to make a part for the B83. The process is very sensitive to the specific chemical and mechanical characteristics of the metal. Attempts to characterize the metal have been only partially successful. Although we believe we now understand the important parameters (three years into production), we bought material from two lots of rolled sheet steel so that we would have enough material for the entire B83 build.

In another example, the thin-walled tubing used to make a part for the W84 proved to be very sensitive to the process used for making the tubing. After trying tubing from several vendors, we decided to buy from a single vendor. Even so, we must inspect every inch of the tubing, rejecting more than 50%. We do not know what makes tubing from this vendor work well; we just know from our tests that it does.

It should be noted that material specifications are based on quantitative analysis using techniques accepted today. They are truly applicable only when comparing materials, and should not be regarded as an absolute specification. Ten or twenty years from now, analysis techniques then may reveal that what appears today to be the same material may not be.

Handling Deviations from Specifications. Warhead requirements are sometimes driven by physics or engineering issues that are too complex to be detailed in a production specification or are not fully understood but have been proven successful through nuclear testing. Hence, the acceptance criteria may be very tight (due to lack of understanding of what the requirement should be), and deviations are expected. These are handled in the production process through a deviation request system that requires evaluation by a knowledgable designer. The designers and the manufacturers of weapons parts will not always know the details of what will be troublesome to manufacture when production starts. We may have to take a "see what happens" approach in early production. As carefully designed tooling and processes prove not to work exactly as predicted, the question of changing the process or tooling becomes one of both cost and schedule. Only by knowing the engineering and physics function or by redoing physics calculations or engineering tests can decisions be made that do not compromise the design. Test-experienced people are needed to make these decisions.

A large number of the deviations are small nicks and scratches on parts that come from normal handling. In some cases, such scratches can affect the performance of a weapon; in most cases, the designers know from test experience whether the nicks will matter. Our procedures require that each such instance be evaluated and a decision made on the individual item. Without these personal interactions, the reject rate would be excessively high or the product faulty. We currently process about 150 to 200 evaluation requests per system per month for all production plants. This number seems large until one considers the total number of individual features that must be assessed; the B83 and W84 each have nearly 1000 features to be checked on LLNL parts at the Y-12 plant alone!

Sometimes designer judgment and computer calculations are not sufficient to determine the effect of a defect. For example, in making the device for a development nuclear test for the B83, a gap in a crucial part developed during fabrication. Several experienced designers ran hundreds of hours of computer calculations to determine whether the crack would affect warhead performance, but they could not come to a clear consensus. Up to the time of the actual nuclear test, there were worries that the crack might substantially degrade the device performance; no one could certify with certainty that it would not. Due to time pressures, it was not expedient to reject the device and build another. In this case, the judgment made by test-experienced designers proved to be correct as the warhead performed as designed. However, without the nuclear test, we would have not been able to certify with confidence the performance of this particular device.

Specifying the Art of Certain Processes. Many processes, although covered by specifications, are more of an art than a science. These are quite often developed (if not invented) at the design laboratories and must be monitored during production by knowledgable people.

An example of this is a recent problem with a W84 component. A solid-state bonding process is used to join dissimilar metals. The quality of the product is critically dependent on good process control and the close attention of well-trained personnel because there is no adequate nondestructive testing technique that can evaluate the quality of the bonds. Failure of these bonds is a time-dependent mechanism that has been observed in some early production units. To prevent failures, the process must be carefully managed.

One of the key features of this process is the assured removal of all oxide from the surface before a layer of another metal is applied. Etching of the base metal and the deposition of the other metal take place in a vacuum chamber. Although we have established parameters to remove all the oxide, simple things such as the way in which the part is clamped in its holding fixture can affect the rate of oxide removal. Thus, some evaluation must be made on each part to assure that it is indeed oxide-free before the deposition of the other metal is begun. Although we have tried several techniques to make this evaluation with instrumentation, we have found none equal the human eye (two pairs, actually, as we ask for verification by an inspector as well as the operator) for detecting the change to a shiny, then slightly hazy, appearance that indicates a clean surface.

