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Maintaining the U.S. Stockpile of Nuclear Weapons During a Low-Threshold or Comprehensive Test Ban

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Foreword

This report is an abridged version of a classified study prepared at the request of members of the United States Congress. Asterisks and leaders indicate deleted material.

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Maintaining the U.S. Stockpile of Nuclear Weapons During a Low-Threshold or Comprehensive Test Ban

Abstract

We review here results of several classes of U.S. nuclear weapons tests conducted within the past decade, together with the principal strengths and weaknesses of nuclear weapons themselves. It is found that a high degree of confidence in the reliability of the existing stockpile is justified, and that it is sufficiently robust to permit confidence in the reliability of remanufactured warheads in the absence of nuclear explosive proof-tests.

We also review problems encountered with the 14 nuclear weapon designs since 1958 that have been frequently and prominently cited as evidence that a Low-Threshold Test Ban (LTTB) or a Comprehensive Test Ban (CTB) would preclude the possibility of maintaining a reliable stockpile. It is concluded that that experience has little if any relevance to the question of maintaining the reliability of the stockpile of nuclear weapons that exists in 1987.

Work can be done in areas relating to, and including, nuclear weapons research, engineering, and effects during a LTTB. A significant and challenging scientific and engineering program could be conducted at the weapons laboratories that would engage the interest and maintain the skills of weapons scientists and engineers. They would, therefore, have little incentive to leave the weapons laboratories, and their expertise would continue to be available when needed to monitor the stockpile and the quality of remanufactured warheads. A CTB would severely limit such a program, but if it were preceded by a LTTB, there would be time to make necessary changes to reduce the present reliance of the production complex upon the advice and counsel of weapons lab personnel.

Further, we will discuss actions necessary to assure the future availability of materials needed to remanufacture nuclear weapons in the existing stockpile and the reliability of repackaged nuclear weapons.

It is recommended that the Department of Energy be encouraged to undertake the formulation and execution of a Readiness Program whose purpose is to ensure that the U.S. is prepared to maintain the reliability of its stockpile of nuclear weapons in the absence of nuclear explosive tests, and that funds earmarked for this purpose be provided.

Introduction

This independent technical review of the present reliability of the U.S. stockpile of nuclear weapons, and its future maintainability during a Low-Threshold Test Ban (LTTB) or Comprehensive Test Ban (CTB), was prepared in response to a letter of March 30, 1987, from the Honorable Les Aspin et al. to Dr. Roger Batzel, Director of the Lawrence Livermore National Laboratory (LLNL).

A copy of the letter is provided in Appendix A. It poses the question of stockpile reliability and maintenance as follows:

> 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.

We have taken the liberty of rephrasing this key technical question and dividing it into two parts:

1. How reliable are the nuclear weapons in the U.S. stockpile today?
2. Could the reliability of the stockpile be maintained for the foreseeable future within the limitations of a LTTB?

We also consider the question of stockpile maintenance during a CTB, which we presume to be preceded by a LTTB of appreciable duration.

Our answers are based upon a detailed review and evaluation of the U.S. nuclear test record of the past decade, and upon consideration of the properties of nuclear weapons themselves. We shall begin by presenting our definition of what constitutes an adequately tested nuclear warhead, and then describe the extent to which the present stockpile has been adequately tested. (We prefer the term "adequately tested" to the term "thoroughly tested" as being more to the point.)

A list of the weapons currently in the U.S. nuclear stockpile is provided in Table 1.

Table 1. Weapons currently in U.S. nuclear stockpile.

Warhead	Weapon system	Stockpile entry data[a]
W33	8" artillery fired projectile	1949, 1957
B28	Strategic bomb	1958
W31	Surface-to-air missile	1959
B43	Strategic and tactical bomb	1961
W44	Surface-to-underwater missile	1961
W45	Surface-to-surface missile	1962
W48	155-mm artillery fired projectile	1964
B53	Strategic bomb	1962
W50	Tactical surface-to-surface Missile	1963
W56	Minuteman II ICBM	1963
W55	Underwater-to-underwater missile	1964, 1972
B54	Demolition munition	1964
B57	Air Force bomb/Navy depth bomb	1964
B61	Tactical and strategic bombs	1968, 1975, 1977, 1979, 1985
W62	Minuteman III ICBM	1970
W68	Poseidon C3 SLBM	1970
W69	Short-range tactical missile (air-to-surface)	1972
W70	Lance surface-to-surface tactical missile	1973, 1981
W76	Trident I SLBM	1978
W78	Minuteman III ICBM	1979
W80	Cruise missile (Air Force and Navy)	1980, 1984
W79	8" artillery fired projectile	1981, 1983
B83	Strategic bomb	1983
W85	Surface-to-surface tactical missile	1983
W84	Ground-launched cruise missile	1983
W87	MX ICBM	1986

[a] More than one date indicates a modified version of the original design was deployed.

What Constitutes Adequate Nuclear Weapons Testing?

A wide variety of nonnuclear tests are required in predeployment development and in postdeployment inspection and maintenance of nuclear weapons. These include chemical compatibility and aging tests; mechanical shock, vibration, and acceleration tests; electrical system and component tests; and high-explosive (HE) driven implosion tests. Within the limits of a 1-kt LTTB, nuclear explosive tests to evaluate one-point safety, reduced yield tests of primaries and single-stage weapons, and some nuclear effects and vulnerability tests could also be conducted. All of these tests could continue under a LTTB and are not at issue.

A current nuclear explosive test necessary to consider a weapon to be adequately tested is the detonation of a war reserve production unit or preferably a unit withdrawn from stockpile that is provided with end-of-life conditions and minimally modified to comply with existing treaty limitations (presently 150 kt). To the extent that it is feasible, it is desirable that it have been subjected to a simulated stockpile-to-target sequence of the enabling actions and most severe operating conditions it will encounter before detonation in actual use.

In recent years, it has become standard practice to conduct such tests, referred to as production verification tests or stockpile confidence tests (SCTs). For example, it is stated that:

> The production verification test is usually the first nuclear test of a weapon in its actual stockpile configuration. Production verification nuclear tests have been routinely conducted on warheads for all recent weapon systems, and the test results are used to support our calculations on which the nuclear yield certification for the weapon is based (i.e., the yield we certify it would produce if unmodified for treaty compliance).[1]

The requirement of a SCT is both reasonable and prudent. The results of the SCTs show, however, that even in the absence of a nuclear test of the production or stockpile version of the weapon, the reliability of the otherwise well-tested weapon is very high. Only one of the many SCTs indicated a possible problem resulting from a difference between the stockpiled version of the warhead and the version that was tested. This favorable record supports the view that confidence in the reliability of remanufactured nuclear weapons, which had been adequately tested when originally stockpiled, would be justified without requiring additional proof tests.

Has the Existing Stockpile Been Adequately Tested?

Stockpile confidence tests have been conducted from 1979–1986 in which the expected yield exceeded 1 kt. The weapon designs tested represent . . . the total number of weapons currently in stockpile. A list of the different designs tested, together with a brief review of the test results, is provided in Appendix B.

In only one of the SCTs did the test disclose a problem that needed correction. Both the primary and secondary yield were lower than expected. The performance of the other designs was found to be satisfactory, the root-mean-square (rms) difference between the yields expected and those observed amounting to less than . . . . A second SCT confirmed that the problem discovered had been satisfactorily corrected.

Applying the definition of "adequately tested" given in the preceding section, we conclude that . . . the weapons currently in stockpile have not been adequately tested. In the absence of information to the contrary, however, we would have no reason to expect those that were inadequately tested to perform either better or worse than those that had been adequately tested. That is, we would expect comparably good performance, but could not rule out the possibility that the performance might be significantly poorer.

Even though the existing stockpile of nuclear weapons has, strictly speaking, not been adequately tested in its entirety, its reliability should nonetheless be expected to be fully adequate for purposes of deterrence.

The Often-Cited 14 Weapons Designs: Lessons Taught and Learned

Problems encountered with 14 different nuclear weapon designs since 1958, which required post-deployment nuclear tests to correct, have often been cited as evidence that the existing stockpile of nuclear weapons could not be satisfactorily maintained in the absence of further nuclear explosive tests. The 14 weapon designs, together with an identification of the origin of the problem that needed correction, are listed in Appendix C. (A fifteenth nuclear weapon design, which was given a postdeployment nuclear test in 1987, can now also be added to this list of 14. The nature, results, and implications of this test are likewise described in Appendix C.) In his written testimony before the Senate Armed Services Committee on February 26, 1987, Director Roger Batzel of LLNL stated that

> Approximately, one-third of all modern weapon designs placed in the U.S. stockpile have required and received postdeployment nuclear tests for resolution of problems. In three-fourths of these cases, the problems were discovered only because of the ongoing nuclear testing.

