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Report to Congress: Assessment of the Safety of U.S. Nuclear Weapons and Related Nuclear Test Requirements

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Abstract

The principal safety features included in the design of modern nuclear weapons are described briefly, and each nuclear weapon currently in the stockpile or under development is given a comparative safety rating from "A" through "D," indicating the extent to which these safety features are included in its design.

The list is then narrowed by deleting weapons currently scheduled for retirement and short-range, surface-to-surface tactical nuclear weapons that will likely be returned to the U.S. and placed in storage. With the exception of the Minuteman and Trident ballistic missile warheads, all warheads in this projected future stockpile will have both of the most important design features that contribute to nuclear weapon safety: enhanced electrical isolation (EEI) and insensitive high explosive (IHE).

It is argued that only a modest number (10–20) of nuclear tests would be needed to develop warheads with both EEI and IHE to replace existing Minuteman and Trident warheads (that lack only IHE) should that be deemed necessary. All warheads in the projected stockpile would then meet modern standards of nuclear weapons safety.

Rather than rely on fire-resistant pits, as recommended by the Drell Panel,[1] to reduce the risk of plutonium dispersal in a crash or fire involving an aircraft with nuclear warheads aboard, an alternative is proposed: to prohibit, in peacetime, air transport of nuclear warheads or their deployment aboard aircraft in proximity to operating runways, being refueled, or starting their engines.

It is concluded that the safety of the U.S. stockpile can be brought up to a level that meets modern standards within a few years and with a modest number of nuclear tests, given an appropriate retirement schedule for older weapons in the stockpile, and restrictions on the air transport of nuclear weapons and their deployment aboard aircraft .

It is recommended that the Departments of Energy and Defense be encouraged to undertake, as a part of the existing Nuclear Test Ban Readiness Program, the formulation and execution of a joint program to ensure that the U.S. stockpile of nuclear weapons meets modern safety standards by the year 1996.

Introduction

This independent technical assessment of the safety of U.S. nuclear weapons and related nuclear explosive test requirements was prepared in response to a letter of November 19, 1990, from the Honorable Edward M. Kennedy et al. to Mr. John Nuckolls, Director of the Lawrence Livermore National Laboratory (LLNL). The task to be accomplished and specific questions to be answered are described in this letter, a copy of which is provided in Appendix A.

On February 27, 1990, certain issues were raised regarding the safety of the U.S. nuclear arsenal by the directors of the nuclear weapon design laboratories during a hearing before the Department of Energy Defense Nuclear Facilities Panel of the House Armed Services Committee. As a result, a three-person panel, chaired by Dr. Sidney D. Drell of Stanford University, was established to evaluate these issues and to advise the Committee. (See Appendix B, letter from the Honorable Les Aspin et al. to the Honorable James D. Watkins, May 3, 1990.) Shortly thereafter, these safety concerns were brought to the attention of the public in a series of six articles by R. Jeffrey Smith in the *Washington Post* during May 23-29.

The importance of nuclear testing for the detection and correction of possible weaknesses in nuclear weapons safety was stressed strongly by the President's National Security Adviser, Brent Scowcroft, in a letter of July 9 to Senator Kennedy in which he stated (see Appendix A):

"Recent revelations regarding the safety of certain nuclear warheads underscore the importance of testing, both as a vehicle for detecting possible weaknesses in weapons safety and in devising appropriate corrective measures for any such weaknesses. To do otherwise would create uncertainty as to the safety of the stockpile, and render us unable to make safety improvements and unable to react to new threats."

The press accounts highlighting questions about the safety of U.S. nuclear warheads, together with the possibility suggested by General Scowcroft's letter that extensive and continuing nuclear explosive testing might be required to correct these safety problems, indicated that their resolution might have significant arms control implications. Concern within the House Foreign Affairs Committee over these implications resulted in a letter of July 17, addressed to me by its Chairman, the Honorable Dante B. Fascell, requesting that I conduct an assessment of the safety of our nuclear warheads and provide my views on several specific questions. My reply was transmitted to Congressman Fascell on August 28, being necessarily brief due to the time constraints then imposed.*

On November 19, Senator Kennedy and other members of the Congress, referred to in the above letter, asked that a more comprehensive assessment of U.S. nuclear weapon safety and related nuclear test requirements be undertaken than that submitted to Congressman Fascell. This report is the response to that request.

The report of the Drell Panel on nuclear weapons safety was presented at a hearing of the Nuclear Facilities Panel of the House Armed Services Committee on December 18, 1990. The subject matter of the Drell Panel's report differs significantly from this one in at least two respects. It provides detailed discussion and recommendations concerning organizational arrangements within the Departments of Defense/Energy that relate to nuclear weapons safety, an important matter not considered in this report. However, it does not consider the nature and number of nuclear tests that might be required to implement the safety improvements it recommends—a matter with significant national security and arms control implications that this report will deal with in some detail.

To efficiently focus attention on the essentials, we shall proceed directly to a consideration of the safety-related characteristics of the individual warheads in the present and planned U.S. stockpile of nuclear weapons.

Principal Means of Providing Nuclear Warhead Safety

The principal means of providing for nuclear warhead safety are the use of:

Enhanced Electrical Isolation (EEI): Reduces the chance of the warhead's detonators being fired electrically in an accident to less than one in a million. It was first introduced in the B61-5 tactical bomb in 1977. [This safety feature is referred to in the Drell Panel Report and elsewhere as Enhanced Nuclear Detonation Safety (ENDS).]

Insensitive High Explosive (IHE): A high explosive that is much less sensitive to being detonated by fire or impact than is the HE used in all nuclear warheads that entered the stockpile prior to 1978.

Fire-Resistant Pit (FRP). The pit of a nuclear weapon is the part of the primary, or first stage of the weapon, that contains the plutonium. If the plutonium is encased within a ductile, high-melting-point metal shell that can withstand prolonged exposure to a jet fuel fire (~1000 °C) without melting or being eaten through by the corrosive action of molten plutonium, it then qualifies as an FRP. Although the plutonium itself may melt, it will remain contained within the encasing shell and not be dispersed into the environment.

Mechanical Safing (MS): Can virtually eliminate the possibility that any significant nuclear yield will result from an accident in which the warhead's high explosive is detonated. (A nuclear yield is defined as significant if it exceeds that equivalent to exploding four pounds of HE.) Mechanical safing has been used successfully for more than 20 years.

Separable Components (SC): A means of achieving many-point safety by physically separating the plutonium in the warhead from the HE by a sufficient distance and/or barrier before arming the weapon. Accidental detonation of the HE could not then result in either plutonium dispersal or nuclear yield. (No warhead in stockpile utilizes this concept.)

One-Point-Safe (OPS) Design: Insures no significant nuclear yield will result if the warhead's HE is detonated at any one point.

*This reply has since been published in *The Bulletin* of the Atomic Scientists, Vol 7, No. 3, April 1991, pp. 32-34.

The Drell Panel Report provides a far more thorough and detailed discussion of EEI, IHE, and the properties of missile propellants and their relation to nuclear weapon safety than is presented here. That excellent tutorial discussion is reproduced for reference in Appendix C.

(Please recall that the Drell Panel Report refers to EEI as enhanced nuclear detonation safety (ENDS), describing the result of this safety measure rather than the means used to achieve it as we have done.)

One-Point Safety

In 1968, a quantitative safety requirement was established that all nuclear warheads in the stockpile shall be one-point safe, which means if the HE in the warhead is detonated at any single point, there will be less than one chance in a million that any significant nuclear yield will result (specifically, no more nuclear yield will result than that equivalent to exploding four pounds of HE).

Nuclear warheads are also required to be inherently one-point safe, that is, one-point safety shall be obtained without the use of a nuclear safing device (such as mechanical safing). (See Appendix D for the official specification of warhead safety criteria.) This requirement should not be interpreted as prohibiting the use of a mechanical safing device, but rather as a requirement that one-point safety should obtain even in its absence.

Many-point detonation safety of a sealed pit warhead can, strictly speaking, only be obtained by means of mechanical safing. (In the absence of mechanical safing, a large nuclear yield will surely result if near-simultaneous detonations should accidentally occur at or near the warhead's detonators.) Indeed, it is possible that an inherently one-point safe warhead, without mechanical safing, could be less safe than a mechanically-safed warhead that was not inherently safe. For this reason, the requirement of inherent safety should be reconsidered and possibly modified.

Nuclear Safety

A warhead has the property of nuclear safety, or of being nuclear-safe, to the degree to which no accidental release of a significant amount of nuclear explosive energy, or nuclear yield, is possible.

EEI and IHE each reduce the risk that a warhead's HE will be accidentally detonated; the former electrically, and the latter mechanically. Therefore, each contributes to both nuclear safety and plutonium-dispersal safety (see below).

MS and OPS each contribute to nuclear safety but not to plutonium-dispersal safety because neither reduces the risk that a warhead's HE will be accidentally detonated. MS provides both many-point and one-point safety.

Plutonium Dispersal Safety

FRP contributes to plutonium-dispersal safety in those accidents in which a warhead is subjected to fire, but only if the warhead's HE does not detonate.

The areal extent of possible plutonium dispersal that can result from a fire in which the HE detonates is far larger (typically one-hundred times larger) than if it does not. Detonation of the HE causes most of the plutonium to be aerosolized into small micron-sized particles of plutonium oxide that can be carried aloft and dispersed by local winds over a large area. EEI and IHE are, therefore, far more significant contributors to plutonium-dispersal safety than are FRPs.

Safety Standards for Nuclear Weapons

The existing nuclear weapons safety process, and the safety standards that have been specified for the stockpile, are set forth in the Drell Panel Report and reproduced for reference in Appendix D.

Comparative Safety of U.S. Nuclear Warheads

Table 1 lists the U.S. nuclear weapons currently under development or presently in the stockpile. The weapons in the stockpile are listed in order of stockpile entry date, beginning with the most recent, and are assigned a relative safety grade ranging from "A" to "D," with "A" being the highest grade and "D" the lowest.

Table 1. Warhead safety ratings.

Warhead	Weapon system	Stockpile entry date	Safety "grade"	Warhead	Weapon system	Stockpile entry date	Safety "grade"
Development				W61	Earth penetrator	------	B
W91	SRAM T	-------	A	B61-8	Tactical bomb	------	B
W89	SRAM II	------	A	B61-9	Tactical bomb	------	B
B90	Tactical bomb, NDSB	------	A	B61-6	Tactical bomb	------	B

Table 1. Warhead safety ratings (cont.).