Complex Manufacturing Processes. Estimates of the time to restart production are weapon-specific and depend on the time since last manufacture. Given the highest priorities, sufficient resources, and adequate documentation, the issue becomes one of requalifying old and unique processes. A significant part of the problem is that the documentation for older systems is much less extensive than that for new systems. For relatively simple warheads that do not depend on unique or obsolete processes, about a year from authorization of the rebuild to first production unit may be reasonable. However, some weapons may involve processes that take many years to develop for production, and it could take a significant amount of development time to requalify them.

For instance, the fabrication of some parts for the W70 and W71 required the development of a complex process of part fabrication, special material procurement and certification, assembly by automated equipment and technician handicraft, inspection, test firing and statistical data evaluation, and finally, iterations of the above steps until a satisfactory product was obtained. The parts were fabricated by injection-molding of plastic into a complex die. The injection-molding process, used in toy making, had to be upgraded beyond the state of the art. Contour tolerances of this complex shape were tighter by a factor of ten than those required in industry. Fabrication of these components required the efforts of three of the production plants, which created a complex problem in coordination, both during development and in production.

In the case of a part for the W79, it took about five years to transfer an aqueous plating process developed at LLNL to the production complex. Requirements for scratch-free and flaw-free surfaces required the development of special handling and inspection processes that yielded a product with only a 30% acceptance rate. Even though each step of the process had a yield of better than 90%, the large number of steps resulted in the low final yield. It took about a year from the start of production to the completion of a part.

Possible Near-Future Remanufacturing Need. A situation is now occurring that may provide direct experience with remanufacturing. Three systems (the WYY, W62, and the W56) use some similar parts in which a time- and temperature-dependent reaction is apparently occurring. (Note: the WYY cannot be identified for classification reasons.) These systems are being monitored and, unless they are retired first, they will have to be retrofitted. Retrofit of these systems will vary from minor disassembly and reassembly of the WYY to a major disassembly and reassembly of the W56. If this is required for the W56, it will test many of the issues of remanufacturing, particularly material availability, expertise, and the need for nuclear testing. Such a retrofit of the W62 would be very difficult because of the way the weapon has been assembled and would involve major elements of remanufacture.

Conclusion

The reliability of remanufactured warheads is the fundamental issue. The remanufacturing of warheads, in itself, does not automatically reestablish confidence in the reliability of the system. With testing and verification, old systems and their reliabilities can be rejuvenated. However, testing is often essential to establish the reliability of the remanufactured product. Testing is the essence of any quality-assurance program, whether it be for automobiles, rocket motors, or nuclear weapons.

Appendix E. Senate Armed Services Committee Language for the FY 1988 Authorization Bill

STUDY OF THE FEASIBILITY OF REDUCED RELIANCE ON UNDERGROUND NUCLEAR TESTING

The Committee notes that on a number of occasions, Congress has expressed the sense that it is desirable, from the point of view of arms control, to place further limitations on the size and/or number of nuclear tests. The Committee believes that nuclear test limitations should be an integral part of a comprehensive approach to arms control, with further limitations on nuclear testing established in conjunction with further progress in other areas of arms control.

The Committee notes also the continuing controversy over the extent to which the reliability of the nuclear weapon stockpile, or our confidence in it, would be affected during a prolonged period of substantial limits on testing beyond those in the Threshold Test Ban Treaty. While there is a range of opinion expressed by the expert community on this subject, the Committee believes that the gravity of the issue is such that a conservative position should be taken. That is the Committee believes that we must understand how to deal with some degree of unreliability that might develop over time.

The Committee also notes that there is disagreement in the expert community as to the yield above which nuclear tests can be reliably identified as such -- the range of disagreement extending approximately between 1 kiloton and 10 kilotons.