In an earlier (spring 1986) written response to a question by Senator Edward Kennedy of the Senate Armed Services Committee, Director Batzel stated

> In actual fact, in the 25 years since testing resumed after the 1958–1961 nuclear test moratorium, one-third of all modern weapon designs *that were thoroughly tested before entering the stockpile* have required postdeployment nuclear tests. [Emphasis added.]

Note that the description of these designs as having been "thoroughly tested before entering the stockpile" was dropped from his later testimony of February 1987.

The "one third" is elaborated further in an unclassified version of an April 17, 1986, classified response by Admiral Sylvester R. Foley, Jr., Assistant Secretary for Defense Programs, U.S. Department of Energy (DOE), to questions from Congressman Edward J. Markey:

> Since 1958, 14 of the 41 weapon designs in stockpile or 34 percent of the weapons have required post-development nuclear tests to resolve problems. In three-fourths of these cases, the problems were discovered as the result of nuclear tests, and additional tests were required to confirm that the "fix" was satisfactory. Since 1970, six tests in this category have been required.

Most recently, in an article that appeared in the *Los Angeles Times* on May 13, 1987, Secretary of Defense Casper Weinberger states categorically that

> Any claim that nuclear testing is unnecessary is simply and demonstrably false. Over one-third of all nuclear-weapon designs introduced into our stockpile since 1958 have encountered reliability problems, and 75% of these were discovered and subsequently corrected thanks to actual explosive testing.

Past problems encountered with 14 of the 41 weapon designs in stockpile did indeed require postdeployment nuclear tests for their resolution. If the present stockpile is as prone to problems that would require nuclear tests to resolve as this experience appears to suggest, then Secretary Weinberger's argument that nuclear testing must be allowed to continue would be reasonable, if not compelling. The question is, is it?

To answer this question, we need to examine the kind of problems that were encountered with the 14 weapon designs and the circumstances in which they arose. We note that the 14 designs can be cleanly divided into two distinct groups that we shall term the "Sixties Nine" and the "Eighties Five." Problems with the Sixties Nine were discovered and corrected during 1962–1964, shortly after the end of the 1958–1961 Moratorium on nuclear weapons testing. Problems with the "Eighties Five" were discovered and corrected much more recently during 1980–1985.

With respect to the Sixties Nine, the rush to build and stockpile nuclear weapons during the 1958–1961 Test Moratorium led to a stockpile that was very poorly tested by today's standards. Our understanding of how nuclear weapons work, our experience with nuclear tests, and our computational capabilities were all significantly inferior to that which exists today. There has been no rush to build the present stockpile, and it has benefited from a quarter-century of additional nuclear and nonnuclear tests since the hectic days of the Moratorium. For these reasons, it is concluded that experience with the Sixties Nine, long ago, has little or nothing to say about the reliability of the stockpile of nuclear weapons that exists today.

With respect to the Eighties Five, the post-deployment nuclear tests of these five designs would not have been necessary had they been subjected to the more rigorous standards of nuclear weapon testing that have become routine and have been applied to... the weapons now in stockpile. We are referring to the practice of conducting a proof test of an actual stockpiled weapon with simulated end-of-life and stockpile-to-target conditions.

Important lessons have indeed been taught by the difficulties experienced with the Sixties Nine and the Eighties Five. These lessons have been learned long ago in the case of the Sixties Nine, and more recently in the case of the Eighties Five, and do not need to be relearned.

The Robustness of U.S. Nuclear Weapons

Robustness of U.S. nuclear weapons can be determined from the results of their nuclear explosive tests, together with a knowledge of how they work or fail to work. We shall begin with a brief discussion of how they do or do not work, and then examine the test record.

How They Work and How They Fail

Explosion of a single-stage nuclear weapon, or of the first stage (primary) of a thermonuclear weapon, is a four-step sequence.

1. Chemical HE implosion.
2. Unboosted nuclear fission.
3. Thermonuclear fusion (ignition and burning of the deuterium-tritium boost gas.)
4. Boosted nuclear fission.

The first two steps can be fully tested and explored within the yield limitation of a LTTB, whereas only step 1 can be fully tested within the limits of a CTB, demonstrating an important difference between these two nuclear test bans.

If the threshold yield of a LTTB was as high as..., then the primaries of... the nuclear weapons presently in stockpile could be tested through step 4 at their full boosted yield. If the threshold was reduced, full boosting would be precluded, but valuable partial boosting tests could still be done. These lower yield tests could provide assurance that expected yields would be achieved with full boosting, particularly if large yields were permitted. This possibility is exemplified by the yield range of the W84 primary, as shown in Appendix D.

The explosion of the second stage (secondary) of a thermonuclear weapon also commonly consists of a similar sequence.

1. Radiation implosion, driven by the thermal radiation emitted by the exploding primary.
2. Thermonuclear fusion of lithium-deuteride fuel.
3. Nuclear fission of uranium.

The chemical energy used to drive the primary amounts to less than... of a ton of HE, whereas the thermal energy available to drive the secondary is thousands of times greater. For this reason, secondaries are conservatively designed, with the result that..., as shown in Appendix E.

The primary is, therefore, the weaker link in the primary-secondary chain. It has been aptly termed the bellwether of thermonuclear weapon performance by Dr. Richard L. Wagner, Assistant Secretary of Defense for Atomic Energy, in Congressional testimony:

> We can test, for example, the primary or a combination of the primary and an altered secondary, which would not exceed the threshold.
>
> The primary design is the sort of bellwether of whether it will work, and so, we can test all primary designs which are at a lower yield thereby giving us continued reasonable assurance that the weapon will work at its full yield.[2]

The bellwether, in turn, of primary performance is step 3—boosting. It, then, represents the bellwether of nuclear weapon performance, single-stage or thermonuclear, because boosting is relied upon in modern nuclear weapons. Boosting increases the yield by a large amount. Failure of nuclear weapons to perform properly when tested has been rare, as the test record to be discussed will show....

The most stringent test of a nuclear weapon is, therefore, a test under conditions..., which include:

- Use of aged end-of-life conditions.
- Exercise of a lower yield.
- Conditions that may alter the implosion, such as temperature extremes.

Many of the failures of nuclear weapons in the past can be attributed to failure to test their performance under these stressful conditions.

What the Test Record Shows

In considering the test record, we shall concentrate on the explosive yield of the primary, in the case of thermonuclear weapons, because it is the more sensitive measure of performance. The yield of the primary . . . , as demonstrated in Appendix E. In the case of a single-stage weapon, its yield can vary by 30% with only a 10% variation in its effective blast area. The record of recent U.S. nuclear tests demonstrates that variations in yield exceeding . . . are rare, and only occur in circumstances in which previous test experience is meager and large uncertainty in yield is indeed expected. Such circumstances do not apply to the weapons in the existing stockpile.

Results from four classes of nuclear weapons tests are provided and discussed in Appendices B and F–J. The four classes considered are:

1. Stockpile confidence tests (1979–1986).
2. All nuclear tests with yields exceeding 1 kt during the recent five-year period (1980–1984).
3. First nuclear test of new primaries (1977–1986).
4. Primary performance in the sequence of nuclear tests of the W84 (1978–1985).

We shall be concerned with the yield of the primary only, if the weapon is thermonuclear, and only in those tests for which the expected yield exceeded 1 kt, which includes the great majority of tests performed. Tests with yield less than 1 kt would not be forbidden by a LTTB.

In all four classes of tests, the record of yield predictability is remarkably good. In no case among the SCTs or among the sequential tests of the W84 primary, did the predicted yield differ from the observed yield by more than . . . . The rms prediction error amounted to only . . . and . . . , respectively, an uncertainty . . . the approximately 5% uncertainty in the yield measurement itself.

Of the first-time tests of new primaries during 1977–1986, in only one case did the predicted yield differ from that observed by more than . . . . For the nuclear weapon tests during 1980–1984, in only six cases did the yields differ by more than . . . . In only one of the latter six cases, could the poor yield predictability be considered to have been a surprise (see Appendix G). Nor should the poor performance of the primary in . . . have been a surprise, as explained in Appendix H. Had . . . been conducted before rather than after the weapon had been stockpiled, as it should have been, there would have been *no* surprises; that is, prediction errors exceeding . . . among these four distinctly different classes of weapons tests.