Warhead	Weapon system	Stockpile entry date	Safety "grade"
Stockpile			
(Entered stockpile after 1979)			
B61-10	Tactical bomb	1990	B
W88	Trident II D5 SLBM	1990	C
B53-1	Strategic bomb	1988*	C-
W87	MX Peacekeeper ICBM	1986	A
B61-7	Strategic bomb	1986	B
W80-0	Cruise missile, SLCM	1984	B
B28-0,1	Strategic bomb	1983*	C-
W84	Cruise missile, GLCM	1983*	~~B~~ A
B83	Strategic bomb	1983	A
W85	Pershing II IRBM	1983*	B
W80-1	Cruise missile, ALCM	1982	B
W70-3	Lance SSTM	1981	D
W79	Artillery shell, 8 in.	1980	C+
B61-3	Tactical bomb	1980	B
B61-4	Tactical bomb	1980	B
W78	Minuteman III ICBM	1980	C
W76	Trident I, II C4 SLBM	1979	C

Warhead	Weapon system	Stockpile entry date	Safety "grade"
(Entered stockpile before 1979)			
B61-5	Tactical bomb (=> B61-8)	1977*	C
B61-2	Tactical bomb (=> B61-8)	1976*	D
W71	Spartan ABM	1975*	D
W70-1,2	Lance SSTM	1973	D
W69	SRAM A (=> SRAM II)	1972*	D
W68	Poseidon SLBM	1970*	D
W62	Minuteman III ICBM	1970*	D
W56-4	Minuteman II ICBM	1968	C+
B61-0	Tactical bomb (=> B61-6,9)	1968*	D
B57-1,2	Depth/strike bomb	1963*	D
W48	Artillery shell, 155-mm	1963*	D
W50	Pershing 1A IRBM	1963*	D
B43	Tactical bomb	1961*	D
W33	Artillery shell, 8-in.	1956	NA

* An asterisk indicates warheads that have been retired or are being retired. The symbol => means "to be replaced by."

The grading system used in Table 1 is as follows:

- A: Has EEI, IHE, and FRP.
- B: Has EEI, and IHE.
- C+: Has improved safety.
- C: Has EEI.
- C-: Does not have full EEI.
- D: Has none of the above safety features.
- NA: Not applicable. The W33 does not contain plutonium and is not a sealed pit design. It is a two-component, gun-assembled weapon that fully satisfies modern safety requirements when the two components are stored separately.

Eliminating from the list those warheads that have been retired, are being retired, or are currently scheduled for retirement, together with warheads for the short-range, surface-to-surface tactical nuclear weapons (whose utility has become questionable in view of German reunification and the termination of the Warsaw Pact), reduces the weapons remaining in stockpile to those listed in Table 2

Note that a major improvement in stockpile safety will result from the retirement of the short-range tactical weapons and the planned retirement of the older types of warheads in the stockpile. All will have a grade of "C" or better. With the exception of the Trident I, II C4, and Trident II D5 SLBM warheads and the Minuteman III ICBM warheads, all the warheads remaining in stockpile have the safety advantages of both EEI and IHE.

Table 2. Warhead safety ratings (with accelerated retirement schedule.

Warhead	Weapon system	Stockpile entry date	Safety "grade"
B61-10	Tactical bomb	1990	B
W88	Trident II D5 SLBM	1990	C
W87	MX Peacekeeper ICBM	1986	A
B61-7	Strategic bomb	1986	B
W80-0	Cruise missile, SLCM	1984	B
B83	Strategic bomb	1983	A
W80-1	Cruise missile, ALCM	1982	B
B61-3	Tactical bomb	1980	B
B61-4	Tactical bomb	1980	B
W78	Minuteman III, ICBM	1980	C
W76	Trident I, II C4 SLBM	1979	C

The Minuteman Missiles

The W78 warheads of the Minuteman III missiles are currently not scheduled for retirement. These missiles use a nondetonatable Class-1.3 rocket propellant in the first two stages, and a detonatable Class-1.1 propellant in the third stage, as does the modern MX Peacekeeper missile. (See Appendix C for further discussion of missile propellants and their safety). The Minuteman III carries up to three warheads.

Only one "Broken Arrow" or potentially serious nuclear weapon accident has occurred with a Minuteman missile during their 28 years of deployment. (See Appendix E for the definition of DOD nuclear accident categories). In 1964, a W56-1 warhead fell 75 feet when a retrorocket fired accidentally. The warhead was damaged, but its HE did not detonate and there was no dispersal of plutonium.

The land-based ICBM force would be brought up to modern standards of safety if the W56 and W78 warheads were retired or replaced with a modern warhead, such as the W87 MX warhead or a modification thereof.

The Trident Missiles

The W76 Trident I, II (C4) submarine-launched ballistic missiles were first deployed in 1979 and are not currently scheduled for retirement. The W88 Trident II (D5) SLBMs have only recently begun to be deployed. Both missiles use a detonatable Class-1.1 rocket propellant in all three stages.

No Broken Arrow accidents have involved these SLBMs or their predecessors, the Polaris and Poseidon missiles.

Both the W76 and the W88 have EEI, but not IHE or FRP. The C4 and D5 missiles each carry up to eight warheads that are adjacent to and surround the third-stage rocket motor. Safety concerns are raised by the juxtaposition of the detonatable third-stage rocket propellant with as many as eight warheads that do not use IHE. These safety concerns apply equally to both the W88 D5 missiles currently being deployed and the far larger number of W76 C4 missiles already deployed, a point largely overlooked by the Drell Panel.

Following a recommendation of the Drell Panel, a procedural change was made in the manner in which Trident missiles are loaded onto submarines: The warheads are no longer mated to the missile until *after* the missile has been loaded into the launch tubes. This eliminates the possibility that the accidental detonation of a missile's propellant, during loading of the missile into a launch tube could result in the detonation of any (or all) of the missile's warheads.

These safety concerns could perhaps be resolved in the case of the D5 missile by replacing the W88 warheads with a smaller number of MX W87 warheads, or by replacing the W88 nuclear explosive components with those of the W89 SRAM II or a modification thereof and by replacing the third-stage propellant with a nondetonatable Class-1.3 propellant. Replacement of the C4/W76 warheads with warheads using IHE will probably require a new warhead to be designed and tested, rather than replacement by a modified version of an existing warhead.

Fire-Resistant Pits

The Report of the Drell Panel on Nuclear Weapon Safety recommends that all bombs and air-launched cruise missiles loaded onto aircraft be built with the three safety features—EEI, IHE, and a FRP; that is, have an "A" safety rating in our grading system. This recommendation applies to existing warheads as well as those yet to be built. Referring to Table 2, we see that four bombs, the B61 mods 3,4,7, and 10, and the W80-1 air-launched cruise missile achieve only a grade of "B." They all lack fire-resistant pits.

To rebuild the large number of these warheads already in stockpile with FRPs would be a major undertaking, requiring each to be disassembled and reassembled with a redesigned, refabricated pit. The modification needed to provide these warheads with FRPs is sufficiently significant that at least one nuclear explosive test would probably be needed for each of the five types of warheads being modified to verify proper performance of the new design.

A fire-resitant pit is designed to contain and prevent dispersal of the pit's plutonium, should the pit be subjected to an aircraft fuel fire (~1000 °C) for a period of several hours. It might mitigate, but would not prevent, plutonium dispersal in a fuel fire following an aircraft crash if the containment were punctured or breached by the impact of the crash. It would have no effect on reducing plutonium-dispersal should the HE detonate.

A rocket-propellant fire can be much hotter (~2000 °C) than an aircraft fuel fire and could render the FRP ineffective by melting the refractory metal shell intended to contain the plutonium and thus prevent its dispersal. FRPs are, therefore, most likely to be effective in bombs and cruise missiles equipped with IHE and least likely to be effective in rocket-fueled missiles not equipped with IHE.

An alternative to providing bomb and cruise missile warheads with FRPs would be to use the following safety measures to reduce the need for them. In peacetime, these measures would prohibit:

(a) The transport of nuclear weapons by air or their deployment aboard aircraft in close proximity to operating runways.

(b) The refueling or engine startup of aircraft with nuclear weapons onboard or nearby.

A summary of accidents involving U.S. nuclear weapons and nuclear weapon systems is provided in Appendix E. The large majority (84%) of these accidents involved aircraft.

Separable Components

If the plutonium of a warhead were contained in a shock and fire-resistant enclosure separated from its HE by a sufficient distance and/or material barrier before the warhead was armed, detonation of the HE could not result in either nuclear yield or plutonium dispersal. The arming process would, when called on, bring the plutonium and HE together into the required firing configuration, necessitating that one or both materials to be moved into position somehow.

A particularly simple form of the separable components concept was used in the early days (between 1945 and 1951) of nuclear weapons. A removable capsule of fissionable material was inserted manually enroute to the target and removed manually before landing if the mission aborted. Without the capsule, the weapon was absolutely nuclear safe. The capsule was stored separately from chemical explosives.

In 1952, missiles and bombs began to be carried external to the aircraft, requiring mechanical rather than manual insertion of the capsule. This was accomplished by means of an electrically operated screw-jack that was reversible prior to landing. The safety of this arrangement could, however, be compromised by the possibility of inadvertent or accident-caused operation of the motor.

Separable components were abandoned in 1957 in favor of sealed pit designs, in which the fissile material is permanently sealed within the high explosive, and have not been used since.

Separable component designs that would ensure nuclear safety and virtually eliminate the possibility of plutonium dispersal have received and continue to receive considerable attention. However, such designs involve substantial penalties of size, weight, and complexity and are likely to be less robust and dependable than current designs. For these and perhaps other reasons, they have never been put into practice. Implementation of the safety benefits of these designs, should they be successful, would be a major and protracted undertaking requiring a very large number of nuclear tests.

Response to Congressmens' Questions

The questions posed by Senators Kennedy, Wirth, and Harkin, and Representatives Fascell and Markey in their letter of November 19, 1990 (Appendix A), are reproduced on the following pages, together with our answers to them.

Questions 1 and 2:

1. How many, and which, warheads in the current nuclear stockpile have developed nuclear safety problems, and how many weeks, months, and years after the warhead's entry into the stockpile did these problems develop?

2. What fraction of nuclear safety problems have been traced to warhead aging effects, to inherent design defects, and to other causes?