Finally, the Committee notes the salutary precedent, established at the time of the TTBT, of providing safeguards concomitant to nuclear testing limitations. The Committee continues to support the ratification and entry into force of the TTBT and PNET, subject to improved verification procedures.

In light of these several considerations, the Committee believes that, as a safeguard against the implementation at some future date of further test limitations, the Administration should begin to assess the feasibility of modifying the nuclear stockpile in ways which would minimize both the likelihood and the impact of unreliability which might develop during a period of further restricted testing. If such measures are feasible, DoD and DoE should undertake a program to evaluate the cost and timetable to prepare a more durable stockpile and to implement such changes as may be needed to delivery systems. That is, the Committee seeks to understand the feasibility of a posture for the nation's nuclear weapon stockpile which, in the face of long-term and substantial further limitations on testing, would be as well suited as possible to preserving the essential elements of our national security.

To this end, therefore:

I. The Nuclear Weapons Council (NWC) shall direct the Department of Energy (DoE) to study the extent to which it is feasible to prepare the stockpile to be less susceptible to unreliability during long periods of substantially limited testing. The DoE shall report its findings through the NWC to the Committees on Armed Services and Appropriations of the Senate and the House of Representatives not later than 1 July 1988. This report shall include an assessment of the feasibility of developing and stockpiling nuclear warheads which would be either

a) less subject than current warheads to degradation while in stockpile for long periods of time; or
b) more amenable than current warheads to realiability assessment and, where necessary, to reliable repair, both accomplished without nuclear testing; or both.

The report should describe ways in which existing and/or new types of calculations, non-nuclear testing, and permissible but infrequent low yield nuclear testing might be used to move toward these objectives. To the extent it is determined feasible in this study to achieve these objectives, the report should describe the scope and nature of the research, development and testing program needed, first, to fully assess this issue and then to prepare designs for more durable warheads, including:

1. any nuclear testing required before further limits are imposed;
2. the type and cost of any additional facilities, such as non-nuclear or allowed low-yield nuclear testing facilities, which would be required either before or after the commencement of further limits on testing; and
3. the lead-time required to move to a regime of fewer tests.

Finally, the report should estimate the penalties in size, weight, safety, or other characteristics that more durable warheads would impose on the military systems of which they might be a part.

II. Concurrent with this tasking, the NWC shall direct the DoD to study the following:

a) the extent to which the military capabilities of the nuclear warhead stockpile might be affected by incorporation of such more durable warhead designs;
b) the extent to which commonality among such designs in the stockpile (i.e., using the same warhead design for more than one system application) might be desirable or feasible, considering advantages

and disadvantages of commonality both for durability and for minimizing degradation of military characteristics;

c) ways in which such possible degradation of military characteristics might be partly or fully compensated for by changes in other nuclear weapon system characteristics; and

d) whether there could be degradation of weapon system survivability in ways similar to those which might produce warhead reliability degradation during prolonged further nuclear test limitation, and, if so, whether there are ways to provide additional durability of survivabiltiy of measures put in place either before or after commencement of such further test limitations.

The DoD shall report its findings on the above through the NWC to the Committees on Armed Services and Appropriations of the Senate and the House of Representatives not later than 1 July 1988.

For the purposes of the reports of Sections 1 and II, the Departments shall assume that the further test limits would preclude nuclear tests above a) 1 kiloton or b) 10 kilotons.

III. Concurrently with the above reports, the President shall report to the Congress on considerations pertaining to the relationship between:

a) various types and degrees of progress in other areas of arms control -- for example, further limitations on the number or characteristics of nuclear weapons systems, their geographical deployment, or limitations on other military systems such as chemical weapons or conventional forces; and

b) progressively more stringent limitations on nuclear testing, such as reductions in yield threshold below the TTBT, limitations on numbers of tests, or combinations of these, including, but not limited to, limitations as stringent as a complete ban on tests above 1 kiloton.