Clearly, this impressive record would not have been possible if U.S. nuclear weapons were not comfortably tolerant of the small variations in materials and manufacturing that accompany any practical production process. This is particularly well illustrated by the excellent performance of the new primary designs the very first time they were tested. It is also illustrated by the results of the SCTs. The units tested in these SCTs differed from those previously tested in that they were production-line units as opposed to final development preproduction units. The differences between them evidently had little or no effect, with only one exception, on their performance.

The test record indicates that the nuclear weapons in the existing U.S. stockpile are sufficiently robust to allow for future replication. Careful attention will need to be given to those factors upon which boost performance is sensitively dependent, but the test record does not support the thesis that reliable remanufacture cannot be accomplished. This conclusion is in agreement with earlier statements by nuclear weapon authorities Dr. Hans A. Bethe, Norris E. Bradbury, Richard L. Garwin, J. Carson Mark, and Andrei Sakharov affirming the possibility of reliable remanufacture without nuclear explosive proof-tests (see Appendix K).

Can Stockpile Reliability be Maintained by Remanufacture During a Low-Threshold Test Ban ?

There is only one example in the history of the U.S. stockpile in which the production of a nuclear warhead was terminated and then it was subsequently remanufactured. Although some difficulty was experienced in remanufacture as a result of the unavailability of certain original materials, these difficulties were successfully overcome. Confidence in the efficacy of remanufacture was such that the replicated warheads were certified for stockpile without requiring a nuclear test.

Proof, by demonstration, of the ability of the nuclear weapons production complex to successfully replicate nuclear weapons has never been undertaken. The one fortuitous example of a presumably successful remanufacture is not sufficient to prove the point. In this circumstance, it is necessary to resort to indirect rather than direct evidence to reach an informed judgment. We need to consider the elements that are essential to the process of remanufacture and their future availability. They are:

1. Specifications and procedures.
2. Materials.
3. Tools and equipment.
4. Know how.

The first three of these elements have been considered in the response of Admiral Foley, to questions submitted by Congressman Samuel Stratton in the hearing before the House Armed Services Committee, Subcommittee on Procurement and Military Nuclear Systems, on February 19, 1986 (unclassified version).

QUESTION: Do nuclear warhead design and product specifications contain sufficient information to permit the manufacturer to produce successfully a thoroughly tested warhead?

ANSWER: Although great progress has been made in the computer simulation of the functioning of a nuclear warhead, it has not advanced to the point that the Department of Energy can certify a *totally new* warhead design without underground nuclear testing. [Emphasis added.] On the other hand, if one starts with a warhead design that has been thoroughly tested (including underground nuclear testing), the design and product specifications will normally contain sufficient information to permit successful production. In essence, this is exactly how the Department of Energy produces new warheads. In addition, it is Department of Energy practice to subject newly fielded warheads to a stockpile confidence test, an underground nuclear test conducted after the warhead has been exposed to the normal environments it will experience in Department of Defense custody within a year to two after fielding.

QUESTION: Given sufficient funding by Congress, couldn't DOE make available the proper materials, fabrication techniques, and equipment needed to permit remanufacture of an existing, well-tested warhead using the original design and product specifications?

ANSWER: New warhead or bomb military characteristics submitted by the Department of Defense for acceptance by the Department of Energy normally contain a requirement that the design, development, and production of the warhead (or bomb) be well documented and involve processes that to the extent possible allow replication of the warhead (or bomb) at a future date. [See, for example, Appendix L.] *Assuming, therefore, that vendor-supplied materials and components are still available at the time desired for remanufacture (and this will not necessarily be the case), the remanufacture of existing, well-tested warheads is possible.* [Emphasis added.]

If we assume that the warheads in the existing stockpile have been well-tested, and the evidence of the SCTs that have been performed strongly supports this assumption, and provide for the future availability of necessary vendor-supplied materials and components, then it is the testimony of the DOE as expressed by Admiral Foley that remanufacture is indeed possible. It seems clear that *if appropriate action were taken in advance*, the future availability of these components and materials could be assured. These actions would include appropriate stockpiling of materials, tools, jigs, and equipment, and thorough documentation of preparation and fabrication methods. It would also be necessary to ensure that vendors provide timely notification of plans to discontinue production of necessary materials and components so that other sources or means of production could be established. This would be particularly essential in the case of sole-source suppliers of materials for which there was little or no demand other than in the production of nuclear weapons.

If there are materials needed in the manufacture of some weapons now in stockpile that have *already* become unavailable, prompt corrective measures will be required. Redesign using available materials may then be necessary, followed by a nuclear explosive test to validate performance.

The fourth element essential to the process of remanufacture is know-how. It can be divided into two categories: production know-how and design know-how. By "production know-how," we refer to the knowledge and experience of people in the DOE nuclear weapon production complex. Maintaining this production know-how during a LTTB would occur in a natural way because the remanufacture of nuclear weapons would take place on a continuing basis. If the mean lifetime of a warhead in stockpile were 20 years, for example, before replacement by remanufacture became necessary, then the remanufacture rate to maintain the existing stockpile of weapons would be . . . , the same rate of production that has been in existence for some time. There would be no adverse impact on the stability of the work force or the continuity of effort.

By "design know-how," we essentially refer to the knowledge and experience of scientists, engineers, and technicians at the two weapon design laboratories, Livermore and Los Alamos. Maintenance of design know-how to ensure confidence in the reliability of the existing stockpile is perhaps the most contentious item that concerns this issue. There are two independent points to be considered.

1. It has been argued that the skills and know-how of experienced nuclear weapons scientists and engineers must continue to be available if confidence in the reliability of the stockpile is to be maintained. This know-how is said to be needed to properly monitor the condition of the stockpile, to decide when remanufacture is called for, and to ensure that remanufacture is properly carried out.

2. It has been further argued that if there were a total ban on all nuclear testing (that is, a CTB), then these needed nuclear weapons specialists would become restless and would quit the weapons labs to undertake more interesting and rewarding work elsewhere. Even if they did not, they would lose their capabilities through lack of opportunity to exercise them.

With respect to the second point, it is important to distinguish between the effect of a CTB, and that of a LTTB with a yield threshold of 1 kt or greater. A very broad spectrum of nuclear weapons research could be carried out with yields limited to 1 kt, including:

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- * * *
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There is no doubt that an interesting and vigorous program of theoretical, experimental, and computational nuclear weapons research could be conducted within the limits of a LTTB that would engage the interest and maintain the skills of nuclear weapon designers. Some might leave the weapons laboratories if higher yield tests were ruled out, but most, particularly the more senior and experienced scientists and engineers, would stay on.

The situation would be considerably different during a CTB. In the absence of nuclear experiments, weapon designers would become "rusty" with time through lack of practical hands-on experience. Assuming that a CTB would not be agreed to without adequate provision for its verification, however, Soviet weapon designers would also become rusty through lack of exercise. In the minds of many, this would be a desirable result.

Although these designers could eventually become out of practice, it does not follow that the majority would leave the weapons labs. The weapons labs are widely believed to be good places to work for many reasons that have nothing to do with the nuclear test program, and of course these attractive aspects would be continued or augmented whether or not nuclear testing were further restricted or stopped. In this regard, Dr. John D. Immele, LLNL Deputy Associate Director for Nuclear Design, has stated:

> A CTBT (or severe quota) would result in greater diversification of designers into complementary activities, e.g., ICF [Inertial Confinement Fusion], Lab XRL [Laboratory X-Ray Laser], ACO [Advanced Conventional Ordnance], pulse power, non-nuclear SDI [Strategic Defense Initiative].

That is, the interest, experience, and skills of the designers could be engaged in a number of activities closely related to those of nuclear weapons design.

Finally, it makes sense to limit our horizon to one generation, 20 years from now, on the grounds that much will change and can be done during that time. Beyond that horizon, our vision is surely blurred anyway. We note that many experienced weapon design engineers and physicists are now of middle age, have their roots down and their careers well-established. Some may leave, but many will continue to work at the weapons labs for the next 20 years to retirement. Even those that leave would be available on a consulting basis, should the need arise.

In view of the fact that experienced weapon designers will remain available for the foreseeable future, the question of whether or not the existing stockpile of nuclear weapons can be maintained without them does not need to be immediately answered. There is time to study the problem and make those changes that will reduce the need for their future involvement. Such changes would likely include improved, better-illustrated, and more complete production and inspection manuals; education and instruction courses for production staff; and possibly the help of "expert systems" methodology to systematize and computerize some of the production monitoring tasks the weapons experts are now called upon to do.

