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OF THE

PANEL ON NUCLEAR WEAPONS SAFETY

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EXECUTIVE SUMMARY

Concerns that have been raised recently about the safety of several of the nuclear weapons systems in the U.S. arsenal have led the government to take immediate steps to reduce the risk of unintended, accidental detonations that could result in dispersing plutonium into the environment in potentially dangerous amounts, or even generate a nuclear yield. These steps include temporarily removing the short-range air-to-ground attack missiles, SRAM-A, from the alert bombers of the Strategic Air Command and modifying some of the artillery-fired atomic projectiles (AFAPs) deployed with U.S. Forces. In addition, the Departments of Defense and of Energy, which hold dual responsibility for the surety of the U.S. stockpile of nuclear weapons systems—i.e., for their safety, their security, and their control—have initiated studies looking more broadly into safety issues.

This is a very important, as well as opportune, moment to undertake a safety review of nuclear weapons for reasons that go well beyond the immediate concerns of several specific weapons. As we enter the last decade of the 20th century, the world is in the midst of profound, and indeed revolutionary, changes in the strategic, political, and military dimensions of international security. These changes, together with a continuing rapid pace of technical advances, create an entirely new context for making choices in the development of our nuclear forces for the future. It is likely that, in the future, the U.S. nuclear weapons complex will evolve into a new configuration—perhaps smaller and less diverse and at lower operating expense but with enhanced requirements for safety and control.

In this report we propose organizational initiatives to strengthen and make more fully accountable the safety assurance process, and we identify priority goals for enhancing safety in a timely fashion. We emphasize the importance of developing the data bases and performing credible safety analyses to support weapons design choices. We also affirm the importance of vigorous R&D efforts in the DOE weapons laboratories in search of new technologies leading to significant advances in safety-optimized designs.

The starting point of our study is provided by two recent analyses which included inquiries into the nuclear weapons safety process: The 1985 President's Blue Ribbon Task Group on Nuclear Weapons Program Management, chaired by Judge William T. Clark, and the 1988 DOE Nuclear Weapons Safety Review Group, chaired by Gordon Moe. Both of these panels addressed long-standing concerns with stockpile safety and made important recommendations, a number of which were implemented, including in particular creation of a Nuclear Weapons Council (NWC) and an NWC Weapon Safety Committee. It is our present finding that although many problems have been, or are being, fixed, still more remain to be addressed. We are concerned, as were these earlier panels, that serious issues that had been known for at least a decade remained unattended for so many years.

We make seven major recommendations for strengthening the safety assurance process. They should be implemented promptly and effectively.

1. Create joint DOD/DOE dedicated "Red Teams" with the important responsibility to scrutinize and challenge the weapons designs and operational procedures for each nuclear weapons system remaining in the stockpile or under development. The Red Teams would normally interact directly with the Weapons Design Teams. However, in case of unresolvable differences of views on safety issues, the Red Teams would have direct channels up the line of authority to the Nuclear Weapons Council and to the Secretaries of Defense and Energy if necessary.

2. Create a Joint Advisory Committee for Nuclear Weapons Surety which would report directly to the two Secretaries of Defense and Energy. This committee would be responsible for examining ongoing practices in both DOD and DOE with respect to nuclear weapon surety, would have oversight of the surety reviews conducted on specific systems, and would identify and inform the Secretaries of any serious surety issue and provide advice as to the appropriate response.

Together with the Red Teams, the Joint Advisory Committee will provide confidence that all surety issues and requirements for the U.S. stockpile are identified, given a thorough technical analysis, and addressed in a timely fashion.

3. Strengthen and more tightly focus the responsibilities of the two offices charged with managing nuclear weapons issues within the Departments of Defense and Energy. Within Defense this is the Office of the Assistant to the Secretary of Defense for Atomic Energy [ATSD(AE)]; and, in Energy it is the Office of the Assistant Secretary for Defense Programs (ASDP). To be effective the charters of both of these offices must clearly delineate their responsibilities and assure their direct access to their respective Secretaries on critical and dangerous issues of nuclear weapons system surety. In particular, the ATSD(AE) should be given a more senior status as a member of the Nuclear Weapons Council (NWC) and upgraded to the same status as an Assistant Secretary of Defense, with a direct line of reporting to the Secretary.

4. The Deputy Assistant Secretary for Military Applications (DASMA), who plays a crucial role within the DOE Office of the ASDP and also chairs the Nuclear Weapons Council Weapons Safety Committee (NWCWSC), currently is required to be a flag-rank officer on active military duty. We recommend that the occupant of this position be chosen as the most qualified individual—civilian or military.

5. Designate the Assistant Secretary for Defense Programs (ASDP) in DOE as chairman of the Nuclear Weapons Council, whose other two members are from Defense (the DDRE and the Vice Chairman of the JCS), on all matters of nuclear safety in order to assure a better balance of interest in safety versus military requirements.

6. Develop a joint DOD/DOE training program for new appointees (at the mid-levels and higher) with official responsibilities in the nuclear weapons complex, particularly for weapons safety and security. A training program of perhaps one month's duration, organized and presented by the weapons laboratories and the Defense Nuclear Agency, with support from the military services, would be valuable to preparing officials for executing their responsibilities with a better awareness of their enormous importance.

It would also greatly help in recruiting highly qualified technical leaders for these positions if legislation were passed—consistent with legitimate concerns about conflict of interest—that would permit such personnel to accept temporary government positions of authority and still be permitted to return to their original positions after their tour of duty. According to current law, individuals returning to their original positions are limited to an advisory capacity while in government. This presents a particularly acute problem in so narrow a specialty as nuclear weapons science and technology which is heavily concentrated in only a few contractors and government laboratories.

7. The Secretaries of Defense and Energy should issue a joint policy directive emphasizing the importance of the safety and security dimensions of our nuclear weapons systems in the new post-Cold War world, and formulating an appropriate strategy for redressing safety concerns in the existing stockpile in a timely manner by a combination of retirements, improvements, and development of new weapons systems. In particular, they should launch a competitive priority effort at the weapons laboratories for new warhead designs that are as safe as physically possible against unintentional, accidental, or unauthorized detonation leading to a nuclear yield or the dispersal of plutonium. These designs would then be evaluated to see if they were militarily acceptable in view of whatever weight, yield, or operational penalties they might entail.