Answer:

Safety problems with nuclear warheads are generally inherent in the design of the warhead itself, not the result of aging or other causes. Such problems may not be identified until long after the warhead enters stockpile, but they were there to begin with.

Metals corrode, and organic materials such as plastics, adhesives, and HE that are present in a nuclear warhead will deteriorate with age. Such aging effects degrade a warhead's reliability rather than its safety. (The sensitivity to impact or fire of the HE used in nuclear warheads does not increase significantly with age.)

A severe case of aging was the deterioration of the HE in the W68 Poseidon warhead, which produced a harmful, chemically reactive effluent. This resulted in a potential loss of warhead reliability that necessitated a complete rebuild of all W68 warheads in stockpile. The reliability, but not the safety, of the warhead was affected.

Question 3:

Which warhead safety problems—and what fraction of the total number of such problems—will be resolved within the next five years by already scheduled retirements from the stockpile?

Answer:

Forty-two percent of the warhead types with EEI but without either IHE or FRPs are scheduled for retirement within the next five years. Sixty percent of the warhead types without IHE, FRPs, or full EEI are scheduled for retirement within the next five years.

If the warheads for the short-range, surface-to-surface, tactical nuclear weapons, together with those warheads currently scheduled for retirement, were retired within the next five years, these percentages would increase from 42 and 60% to 84 and 100%, respectively. Such an accelerated retirement schedule would result in a major improvement in the safety of of the nuclear weapons stockpile, which would then consist of those warheads listed in Table 2 (plus warheads now under development that will enter stockpile within the next five years).

Question 4:

For those warheads not scheduled for retirement, which of the remaining safety problems in the stockpile could be alleviated to an acceptable degree of risk by restrictions on air transport of the warheads and/or other handling restrictions?

Answer:

Warheads that use conventional HE but are not scheduled for retirement are the Minuteman III ICBM and Trident SLBM warheads (see Table 2) and the short-range, surface-to-surface tactical nuclear weapons, i.e., the W48 and W79 AFAPs and the W70 Lance SSTMs. From the standpoint of safety, none of these weapons lacking IHE should be transported by air due to the risk of extensive plutonium dispersal that could result from a crash and/or fire.

In the case of ICBM and SLBM warheads, air transport is not needed and should not be used.

The risk of plutonium dispersal presented by the AFAPs and SSTMs is likely to be transitory because these tactical nuclear weapons seem destined to be returned to the U.S. and placed in storage. In the meanwhile, the risk of a plutonium dispersal accident could be reduced to an acceptable level by discontinuing their transport by air.

None of the warheads in the current stockpile have FRPs except the W87 MX ICBM and the B83 Strategic Bomb.

W84 GLCM,

This safety deficiency is not nearly as serious as the absence of IHE and could presumably be reduced to an acceptable level by prohibiting air transport of these warheads or their deployment aboard aircraft in close proximity to operating runways, being refueled, or starting their engines.

The plutonium-dispersal hazard presented by the absence of IHE and FRPs in the Minuteman ICBM and Trident SLBM warheads could be reduced significantly by improved handling procedures, particularly during loading of the missiles into their silos or launch tubes. (In a recent accident at Edwards Air Force Base on September 7, 1990, a segment of a Titan 4 rocket motor containing 270,000 lb of a nondetonatable solid propellant dropped 100 ft to the ground and ignited upon impact. No nuclear weapons were involved, but the accident served as a reminder that dropping a solid-fuel rocket motor can result in propellant ignition and fire.)

Following a recommendation of the Drell Panel Report, a procedural change was made in the manner in which Trident II missiles are loaded onto submarines: the warheads are no longer mated to the missile until after the missile has been loaded into its launch tube. This eliminates the possibility that the accidental detonation of a missile's propellant, during loading into a launch tube, could result in the detonation of any (or all) of the missile's warheads and significantly reduces the risk of a plutonium-dispersal accident during loading.

The Minuteman missiles differ from the Trident missiles in that they do not employ a detonatable propellant in either the first or second stages and, therefore, present somewhat less risk of a plutonium-dispersal accident. The third stage does employ a detonatable propellant, however, and the possibility always remains that an accident could lead to a propellant fire, as was the case with the Titan 4 accident. This possibility suggests that the procedure now used to load Trident missiles into their launch tubes be adopted to load Minuteman missiles into their silos; that is, to mate the warheads to the missile after loading it into its silo rather than before, if that is not the present practice.

Keeping the missiles and warheads apart during missile loading would decrease the risk of a plutonium-dispersal accident with the Minuteman and Trident missiles, but does not compensate for their lack of IHE.

Question 5:

a. Which warheads have safety problems not amenable to resolution by retirement or transport/handling restrictions that require nuclear explosive tests for their resolution?

b. What numbers and yields of tests would be required to resolve the subset of warhead safety problems identified in (a) above?

Answer:

Weapons that may be considered to have safety problems not amenable to resolution by retirement or transport/handling restrictions are the Minuteman and Trident warheads, which lack IHE. These problems could be resolved either by replacing the warheads with new designs having both IHE and FRPs or, in some cases, by replacing them with warheads already in stockpile or currently under development that have IHE and FRPs.

If the warheads were to be replaced with newly designed warheads, an effort would be made to design the new nuclear system to fit within the old reentry body (RB), thereby maximizing the use of existing assets and minimizing the need for costly missile alterations and missile tests. Such replacements would be difficult if the warhead yield were not to be reduced somewhat because the larger volume of less energetic IHE needed would be difficult to fit into the limited diameter and volume of the old RB. Such an approach would minimize missile costs at the expense of requiring a substantial number of nuclear tests to develop and test the new designs.

If, on the other hand, the old warheads were to be replaced by fully tested IHE warheads already in stockpile, the requirement for nuclear tests would clearly be minimized. These IHE warheads would generally not have the same weight, yield, and other characteristics as the warheads they would replace, however, and there might be difficulties in mating the new warheads to the old missile that would be costly to resolve.

Examples of replacements that might be possible would be the replacement of the W78 Minuteman III warheads with the W87 MX warheads and the replacement of the W88 Trident II warheads with either the MX warheads or of the W88's nuclear explosive components with those of the W89 SRAM II.

Replacement of the W88 nuclear explosive with that of the W89 SRAM II would probably require only a single production verification test if Rocky Flats were in operation to fabricate the already-tested SRAM II pits. At least two nuclear tests would probably be required if Rocky Flats is not operating, requiring the use of pits salvaged from retired warheads. In the first instance, a yield of 150 kt would be desirable, but a somewhat lower yield might be acceptable. In the second instance, at least one test at **** kt or less and one test at 150 kt or somewhat lower would be needed.

Question 6:

If nuclear explosive tests were used to resolve all outstanding safety problems of weapons in or entering the nuclear stockpile that are not scheduled for retirement by 1995, how many tests and what yields would be required?

Answer:

The stockpile currently contains 13 warhead types with a safety grade of less than "B" (neither IHE or FRP) and 20 warhead types with a safety grade of less than "A" (no FRP), none of which is scheduled for complete retirement before 1995.

Providing a warhead with IHE that does not already have it would constitute a major change and an essentially new design. Therefore, in the absence of new and additional constraints on testing, it would demand a number of nuclear tests comparable to that a new design would customarily receive.

Incorporating an FRP into a warhead already equipped with IHE is a less significant design change than introducing IHE. However, nuclear tests would be needed to verify proper performance, although a smaller number of tests might suffice.

If we assume an average of six nuclear tests is required to incorporate IHE in each of those 13 warhead types that don't have it, a total of approximately 80 nuclear tests will be needed. To provide both IHE and FRPs to those 20 warhead types that don't have both would require approximately 100 tests, assuming that an average of only three tests per warhead type is needed to introduce FRPs into warheads that already have IHE. In either case, a large number of nuclear tests would be needed.

Were the retirement rate to be accelerated so that all weapons currently scheduled for retirement before the year 2000 would be retired before 1995, the number of nuclear tests needed to bring the safety of those remaining in stockpile up to at least a "B" rating by 1995 would be substantially reduced. In this instance, there would be only 3 weapon types not having IHE and 9 not having both IHE and an FRP. Using the same average number of nuclear tests needed per weapon type, a total of approximately 20 nuclear tests would be needed to upgrade the stockpile to a "B" safety rating, and approximately 40 tests would be needed to provide an"A" rating. These results are summarized in the test table at right.

Test table. Estimated number of nuclear tests needed to upgrade the 1995 stockpile to a safety rating of:

	"A"	"B"
Existing retirement schedule	100 (50)	80 (40)
Accelerated retirement schedule	40 (20)	20 (10)

(Assumes 6 tests per weapon type upgraded to introduce both IHE and FRPs and 3 tests per weapon to introduce FRPs into warheads that already have IHE. If, by means of warhead substitutions, economizing on tests, and the like, the average number of tests per weapon type upgraded were reduced by 50%, for example, the number of tests needed would be correspondingly reduced to those shown in parentheses.)

Note that the number of tests listed does not include those that would be needed to upgrade the safety of weapons currently under development. All of these will have at least a "B" rating, but the B61-6,8,9 tactical bombs and the W61 earth penetrator are not presently scheduled to have FRPs. Note also (see table above) that the incremental number of nuclear tests needed to upgrade the 1995 stockpile from a "B" to an "A" rating is approximately 20 (10), independent of whether the retirement schedule is accelerated.

The distribution of nuclear explosive yields associated with these safety upgrade tests, in the absence of yield constraints other than the existing 150-kt limit, can reasonably be expected to approximate the distribution of yields of the U.S. nuclear weapons test program in recent years. Using the five-year period of 1980 through 1984, the distribution of yields was that given in the yield table that follows:

Yield table. Percentage P of tests conducted with yield less than Y.[2]

Y(kt)	1	5	10	20	50	150
P(%)	5	18	34	62	74	100

More than half the tests would be expected to have yields of less than 20 kt, and the rest would be expected to lie between 20 and 150 kt, with considerable clumping in the vicinity of the 150-kt yield limit. This distribution will better characterize the larger number of tests (80–100) needed in the case of the existing retirement schedule than the much smaller number of tests (20) needed to provide a "B" safety rating for the stockpile in the case of the accelerated retirement schedule. In this latter case, the three warhead types needing upgrading are all ballistic missile warheads (W88 Trident D5, W76 Trident C4, and W78 Minuteman III).