The robust character of the nuclear weapons in the present stockpile, together with the ample time available to accomplish the task, suggests that it will eventually be possible to be confident of the reliability of remanufactured nuclear weapons without requiring the services of nuclear weapon design engineers and scientists that have themselves benefited from direct experience with nuclear explosive tests.

Would Repackaged Weapons be Reliable?

If nuclear test restrictions were such that no new warhead or bomb designs could be added to the stockpile, an important question that would arise is the extent to which weapons already in the stockpile could be used in new and different delivery systems from those for which they had originally been designed. Here we are speaking of repackaging the nuclear warhead only, not exposing it to a more stressful environment in its stockpile-to-target sequence than it had heretofore been designed to survive.

The materials, and their location, that surround the nuclear assembly system of the warhead or bomb can influence its performance in two ways. They can influence the HE-driven implosion hydrodynamically, and they can influence the nuclear performance neutronically. If the surroundings change, the implosion might be more or less tamped or otherwise differently perturbed, and/or more or less neutrons might be reflected back into the nuclear assembly system, altering its nuclear performance.

It is, therefore, necessary to check that repackaging has not significantly altered the hydrodynamics or neutronics of the nuclear assembly system. Fortunately, this can be done without the need of a nuclear explosive test. The hydrodynamic influence can be checked by conducting a test implosion producing less than 1 kt of explosive yield, or under conditions in which there is no nuclear yield at all. Indeed, in some situations it will be clear, without any test, that the influence of the altered surroundings on the implosion could not be detrimental. The neutronic influence would be calculated with existing large "super computers" employing suitable Monte Carlo neutronics codes; the validity of the calculations could be checked by means of neutron transport measurements in the laboratory. The calculations would be done conservatively to ensure that the effects of repackaging would not be larger than calculated.

Admiral Foley, in addition to responding to questions concerning remanufacture referred to in the previous section, had this to say about repackaging:

> QUESTION: Couldn't an existing warhead be used on a new delivery system that has been adapted so that its design is compatible with the warhead?
>
> ANSWER: The basic answer to this question is yes. However, because the cost of a new warhead is usually only a fraction of the cost of the associated delivery system, the reverse is normally the case; i.e., an existing warhead is adapted to be compatible with the delivery system. In fact, many of our Phase 2 feasibility studies and Phase 2A design definition and cost studies are oriented specifically toward examining the application of existing warhead designs to a new weapon system.

While there will be constraints placed upon repackaging so that warhead performance is not adversely affected, repackaging is largely governed by considerations of cost rather than questions of feasibility.

How Would Nuclear Weapon Effects Tests be Influenced by a Low-Threshold Test Ban?

All of the weapon effects tests conducted during the past decade by the Defense Nuclear Agency (DNA) of the Department of Defense (DOD), the agency responsible for such tests, have utilized nuclear explosives with yields less than . . . . All could have been conducted within the limitation of a . . . LTTB, had that been necessary. The purpose of such tests is to expose military hardware, usually reentry vehicles and their contents, to the neutrons, gamma rays, x rays, and electromagnetic pulse that are produced by nuclear explosives, to evaluate its vulnerability to nuclear attack. Some small-scale modeling experiments at very low yield have also been conducted to explore the cratering effects of nuclear explosions.

One important vulnerability test is exposure of a reentry vehicle to . . . . These . . . are now provided by a nuclear explosive having a total yield less than had previously been required. Concerning this lower yield source of . . . :

> The . . . device performed as predicted, thereby certifying the . . . as a reliable, low-yield, . . . source suitable for use in DNA's low-yield exposure test bed. The . . . was designed specifically to produce an output . . . spectrum very similar to that of the . . . device, permitting its use as the source for DNA exposure tests (which in the past have used the . . .). The use of the lower-yield . . . device is expected to decrease the test costs, since the exposure area can be placed closer to the device, which reduces the mining, construction, and containment costs.

There is little doubt that all of the DNA vulnerability tests conducted during the past decade can now be done without exceeding the yield limit of a . . . LTTB. With further development of still lower yield sources, which would require only low-yield nuclear tests for certification, DNA effects tests could be carried out within a . . . limit.

Summary and Conclusions

Primarily, two questions have been addressed here:

1. How reliable are the nuclear weapons in the U.S. stockpile?
2. Could the reliability of the stockpile be maintained for the foreseeable future within the limitations of a LTTB?

Consideration has also been given to the question of maintaining the reliability of the stockpile during a CTB, presumably preceded by a LTTB of appreciable duration.

The nuclear test record of the past decade, together with properties intrinsic to nuclear weapons themselves, leaves no doubt about the answer to the first question. A high degree of confidence in the reliability of the existing U.S. stockpile of nuclear weapons is justified.

Before answering the second question, it needs to be understood that

- Maintenance of the stockpile is to be accomplished by remanufacture, when required, of the nuclear weapons now in stockpile. Manufacture of new nuclear weapon designs for whatever purpose is specifically excluded from consideration.
- The foreseeable future is defined as the 20-year period after the LTTB goes into effect.
- The nuclear explosive yield threshold of the LTTB is considered to be at least 1 kt. (Tests with yields greater than the threshold are forbidden.)

With this understanding, the answer to the second question is affirmative, provided that:

- A vigorous scientific and engineering program will continue to be supported at the weapon design laboratories in areas of, or related to, nuclear weapons research and engineering that will include those nuclear explosive tests permitted within the limits set by a LTTB.
- Necessary action will be taken to ensure future availability of all materials needed for manufacture of nuclear weapons of the same type presently in stockpile.

An unbiased evaluation of the test record of the past decade shows that the performance of U.S. nuclear weapons, with the exception of a small number of identifiable high-risk tests, is predictable and reliable to a truly remarkable degree. The nuclear test record, together with properties intrinsic to nuclear weapons themselves, clearly indicates that the nuclear weapons in the present U.S. stockpile are sufficiently robust to allow reliable replication, if necessary. Under the conditions outlined above, it is concluded that the necessary materials and expertise required for the remanufacture of the existing stockpile can and will be available, and that remanufacture can be successfully accomplished.

It should also eventually be possible to maintain the reliability of the stockpile within the limits of a CTB. Presently the nuclear weapons production complex depends upon the advice and counsel of weapons design engineers and scientists at the weapon design laboratories to monitor the quality of the materials, components, and weapons produced. It will be more difficult to retain the skill, interest, and services of these people in the absence of a program of nuclear tests. Assuming, however, that a CTB would be preceded by a LTTB, as seems desirable and indeed probable in view of current legislative actions by the House and Senate, there would be ample time to make required changes to minimize reliance of the production complex upon weapons lab design personnel. Even though nuclear tests would be ruled out in these circumstances, it is assumed that a vigorous program would continue to be supported at the laboratories in areas complementing and related to nuclear weapons science and engineering.

A detailed review of the problems encountered with the 14 weapon designs since 1958 that have been frequently and prominently cited as evidence that a LTTB or a CTB would preclude the possibility of maintaining a reliable stockpile, shows that this experience has little if any relevance to the question of maintaining the reliability of the stockpile of nuclear weapons that exists in 1987.

Recommendations

During the Moratorium of 1958-1961, a Readiness Program was instituted whose purpose was to ensure that the U.S. would be in good position to resume nuclear testing should the Moratorium suddenly be terminated. What is needed today is a Readiness Program whose purpose is to ensure that the U.S. is in good position to maintain the reliability of its stockpile of nuclear weapons in the absence of nuclear explosive tests. There is much work to be done, inasmuch as preparations for future remanufacture of the nuclear weapons now in stockpile must be done individually for each different weapon design on a case-by-case basis.

It is recommended that the DOE be encouraged to undertake the formulation and execution of such a plan, and that funds earmarked for this purpose be provided. The Readiness Program would require the participation of representatives of the nuclear weapons production complex, the nuclear weapons design laboratories, DOE headquarters, and DOD. It would appropriately be directed by the Albuquerque Operations Office of DOE.