The primary goal of these seven recommendations is to establish a process for safety assurance that is pro-active, effective, and vigilant in search of the desired balance between maximum safety and reasonable military requirements.

Our four major recommendations for enhancing the safety of nuclear weapons systems by reducing the risks of an unintended, accidental, or unauthorized nuclear detonation or dispersal of plutonium apply both to the warheads themselves and to the entire weapon system. For the warheads they imply design choices for the nuclear components, the high explosives, and the electrical arming system. For the weapons system—i.e., the rocket motors to which the warhead is mated in a missile and the aircraft or transporter that serves as the launcher—safety implies choices of propellants and operational procedures as well as system designs.

1. Adopt and implement as national policy the following priority goals for improving the safety of the nuclear weapons systems in the stockpile, using available technology:

- equip *all weapons* in the stockpile with modern enhanced nuclear detonation safety (ENDS) systems.

- build *all nuclear bombs loaded onto aircraft*—both bombs and cruise missiles—with insensitive high explosives (IHE) and fire-resistant pits. These are the two most critical safety features currently available for avoiding plutonium dispersal in the event of aircraft fires or crashes.

There are no technical reasons for the DOD and DOE to delay accomplishing these safety goals for existing stockpile weapons; they should be given higher priority than they currently receive.

2. Undertake an immediate national policy review of the acceptability of retaining *missile systems* in the arsenal without IHE or fire-resistant pits in their nuclear warheads and without using a safer non-detonable propellant in rocket stages that are in close proximity with the warheads. Such a review will have to look at each missile system on a case-by-case basis, considering such factors as the way they are handled and loaded and the military requirements, as well as making a technical determination of how important these choices are to safety.

The Trident II (D5) missile system presents a special case to consider in the recommended policy review. It is a new, modern system that is slated to be a major component of the future U.S. strategic deterrent. At the same time the design choices that were made for the W88 in 1983 raise safety questions: the 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 a high energy detonable propellant. Today, seven years after these design choices were made, we have a new and better appreciation of uncertainties in assessing, for example, the probability that accidents in handling the D5 missile system might lead to dispersal of harmful radioactivity; the country has different perceptions of its strategic needs in the post-Cold-War era; the public has very different perceptions about safety; and the acquisition of W88 warheads for the D5 missile is still in the early stages and has been interrupted for the present and near-term future by the shutdown of the Rocky Flats plant where new pits for nuclear primaries are manufactured.

These circumstances present the country with a tough choice: Should we continue with production and deployment plans for the D5/W88 as presently designed or should we use the lull in production to redesign the missile with safety-optimized design features. This is a critical issue to be resolved expeditiously by the recommended policy review. It requires a broad, in-depth examination beyond our present review.

3. Develop the data bases and perform the system safety analyses that are required to support design choices critical to the overall risk and safety levels before proceeding with new weapons developments. Provide the resources necessary to support this work.

4. Affirm enhanced safety as the top priority goal of the U.S. nuclear weapons program and direct and appropriately fund DOE weapons laboratories, in fulfilling their national responsibilities, to vigorously pursue R&D in search of new technologies that could create new possibilities for significant advances in safety-optimized designs.

In a classified section of this report we discuss individual weapons systems and the safety concerns arising from the technology they incorporate and the handling and deployment procedures they experience. Finally we discuss improvements or changes that would enhance their safety.

To accomplish the goals we have set out in this study the U.S. nuclear weapons program will have to give higher priority and devote more of its resources to efforts to enhance safety—taking a long-range view in search of big advances in technology beyond just evolutionary, incremental improvements. Such a call for reorienting the emphasis of the current program should not be viewed as requiring an enlargement of the total program particularly as we look forward to maintaining a smaller nuclear force in the new strategic environment. It does however require that adequate and steady resources be made available for the RDT&E needed to underpin such a program.

I. INTRODUCTION

Concerns about the safety of several of the nuclear weapons systems in the U.S. arsenal have led the government to take immediate steps to reduce the risk of unintended, accidental detonations that could result in dispersing plutonium into the environment in potentially dangerous amounts or even generate a nuclear yield. These steps include temporarily removing the short-range air-to-ground attack missiles, SRAM-A, from the alert bombers of the Strategic Air Command and modifying some of the artillery-fired atomic projectiles (AFAPs) deployed with U.S. Forces. In addition, the Departments of Defense and of Energy, which hold dual responsibility for the surety of the U.S. stockpile of nuclear weapons system—i.e., for their safety, their security, and their control—have initiated studies looking more broadly into safety issues.

The House Armed Services Committee, joined by the Senate Armed Services Committee, has also requested an independent review of the safety of the U.S. nuclear weapons. The safety, security, and control of nuclear weapons are different, but related, issues. Nuclear weapons safety is concerned with the prevention of unintended nuclear detonations or the release of hazardous radioactive materials from weapons in their normal environments or from weapons that may be exposed to abnormal environments due to accidents, fires, or natural causes. Nuclear weapons system security is concerned with preventing unauthorized physical access; and weapon system control is concerned with preventing unauthorized use. Measures to provide for any one of these issues affect the other two. In preparing this report we emphasize nuclear weapon systems *safety* as requested by the Armed Service Committees.

We accept, as given, the continued maintenance of nuclear forces at some level for the foreseeable future, and address three fundamental aspects of U.S. nuclear weapons safety:

1. How can the nation's safety assurance process be strengthened?
2. Are appropriate criteria for safety applied in designing, developing, and maintaining nuclear weapons systems? Can they be enhanced by new technologies?
3. Do currently deployed nuclear weapons systems and new ones now in planning or under development meet desired safety criteria?

This is a very important, as well as opportune, moment to undertake a safety review of nuclear weapons for reasons that go well beyond the immediate concerns of several specific weapons. As we enter the last decade of the 20th century, the world is in the midst of profound, and indeed revolutionary, changes in the strategic, political, and military dimensions of international security. These changes, together with a continuing rapid pace of technical advances, create an entirely new context for making choices in the development of our nuclear forces for the future. It is likely that, in the future, the U.S. nuclear weapons complex will evolve into a new configuration—perhaps smaller and less diverse and at lower operating expense but with enhanced requirements for safety and control.