These estimates of yields and numbers of tests should be considered only rough estimates. A more accurate estimate would require a case-by-case determination of the number of tests expected to be needed, and the yield of each of these tests, for each warhead type to be upgraded.

It is clear that the number of nuclear tests needed to upgrade stockpile safety would be reduced dramatically as a result of an accelerated retirement schedule and a requirement for all warheads to have IHE but not FRPs. Air transport of those warheads lacking FRPs would be prohibited, and other handling restrictions would be imposed to reduce the risk of plutonium dispersal in aircraft fires rather than relying on FRPs for this purpose.

Further reductions in the number of nuclear tests needed to upgrade stockpile safety would result if the Minuteman II and III warheads were retired and replaced with W87 MX warheads and the W88 warheads were either replaced with W87 MX warheads or had their nuclear explosive components replaced with those of the W89 SRAM II. The only warhead safety upgrade then remaining to be done would be that of the W76 Trident C4 warhead, which would require perhaps as few as six nuclear tests to accomplish. If two W87 tests and two W89 tests were allowed for, a total of only 10 nuclear tests would be needed.

Question 7:

a. What nonnuclear-explosive measures, if any, are currently used to assess the desired "one-point safety" characteristic of nuclear weapons?

Answer:

As a result of increasing computer capability in memory and CPU speed, it has recently (since 1988) become possible to conduct moderately faithful computer simulations of the complex three-dimensional (3D) hydronuclear behavior of a nuclear warhead implosion system detonated at any point or points of its HE charge. This permits a preliminary evaluation of the one-point safety of a nuclear warhead without the need for a nuclear test. Such computer simulations are still too rudimentary to be relied on to certify one-point safety, but are currently used as a valuable guide in determining what point of detonation is likely to be the severest test of one-point safety. Nuclear one-point safety tests are then conducted with this information to guide them. These latter tests are then determinative of the existence or nonexistence of one-point safety.

b. What revised and/or aditional nonnuclear-explosive measures could be employed to establish that thoroughly tested nuclear warhead designs in or entering the stockpile would continue to meet the one-point safety criterion?

Answer:

Hydronuclear experiments could be conducted to evaluate one-point safety as was done during the nuclear weapon test moratorium of 1958-61.[3] These neutron-multiplying, subcritical experiments are done with a warhead implosion system and pit that has been modified to reduce its criticality by either reducing the amount of fissile material present or by using a less-fissile isotope of the normal fissile material.

These hydronuclear experiments are conducted at very small nuclear yields that can be safely contained within a suitable containment vessel. For example, the highest nuclear yield of the 35 hydronuclear experiments conducted at Los Alamos during the test moratorium was four-tenths of one pound HE equivalent. The other 34 tests produced yields at least a factor of 10 lower than that.

Question 8:

If nuclear explosive tests were permitted under a future testing restriction to resolve nuclear weapon safety issues, what yield threshold level would be required to:

a Demonstrate one-point safety of nuclear weapon primary stages?

b. Reduce the risk of plutonium scatter in an accident by incorporating new chemical explosives in the primary of a weapon of proven design, with high confidence that the overall weapon so modified will exceed a certain predicted minimum yield?

Answer:

The improved capability to predict the yields of one-point safety tests that results from the more realistic computer models available today, together with the extensive data base that has accumulated over the years, implies that adequate one-point safety tests could accomodate a yield threshold as low as one-hundredth of a ton of HE or perhaps less. Therefore, no reasonable yield threshold that can be envisaged is likely to interfere seriously with the demonstration of one-point safety of nuclear weapon primary stages.

The incorporation of new chemical explosives in the primary of a weapon of proven design represents a major change in the weapon's design. Proof of performance would require at least one nuclear test of the new primary design—preferably at full yield or possibly at several-fold reduced yield—and, depending on the circumstances, might require several more. In most cases, such tests could be conducted at full yield within a yield threshold of **** kt and, at reduced yield, of less than **** kt.

At least one test of the secondary would generally be required in the case of a thermonuclear weapon. In all cases, the test yield required would be considerably greater than **** kt and, in the case of high-yield strategic weapons, would preferably approach the current yield threshold of 150 kt.

If the new primary were designed, and observed, to provide an implosion drive to the secondary that was at least as strong as that provided by the original primary, it is possible no test of the secondary would be deemed necessary. This is not to say that a proof test of the total system would not be desirable.

One-point safety tests can be conducted within any reasonable yield threshold that may be envisaged. On the other hand, any change in a warhead's chemical explosive will require nuclear tests (perhaps many) and generally require tests with relatively high yields. The same may be said of a change in the warhead's pit to make it an FRP.

Summary and Conclusions

A key element in improving the safety of the U.S. nuclear weapons stockpile is the timely retirement of most older warheads in the present stockpile. More than half the nuclear weapons in the stockpile today were designed at least 20 years ago and do not have some important electrical, nuclear, and plutonium-dispersal safety features of modern weapons. This is not to say they are unsafe, but that their safety is clearly not up to modern standards. When those weapons now tentatively scheduled for retirement by the year 2000 are no longer in the stockpile, the remaining warheads will—with the exception of the Minuteman and Trident ballistic missile warheads and the short-range surface-to-surface tactical nuclear weapons deployed in Europe—all have the modern safety features of both IHE and EEI.* In view of the reunification of Germany and the termination of the Warsaw Pact, it is anticipated that U.S. short-range surface-to-surface tactical nuclear weapons will be withdrawn from Europe and either safely stored or dismantled. Accelerating the existing schedule of warhead retirement would result in a significantly safer stockpile of nuclear weapons at an earlier date, possibly as early as 1995.

If a decision were made to replace the W78 Minuteman III, W76 Trident I, II C4, and W88 Trident II D5 ballistic missile warheads with new designs having the modern safety

*Enhanced electrical isolation (EEI) safety is referred to in the Report of the Drell Panel on Nuclear Weapon Safety as enhanced nuclear detonation safety (ENDS).

features of EEI, IHE, and an FRP, past experience indicates that an average of six nuclear tests per weapon type, or a total of about 20 tests for the three types, would be needed to complete their development.

If the W78 ICBM and W88 SLBM warheads, or their nuclear explosive components, were replaced by existing, rather than newly designed, warheads having modern safety features and that are already in stockpile or well along in development, such as the W87 MX and W89 SRAM II warheads, only the W76 Trident I,II warheads would have to be replaced with a new design. In this case, the total number of tests needed would not be expected to exceed 10 tests, half the number needed for three all-new designs.

It follows, within the limits of a modest number (10-20) of nuclear tests, that the safety of the stockpile can be improved so that all warheads in stockpile not currently scheduled for retirement will have the benefits of both IHE and EEI.

The Drell Panel recommends a broad and in-depth examination of the safety of the Trident II (D5) missile system in view of the fact that its W88 warheads are not equipped with IHE and are mounted in a through-deck configuration in close proximity to the third-stage rocket motor that uses high-energy, 1.1-class, detonatable propellant. We concur with the need for such an in-depth examination of the D5/W88, but we do not agreee with the Drell Panel's apparent exemption of the Trident I, II (C4) missile system from similar examination. The C4 W76 missiles raise safety concerns that are essentially identical with those of the D5/W88 and are currently deployed in far greater numbers.

The Drell Panel recommends that "all nuclear bombs loaded onto aircraft—both bombs and cruise missiles—[be built] with both IHE and FRPs." As we have pointed out, a modest number of nuclear tests will suffice to provide a stockpile in which all warheads will have both EEI and IHE. If all nuclear bombs loaded onto aircraft are required to have FRPs as well, a large number of bombs and cruise missiles already in stockpile will have to be rebuilt. This would be a major undertaking, requiring that each be disassembled and reassembled with a redesigned, refabricated pit. The modification required to provide these bombs and missiles with FRPs represents a design change that is sufficiently significant to mandate at least one, and perhaps several, nuclear explosive tests for each of the five types of warheads being modified.

Rather than rely on FRPs to reduce the risk of plutonium dispersal in a crash or fire involving an aircraft with nuclear warheads aboard, an alternative would be to virtually eliminate their need by prohibiting, in peacetime, air transport of these warheads or their deployment aboard aircraft that are in close proximity to operating runways, being refueled, or starting their engines. This latter alternative would eliminate the need for nuclear tests or rebuilding of the large number of stockpiled bombs and cruise missiles that have EEI and IHE but not FRPs.

The Drell Panel also recommends an aggressive study of all advanced design concepts for enhancing the safety of nuclear weapons and the development of truly innovative warhead designs that are as safe as practically achievable, consistent with reasonable military requirements. This goal has been actively pursued at the three nuclear weapons design laboratories for many years and has resulted in major and innovative improvements in nuclear weapon safety, including the introduction of EEI, IHE, and the FRP. The study of the separable-components concept as applied to sealed-pit warheads, the example of a truly innovative design referred to by the Drell Panel for purposes of illustration, has been under active study and limited development for at least 15 years without, as yet, a practical result.

While one cannot predict the future, the prospects of developing a practical separable component design do not appear promising. Nor is it clear that the limited safety improvement afforded by separable components beyond that of warheads already possessed of modern safety features would be worth the costs involved. The introduction of nuclear weapons of such complex design into the stockpile is likely to result in a less robust and reliable stockpile and would require both a major and extended nuclear test and missile test program.

We have estimated that a modest number (10-20) of nuclear tests would suffice to replace the W78 Minuteman III, W76 Trident I,II C4, and W88 Trident II D5 ballistic missile warheads with warheads having the modern safety features of EEI, IHE, and an FRP. The Drell Panel has recommended an immediate national policy review of the acceptability of retaining missile systems in the arsenal that do not use the safer nondetonatable class-1.3 propellant in rocket stages that are in close proximity to the warheads as well. A change in missile propellant would require missile tests but no nuclear tests, thus leaving our estimate of 10-20 nuclear tests unchanged.

A further note is that one-point safety tests can continue to be conducted within any reasonable limit on nuclear weapons test yields that might be negotiated. The improved capability to predict yields of one-point safety tests that results from the more extensive computer models available today, together with the extensive data base that has accumulated over the years, implies that adequate one-point safety tests could accomodate a yield threshold as low as one one-hundredth of a ton of HE or perhaps less.

In sum, we conclude that the safety of the U.S. stockpile of nuclear weapons can, within a few years, be brought up to a level that meets modern standards. At most, this upgrading will require a modest number of nuclear explosive tests, given an appropriate retirement schedule for older weapons in the stockpile and restrictions on the air transport of nuclear weapons and their deployment aboard aircraft in peacetime.