Appendix A.
Letter from the Honorable Les Aspin et al. to Dr. Roger Batzel, March 30, 1987

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, Some Little-Publicized Difficulties with a Nuclear Freeze, R&D Associates. Report RDA-TR-122116-001, October, 1983. (Unclassified)

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

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

3. Dr. Roger Batzel, Classified Addendum. 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.
Results of Stockpile Confidence Tests (1979–1986)

During the recent eight-year period of 1979–1986, there have been a total of . . . SCTs, most of which had expected yields greater than 1 kt. The expected and measured primary and total yield of each of these tests, and the error in predicting the total yield of each is given in Table B1. Predictions of the total yield have been remarkably accurate, the rms error amounting to only . . . . The distribution of the yield prediction errors is shown in the bar graph of Fig. B1. In only three instances did the measured yield differ from the expected yield by more than . . . . The error of the yield measurement itself is believed to be in the neighborhood of ±5%.

In only one instance, the test of the W84 warhead, did the SCT disclose a problem that required modification of a stockpiled weapon. The only action needed to correct the problem was . . . . No change in the nuclear assembly system was required.

Table B1. Deleted.

Figure B1. Deleted.

Weapons to be tested early in their stockpile life are usually taken from the stockpile within the first year of deployment. They do receive some limited stockpile exposure, such as transport and handling by the responsible military services. Many older weapons that have been in the stockpile for a number of years have also been tested as a part of the SCT program. An example is the successful test of a warhead suitably altered to comply with the 150-kt limit of the Threshold Test Ban Treaty, that had been in stockpile for about 20 years.

The SCTs conducted during 1979–1986 are representative of approximately . . . of the total number of weapons in stockpile, depending on whether a test of a single mod is assumed to test only that mod or all mods of the same weapon. Assuming the former, we may say that those different kinds of weapons that have been given SCTs account for . . . the existing stockpile. Had SCTs been performed on those kinds of weapons that account for the remaining stockpile, it is reasonable to expect, though not certain, that similarly favorable and reassuring results would have been obtained.

We therefore conclude that the available evidence, particularly the results of the SCTs that have been performed, indicates that the reliability of the existing stockpile is indeed sufficient for its intended purpose of deterring a nuclear war. We note that the problem with the W84 that was discovered in 1984 has been corrected.

Appendix C.
Problems Encountered with the Often-Cited 14 Weapon Designs: The Sixties Nine and the Eighties Five

The 14 weapon systems that have required nuclear testing either to identify or confirm a problem or to assure that it has been fixed, together with an identification of the origin of the problem, are listed in Table C1. It is important to note that these 14 weapon systems can be cleanly divided into two distinct groups—the Sixties Nine and the Eighties Five. Problems with the Sixties Nine were discovered and corrected during 1962–1964, shortly after the end of the 1958–1961 Moratorium on nuclear weapons testing. Problems with the Eighties Five were discovered and corrected more recently (1980–1985).

The Sixties Nine

The nine nuclear weapons in this group are the B28, B43, W44, W45, W47, W50, W52, B57, and W59. (Three of these weapons, the W47, W52, and W59, were retired from stockpile ten or more years ago.)

It is essential to recognize that the circumstances that surrounded the postdeployment nuclear tests of these nine weapons were very different from those that would exist if a 1-kt limit on nuclear testing were imposed today.

- The state of knowledge and experience with nuclear weapons was significantly inferior to that which exists today. This was particularly true in the vital area of boosted fission. We now have the benefit of a quarter-century of added experience with many hundreds of nuclear tests.
- Evidence of this need for information is suggested by the desperate pace of nuclear testing that took place during the month preceding the Test Moratorium. Thirty nuclear tests were conducted, representing a testing rate that is nearly 20 times the U.S. nuclear testing rate that now exists and has existed for

Table C1. Fourteen weapon systems that have required nuclear testing either to identify or confirm problems or to assure performance after modifications.

Weapon	Problem	Problem origin
	The Sixties Nine	
B28	Performance with aged tritium (1962) –1958)	a
B43	Performance with aged tritium (1962) –1961)	a
W44	Performance with aged tritium (1962) 1961	a
W45	Performance with aged tritium (1964) 1961	a
W47	Neutron vulnerability (1962) 1962	b
W50	Performance with aged tritium (1962) 1963	a
W52	Improved HE safety (1963) 1962	c
B57	Performance with aged tritium (1962) 1964	a
W59	Performance with aged tritium (1962) 1962	a
	The Eighties Five	
B61	Low-temperature performance (1981) 1979 (ok)	d
W68	Deterioration of HE (1980) 1970	c
W79	Performance with new gas fill system (1982) 1981	e
W80	Low-temperature performance (1981) 1980	d
W84	Stockpile confidence — no problem anticipated (1984) 1983	e

[a] Effect of aged component not tested.
[b] Vulnerability requirement not tested.
[c] Significant modification made but not tested.
[d] Environmental requirement (severe) not tested.
[e] Production version not tested.

many years. Ten of these tests were conducted during the last five days preceding the Moratorium. At the present rate of testing, ten nuclear tests would extend over months.

- For the past decade, the stockpile has existed in a state of quasi-equilibrium in which the total number of weapons has been nearly constant. During this period, new weapons were added to the stockpile at a rate slightly less than that at which older weapons were being retired. In sharp contrast, the average build-rate during the three-year Test Moratorium was . . . .
- A LTTB with a threshold of 1 kt or greater would present conditions significantly different from those during the Moratorium in which *no* nuclear testing was permitted. Such a LTTB would have allowed all one-point safety tests to have been done (and many were needed), and most primaries and single-stage weapons to have been tested at their full unboosted yield.

The limited state of knowledge and experience that existed during the Moratorium when weapons were rushed into the stockpile is exemplified by the fact that . . . was conducted for this purpose nearly a year after post-Moratorium testing had resumed. It was known that . . . would result in reduced explosive yield for three reasons.

* * *

Since the days of the Moratorium, it has been standard practice to conduct a nuclear test of a weapon with aged, end-of-life conditions, typically aged . . . years or more depending on the components, before certifying it for stockpile. Weapons in the existing stockpile have all been subjected to such tests during their development phase and, in many cases, in postproduction or SCTs as well, in sharp contrast to the seven weapons that received no such tests prior to stockpile certification in the early sixties.

The two remaining weapons of the Sixties Nine are the W47 and the W52, weapons that were retired from stockpile ten or more years ago. About the W47, Dr. Jack Rosengren has this to say:

> In developing the [W47 and W56] warheads *the [Livermore] Laboratory had paid much more attention to achieving a workable design than to avoiding vulnerabilities.* [Emphasis added.]

In spite of inattention to vulnerability aspects of design, the W47 was certified for stockpile during the Moratorium without a vulnerability test. When testing resumed, . . . uncovered a severe vulnerability problem.

* * *

The test of the W47 was prompted by a prudent concern that its vulnerability . . . needed to be evaluated in a nuclear test. Had it not been for the Moratorium and the rush to stockpile the W47 during that period (conditions markedly different from those that apply to the existing stockpile), the needed vulnerability test would have been conducted before rather than after stockpile entry. Postdeployment tests would not have been needed.

In the case of the W52, its HE was changed. This substantial change took place during the Moratorium, and the new version was stockpiled without a nuclear proof-test. When it was later tested . . . it failed, providing . . . of its expected yield. Once again, the Moratorium rush resulted in insufficiently tested nuclear weapons being certified for stockpile. No weapon exists in the stockpile today, nor has it since the early sixties, that employs an HE that is different from that with which it was tested. Such a substantial change mandates one or more nuclear explosive tests.

The rush to build during the Moratorium, combined with the absence of testing, led to a stockpile that was very poorly tested by today's standards. Our understanding of how nuclear weapons work, our experience with nuclear tests, and our computational capabilities were all significantly inferior to that which exists today. There has been no rush to build the present stockpile, and it has benefited from a quarter-century of additional nuclear tests since the hectic days of the Moratorium. For these reasons, experience with the Sixties Nine has little or no relevance to the reliability of the existing stockpile of nuclear weapons.

The Eighties Five

The five nuclear weapons in this group are the B61, W68, W79, W80, and W84. The actual or potential difficulties with these weapons differed from those of the Sixties Nine in that they were unrelated to the Moratorium. Postdeployment nuclear tests of the B61 and W79 disclosed that the potential difficulty anticipated had in fact not materialized, and corrective action was unnecessary.