With these developments there also arise new challenges to the continuing effort to establish the proper balance between military requirements for new strategic and tactical nuclear weapons capabilities, and operational constraints and the associated technical design characteristics which must be accepted in order to meet the desiderata for weapon safety, security, and control. The DOD and DOE have been steadily improving the surety of the nuclear weapons stockpile through technical programs as well as policy guidance. Since the U.S. terminated air-borne alert by nuclear loaded SAC bombers in 1968, there have been no damaging accidents or otherwise unintended incidents leading to a nuclear yield or to dispersal of plutonium by any of our nuclear weapons. There have never been any accidents leading to a nuclear yield. We commend the two departments for this safety record. We are particularly impressed by the extreme care and high professionalism of the military services in their managing and maintaining security of deployed nuclear weapons systems.

Nevertheless, as made clear by the concerns and actions described in our opening paragraph, there is still room for substantive improvement in nuclear weapons safety. The existing process and criteria have evolved gradually over the years since the 1950s. During this period, a large nuclear weapons stockpile was built in the chilling environment of the Cold War. Modernization and improvement programs gave priority to military requirements, such as achieving maximum yield-to-weight ratios for warheads and maximum payloads and ranges for missiles. Safety in general was not viewed with the same urgency; and based on the perception that our weapons designs and handling procedures resulted in an adequately high degree of safety, policy guidance, as stated in its most recent form, called for nuclear weapons "to incorporate maximum safety consistent with operational requirements" (DOD Directive 3150.2; Feb. 8, 1984). Modification of stockpile weapons in order to bring them up to modern safety criteria has proceeded slowly under a stockpile improvement program that, within its budgetary limits, has in the past given priority to the production of new weapons. [1] As a result, in anticipation of acquiring new weapons systems, many older ones remain in today's nuclear stockpile that do not meet present nuclear weapons design criteria.

The need at present is to adapt a safety process that was designed to meet the needs of the Cold War to the major political, military, and strategic changes that have occurred so rapidly. Looking into the future a new balance must be struck between the desired military characteristics and requirements for enhanced safety. On the one hand, the military requirements are changing and, on the other, safety standards can be raised if we take advantage of important new technical advances. It makes a big difference whether top priority is given to achieving maximum military effectiveness or achieving maximum safety in designing nuclear weapons. These two requirements are often somewhat at odds with one another, and determining the appropriate balance between them in making design choices is clearly sensitive to the changing, and not entirely predictable, strategic environment.

[1] For a fuller statement of this concern see the 1985 Report of the President's Blue Ribbon Task Group on Management of the Nuclear Weapons Program (chaired by Judge William T. Clark). This appears on page 19 of the Report's Appendix on Requirements Issues which is included in Appendix B with the classified portion of our report. The original DOD policy was set down in a 1979 letter from then ATSD(AE) James T. Wade to Major General Joseph Bratton, which is also reproduced in Appendix B.

In this report we recommend new initiatives in the nuclear weapon safety process in order to adapt it to better meet the challenge of maximizing safety in appropriate balance with reasonable military requirements in preparing our nuclear weapons for the future. We also recommend specific actions to improve the safety of the nuclear weapons stockpile.

This report is organized as follows: Section II reviews the current safety standards for nuclear weapons and the policy guidance in DOD and DOE for fulfilling their safety responsibilities. Section III addresses the first of the three questions posed above and presents our findings and recommendations for strengthening the safety assurance process. Section IV addresses the second of the above questions, describing the individual technical factors that contribute to safety and recommending the priority actions that will enhance the safety of the nuclear weapons stockpile. Section V addresses the third question of whether existing and planned weapons meet the desired safety criteria. It is presented as a separate classified (Secret-RD) section of this report together with a relevant appendix.

II. SAFETY STANDARDS FOR NUCLEAR WEAPONS

In this section we describe the existing nuclear weapons safety process and the safety standards that have been specified for the stockpile. 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 assure 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:

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.

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

FIG. 1

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 of 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 required to survive without degradation in 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."

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.")

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

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, henceforth denoted 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, henceforth denoted 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.

Inevitably there will be tensions in seeking the proper balance between military requirements, including weapon readiness, and the operational constraints and technical design characteristics which provide for weapon safety and security. Finding the right balance requires an effective process, which ensures close cooperation between DOD and DOE and provides for full understanding and evaluation of the safety and security issues along with the operational consequences, in all decisions affecting our nuclear weapons stockpile.

III. THE SAFETY ASSURANCE PROCESS

In this section we address the first of the three basic issues raised in the Introduction: "How can the nation's safety assurance process be strengthened?" In our study we have reviewed the results of two recent studies which included inquiries into the nuclear weapons safety process: The 1985 President's Blue Ribbon Task Group on Nuclear Weapons Program Management, chaired by Judge William T. Clark, and the 1988 DOE Nuclear Weapons Safety Review Group, chaired by Gordon Moe. Both of these panels addressed long-standing concerns with stockpile safety and made important recommendations, a number of which were implemented, resolving some of these concerns. It is our present finding that although many things have been, or are being, fixed, still more remain to be addressed. We are concerned, as were these earlier panels, that serious issues that had been known for at least a decade remained unattended for so many years.

We believe that basic changes in the process to enhance safety of the nuclear weapons should be made in a timely manner. These

will complete the process started during the past four years and will help ensure that future concerns about safety will be addressed promptly and effectively. Moreover, we see the present as a particularly opportune time to make these changes. The worldwide strategic-military context is changing radically and with it so have the military requirements on our nuclear weapons.

We first give a brief summary of the Clark and Moe studies since their recommendations and subsequent actions by the DOD and DOE provide the point of departure for our own findings and recommendations. Although the Clark Task Group judged the DOD/DOE relationship for managing the nuclear weapons program to be "sound", it found deficiencies in the dual agency control of weapons safety, security and control and called for administrative changes to overcome the inadequacies it found in the means to provide oversight and to resolve problems.

In particular, it noted that [2] "Technical means to improve stockpile safety were identified in 1973.", adding that "The Task Group finds it distressing that it took until 1984 to begin modifying weapons".

Two of the primary recommendations of the Task Group were to:

1. Create the Nuclear Weapons Council (NWC) to ensure that the DOD/DOE fulfill their responsibilities and that independent judgments are maintained in considering surety issues for existing weapons and proposed new weapon program starts.
2. Issue a Presidential Directive to ensure continuing dual agency responsibility for nuclear weapon surety.