Recommendations

We recommend that the Departments of Energy and Defense be encouraged to undertake, as a part of the existing Nuclear Test Ban Readiness Program, the formulation and execution of a joint program whose purpose is to ensure that the U.S. stockpile of nuclear weapons will meet modern standards of safety by the year 1996.

The year 1996 is specified because the Nuclear Non-Proliferation Treaty comes up for review in 1995. The U.S. might then, or soon thereafter, choose to join in a partial or comprehensive ban on nuclear weapons testing and should not be unnecessarily limited in its exercise of this option by concerns about the safety of its nuclear weapons stockpile.

References

1. S.D. Drell, J.S. Foster, Jr., and C.H. Townes, *Report of the Panel on Nuclear Weapons Safety* , House Armed Services Committee, December 1990.

2. R.E. Kidder, *Militarily Significant Nuclear Explosive Yields*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-93194 Preprint, August 1985.

3. R.N. Thorn and D.R. Westervelt, *Hydronuclear Experiments*, Los Alamos National Laboratory, Los Alamos, NM, LA-10902-MS, February 1987.

Abbreviations Used

ABM	Antiballistic missile
AFAP	Artillery-fired atomic projectile
ALCM	Air-launched cruise missile
CPU	Central processing unit
DOD	Department of Defense
DOE	Department of Energy
EEI	Enhanced electrical isolation
ENDS	Enhanced nuclear detonation safety
FRP	Fire-resistant pit
GLCM	Ground-launched cruise missile
HE	High explosive (conventional)
ICBM	Intercontinental ballistic missile
IHE	Insensitive high explosive
IRBM	Intermediate-range ballistic missile
LLNL	Lawrence Livermore National Laboratory
MS	Mechanical safing
NDSB	Nuclear depth/strike bomb
OPS	One-point safety
RB	Reentry body
SC	Separable components
SLBM	Submarine-launched ballistic missile
SLCM	Sea-launched cruise missile
SRAM	Short-range attack missile
SSTM	Surface-to-surface tactical missile

Appendix A.
Letter from Edward M. Kennedy to John Nuckolls

Congress of the United States
Washington, DC 20515

November 19, 1990

Dr. John Nuckolls, Director
Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, CA 94550

Dear Dr. Nuckolls:

Recently, members of Congress concerned about the future course of the nuclear testing negotiations received a letter from the President's National Security Adviser, Brent Scowcroft. In that letter he stated:

> "Recent revelations regarding the safety of certain nuclear warheads underscore the importance of testing, both as a vehicle for detecting possible weaknesses in weapons safety and in devising appropriate corrective measures for any such weaknesses. To do otherwise would create uncertainty as to the safety of the stockpile, and render us unable to make safety improvements and unable to react to new threats."*

As you may know, members of Congress have on previous occasions sought the advice of Dr. Ray Kidder of your laboratory on technical matters relating to the readiness of the U.S. nuclear stockpile for further testing restrictions, including a comprehensive test ban. Dr. Kidder has earned a reputation for incisive empirical analysis of these issues that is free of the ideological spin imparted by other participants in the test ban debate.

We ask your assistance in once again obtaining the benefit of Dr. Kidder's expertise, this time on technical matters relating to maintaining the safety of nuclear weapons in a highly restrictive or comprehensive test ban environment. Specifically, we would like Dr. Kidder to conduct a thorough and comprehensive review of the procedures followed, information obtained, and the technical implications for weapon safety of:

-- all one-point safety tests of weapons currently in, or soon to enter, the nuclear weapons stockpile;

-- all tests that have been conducted to determine the effects of fire and/or impact on simulated nuclear

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* Letter from Brent Scowcroft to Senator Kennedy, et al., The White House, July 9, 1990, p.1

weapons of the types currently in or soon to enter the nuclear weapons stockpile;

-- all nuclear weapon accidents, particularly those in which there was the risk or occurrence of plutonium dispersal and/or HE detonation.

In addition, we request that Dr. Kidder's review include, but not necessarily be limited to, responses to the following questions:

1. How many, and which warheads in the current nuclear stockpile, have developed nuclear safety problems, and how many weeks, months, or years after entry of the warhead into the stockpile did these problems develop?

2. What fraction of nuclear safety problems have been traced to warhead aging effects, what fraction to inherent design defects, and what fraction to other causes?

3 Which warhead safety problems -- and what fraction of the total number of such problems -- will be resolved within the next five years by already scheduled retirements from the stockpile?

4 Of those warheads not scheduled for retirement, which of the remaining safety problems in the stockpile could be alleviated to an acceptable degree of risk by restrictions on air transport of the warheads and/or other handling restrictions?

5. (a) Which warheads have safety problems, not amenable to resolution by retirement or transport/handling restrictions, that require nuclear explosive tests for their resolution?

(b) What numbers and yields of tests would be required to resolve the subset of warhead safety problems identified in (a) above?

6. If nuclear explosive nuclear tests were used to resolve all outstanding safety problems of weapons in or entering the nuclear stockpile that are not scheduled for retirement by 1995, how many tests -- and what yields -- would be required?

7. (a) What non-nuclear-explosive measures, if any, are currently used to assess the desired "one-point safety" characteristic of nuclear weapons.

(b) What revised and/or additional non-nuclear-explosive measures could be employed to establish that thoroughly-tested nuclear warhead designs in or entering the stockpile would continue to meet the one-point safety criterion.

8. If nuclear explosive tests were permitted under a future testing restriction to resolve nuclear weapon safety issues, what yield threshold level would be required to:

(a) demonstrate one-point safety of nuclear weapon primary stages;

(b) reduce the risk of plutonium scatter in an accident by incorporating new chemical explosives in the primary of a weapon of proven design, with high confidence that the overall weapon so modified will exceed a certain predicted minimum yield.

Finally, we request that Dr. Kidder be provided with access to the full range of laboratory personnel, data bases and test records required to prepare an accurate and complete report as outlined above, including the briefing materials and records previously made available to the Drell Panel on Nuclear Weapons Safety. Our intention is that Dr. Kidder's report serve as an independent "peer review" of the analysis and conclusions of that panel's report.

Should you or other members of your technical staff wish to comment on Dr. Kidder's analysis, we would of course welcome the submission of such comments, and his responses thereto. If possible, we would like to receive Dr. Kidder's unclassified report, with classified appendices as necessary, not later than April 15, 1991.

Sincerely,

Edward M. Kennedy

Dante B. Fascell

Timothy E. Wirth

Edward J. Markey

Tom Harkin

Appendix B.
Letter from Les Aspin to the Honorable James D. Watkins

U.S. House of Representatives
COMMITTEE ON ARMED SERVICES
Washington, DC 20515
ONE HUNDRED FIRST CONGRESS
LES ASPIN, WISCONSIN, CHAIRMAN

May 3, 1990

The Honorable James D. Watkins
Secretary of Energy
1000 Independence Avenue, S.W.
Washington, D.C. 20585

Dear Mr. Secretary:

The safety and security of the U.S. nuclear forces are of vital importance to our nuclear deterrent. This subject has been a matter of continuing concern to the Armed Services Committee. We recognize the Department of Energy shares this concern and has recently taken initiatives in this area.

Notwithstanding the department's initiatives, certain issues were raised regarding the safety of our nuclear arsenal by the directors of the national laboratories during a recent hearing before the Department of Energy Defense Nuclear Facilities Panel. We have empaneled three eminent physicists, Dr. Sidney D. Drell of Stanford University, Dr. John S. Foster, Jr. of TRW Corporation and Dr. Charles H. Townes of University of California at Berkeley, to evaluate these issues and to provide us with their advice.

We write to request your assistance and to invite your participation. We ask that you provide the panel with full access to the department and the national laboratories and to any ongoing studies they require for their assessment.

We believe an independent assessment will be as valuable to the department as it will be to the Congress. We will appreciate your assistance with this critically important matter.

Respectfully,

Les Aspin

William L. Dickinson

John M. Spratt, Jr.

Jon Kyl

Appendix C.
Nuclear Safety Criteria

The following descriptive and tutorial material concerning Nuclear Safety Criteria was obtained from Section IV of the *Drell Panel Report on Nuclear Weapons Safety.*

It is important to recognize at the outset that there is no clear answer to the question "How safe is safe enough?" What is called for is judgment, informed by careful analyses and an adequate data base, as to how far to push, or to relax, safety standards. Informed judgment on such an issue requires a realistic assessment of the risks and benefits. These include military requirements both now and for the future; factual data on the behavior of individual system components under abnormal circumstances that can be plausibly created; careful modeling of complex weapons systems as a whole in order to estimate overall system safety under the same abnormal circumstances; careful analysis of operational procedures that cause risks to safety and can be changed; and a sense of when one has reached the point in the design parameters such that, even by making a major commitment of resources and a significant compromise in important military characteristics, further gains in safety would only be marginal at best.

There is nothing magic about criteria like "one in a million" or "one in a billion" or "a nuclear yield limit of less than 4 pounds of TNT equivalent". These are very exacting safety criteria to satisfy. One should try to do even better if practical, but it is most important to be confident in actually having achieved these stated criteria. What makes this requirement unique is the importance of guarding against a nuclear explosion or the dispersal of plutonium. Such events could be enormously more devastating than other accidents involving civilian aircraft, for example, about which we have accumulated experience through the years. In no sense would a high yield nuclear detonation be acceptable.

Because the consequences of a nuclear weapons accident are potentially so harmful, both physically and politically, major efforts are made to protect nuclear weapons systems from detonating or dispersing harmful radioactive material if exposed to abnormal environments, whether due to accidents or natural causes, or resulting from deliberate, unauthorized intent. They are also carefully guarded against theft. This protection is achieved by a combination of design features, operational procedures, and special administrative safety rules. Missiles armed with nuclear warheads also contain certain features which protect them against deliberate or accidental unauthorized launch, and selected nuclear warheads contain use controls. These are designed to ensure authorized weapon use while inhibiting, delaying, or preventing unauthorized use.