In the case of the W68, a complete rebuild of all weapons in stockpile was undertaken in which the HE (LX-09), which was found to produce a harmful chemically reactive effluent, was replaced with LX-10. Rosengren indicates that

> On the basis of the earlier nuclear tests, LLNL was confident of the reliability of the modified warheads, and the (certifying) Laboratory did not require a new nuclear test. However, as a "final development test," LLNL did test the W68 again after the retrofit. In this test, LLNL used a weapon that was in many ways at the edge of acceptable tolerances and had one limited-life component with an age that was over that of any to be used in the stockpile. This extreme test device performed successfully, confirming the Laboratory's confidence.[8]

Although a nuclear test was not believed to be required, it was nonetheless prudent to test this modification of the W68. There has been no further use of LX-09 in any nuclear weapon; its first and last use was with the W68.

The test of the W80 air-launched cruise missile was to determine if the weapon would function properly . . . .

* * *

As a result, it was decided to test the performance of the B61 (Mod 4) tactical bomb. The overall performance was considered to be satisfactory. No modification of the stockpiled B61 was required.

The remaining two weapon designs that required postdeployment nuclear tests were the W79 and the W84. In neither case had the stockpiled version of the weapon been tested. Since the W79 had last been tested, there had been a number of minor changes in warhead parts, some structural changes in the system . . . . In view of these changes, it was decided to conduct . . . to check the performance of a stockpiled war reserve unit under relatively severe end-of-life conditions . . . the overall performance of the W79 was deemed satisfactory.

In the case of the W84 . . . . It was stated that

> The loss in yield has been attributed to the effects of a combination of uncalculable engineering changes which were required between the previous development tests and the actual stockpile configuration.

That is, there were known differences between the device tested and the stockpiled weapon. Those differences resulted in a loss in yield, for reasons not fully understood.

Summarizing the experience with the Eighties Five, we find that:

- Postdeployment tests of the B61 and the W80 were conducted to test *for the first time* their performance in their stockpile-to-target sequences, there being reason to question that performance. The B61 performed satisfactorily, whereas the W80 did not.
- Postdeployment tests of the W79 and the W84 were conducted to test *for the first time* the version of the warhead that had been placed in stockpile. The W79 performed satisfactorily; the W84 did not.
- A postdeployment test of the W68 was conducted to test *for the first time* a modification, which employed a different HE. The HE originally employed had not been adequately tested for chemical stability and compatibility prior to stockpile certification and was later found to be unsatisfactory.

The postdeployment nuclear tests of the Eighties Five would not have been necessary had requisite chemical and nuclear tests been conducted in advance of their deployment.

A 1987 Addition to the Postdeployment Tests

A successful postdeployment nuclear test can now be included with the postdeployment examples discussed above. The . . . was a one-point safety test . . . . The results of the test agreed well with predictions, and demonstrated very conservative safety . . . .

It would have made no difference had a LTTB been in effect for this test because there was no possibility that the test yield could approach 1 kt. This one-point safety test can, therefore, hardly be presented as evidence that a LTTB would interfere with the maintenance of a reliable stockpile.

Appendix D.
Yield Control

* * *

No change in the nuclear assembly system was required.

Figure D1. Deleted.

Appendix E.
Dependence of Secondary Yield on Primary Yield in Thermonuclear Weapons

It is a property of thermonuclear weapons that the yield . . . .

* * *

The relationship between the primary and secondary yield of the . . . missile warhead currently in stockpile is shown in Fig. E1. The calculated secondary yield (solid curve) varies by . . . as the primary yield ranges . . . in yield. Also shown are the results of nuclear explosive tests and the corresponding calculations, which differ from the experimental results by less than . . . .

Figure E1 also illustrates the property that the . . . . This can be used to advantage to increase weapon reliability and robustness . . . .

Similar calculated curves for three additional thermonuclear weapons are shown in Fig. E2. The primary and secondary yields, Y_p and Y_s, respectively, have been scaled . . . for convenience.

All these weapons show the same characteristic . . . . Satisfactory performance can be expected with primary yields varying from approximately . . . .

* * *

Figure E1. Deleted.

Figure E2. Deleted.

Appendix F.
Results of All Nuclear Tests With Yields Exceeding 1 kt During the Recent Five-Year Period (1980–1984)

The recent, overall capability of the weapons labs to predict the performance of nuclear weapons is illustrated in Fig. F1. The error in predicting the yield of the primary in the case of thermonuclear weapons, or in predicting the total yield in the case of single-stage weapons, was less than . . . in more than 90% of the . . . nuclear tests conducted during the five years from 1980-1984 in which the total yield exceeded 1 kt. Bar graphs showing the distribution of yield prediction errors of the Livermore and Los Alamos tests for which the error was less than . . . are provided in Figs. F2 and F3, respectively. The rms prediction error in these tests is essentially the same for both labs: . . . for Livermore and . . . for Los Alamos.

The predicted yields of six of the tests exceeding a kiloton were in error by more than . . . . On the high side, the yield with the largest error was . . . that predicted; on the low side, it was . . . that predicted. For each of these six outliers, there was reason to anticipate the possibility of unusually large errors in yield prediction, as explained in Appendix G.

With the exception of the six cases in which difficulties in yield prediction could reasonably have been anticipated, and in most cases were, the recent five-year test results exhibit an rms yield prediction error of only . . . . Considering the fact that the experimental error in measuring the yield itself is thought to be on the order of 5%, and that this source of error contributes to the yield prediction error, it is clear that the existing ability to predict the yield of nuclear weapons, with very few exceptions, is remarkably good.

Figure F1. Deleted.

Figure F2. Deleted.

Figure F3. Deleted.

Appendix G.
Six Nuclear Tests During 1980–1984 for Which Predicted Yields Were in Error by More Than . . .

During the five-year period of 1980–1984, there were six nuclear tests in which the predicted primary yield differed from that observed by more than . . . . The observed/predicted yield ratios of these six tests were previously discussed in Appendix F. What, if anything, was unusual about them? Let us consider them individually.

The . . . was conducted as a proof test to determine, for the first time, if the weapon would function properly . . . .

* * *

Clearly this test would not have been performed at all, had there not been some concern that . . . might significantly degrade warhead performance. It should have been conducted before stockpile certification, rather than after deployment.

* * *

None of the primaries in the existing stockpile employ the . . . .

. . . was an advanced development test of a *new* weapon utilizing . . . ; the second test of a concept first tested in . . . . In . . . , however, the material used was replaced. About these very substantial modifications it was stated that

> Modifications made in . . . were not adequately characterized in the calculations. Computer modeling of some of *the new features* in this device was not correct and resulted in an overestimate . . . and consequently a low . . . performance. [Emphasis added.]

The device gave only . . . the yield expected. It was only the second test of a rather challenging concept and embodied important new features that had not been adequately characterized.

. . . was the *first* in a series of tests of a *new* warhead that depended upon . . . .

* * *

Kemic's comments about this possibility of failure are as follows.

> The possibility of this outcome had been considered in recognition of the *extreme complexity* in the process of extrapolating from the . . . to determine proper . . . . [Emphasis added.]

That is, the failure of this first test was a disappointment, but not a surprise, considering the extreme complexity accorded the required extrapolation.

The . . . and . . . events were closely related. Both tested the performance of the . . . and both suffered from a lack of information for determining . . . . Concerning . . . it was stated:

> This occurrence had been considered to be one of several possible outcomes of the experiment due to the difficulty of determining . . . .

As was true of . . . , the failure to achieve the desired yield was a disappointment, but not a surprise.

It was known in advance that the uncertainty was somewhat larger than usual because

- Only a short time had been available to design components.
- No . . . test was fielded.
- Systematics . . . did not exist.

The measured yield indeed fell within this anticipated range. There was neither surprise nor disappointment by this result.

Summary

These six outlying tests can be briefly characterized as follows

- First nuclear test of . . . .
- First development tests of a new, unusual, and complex design.
- First tests . . . sensitive to data that was not available.
- First test of primary, subject to large, known uncertainties in design. Performed within expectations.

. . . were disappointments, but clearly not surprises. . . . was neither a disappointment nor a surprise. . . . was the only event of the six outliers that qualifies as a surprise. Its failure was unquestionably a surprise to those who had certified its performance for stockpile. There is also no question that the postdeployment test of the . . . was deemed necessary. The effort and expense of conducting such a test was justified by the uncertainty in the required . . . performance of the . . . , performance that had never been checked in any nuclear test. It was recognized that the . . . had not been adequately tested before being certified.

Appendix H. Results of the First Nuclear Test of New Primaries During the Past Decade (1977–1986)

During the past decade, new boosted primaries have been designed and developed by the weapons laboratories . . . performed satisfactorily the very first time they were tested, the observed yield in no case falling short of that expected by more than . . . (See Tables H1 and H2 and Fig. H1). The one new primary that failed was of a more complex, less predictable design than the others. This primary was subsequently redesigned, tested, and failed again. None of the primaries in the existing stockpile employ . . . .