The first of these recommendations was accepted and the NWC created, with the responsibility, according to Public Law 99-661 to "consider safety . . . issues for existing weapons and for proposed new weapon program starts." It is composed of three members as follows:

1. The Director of Defense Research and Engineering, Chair
2. The Vice Chairman of the Joint Chiefs of Staff
3. One senior representative of the DOE appointed by the Secretary of Energy: currently [3] designated to be the Assistant Secretary, Defense Programs.

Although no direct action was taken on the second recommendation, a National Security Decision Directive issued in 1988 reaffirms that DOD and DOE share the responsibilities to identify and resolve nuclear safety problems connected with nuclear weapons.

Our investigation leads us to concur with the above-stated findings of the Clark Task Group and to endorse the importance of these two recommendations.

The principal recommendations of the Moe Panel in July 1988 may be summarized as follow:

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[2] See classified Appendix B to this report for specific concerns raised by the Task Group in a classified Appendix on Requirements Issues to their report.

[3] Shortly before the completion of this report the appointment of Richard A. Claytor (Capt., U.S. Navy, ret.) as Assistant Secretary, Defense Programs, was announced and confirmed by the Senate on October 19.

1. Emphasize responsibility of DOE line management for nuclear weapon safety and strengthen its ability to carry out this responsibility.
2. Provide active top-level DOE leadership on safety issues. Particular steps to implement this leadership include assuming chairmanship of the NWC when considering safety issues and creating a Nuclear Weapon Council Weapons Safety Committee (NWCWSC) to be chaired by the DOE's Deputy Assistant Secretary for Military Applications (DASMA).
3. Ensure a broad, balanced review and analysis of safety issues with substantive issues being elevated to the NWC and with the Secretaries of DOD and DOE being kept fully informed.

The Moe Panel also presented the following important concluding thought:

"Attention to safety has waned, and we still have risks from weapons that will remain in the stockpile for years. The potential for a nuclear weapon accident will remain unacceptably high until the issues that have been raised are resolved. It would be hard to overstate the consequences that a serious accident could have for national security."

Progress subsequent to the Moe Panel's report includes the creation of the NWCWSC in the fall of 1989 under DASMA chairmanship with the charge to bring safety issues before the NWC, and the undertaking of safety reviews on the transportation of nuclear weapons and on the safety of the Air Force SRAM-A missile system. As to the recommendation to strengthen the ability of DOE's line management to carry out its responsibility for safety, we note that the management of nuclear weapons matters within DOE is the responsibility of the Assistant Secretary for Defense Programs (ASDP) and is centered in that office. The fact that the position of ASDP was vacant, or filled only on an acting basis, for more than three years prior to October 1990 clearly hampered the ability of DOE to provide strength in fulfilling its shared responsibilities with DOD in finding and setting a proper balance between safety and military requirements for the U.S. nuclear weapons systems.

Panel Findings

The findings of our review of the nuclear weapons safety assurance process can be summarized as follows: The creation of the Nuclear Weapons Council (NWC), as recommended by the Clark Task Group, and the NWC Weapon Safety Committee (NWCWSC), as recommended by the Moe Panel, are important steps in strengthening the safety assurance process, but they do not go far enough to assure its vitality and effectiveness in the future.

We still see a need to improve the process and provide confidence that all surety issues and requirements for our future stockpile are identified and given a thorough technical analysis before a weapon system is approved for deployment. The process must ensure that the data base needed to support decisions is established and safety considerations are weighed with appropriate priority in addressing changing military requirements. In any disputes the burden of

proof must be placed on proving the system to be safe rather than being satisfied with lack of evidence that it is unsafe. The process must provide a strong "pull" assuring that any and all concerns about the safety—or the lack of data upon which to base a valid judgment—are elevated to the level of Secretaries of Defense and Energy before a decision to go ahead is made. It should also ensure that concerns about stockpile safety are addressed in a timely fashion. Whereas some concerns have been resolved in an exemplary fashion—viz., the rapid attention given to removing a serious safety concern by modifying the AFAPs referred to in the introduction—others have remained for far longer than necessary or desirable.

Recommendations

We make these recommendations for strengthening the safety assurance process with the following conviction. No matter how successful—and lucky—a system has been, it must not be allowed to breed complacency or justify the status quo. When one considers the potential for tragedy should a serious accident occur and considers consequences of such an accident for our national security, it is clear that no reasonable effort should be spared to retain full vigor and care in the safety assurance process and to prevent any such accident from occurring.

1. The safety criteria for nuclear weapons that we reviewed in Section II—viz., a 1 in 10^6 probability for premature detonation of a warhead in an abnormal environment or avoidance of plutonium dispersal in an accident—are very demanding requirements on the safety assurance process. To satisfy them requires an adequate data base, careful fault tree analyses that incorporate all threatening environments, and a certain amount of good judgment. It takes a special organization and analysis capabilities in order to develop confidence in meeting such exacting standards. In particular, there should be a procedure for challenging the weapons designs and handling procedures in search of dangers that may have been overlooked or not properly evaluated.

We recommend that a joint DOD/DOE dedicated "Red Team" be created as an important mechanism for exercising this responsibility for each nuclear weapons system in the stockpile or under development. The Sandia National Laboratory (SNL), which has prime responsibility for weapons system integration of the nuclear warheads within DOE, would be assigned the prime responsibility for interfacing with the relevant Service and with DOD. Sandia would receive from the DOD the system configuration in accord with the designated military requirements and would be responsible for "red teaming" the effort to expose technical defects in the weapon systems surety. The Los Alamos National Laboratory (LANL) or the Lawrence Livermore National Laboratory (LLNL) would chair the Red Team review of the other laboratory's design and would provide technical support through its analyses of the risk of nuclear yield or plutonium dispersal resulting from potential abnormal environments to which the warhead may be subjected (i.e., drop during handling, fuel or propellant fire, etc.).

The Defense Nuclear Agency (DNA) in DOD would be assigned the prime responsibility for "red teaming" the operational aspects of the surety of deployed nuclear weapons systems in their actual military configurations. Members of this effort would include military officers assigned to DNA from the field commands as well as DNA's in-house engineers and scientists, plus scientists and engineers from the service laboratories.

In order to ensure that the findings of the Red Team are accepted as credible, it is vital that DOD and DOE should jointly be responsible for and participate in the Red Team activity; i.e., it must be a dual agency responsibility. Also, to avoid conflicts of interest no Red Team member should be a member of the development team for the weapon systems being analyzed.