Safety requirements for nuclear weapon systems apply both to the warheads themselves and to the entire weapon system. For the warheads this implies design choices for the nuclear components as well as for the electrical arming system that meet the desired safety standards. For the weapon system–i.e., the rocket motors and propellant to which the warhead is mated in a missile and the aircraft or transporter that serves as the launcher–safety implies, in addition to design choices, operational, handling, transportation and use constraints or controls to meet the desired safety standards. Monitoring the nation's nuclear weapons systems and ensuring that they meet the established standards for safety, security, and control is a continuing process. New warheads and delivery systems are designed with modern safety and control features and introduced into the stockpile. Some of the older weapons that do not meet modern safety criteria are retired; others that are planned for retention in the stockpile are modified by the stockpile improvement program to bring them up to modern weapons safety criteria.

Technical advances have permitted great improvements in weapons safety since the 1970's. At the same time technical advances have greatly increased the speed and memory capacity of the latest supercomputers by factors of 100 and more. As a result it has become possible, during the past three years, to carry out more realistic calculations in three-dimensions to teach the hydrodynamic and neutronic development of a nuclear detonation. Earlier calculations were limited to two-dimensional models. The new results have shown how inadequate, and in some cases misleading, the two-dimensional models were in predicting how an actual explosion in the real three-dimensional world might be initiated leading to dispersal of harmful radioactivity, or even to a nuclear yield. A major consequence of these results is a realization that unintended nuclear detonations present a greater risk than previously estimated (and believed) for some of the warheads in the stockpile. These new findings are central to an assessment of nuclear safety and of the potential to improve stockpile safety. Described below are the individual components that contribute to the overall safety of a nuclear weapon system as a basis for evaluating how the design choices affect the safety of the weapon system.

Enhanced Nuclear Detonation Safety (ENDS)

The ENDS system is designed to prevent premature arming of nuclear weapons subjected to abnormal environments. The basic idea of ENDS is the isolation of electrical elements critical to detonation of the warhead into an exclusion region which is physically defined by structural cases and barriers that isolate the region from all sources of unintended energy. The only access point into the exclusion region for normal arming and firing electrical power is through special devices called strong links that cover small openings in the exclusion barrier. The strong links are designed so that there is an acceptably small probability that they will be activated by stimuli from an abnormal environment. Detailed analyses and tests give confidence over a very broad range of abnormal environments that a single strong link can provide isolation for the warhead to better than one part in a thousand. Therefore, the stated safety requirement of a probability of less than one in a million (see Fig. 2, Appendix D) requires two independent strong links in the arming set, and that is the way the ENDS system is designed. As noted earlier in Section II (Appendix D) both strong links have to be closed electrically–one by specific operator-coded input and one by environmental input corresponding to an appropriate flight trajectory–for the weapon to arm.

ENDS includes a weak link in addition to two independent strong links in order to maintain assured electrical isolation at extreme levels of certain accident environments, such as very high temperatures and crush. Safety weak links are functional elements (e.g., capacitors) that are also critical to the normal detonation process. They are designed to fail, or become irreversibly inoperable, in less stressing environments (e.g., lower temperatures) than those that might bypass and cause failure of the strong links.

The ENDS system provides a technical solution to the problem of preventing premature arming of nuclear weapons subjected to abnormal environments. It is relatively simple and inexpensive and lends itself well to a probabilistic risk assessment of the type in Fig. 2 (Appendix D). As noted earlier ENDS was developed at the Sandia National Laboratory in 1972 and introduced into the stockpile starting in 1977. As of the beginning of this year slightly more than one-half of the weapons in the stockpile (52%) will be equipped with ENDS. The remaining ones await scheduled retirement or modernization under the stockpile improvement program. Until then they do not meet the established stockpile safety criteria.

The weapon without the modern ENDS systems that has caused the greatest concern as a result of its means of deployment is the W69 warhead of the SRAM-A missile aboard the strategic bomber force and various older models of aircraft-delivered tactical and strategic bombs. Since 1974 concerns have been raised on a number of occasions about the safety of this deployed system. A particular concern is the potential for dispersal of plutonium, or even of the generation of a nuclear detonation, in the event of fire aboard the aircraft during engine-start readiness drills, or of an impact involving a loaded, ready-alert aircraft (i.e., the ALFA force) should an accident occur near the landing and take-off runways during routine operations of other aircraft at a SAC base. In spite of these warnings, many remained on alert or in the active stockpile as recently as six months ago.[1] Since then, following public disclosure of the safety concern, the SRAM-A has been taken off the alert SAC bomber force,[2] with its ultimate fate awaiting completion of an Air Force SRAM-A safety study now in progress.

Insensitive High Explosives

Nuclear warheads contain radioactive material in combination with high explosives. An accident or incident causing detonation of the high explosive would result in radioactive contamination of the surrounding area.

As described earlier in Section II (Appendix D), the consequences of a violent accident, such as airplane fire or crash, may be very different depending on whether the high explosive is the insensitive (IHE) or conventional (HE) type. In such incidents HE would have a high probability of detonating in contrast to the IHE. The importance of this difference lies in the fact that detonation of the HE will cause dispersal of plutonium from the weapon's pit. The following table shows several measures that are indicative of the different detonation sensitivities of the two forms of explosives:[3]

Table 1

	Conventional HE	IHE
Minimum explosive charge to initiate detonation (ounces)	$\sim 10^{-3}$	>4
Diameter below which the detonation will not propagate (inches)	$\sim 10^{-1}$	1/2
Shock pressure threshold to detonate (kilobars)	~ 20	~ 90
Impact velocities required to detonate (miles/hour)	~ 100	~ 1200-1300

[1]The fact that it took until 1984 to *begin* modifying stockpile weapons led to the expression of distress by the Clark Blue Ribbon Task Group in 1985.
[2]The decision on SRAM-A was announced by Secretary Cheney on June 8, 1990.
[3]Tables 1 and 2 are adapted from the presentation to the Panel by the Lawrence Livermore National Laboratory, June 19, 1990.

In contrast to the safety advantages, IHE contains, pound for pound, only about two-thirds the energy of HE and, therefore, is needed in greater weight and volume for initiating the detonation of a nuclear warhead.

It is generally agreed that replacing warheads with HE by new systems with IHE is a very effective way–perhaps now the most important step–for improving safety of the weapons stockpile against the danger of scattering plutonium. The understanding[4] between DOE and DOD in 1983 calls for the use of IHE in new weapon systems unless system design and operational requirements mandate use of the higher energy and, therefore, the smaller mass and volume of conventional HE. It was also "strongly recommended" by the Senate Armed Service Committee[5] in 1978, under Chairman John Stennis, that "IHE be applied to all future nuclear weapons, be they for strategic or theatre forces."

Although IHE was first introduced into the stockpile in 1979, as of the beginning of 1990 only 25% of the stockpile is equipped with IHE. The reason for this is that in decisions made up to the present, technology and operational requirements were judged to preclude incorporation of IHE in Artillery-Fired Atomic Projectiles (AFAPs) and Fleet Ballistic Missiles (FBMs). The small diameters of the cannon barrels (155 millimeters or 8 inches) pose very tight geometric constraints on the design of AFAPs. As a consequence there is a severe penalty to nuclear artillery rounds relying on IHE. On the other hand, options existed to go either with HE or IHE in choosing the warhead for the Trident II, or D5, missile. Of course, there are also geometric constraints on the Navy's FBMs that are set by the submarine hull design. However, the missile dimensions have expanded considerably in the procession from the Poseidon C3 and Trident I(C4), which were developed before IHE technology was available, to the D5 missile which is 44 feet long and 83 inches in diameter. When the decision was made in 1983 to use conventional HE in the D5 warhead it was based on operational requirements, together with the technical judgment that the safety advantage of IHE relative to HE was relatively minor, to the point of insignificance, in view of the geographic protection and isolation available to the Navy's FBMs during handling and deployment.

A major requirement, as perceived in 1983, that led to the decision to use HE in the W88 was the strategic military importance attached to maintaining the maximum range for the D5 when it is fully loaded with eight W88 warheads. If the decision had been to deploy a warhead using IHE the military capability of the D5 would have had to be reduced by one of the following choices:

- retain the maximum missile range and full complement of 8 warheads, but reduce the yields of individual warheads by a modest amount.
- retain the number and yield of warheads but reduce the maximum range by perhaps 10%; such a range reduction would translate into a correspondingly greater loss of target coverage or reduction of the submarine operating area.
- retain the missile range and warhead yield but reduce the number of warheads by one, from 8 to 7.

Missile Propellant

Two classes of propellants are in general use in long range ballistic missiles of the U.S. One is a composite propellant and is dubbed as "1.3 class". The other is a high energy propellant dubbed as "1.1 class." Their relevant properties are listed in Table 2:

Table 2

	1.3 Composite	1.1 High Energy
Minimum explosive charge to initiate detonation (ounces)	>350	~ 10^{-3}
Diameter below which the detonation will not propagate (inches)	>40	~ 10^{-1}
Shock pressure threshold to detonate (kilobars)	(1)	~ 30
Specific impulse (seconds)	~ 260	~ 270

[1]No threshold established.

[4]This is spelled out in two memoranda. The then ASTD(AE). Richard L. Wagner, wrote on April 28, 1983: "In most of the newer nuclear weapons we are using this insensitive high explosive and, where appropriate, plan to retrofit older nuclear war heads in the stockpile with IHE."...the DOD policy for new nuclear weapon development is that IHE will be used unless the Military Department responsible for the nuclear weapon development requests an exception from USDRE (Under Secretary of Defense for Research and Engineering) through the ATSD(AE). Such requests will be considered favorably where the military capability of the system clearly and significantly would be degraded by the incorporation of IHE." The then Director of Military Application in DOE, Major General William Hoover wrote: "Based on this policy, we should expect IHE to be included in the draft Military Characteristics for most new systems. It is our intention to support these requirements whenever feasible."

[5]Recommendations of the Senate Armed Services Committee presented on May 17, 1978, by Chairman John Stennis. (See Report No. 95-961; page 10).

The important safety difference between the two propellant classes is that, although both ignite with comparable ease, Table 2 shows that it is very much more difficult, if not impossible, to *detonate* the 1.3 class propellant, in contrast with 1.1 class. On the other hand, the 1.1 propellant has the advantage of a 4% larger specific impulse which propels a rocket to greater velocity and therefore to longer range. For example, if the third stage propellant in the D5 were changed from 1.1 to 1.3 class with all else remaining unchanged, the decrease in missile range would amount to 100-150 nmi, which is less than 4% of maximum range.