This experience demonstrates that the ability of the weapons labs to predict the performance of newly designed, as yet untested, boosted primaries of the kind currently in stockpile is indeed impressive — there were no significant surprises. This could hardly have been the case had these primaries been sensitive to differences that inevitably exist between the weapon configuration calculated and the weapon tested.

Table H1. Deleted.

Table H2. Deleted.

Figure H1. Deleted.

Appendix J.
Primary Performance in the Sequence of Nuclear Tests of the W84 (1978–1985)

The error in predicting the yield of the primary is shown in Fig. J1(a) for each of the nuclear tests of the W84.

* * *

If this consistent source of error is removed, the result is shown in Fig. J1(b). The mean error in yield prediction is then reduced to zero and the maximum error is less than . . . , roughly . . . the error in the yield measurement itself. There is no evidence that yield predictability decreases as weaponization features are introduced. . . . is the only discernible source of yield uncertainty in the W84 tests.

Table J1. Deleted.

Figure J1. Deleted.

Appendix K.
Expert Views on Nuclear Weapon Stockpile Maintenance in the Absence of Nuclear Explosive Tests

Bradbury, Garwin, and Mark

The following is a copy of a letter from Drs. Bradbury, Garwin, and Mark to President Jimmy Carter, dated August 15, 1978.

August 15, 1978

President Jimmy Carter
The White House
Washington, D.C. 20500

Dear Mr. President:

As individuals long involved in the conception, design, manufacture, test, and maintenance of many of the United States' nuclear and thermonuclear weapons, we want you to know of our judgment on a question which has assumed considerable prominence in connection with the Comprehensive Test Ban Treaty ("CTBT"). That is the question of the degree of assurance in the continued operability of our stockpiled nuclear weapons in the absence of any possibility of testing with significant nuclear yield (for instance, with testing limited to laboratory-type experiments.)

As you know, the assurance of continued operability of stockpiled nuclear weapons has in the past been achieved almost exclusively by non-nuclear testing--by meticulous inspection and disassembly of the components of the nuclear weapons, including their firing and fuzing equipment. Problems encountered in this inspection are normally validated by additional sampling and solved by the remanufacture of the affected components. This program is, of course, supplemented by the instrumented firing of the entire nuclear weapon with inert material replacing the fissile materials, and the entire program thus far described would be unaffected by the requirements of a CTBT. It has been exceedingly rare for a weapon to be taken from stockpile and fired "for assurance."

It has also been rare to the point of non-existence for a problem revealed by the sampling and inspection program to require a nuclear test for its resolution. There are three acceptable approaches to the correction of deficiencies without requiring nuclear testing:

1) Remanufacture to precisely the original specifications.

2) Remanufacture with minor modifications in surface treatment, protective coatings, and the like, after thorough review by experienced and knowledgeable individuals.

3) Replace the nuclear explosive by one which has previously been tested and accepted for stockpile.

A fourth option, to replace the troubled nuclear system by one not already prooftested may result in improved performance, lesser use of special nuclear materials, or the like, virtues which have more to do with improvement of the stockpile than with confirming its operability.

We believe that the key question to be answered by those responsible for making and maintaining nuclear weapons is

> "Can the continued operability of our stockpile of nuclear weapons be assured without future nuclear testing? That is, without attempting or allowing improvement in performance, reductions in maintenance cost, and the like, are there non-nuclear inspection and correction programs which will prevent the degradation of the reliability of stockpiled weapons?"

Our answer is "yes," and we now discuss the reasons why knowledgeable people may have answered "no" to seemingly similar questions.

First, we confined ourselves essentially to the question, "If the stockpile is not required to improve, can it be kept from degrading?" Others may have had in mind the normal work of the weapons laboratories, by which nuclear weapons are continuously made somewhat more efficient, less costly in terms of nuclear materials, adapted to new packaging requirements, and safer to handle--for instance by the substitution of insensitive explosive. We have participated in such programs and find them both interesting and useful. Were these "improvement programs" carried out long enough without nuclear testing, the weapons thus affected would indeed have uncertain performance; the solution under a CTBT would be to forego such programs in order not to sacrifice stockpile reliability to a desire for minor improvement in performance.

Second, it is true that certain deficiencies have in the past been corrected by the replacement of the affected nuclear system by another one, following a test certifying the replacement model as ready for stockpile. This corrective measure would not be available under a CTBT. But the examples normally cited need not have been corrected in this way; for instance one Polaris warhead problem could readily have been solved by remanufacture with an acceptable change of surface treatment on the component which had caused the problem. The change of nuclear system was not absolutely necessary for the correction of the problem observed.

Finally, it is sometimes claimed that remanufacture may become impossible because of increasingly severe restrictions by EPA or OSHA to protect the environment of the worker. We note that additional protective measures which might be an intolerable cost burden in the manufacture of cardboard or of lightbulbs or of aircraft brakes are easily affordable in connection with the nuclear stockpile. Thus if the worker's environment acceptable until now for the use of asbestos, spray adhesives, or beryllium should be forbidden by OSHA regulations, those few workers needed to continue operations with such material could wear plastic-film suits (supplied with external air) commonly used for isolation against germs and against certain pharmaceuticals. It would be wise also to stockpile in appropriate storage facilities certain commercial materials used in weapons manufacture which might in the future disappear from the commercial scene.

It has been suggested that under a CTBT a President or Congress or the Department of Energy might not provide funds for stockpile maintenance inspection and correction, or that a President might not provide a requested exemption from OSHA or EPA requirements. We see no reason to assume that the national security bureaucracy will not continue to serve the national interest, and we would welcome a statement in conjunction with a CTBT that non-nuclear testing, inspection, and remanufacture where necessary will be fully supported in order to ensure the continued operability of stockpiled nuclear weapons.

We believe that the Department of Energy, through its contractors and laboratories, can through the measures described provide continuing assurance for as long as may be desired of the operability of the nuclear weapons stockpile. We are making this statement available to others in the Executive and the Congress.

Sincerely Yours,

Norman E. Bradbury

Norris E. Bradbury

J. Carson Mark

J. Carson Mark

Richard L. Garwin

Richard L. Garwin

BIOGRAPHIES

Norris Bradbury was the immediate successor to Robert Oppenheimer when, in 1945, Dr. Bradbury became Director of the Los Alamos scientific laboratory and served in that capacity for a quarter of a century until 1970. A physicist and member of the National Academy of Sciences, Dr. Bradbury was also Professor of Physics at the University of California during this period and is a recipient of the Legion of Merit and of the Fermi Award.

Richard Garwin has been a consultant to the Los Alamos Laboratory for almost three decades, since 1950, and is highly regarded in the national security community for his in-depth technical analyses of an extremely broad range of defense issues. A physicist and member of both the National Academy of Sciences and the National Academy of Engineering, he has served as a member of the President's Science Advisory Committee, as a member of the Defense Science Board and as a consultant to the Arms Control and Disarmament Agency, among other agencies.

J. Carson Mark was head of the Theoretical Division of the Los Alamos Scientific Laboratory from 1947 to 1973. This Division was responsible for, and played a key role in, the conception and design of U.S. nuclear and thermonuclear weapons in the fifties and sixties. He continues to be involved in considerations of weapons effects and with the problem of the maintenance of a nuclear weapons capability under nuclear test limitations.

Phone numbers at which the signatories can be reached are --

Bradbury: 505-662-5068 Garwin: 914-945-2555 Mark: 505-667-7612

Sakharov

The following statement of Dr. Andrei Sakharov concerning nuclear weapons testing appeared in the March 16, 1987 issue of *Time*.