The Red Team's interactions would be with the weapons design teams during the "design definition" and "development engineering" phases of the weapons programs. (These are known as Phase 2A and Phase 3, respectively. They follow concept study, or Phase 1, and feasibility study, or Phase 2, and coincide with the assignment of the weapon program to one of the DOE design teams, LANL/SNL or LLNL/SNL.) However, in case of unresolvable differences of views on safety issues the Red Team would have direct channels of access to the NWCWSC, the NWC, and higher levels. The Red Team that we are recommending differs basically from the two currently existing dual agency committees that are concerned with weapon system safety: the Project of Officers Group (POG) and the Nuclear Weapons System Safety Group (NWSSG). Both the POG and the NWSSG are always chaired by the Using Service, and the majority of their members are usually both active duty military officers and civilians who report directly to the military service which is the customer. This structure builds in career conflict-of-interest issues. Furthermore, the groups have different expertise and responsibilities. The POG is primarily a coordinating and interfacing group but is charged with coordinating investigations concerning weapon design tradeoffs that affect weapon safety. The NWSSG reviews the weapon system safety to ensure that the weapon system safety standards are met and develops or, as necessary, revises the safety rules.

Finally we emphasize the extreme complexity of the problem of designing weapons and of analyzing them with three-dimensional weapons codes that require gross approximations in following the neutronic and hydrodynamic development toward a nuclear explosion. In view of this complexity, it is extremely important to retain and adequately support with the necessary resources two totally independent and competitive nuclear design teams for analyzing these effects both with computer simulations and with actual experiments and tests during the concept and feasibility studies in Phase 1 and Phase 2 prior to advancing to Phase 2A and choosing one design team.

2. A Joint Advisory Committee for Nuclear Weapons Surety should be impaneled [4] which would report directly to the two Secretaries of Defense and Energy. This committee would serve three important functions:

- It would provide oversight and would be responsible for examining ongoing practices in both DOD and DOE with respect to nuclear weapon surety.
- It would have oversight of the surety reviews conducted by DOE and DOD organizations on specific systems.
- It would identify and inform the Secretaries of any serious surety issue and provide advice as to the appropriate response. This will ensure that the Secretaries of DOD and DOE are fully informed and involved in resolving any such issue.

By fulfilling these functions the advisory committee would ensure accountability at all levels and strengthen the process for resolving surety issues in an effective, informed, and expeditious manner. This advisory committee would be similar in function to the Nuclear Weapons Safety Committee of the United Kingdom, which is their highest safety policy committee. It should be composed of a small number of senior civilian and retired military individuals having had extensive experience with nuclear weapons surety. In our view the panel might meet twice a year and whenever an important issue arises. Any issue on which there are substantive differences between the DOD and DOE members of the Red Team or with the NWC would be brought to the attention of this committee.

The advisory committee we are recommending differs basically from the Nuclear Weapons Council Weapon Safety Committee created in response to the Moe Panel. The NWCWSC is composed of flag-level members of the DOD and senior members of the DOE, and thus faces a built-in conflict of interest. Its members are not independent of those who are currently responsible for developing and operating the weapons systems. Second, it is at a lower reporting level, with its major reporting channel being to the Nuclear Weapons Council. The members of the NWCWSC are usually not nuclear weapons experts, and they have many other responsibilities that can prevent them from focusing on weapon surety. It is envisioned that the NWCWSC would continue to function in its normal fashion.

The Joint Advisory Committee would provide a high level review mechanism for the Annual Surety Reports on Nuclear Weapons for the President that are prepared annually by DOE and DOD. They, together with members of the NWC should also provide annual briefings on stockpile surety to the appropriately designated Congressional oversight committees.

3. Strengthen and more tightly focus the responsibilities of the two offices charged with managing nuclear weapons issues within the Departments of Defense and Energy. Within Defense this is the Office of the Assistant to the Secretary of Defense for Atomic Energy [ATSD(AE)]; and, in Energy it is the Office of the Assistant Secretary for Defense Programs (ASDP).

To be effective the charters of both of these offices must clearly delineate their responsibilities and assure their direct access to their respective Secretaries on critical and dangerous issues such as safety, security, and control of nuclear weapons. There is consid-

[4] Note that at this level we changed the focus from safety to surety. Specifically, safety, security, and use control should be treated together because of their critical importance and their interdependence.

erable evidence to suggest that over the years both offices have been downgraded in importance and suffered as many other issues have drawn attention away from the nuclear weapons complex.

In DOD, multiple administrative layering has proliferated and by charter the ATSD(AE) reports to the Secretary through three layers of management starting with the Director of Defense Research and Engineering (DDRE). One of the consequences of the new Nuclear Weapons Council (NWC) is to downgrade the ATSD(AE) in Defense relative to the ASDP in Energy. Whereas the ASDP is one of three members of the NWC, the ATSD(AE) chairs the Nuclear Weapons Council Standing Committee (NWCSC) which serves as staff to the NWC. The ATSD(AE) should be appointed as one of three members of the NWC, replacing the DDRE, and upgraded to the same status as an Assistant Secretary in DOD [ASD(AE)] with a direct line of reporting to the Secretary.

The charter of the ATSD(AE) office, in a change from previous practice, now includes responsibilities for chemical and biological warfare issues. The current charter, dated February 4, 1986 and signed by then Deputy Secretary of Defense, William E. Taft IV, provides among other things that the ATSD(AE) is "responsible to the Secretary of Defense through the Undersecretary of Defense for Research and Engineering (note: since downgraded to DDRE), for matters associated with: (1) nuclear and chemical weapons safety, security, and survivability . . . Additionally, the ATSD(AE) serves as the single OSD focal point with responsibility for integrated management of all chemical and biological defense and chemical stockpile destruction matters within DOD."

This new charter poses serious problems because it seriously diverts attention from the main reason for the existence of the office, i.e., nuclear weapons matters. We believe the responsibilities of this office should be redefined and limited solely to matters concerning nuclear weapons systems. The ASD(AE) should be shielded from the enormously wide range of problems that must be addressed in DOD in view of the overwhelming importance of maintaining the efficacy, safety and security of our nuclear weapons. It is infeasible to expect the ASD(AE) to be knowledgeable on critical CW and BW weapons problems [5] at the same time as managing nuclear weapons issues.

The ASDP in DOE has many responsibilities parallel to those of the ATSD(AE) in the Pentagon. This is especially true with respect to safety, security and control of nuclear weapons which DOE develops, builds, tests, transports, and maintains in its custody.