The safety issue of concern here is whether an accident during handling of an operational missile–viz., transporting and loading–might detonate leading to dispersal of plutonium, or even the initiation of a nuclear yield beyond the four-pound criterion stated in Fig. 1 (Appendix D). This issue is of particular concern for the Navy's FBMs. The D5 missile, like its Trident I, C4, predecessor, is designed with a through-deck configuration in order to fit within the geometric constraints of the submarine hull and at the same time achieve maximum range with three boost stages. In this configuration the nuclear warheads are mounted on the post-boost vehicle (PBV) in a circular configuration around, rather than on top of, the third stage motor. Thus if the third stage motor were to detonate in a submarine loading accident, for example, a patch of motor fragments could impact on the side of the reentry bodies encasing each warhead. The concern is whether some combination of such off-axis multipoint impacts would detonate the HE surrounding the nuclear pit and lead to plutonium dispersal or possibly a nuclear yield. In order to assess this concern, it is necessary to make a reasonable estimate of the probability of accidentally detonating the 1.1 propellant in the third stage motor and to calculate or measure the probability of subsequently detonating the HE in the warhead. This could then be compared with results in the event of an accident for such a missile with nondetonable 1.3 class third stage propellant and/or IHE in the warhead and the trade-off between enhanced safety and military effectiveness judged analytically.

Concerning military requirements for the Trident II system, we face the prospect that further reduction in the numbers of warheads will be negotiated in follow-on rounds of the START negotiations. There may then be a need to reduce the number loaded on each missile in order to maintain a large enough submarine force at sea to meet our concerns about its survivability against the threat of anti-submarine warfare. With a reduced loading a safety-class propellant and a fire-resistant pit, could fly to even longer ranges than at present.

We note that a loading accident such as we have been describing presents a safety concern only if the Trident missiles are moved and loaded onto submarines with the warheads already mated to the missile, as is standard U.S. Navy procedure. If the warheads are mated after the missile has already been loaded into the launch tubes there is no handling worry of this type.

Plutonium Dispersal

There are at present no quantitative safety standards for plutonium dispersal. The effort now in progress to see if it is feasible to establish such standards is due to be completed in October 1991. Any proposed standard will necessarily be critically dependent on the type of incident or accident being considered because there is an important difference between dispersing plutonium via a fire, or deflagration, and via an explosive detonation. In the latter case the plutonium is raised to a higher temperature and is aerosolized into smaller, micron-sized particulates which can be inhaled and present a much greater health hazard after becoming lodged in the lung cavity. In the former case fewer of the particulates are small and readily inhaled; the larger particulates, although not readily inhaled, can be ingested, generally passing through the human gastrointestinal system rapidly and causing much less damage. As a result, there is a difference by a factor of a hundred or more in the areas in which plutonium creates a health hazard to humans in the two cases.[6] This means it is necessary to specify both the amount of material and the manner in which it is dispersed in setting safety standards.

[Transportation Safety]

The safety of the U.S. nuclear weapons stockpile against dispersal of plutonium is directly sensitive to the choice of means for transporting nuclear warheads and weapons from production to weapon assembly to deployment sites. A joint DOD/DOE transportation study is now in progress to evaluate the safety and security risks posed by different methods of transportation. It will analyze the risks in terms of types of accidents, types of weapons, and severity of the abnormal environments to which

[6] In the event of a detonation of the HE of a typical warhead or bomb, an area of roughly one hundred square kilometers downwind could be contaminated with radioactivity. Published assessments of clean-up costs for such an area vary greatly; they are estimated to be upward of one-half billion dollars. If a chemical detonation were to occur in several warheads, the contaminated areas and clean-up costs would be correspondingly larger. The number of latent cancer fatalities would be sensitive to the wind direction and the population distribution in the vicinity of such an accident. In the event of a deflagration, or fire, the contaminated area would be approximately one square kilometer.

the warheads may be exposed. These types of studies are based on a fault tree analysis following each step in the handling and loading of nuclear weapons systems in order to calculate the overall level of risk to safety. They are of value in providing analytic tools for comparing different operational procedures. In the case of this study one can evaluate the relative advantages of transporting by air versus rail versus highway versus waterway. At present the DOE transports by air only warheads with insensitive high explosives. On the other hand, the DOD, which faces different logistical as well as political problems with its responsibility for overseas as well as stateside transportation of weapons, has no such policy at present. In the interest of safety against plutonium dispersal there should be a consistent policy governing the very large number of weapons movements whose numbers have typically, in recent years, added up to more than one thousand vehicle trips and one million miles per year.

Appendix D.
Safety Standards for Nuclear Weapons

The following descriptive and tutorial material concerning Safety Standards for Nuclear Weapons was obtained from Section II of the *Drell Panel Report on Nuclear Weapons Safety.*

Safety Standards for Nuclear Weapons

The safety of the U.S. stockpile of nuclear weapons is a dual responsibility of the Departments of Energy and Defense. DOD Directive 3150.2, dated Feb. 8, 1984, and signed by Deputy Secretary of Defense William H. Taft, IV, provides the current policy guidance for the DOD in conducting safety studies and reviews of nuclear weapons systems. In particular, it states:

- "The search for increased nuclear weapon system safety shall be a continuous process beginning as early as possible in development and continuing throughout the life cycle of a nuclear weapon system."
- "The goal of nuclear weapon system safety studies, reviews, rules and procedures is to ensure that nuclear weapons and nuclear weapon systems are designed, maintained, transported, stored, and employed to incorporate maximum safety consistent with operational requirements."

Further, it assigns to the Assistant to the Secretary of Defense (Atomic Energy), [ATSD(AE] the responsibility to "ensure the safety and security of the nuclear stockpile" and to "coordinate proposed safety rules, proposed changes to existing safety rules, and related matters with DOE."

Similar policy guidance for the DOE is contained in the March 1988 "DOE Nuclear Explosives and Weapons Safety Policy" signed by Troy E. Wade, II, then Acting Assistant Secretary, Defense Programs:

"It is DOE policy that the protection of the public health and safety is of paramount concern in the planning and conduct of the Department's nuclear weapons program . . . To this end, the DOE shall maintain a formal, comprehensive and systematic nuclear explosives and weapons safety program."

Responsibility for management of nuclear weapons within DOE is assigned to the Assistant Secretary, Defense Programs (ASDP).

Both the DOD and the DOE have spelled out criteria to be implemented in the design of nuclear explosives and nuclear weapons systems in order to guard against nuclear detonations or the dispersal of harmful radioactive material due to accidents or natural causes or resulting from deliberate, unauthorized acts. Four safety standards for nuclear weapons are stated in DOD Directive 3150.2 (Feb. 8, 1984):

1. "There shall be positive measures to prevent nuclear weapons involved in accidents or incidents, or jettisoned weapons, from producing a nuclear yield."
2. "There shall be positive measures to prevent DELIBERATE prearming, arming, launching, firing, or releasing of nuclear weapons, except upon execution of emergency war orders or when directed by competent authority."
3. "There shall be positive measures to prevent INADVERTENT prearming, arming, launching, firing, or releasing of nuclear weapons in all normal and credible abnormal environments."
4. "There shall be positive measures to ensure adequate security of nuclear weapons, pursuant to DOD Directive 5210.41."

DODD 3150.2 defines positive measure as "a design feature, safety device, or procedure that exists solely or principally to provide nuclear safety." The draft of a revised DODD 3150.2 (July 7, 1989) amends this definition to "a design safety and/or security feature, principally to enhance nuclear safety."

There is a very similar DOE directive on nuclear explosives, which is included here, that has added a fifth requirement with regards to dispersal of plutonium into the environment as formulated in the DOE 1990 Policy Statement 5610.10 (October 10, 1990):

"All DOE nuclear explosive operations, including transportation, shall be evaluated against the following qualitative standards (in the context of this Order, the word, prevent, means to minimize the possibility; it does not mean absolute assurance against):

(a) "There shall be positive measures to prevent nuclear explosives involved in accidents or incidents from producing a nuclear yield."

(b) "There shall be positive measures to prevent deliberate prearming, arming, or firing of a nuclear explosive except when directed by competent authority."
(c) "There shall be positive measures to prevent the inadvertent prearming, arming, launching, firing, or releasing of a nuclear explosive in all normal and credible abnormal environments."
(d) "There shall be positive measures to ensure adequate security of nuclear explosives pursuant to the DOE safeguards and security requirements."
(e) "There shall be positive measures to prevent accidental, inadvertent, or deliberate unauthorized dispersal of plutonium to the environment."

The DOE order defines positive measures as "design features, safety rules, procedures, or other control measures used individually or collectively to provide nuclear explosive safety. Positive measures are intended to ensure a safe response in applicable operations and be controllable. Some examples of positive measures are strong-link switches; insensitive high explosives; administrative procedures and controls; general and specific nuclear explosive safety rules; design control of electrical and mechanical tooling; and physical, electrical, and mechanical restraints incorporated in facilities and transport equipment."

In addition to these qualitative standards, quantitative nuclear weapons safety criteria were established in 1968. These requirements are summarized in the following statements by Carl Walske, then chairman of the DOD Military Liaison Committee:

Fig. 1. Memo, C. Walske, Chairman, Military Liaison Committee to B. Gen. Giller, AEC, 4/68.

One Point Safety Criteria

a. In the event of a detonation initiated at any one point in the high explosive system, the probability of achieving a nuclear yield greater than four (4) pounds TNT equivalent shall not exceed one in one million (1×10^6).
b. One point safety shall be inherent in the nuclear design; that is, it shall be obtained without the use of a nuclear safing device."

Fig. 2. Verbatim extract from a letter from the DOD/MLC Chairman, Carl Walske, to the AEC/OMA on March 14, 1968. (STS stands for "stockpile-to-target sequence.")

Warhead/Bomb Premature Probability Criteria

"The probability of a premature nuclear detonation of a bomb (warhead) due to bomb (warhead) component malfunctions (in a mated or unmated condition), in the absence of any input signals except for specified signals (e.g., monitoring and control), shall not exceed:

Prior to receipt of prearm signal (launch) for the normal (*) storage and operational environments described in the STS, 1 in 10^9 per bomb (warhead) lifetime.

Prior to receipt or prearm signal (launch), for the abnormal (**) environments described in the STS, 1 in 10^6 per warhead exposure or accident."

(*)"Normal environments are those expected logistical and operational environments, as defined in the weapon's stockpile-to-target sequence and military characteristics in which the weapon is not expected to retain full operational reliability".