> Regarding the problem of nuclear testing, I maintain that the combat capability of many new versions of nuclear weapons (of both the fission and fusion kind) can be reliably determined without conducting nuclear tests. A possible exception may be weapons based on new physical and design principles. But existing physical and design principals already are quite sufficient to manufacture nuclear weapons satisfying all military requirements. Testing is not required to develop new versions of weapons differing only in terms of dimensions, weight or other such parameters from those previously tested. Testing is currently not necessary to verify the reliability of older, stockpiled weapons or to verify their ability to withstand the mechanical, thermal and radiation effects they may have been subjected to in combat.
>
> One can in principle divide every nuclear charge into four relatively independent systems: electronic, ballistic, atomic and (for a hydrogen device) thermonuclear. The reliability of the first three systems can be confirmed by laboratory tests supplemented by experiments in which a low-yield fission or fusion reaction releases a small quantity of neutrons, which can be measured by a counter close to the charge to be tested. The fourth system—thermonuclear—does not require testing in the majority of cases, since its reliability may be established by analogy to previously tested charges based on the same physical and design principles. At the same time computer simulations of thermonuclear explosions are also quite helpful (calculations of explosive processes exhibiting spherical symmetry or symmetry of the axis of rotation are completely reliable; the reliability and accuracy of these calculations can be verified by comparing the computer simulation of actual test results obtained for analogous charges exploded in the past).

Bethe, Garwin, and Mark

"Ending Nuclear Tests: A Technical Basis," appeared in the April 1987 *F.A.S. Public Interest Report,* the journal of the Federation of American Scientists (volume 40, no. 4), and relates the views of Drs. Bethe, Garwin, and Mark on a CTB.

ENDING NUCLEAR TESTS: A TECHNICAL BASIS

The attached letter of February 3 was solicited by FAS for release in connection with a demonstration in Nevada, led by Carl Sagan, on the occasion of the U.S. renewing of its testing that ended the Soviet moratorium. The authors are, very senior experts. Hans Bethe, Nobel Prize laureate in physics, was the head of the Theoretical Division at Los Alamos during World War II. Carson Mark was his successor, and Richard Garwin has been consulting for Los Alamos on related subjects since 1950, and is renowned for his analyses of strategic issues.

In view of claims and counterclaims about the need for the United States to continue nuclear explosion testing, we want to summarize our views:

1. Nuclear explosion testing is not needed to ensure the reliability of weapons in stockpile which have been tested in their production version. It is not needed to detect degradation nor to remedy degradation. Non-nuclear testing is used for detection, and remanufacture to original specifications is an adequate remedy. In testimony April 8, 1986 to the Senate Armed Services Committee, the Director of the Livermore Laboratory agreed that, "Given enough time and money, replication could be achieved.'

2. The U.S. could not have confidence in the performance of nuclear weapons put into stockpile without testing, and we recognize that a comprehensive ban on nuclear tests, or one which bans all detectable tests, would prevent the acquisition of warheads of new nuclear design. Nevertheless, the Midgetman missile could perfectly well use the warhead which has been designed and tested for the MX missile—the W87. It might need shock-alleviation mounting for a mobile Midgetman subject to nuclear attack, but the demand for a new warhead is analogous to requiring that one redesign an astronaut before launching him or her into space. Careful attention to packaging will do.

3. Although modern security devices for nuclear weapons could be so closely integrated with the nuclear components that these particular systems could not be added to existing weapons, comparable function can be achieved by a system designed to be suitable for retrofit to existing weapons without testing. Insensitive high explosive (IHE) cannot be incorporated into existing weapons which lack them without nuclear testing, but existing weapons are already proof against accidental nuclear explosion, and we believe the incorporation of IHE is not of highest importance. Concern on this point is primarily a matter of peacetime comfort than of wartime need. Since in the absence of any limit on numbers of tests only some 40% of U.S. weapons now have IHE, we must not be alone in this view.

4. As for verifiability of a CTBT, some 25 unmanned seismic detection systems on the territory of the Soviet Union are probably adequate to provide high confidence of detection, location, and identification of nuclear explosions of yield of one kiloton or more. But a treaty should provide for the installation of as many as are required in areas of poor seismic propagation, even 100 stations if necessary. No seismic system can detect the stations if necessary. No seismic system can detect the smallest "nuclear explosion." We could readily design a reliable nuclear explosive of yield one-thousandth of a kiloton, simply to demonstrate that it could not be detected by a particular seismic system. So a *comprehensive* test ban is inherently not verifiable by seismic means. Yet some of the important benefits of a test ban would be lost if low-yield underground nuclear testing were permitted to the nuclear nations. The solution might be to have an initial ban on all nuclear explosions above 1 kiloton yield, a small initial quota of underground nuclear explosions below that yield, and a requirement to pre-announce all nuclear explosions of *any* yield above one ton, and to provide measurement of their yield by an approved method. The detection of violations would be aided by non-seismic and non-cooperative means, and potential violations of marginal detectability would not represent militarily important advances.

5. The benefits to the U.S. of a test ban arise from denying the *Soviet Union* the progress in nuclear weaponry which can be made only by nuclear explosive testing. For instance, the Secretary of Energy expresses concern about possible Soviet progress on the nuclear-weapon-powered X-ray laser. That would cease under an appropriate test ban. Even if the U.S. were first to achieve a new military capability by nuclear testing, our security might be impaired, on balance, if the Soviets then acquired the same capability; MIRV is generally regarded as a case in point. We believe that an important benefit of a test ban would derive from the much firmer base it would provide for our leadership of a world-wide effort to eliminate the spread of nuclear weapons to additional hands—an effort in which technical measures reinforced by strict sanctions would serve U.S. security interests.

6. It would be imprudent to believe that all parties would permanently abide by a test ban. So it would be necessary for the U.S. to maintain facilities, skills, and a program of research and design to ensure that we recognize the potential advances which might be achieved and are in a position to pursue them if the Soviet Union should renounce the test ban. Readiness to test need not be on a scale of days or weeks, since a year or more is required for a new weapon concept to affect military capability. Our skills should be honed by analysis, simulation, competitive design teams, and by the confrontation of simulation results with explosive-driven assemblies without nuclear yield.

7. We believe that it is in the U.S. interest to see an early end to the testing of nuclear weapons.

Richard L. Garwin (IBM Thomas J. Watson Research Center, and Cornell, Columbia, and Harvard Universities)
Hans A. Bethe (Cornell University)
Carson Mark (retired, Former Head of Theoretical Division, Los Alamos Scientific Laboratory, 1947-1973)

Appendix L.
Letter from Richard D. DeLauer to Herman E. Roser, March 29, 1983

A letter from Richard D. De Lauer, Under Secretary of Defense for Research and Engineering, to Herman E. Roser, Assistant Secretary of Energy for Defense Programs, dated March 29, 1983, states in part:

> Attention must be directed toward a design that offers high reliability that will remain in the strategic arsenal well into the next century. Warhead design should be conservative and should not attempt to extend performance beyond well-established regimes. More specifically, the warhead should:
>
> - Minimize the likelihood of deleterious changes during stockpile life.
> - Enhance insensitivity to any changes that may occur.
> - Optimize the capability to replicate the design should a warhead rebuild program be required in the future.
> - Allow for unforeseeable excursions beyond those nominal conditions described in the Stockpile-to-Target Sequence (STS).

Appendix M.
Biography

Dr. Ray E. Kidder, a Fellow of the American Physical Society, has been a senior physicist at LLNL for 31 years. He has written over 100 classified reports dealing with the physics, properties, design, and effects of nuclear weapons, especially thermonuclear physics and enhanced radiation weapons.

As co-chairman of the "Premortem Committee," he reviewed and evaluated designs of the nuclear warheads and bombs fielded by LLNL, prior to testing in Operation Dominic, the last U.S. nuclear test series in the Pacific, in 1962.

Kidder is also the author of physical models and numerical methods in the fields of thermonuclear physics and magnetohydrodynamics, which have been widely used within the nuclear weapons program. He has contributed to the theory of operation and the design of HE generators of electricity. Further, he directed the Inertial Confinement Fusion program at LLNL for the first ten years of its existence. He also independently discovered, and recommended to the Atomic Energy Commission in 1972, the Atomic Vapor Laser Isotope Separation process that LLNL has subsequently successfully pursued.

More recently, Kidder has been studying the design and application of low-yield nuclear explosives, the design of a reusable underground High-Energy Density Facility capable of safely containing low-yield nuclear tests, and the properties of nuclear-driven directed energy weapons.

Kidder is vice-chairman of the Scientific Advisory Board of the Max-Planck Institute of Quantum Optics, Federal Republic of Germany, and a past member of the Editorial Board of the scientific journal *Nuclear Fusion* of the International Atomic Energy Agency.

Acknowledgments

The author wishes to thank Paul Brown, Stephen Cochran, Raymond McGuire, Charles Wraith, and William Zagotta of LLNL for informative discussions and for their help in collecting some of the nuclear weapon test and design data upon which this report is based. They, of course, bear no responsibility for the accuracy of the report, the views expressed, or the conclusions reached.

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JAS/mp