Contrary to the DOD situation, the ASDP office is totally focused on nuclear weapons. Leadership in this office, which was filled only on an acting basis for more than three years until the recent appointment of Richard A. Claytor (Capt., U.S. Navy, ret.), is a prerequisite to strengthening the DOE's line management for nuclear weapons safety, as also recommended in 1988 by the Moe Panel. The occupant of this office should be assured that nuclear issues

[5] This proposal should not be interpreted as suggesting in any way that attention to CW and BW issues should be de-emphasized. Quite the contrary; it seems reasonable to maintain their oversight function in DDRE as it is now but with the responsible official freed of any responsibility for nuclear weapons.

will be heard at the Secretarial level. We concur with the recommendation of the 1985 Clark Task Group to "strengthen DOE's management attention to its national security responsibilities: . . . These steps should include raising the stature of the nuclear weapons program management within DOE, for example by establishing a separate organizational entity, e.g., an Administration with a clearly demarcated budget, reporting directly to the Secretary."

An additional step that would strengthen the safety process in DOD as well as DOE would be to establish and formally institutionalize direct access to the Secretaries of DOE and DOD by the directors of the three DOE weapons laboratories (LANL, LLNL, and SNL) on exceptional matters concerning the safety, security and control of nuclear weapons and weapons systems.

4. Within the office of the ASDP, the Deputy Assistant Secretary for Military Applications (DASMA) plays a crucial role. By law, the position of DASMA is required to be filled by an active military flag rank officer; the current (and very able) occupant is a one-star rear admiral. This requirement is no longer appropriate, particularly in view of the new responsibility of the DASMA for chairing the Nuclear Weapons Council Weapons Safety Committee (NWCWSC), a very important committee with the responsibility of bringing safety issues up to the NWC. Since the majority of its members are active military—some with two-star rank—the DASMA is clearly put in a career threatening conflict-of-interest position. We recommend that the occupant of this position be chosen as the most qualified individual—civilian or military—and he/she should not be bound by requirements for frequent reassignment which is the norm for military officers.

5. The Nuclear Weapons Council, two of whose members are from Defense (the DDRE and the Vice Chairman of the JCS) and one from Energy (the ASDP) should be chaired on all matters of nuclear safety by the DOE representative in order to assure a better balance of interest in safety versus military requirements. This was also a recommendation of the Moe Panel.

6. A joint DOD/DOE training program should be developed for new appointees (at the mid-levels and higher) with official responsibilities in the nuclear weapons complex, particularly for weapons safety and security. Forty-five years have passed since nuclear weapons were used in anger and twenty-seven since the U.S. signed the Limited Test Ban Treaty which restricts signatories to underground nuclear explosions. With the passage of time, responsible positions are now being filled with a new generation of officials who have never seen nuclear explosions and do not fully grasp their reality and consequences. A training program of perhaps one month's duration, organized and presented by the weapons laboratories and the Defense Nuclear Agency, with support from the military services, would be valuable to preparing officials for executing their responsibilities with a better awareness of their enormous importance.

It would also greatly help in recruiting highly qualified technical leaders for these positions if legislation were passed—consistent with legitimate concerns about conflict of interest—that would permit such personnel to accept temporary government positions of authority and still be permitted to return to their original positions after their tours of duty. According to current law, individuals returning to their original positions are limited to an advisory capacity while in government. This presents a particularly acute problem in so narrow a specialty as nuclear weapons science and technology which is heavily concentrated in only a few contractors and government laboratories.

7. The Secretaries of Defense and Energy should issue a joint policy directive emphasizing the importance of the safety and security dimensions of our nuclear weapons systems in the new post-Cold-War world, and formulating an appropriate strategy for redressing safety concerns in the existing stockpile in a timely manner by a combination of retirements, improvements, and development of new weapons systems. In particular, they should launch a competitive priority effort at the weapons laboratories for new warhead designs that are as safe as physically possible against unintentional, accidental, or unauthorized detonation leading to a nuclear yield or the dispersal of plutonium. These "provably safe" designs would then be evaluated to see if they were militarily acceptable in view of whatever weight, yield, or operational penalties they might entail.

The President should also initiate an interagency study chaired by the National Security Council, on the future of the nuclear stockpile, with particular emphasis on the importance of nuclear weapons surety. Leadership at the top levels of government—including effective Congressional oversight—will be essential in setting a new strategy and insuring that vigor, quality, and priority attention is given to our enlarging safety needs during this period of budget stringency and of major change in the strategic climate. In designing the nuclear weapons stockpile of the future, public interest in safety and concerns about potential or perceived incidents as well as valid military strategic requirements must be fully considered. Improved safety standards for the future can and should be achieved. But to do so, the DOE must commit sufficient resources to the weapons laboratories in support of the necessary strong research, development, testing, and evaluation effort toward enhanced safety.

The primary goal of these seven recommendations is to establish a process for safety assurance that is pro-active, effective, and vigilant in search of the desired balance between maximum safety and reasonable military requirements.

Our recommendations for strengthening the weapons safety assurance process are summarized in the organizational chart of Fig. 3. The four major new elements that we are proposing are the "Red Teams"; the Joint Advisory Committee; a more senior status for the ATSD(AE) who, as ASD(AE), would replace the DDRE as a member of the NWC, would be responsible solely for nuclear weapons issues and would report directly to the Secretary of Defense; and a more senior status for the ASDP in DOE with direct line of reporting to the Secretary of Energy and with the Deputy Assistant Secretary for Military Applications in that office no longer required to be an active military officer.