(**)"Abnormal environments are those environments as defined in the weapon's stockpile-to-target sequence and military characteristics in which the weapon is not expected to retain full operational reliability."

There exists as yet no quantitative standard for plutonium dispersal. An inquiry to determine the feasibility of developing one is presently under way.

These safety standards have stimulated efforts to advance the design of nuclear weapons during the past two decades. In order to enhance electrical safety of nuclear weapons against premature detonation, the concept of a modern enhanced nuclear detonation safety system (ENDS) was developed at the Sandia National Laboratory in 1972 and introduced into the stockpile starting with the Air Force B61-5 bomb in 1977. The basic evaluation idea is to introduce into the firing system two strong links and one weak link that are located in the same environment within a so-called exclusion region. Both strong links have to be closed electrically–one by specific operator-coded information input and one by environmental input corresponding to a trajectory or spin motion appropriate to its flight profile–for the weapon to arm. The weak link on the other hand would be opened, or broken, thereby preventing arming if there were a temperature excursion, for example, due to fire, beyond the set bounds.

Another safety concern arises from the fact that nuclear warheads contain radioactive material in combination with high explosives. In most bombs, the primary is surrounded by a shell of high explosives which, upon detonation, initiates the implosion to generate the nuclear yield. An accident or an incident could cause detonation of the high explosive which, while not leading to a nuclear explosion, could spread plutonium and create a health hazard in the surrounding area. Insensitive high explosives have been developed to reduce this danger.

In all modern nuclear weapons the high explosive used to implode the primary is one of two types: a conventional high energy explosive (HE) which has desirable stability and handling features to improve safety, but which can be detonated in abnormal thermal, pressure, and shock environments; or an insensitive high explosive (IHE) which possesses a unique insensitivity to extreme abnormal environments. In certain violent accidents, such as airplane fires or crashes, HE has a high probability of detonating, in contrast to the IHE. The importance of this difference lies in the fact that detonation of the HE will cause dispersal of plutonium from the weapon's pit. In contrast to its safety advantages, IHE contains, pound for pound, only about two-thirds the energy of HE and, therefore, is needed in greater weight and volume for initiating the detonation of a nuclear warhead. Hence the yield-to-weight ratio decreases for a nuclear warhead when IHE replaces HE.

Appendix E.
A Summary of Accidents Involving U.S. Nuclear Weapons and Nuclear Weapons Systems

The Department of Defense (DOD) divides accidents involving nuclear weapons into four NUCLEAR ACCIDENT CATEGORIES:

NUCFLASH—Identifies and reports an accidental or unauthorized launch or detonation of a nuclear weapon.

BROKEN ARROW—Identifies and reports a Nuclear Weapon Accident, which is any unplanned occurrence involving loss or destruction of, or serious damage to, nuclear weapons or their components, which results in an actual or potential hazard to life or property.

BENT SPEAR—Identifies and reports a Nuclear Incident, which is an unexpected event involving a nuclear weapon, facility, or component, but not constituting a nuclear weapon accident.

DULL SWORD—Identifies and reports a Nuclear Weapon Safety Deficiency, which is a situation or condition which degrades or could degrade nuclear safety but is not serious enough to be a nuclear weapon accident or incident. The nuclear weapon accidents summarized in Table I would be categorized as BROKEN ARROWS.

Summary of Accidents Involving U.S. Nuclear Weapons

In the first decade (1949-1958) of nuclear weapon deployments, all of the nuclear weapons involved in the first thirteen accidents were of the design type where the nuclear material was in a capsule separated from the HE subsystem. Among these events, only two resulted in radioactive contamination, and those were minor and local in extent.

In the next decade, (1958-1968 and for the one accident in the last decade) most of the weapons involved were of the sealed-pit type typical of today's stockpile and, thus, had a potential for either a nuclear detonation or a radioactive material dispersal. However, in no instance was there evidence of a nuclear yield.

There have been some 32 major accidents over the 32-year period. The accident rate was highest at about two per year during the years 1958-1968 when nuclear weapons were routinely flown on airborne alert missions. The Titan II missile system accident in September 1980 was the first major event since the Thule, Greenland, B-52 accident of January 1968. (There have been no BROKEN ARROWS since the Titan II accident in 1980.)

The recently well-publicized accidental fire on an "alert" B-52 bomber loaded with SRAM-A missiles that occurred at Grand Forks, ND, in 1980 is not included in Table I because no damage to the missiles or their components resulted. It would therefore be categorized as a BENT SPEAR rather than a BROKEN ARROW. Nonetheless, this incident has played an important role in bringing into focus concern about nuclear weapon safety. It was considered a close-call by LLNL Director Roger Batzel, who testified before the Senate Appropriations Subcommittee on Defense several years ago that:

> "The wind happened to be blowing down the axis of the airplane. Had the wind been blowing across, rather than parallel to the fuselage, that whole system would have been engulfed in flames,"

including the SRAM-A missiles.

Table I and the discussion immediately preceding it are excerpted from A Summary of Accidents and Significant Incidents Involving U.S. Nuclear Weapons and Nuclear Weapons Systems, Report D, by William L. Stevens, May 1986 (Revised 10/23/86), a draft working paper submitted to the Sandia National Laboratory. The Summary is based on information released by the DOD, in coordination with the DOE, in the (unclassified) document: Narrative Summaries of Accidents Involving U.S. Nuclear Weapons 1950-1980, Department of Defense, 1984.

Table I – Summary of Accidents Involving US Nuclear Weapons

Accident Number	Date	Location	Weapon Configuration: Assembled Weapons	Unassembled Weapons	Component Only	Type of Accident	Nuclear Weapon Response: HE Response: HE Burn	HE Detonate	Contamination
1	02/13/50	Puget Sound, WA	–	X	–	Jettison, 8000'	–	X	–
2	04/11/50	Manzano Base, NM	–	X	–	Crash into mountain	X	–	–
3	07/13/50	Lebanon, OH	–	X	–	Crash in dive	–	X	–
4	08/05/50	Fairfield- AFB,CA	–	X	–	Emergency landing, fire	–	X	–
5	11/10/50	Over water, outside US	–	X	–	Jettison	–	X	–
6	03/10/56	At sea (Mediterranean)	–	–	X	Aircraft lost	–	–	–
7	07/27/56	SAC	–	X	–	B-47 crashed into bunker	–	–	–
8	05/22/57	Kirtland AFB, NM	–	X	–	Inadvertent jettison	–	X	X
9	07/28/57	At sea (Atlantic)	–	X	–	Jettisons, 4500' & 2500'	–	–	–
10	10/11/57	Homestead AFB, FL	–	X	–	Crash on takeoff, fire	X	X(low order)	–
11	01/31/58	SAC base overseas	X	–	–	Taxi exercise, fire	X	–	X
12	02/05/58	Savannah, GA	–	X	–	Mid-air collision, jettison	–	–	–
13	03/11/58	Florence SC	–	X	–	Accidental jettison	–	X	–
14	11/06/58	Dyess AFB,TX	X	–	–	Crash on takeoff	–	X	X
15	11/26/58	Chenault AFB, LA	X	–	–	Fire on ground	X	–	–
16	01/08/59	US Base, Pacific	–	X	–	Ground alert, fuel tanks on fire	–	–	–
17	07/06/59	Barksdale AFB, LA	X	–	–	Crash on takeoff, fire	X (1/5)	–	X (1/3)
18	09/25/59	Off Whidbey Is., WA	–	X	–	Navy aircraft ditched	–	–	–
19	10/15/59	Hardinsburg, KY	X	–	–	Mid-air collision, impact	X (2/2)	–	–
20	06/07/60	McGuire AFB, NJ	X	–	–	Missile fire	X	–	X
21	01/24/61	Goldsboro, NC	X	–	–	Mid-air breakup	–	–	–
22	03/14/61	Yuba City, CA	X	–	–	Crash after abandonment	–	–	–
23	11/13/63	Medina Base, TX	–	–	X	Storage igloo at AEC plant	X	X	X
24	01/11/64	Cumberland, MO	X	–	–	Mid-air breakup, crash	–	–	–
25	12/05/64	Ellsworth AFB, SD	X	–	–	Missile re-entry vehicle fell	–	–	–
26	12/08/64	Bunker Hill AFB, IN	X	–	–	Taxi crash, fire	X (3/5)	–	X (1/5)
27	10/11/65	Wright-Patterson AFB, OH	–	–	X	Transport a/c fire on ground	–	–	X
28	12/05/65	At sea, Pacific	X	–	–	Aircraft rolled off elevator	–	–	–
29	01/17/66	Palomares, Spain	X	–	–	Mid-air collision, crash	–	X (2/4)	X (2/4)
30	01/21/68	Thule, Greenland	X	–	–	Crash after abandonment	–	X (4/4)	X (4/4)
31	Spng'68	At sea, Atlantic	X	–	–	Lost weapons	–	–	–
32	09/19/80	Damascas, AK	X	–	–	Missile fuel explosion	–	–	–

NOTES:

1. USAF 09/19/77 press release to Richard Panter, Eye-Witness News Boston, obtained under the Freedom of Information Act, supplemented by DOD per Appendix I.
2. The term "Assembled Weapon" means either that the separable nuclear capsule was installed but was not in the bomb's pit or sealed-pit type of weapon with the nuclear material integral with the HE subsystem. "Unassembled Weapons" means that the separable nuclear capsule was not installed in the weapon. (the USAF press release for accidents 1-13 used the term "assembled weapon" for the above plus where a capsule was on the aircraft.
3. Contamination from all accidents except 29 & 30 was low in radioactivity and highly localized in area affected.
4. In the parentheses, the first number indicates the number of weapons that had the named response, and the second number gives the total involved in the accident.

Appendix F.
Biography

Dr. Ray E. Kidder, a Fellow of the American Physical Society, has been a senior physicist at the Lawrence Livermore National Laboratory for 35 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.

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 high-explosive generators of electricity. Further, he directed the Inertial Confinement Fusion program at LLNL for the first 10 years of its existence. He also independently discovered, and recommended to the Atomic Energy Commission, 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 directed-energy weapons.

Kidder is an Alexander von Humboldt Award winner, was for 10 years vice-chairman of the Scientific Advisory Board of the Max-Planck Institute of Quantum Optics, Federal Republic of Germany, and is a past member of the editorial board of the scientific journal Nuclear Fusion of the International Atomic Energy Agency.