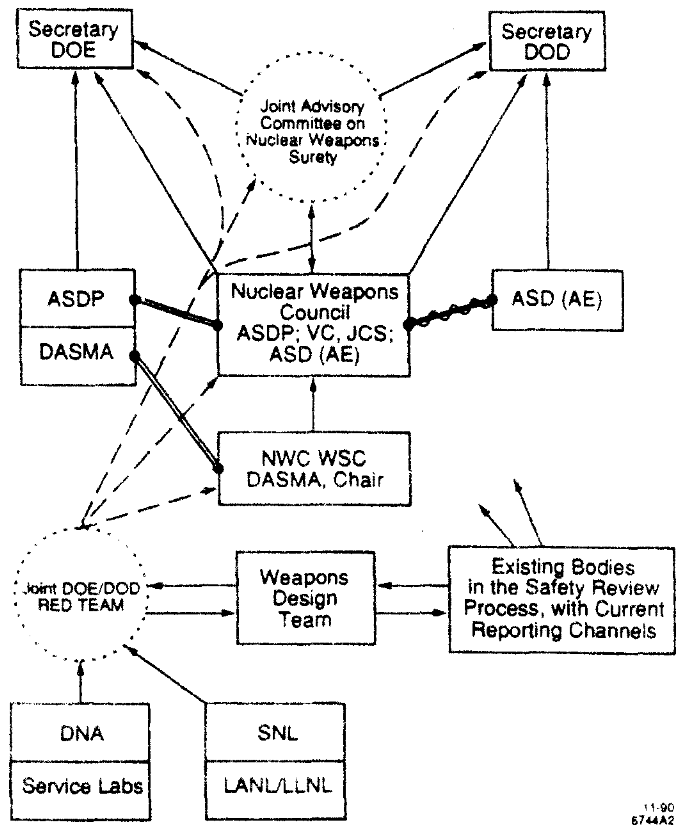

FIG. 3

Key elements of the proposed safety assurance process. Solid lines indicate normal channels of interaction and reporting. Dashed lines indicate channels of direct access in case of remaining differences on safety issues. The wavy line indicates the change in membership of the NWC with the ASD(AE) replacing the DDRE.

IV. NUCLEAR SAFETY CRITERIA

In this section we consider the issue: "Are appropriate criteria for safety applied in designing, developing, and maintaining nuclear weapons systems? Can they be enhanced by new technologies?" Our approach is to describe the individual technical factors that contribute to safety, the safety standards that can be met by design choices, and the methods for determining whether or not the standards are being met.

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 trace 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. We will discuss their specific implications for existing and planned nuclear weapons systems in the next (classified) section of this report. Here we first describe 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) 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 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. 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 a 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. [6] Since then, following public disclosure of the safety concern, the SRAM-A has been taken off the alert SAC bomber force, [7] 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, 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

[6] 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.

[7] The decision on the SRAM-A was announced by Secretary Cheney on June 8, 1990.

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: [8]

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)	$\sim 10^{-1}$	½
Shock pressure threshold to detonate (kilobars)	~20	~90
Impact velocities required to detonate (miles/hour)	~100	~1200–1300

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 [9] 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 [10] 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

[8] Tables 1 and 2 are adapted from the presentation to the Panel by the Lawrence Livermore National Laboratory, June 19, 1990.

[9] This is spelled out in two memoranda. The then ATSD(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 warheads 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."

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

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	O10^{-3}
Diameter below which the detonation will not propagate (inches)	>40	O10^{-1}
Shock pressure threshold to detonate (kilobars)	[1]	O30
Specific impulse (seconds)	O260	O270

[1] No threshold established.

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 re-

maining 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 the propellant which in turn could cause the HE in the warhead to detonate leading to dispersal of plutonium, or even the initiation of a nuclear yield beyond the four-pound criterion stated in Fig. 1. 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 multi-point 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 non-detonable 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 reductions 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-optimized version of the D5, equipped with IHE, non-detonable 1.3 class propellant and a fire-resistant pit, could fly to even longer ranges than at present.

Further analysis of this issue will be presented in the next section of this report. Here 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

As noted earlier 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.[11] This means it is necessary to specify both the amount of material and the manner in which it is dispersed in setting safety standards.

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 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.

Safety Optimized Designs

Important contributions to weapons systems safety result from equipping the warheads with modern enhanced nuclear detonation safety systems (ENDS) and insensitive high explosives (IHE), together with composite propellants of the 1.3 class in the missile engines. The known physical properties of these systems components can be incorporated into specific scenarios for incidents or accidents in making probabilistic risk assessments which can then be compared with the official safety criteria as stated in Figs. 1 and 2. Such comparisons are useful and important to make, but it is also important to understand their limitations. We are dealing with very complex systems, and it is impractical to accurately model every detailed feature of the individual stages and all the interconnections of the weapons stages, motors, and propellants or to accurately anticipate all possible types of accidents. By accumulating a data base from practical experimental tests and by red teaming the weapons designs and handling procedures, we can increase confidence in having achieved the stated safety criteria. But it remains physically impossible to confirm quantitatively for all contingencies that risks such as no more than one in 10^6 or 10^9 have been achieved. What one can do—and this is important to do—is identify the potential sources of the largest safety risks and push ahead with searches for new technologies that do away with them and further enhance weapons safety.

One such technology is a fire-resistant pit (FRP) that would further reduce the likelihood of plutonium dispersal in fire accidents involving warheads equipped with IHE. In particular, current FRP's are designed to provide molten plutonium containment against the (~1000°C) temperatures of an aircraft fuel fire that lasts for several hours. They may fail to provide containment, however, against the much higher temperatures created by burning missile propellant. They would also fail in the event of detonation of the HE and are therefore of primary value to safety only if introduced in weapons equipped with IHE. Some of our newest warheads already incorporate FRPs. Beyond that, however, one can envisage advanced weapons design concepts, familiar in the world of binary chemical weapons, that separate a very hardened plutonium capsule from the high explosive prior to arming the weapon; or similarly separating the high explosive into two non-detonable components. We do not know whether such, or other, advanced design concepts will prove practical when measured against future military requirements, availability of resources, and budget constraints. However, they should be studied aggressively. R&D is not cheap but the payoff can be very valuable in terms of higher confidence in enhanced weapons safety. DOE should support such work with the necessary resources.

Panel Findings

The safety criteria that have been specified for modern nuclear weapons are very demanding. The majority of the weapons in the current stockpile will have to be modified to meet them, unless they are retired. Moreover, for some weapons we still lack necessary data to perform credible safety analyses. With a vigorous R&D program at the weapons laboratories in search of new technologies for advanced design concepts, it should be possible to achieve higher confidence in enhanced weapons safety, particularly with respect to plutonium dispersal for which there currently is no quantitative standard. Although plutonium dispersal is a much less threatening danger than a sizable nuclear yield, it is nevertheless a

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[11] 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.

potentially serious hazard, particularly if the plutonium is aerosolized in a chemical detonation.

RECOMMENDATIONS

1. Adopt and implement as national policy the following priority goals for improving the safety of the nuclear weapons systems in the stockpile using available technology:

- equip *all weapons* in the stockpile with ENDS.
- build *all nuclear bombs loaded onto aircraft*—both bombs and cruise missiles—with IHE and fire-resistant pits. These are the two most critical safety features currently available for avoiding plutonium dispersal in the event of aircraft fires or crashes.

There are no technical reasons for the DOD and DOE to delay accomplishing these safety goals for existing stockpile weapons; they should be given higher priority than they currently receive. For too long in the past the U.S. has retained older weapons that fail to meet the safety criteria proclaimed in 1968 (Figs. 1 and 2). The SRAM-A is one such example, but not the only one. It is not sufficient to pull such weapons off the alert ALFA force but retain them in the war reserve stockpile in view of the hazards they will present under conditions of great stress should we ever need to generate strategic forces in times of heightened crisis.

2. Undertake an immediate national policy review of the acceptability of retaining *missile systems* in the arsenal without IHE or fire-resistant pits in their nuclear warheads and without using the safer non-detonable 1.3 class propellant in rocket stages that are in close proximity with the warheads. Such a review will have to look at each missile system on a case-by-case basis, considering such factors as the way they are handled and loaded and the military requirements, as well as making a technical determination of how important are the choices of IHE versus HE, 1.3 versus 1.1 class propellant, and fire-resistant pits.

The Trident II (D5) missile system presents a special case to consider in the recommended policy review. It is a new, modern system that is slated to be a major component of the future U.S. strategic deterrent. At the same time the design choices that were made for the W88 in 1983 raise safety questions: the 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 a high energy 1.1 class detonable propellant. Today, seven years after these design choices were made, we have a new and better appreciation of uncertainties in assessing, for example, the probability that accidents in handling the D5 missile system might lead to dispersal of harmful radioactivity; the country has different perceptions of its strategic needs in the post-Cold-War era; the public has very different perceptions about safety; and the acquisition of W88 warheads for the D5 missile is still in the early stages and has been interrupted for the present and near-term future by the shutdown of the Rocky Flats plant where new pits for nuclear primaries are manufactured.

These circumstances present the country with a tough choice: Should we continue with production and deployment plans for the D5/W88 as presently designed or should we use the lull in production to redesign the missile with a safety-optimized design incorporating, at a minimum, non-detonable 1.3 class propellant in the third stage and IHE and FRP in the warhead?

This is clearly a critical issue to be resolved by the recommended policy review. It will be necessary to weigh the safety risks of continuing to deploy the present design against the costs and delays of a system redesign in order to make an informed choice. But to be able to do this, further studies are needed:

- to provide the data on which to base a more credible analysis of how well, or whether, the D5/W88 meets modern safety standards
- to estimate the costs and inevitable time delays of implementing any recommended design changes
- to evaluate the impact on anticipated national security requirements if changes to enhance weapons safety resulted in fewer warheads, lower explosive yields, or reduced maximum ranges of the missiles.

To do this requires a broad and in-depth examination that is beyond our present review.

3. Continue safety studies, and in particular fault tree analyses such as recently initiated and currently in progress for evaluating safety of the SRAM-A missile and of the DOD/DOE weapon transportation system. Such fault tree analyses which calculate overall risk and safety levels in terms of the individual steps in the operational procedures and sensitivities of the system components to abnormal environments, provide the necessary analytic tools for evaluating overall systems safety. Very important to such analyses is developing a data base to provide the necessary factual input. The weapons and military laboratories should give priority to doing the experiments for building such a base. They should also receive the resources necessary to support this effort. We believe that it is no longer acceptable to develop weapons systems without a factual data base with which to support design choices that are critical to the systems safety. A critical role of the Red Team in the safety process is to challenge this process by searching out overlooked circumstances that could pose threats to the weapon systems safety.

4. Affirm enhanced safety as the top priority goal of the U.S. nuclear weapons program and direct DOE and DOD, in fulfilling their national responsibilities, to develop nuclear weapons for the future that are as safe as practically achievable, consistent with reasonable military requirements. In particular, the DOE should task and appropriately fund its weapons laboratories to develop truly innovative warhead designs that are as safe as practically achievable. In this connection the requirement of "inherent" one-point safety as stated in Fig. 1 should be reexamined. The enhanced safety resulting if the plutonium capsule is physically separated from the IHE prior to arming may well prove to be more important than whatever weight penalty or decrease in reliability—if any—would result from such a design. All advanced design concepts should be studied aggressively. Subsequently the utility of such designs, together with whatever weight or range penalties they require, would be measured against established military requirements.

Finally, we comment that the above recommendations are concerned directly with weapons safety, which was the focus of this review. However, it is appropriate to add how very impressed we were by the nuclear weapons security measures that we observed at the Navy Trident II Base at Kings Bay, Georgia, and the Air Force SAC Base at Minot, North Dakota. During the limited period of this study we had no opportunity to visit field deployments of Army nuclear weapons.

Concerning use control of nuclear weapons, we are satisfied by the technical measures, including permissive action links (PALs), and the serious attention that use controls receive on Air Force missiles and bombs. Great care is also given by the Navy to maintaining a tight system of use controls on its Trident missiles at sea. However, the Navy's fleet ballistic missile system differs in that, whereas launch authority comes from outside the submarine, there is no requirement for external information to be provided in order physically to enable a launch. It is also important to evaluate the suitability of continuing this procedure into the future.

APPENDIX A—Charge to the Panel and Schedule of Formal Briefings

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

June 5, 1990

Professor Sidney D. Drell
Stanford Linear Accelerator Center
Post Office Box 4349
Stanford, California 94309

Dear Dr. Drell:

Thank you for agreeing to advise us on the safety of certain nuclear warheads in our arsenal. Dr. Foster and Dr. Townes also have agreed to serve, and Secretary of Energy Watkins has responded to our request with the enclosed letter, assuring us of the department's full cooperation and designating Victor Stello, Jr., Deputy Assistant Secretary for Facilities, as your point of contact.

We look to you, Dr. Townes and Dr. Foster to organize this panel and to determine what is necessary to complete your review. We will assist you in any way we can, and we will be pleased to meet with you at the outset to discuss the scope of your review and any support from us that may be helpful. In the conduct of your review, we would like for you to consider the adequacy of current safety standards.

We are grateful for your willingness to undertake this critically important assignment, and we look forward to receiving your evaluation and advice.

Respectfully,

John M. Spratt, Jr.
Member of Congress

Jon L. Kyl
Member of Congress