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A SURVEY OF NUCLEAR WEAPON SAFETY PROBLEMS AND THE POSSIBILITIES FOR INCREASING SAFETY IN BOMB AND WARHEAD DESIGN(u)

Prepared by

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February 1959

THIS DOCUMENT CONSISTS OF 65 PAGE(S)
NO. 1 OF 1 COPIES, SERIES C

ABSTRACT

This report is an attempt to treat the separate problems of nuclear weapon safety in a logical sequence and to outline the various means available for further increasing safety in the ordnance and nuclear design of bombs and warheads. The provision of adequate nuclear weapon system safety from production line to target is, however, a complex tangle of interrelated problems involving the personnel, the materiel, and the operational concepts of the total national defense system. As such, over-all safety is clearly a dual AEC/DOD responsibility. Principal emphasis in this report is placed on those additional safing measures which might be undertaken in AEC designs without major degradations in the competing operational characteristics.

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SUMMARY

Assessment of Hazards

Experience to date with nuclear weapon accidents and incidents supports conclusions that:

a. Inadvertent release of ready bombs and inadvertent launch of ready missiles, which might well be armed as a result of human error, are the most serious safety problems.

b. The incidence of gross human errors in handling, testing, and assembly procedures is second in importance as a safety hazard.

c. The likelihood and degree of severity of accidental nuclear yields from unarmed sealed-pit warheads as a result of severe impact and/or fire in crash, jettison, drop, and storage and transportation accidents are completely overshadowed by the larger hazards above.

d. The spontaneous detonation probability of sealed-pit warheads is least of all hazards.

Though the hazard can not truly be measured by any known means, provision for increased physical resistance of bombs and warheads to deliberate tampering by saboteurs and psychotics bent on producing a nuclear disaster is a real problem. It must be given serious recognition and must influence any approaches to increasing over-all design safety.

Solutions to the Inadvertent Release or Launch Problem

Physical means to reduce the likelihood of accidental release of an armed bomb are being implemented at the AEC/DOD interface associated with the aircraft monitor and control system.

a. The Air Force is equipping T-249 aircraft monitor and control boxes in the field with a mechanical lock and seal to prevent inadvertent arming operations.

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b. Sandia Corporation has released a redesign of the aircraft monitor and control box, the T-249A. This design will prevent the possibility of a previously armed bomb being left in an unsafe condition by improper manipulation of the control switch. The lock and seal feature will also be retained on the T-249A.

c. Methods of incorporating another bomb arming control action, separate from and additional to the T-249 (or T-249A), are under intensive study.

Air Force strategic aircraft are equipped with mechanical locks on the release mechanisms; analogous locks are being incorporated into the bomb release systems of tactical carriers.

Comparable efforts to secure, by means of electrical and mechanical design, the prearming and launch control systems of all ready missiles are necessary to reduce the likelihood of inadvertent launch. These measures are outside the province of AEC design responsibility.

Electrical System Safing Against Human Error

Warhead electrical design, as exemplified in present one-point-safe, sealed-pit systems, is the genuine key to the prevention of accidental, multipoint detonations of sealed-pit warheads. Since human errors are the most prevalent and least predictable causes of safety hazards, designs which minimize the necessity for human activity are required.

a. The concept of a sealed, no-test, no-maintenance warhead (or bomb) still appears the best approach to circumventing the human element to the highest possible degree.

b. In most missile warheads it is feasible to isolate electrically the warhead connector by sealing within the warhead, in series with the electrical input lines, an inertial switch which closes only after the warhead has been committed to a strike trajectory. The only major cost of this measure is some loss in flexibility of application of stockpiled warheads. Such a feature prohibits any disastrous consequences of human error or electrical malfunctions in fuzing systems or test equipment external to the warhead proper. In addition, this feature measurably increases the saboteur/psychotic resistance of the warhead. A trajectory recognition switch is

being incorporated in the ICBM/IRBM warhead designs and should be included in all possible missile warheads.

c. Mechanical isolation of the warhead connector can and should be provided by a sealed or locked cover plate until the last practicable moment in readiness preparation of the weapon system. This is particularly desirable in free-fall bombs, atomic demolition munitions, and low thrust missile warheads for which an internal electrical device can not yet be provided.

Electrical System Safing Measures NOT Recommended

Requirements for additional means of warhead safing which, while superficially attractive, would in the over-all view compromise safety as well as other operational characteristics must be avoided. Examples of such measures are the following:

a. Removability of warhead electrical components. In general, this feature provides critical access to the warhead interior, lessening its resistance to human errors, to sabotage, and to psychotic action.

b. Adding to the series redundancy of safing devices or arming functions in the warhead. In general, the arming intelligence necessary to exploit the safety of an additional function is not available in the weapon system.

c. Separate arming of Zipper initiators. The present practice of simultaneously safing both initiators and firing set through all elements of the arming sequence affords greater safety.

Nuclear System Safing

Techniques of safing which are a part of, or which operate upon, the basic nuclear assembly can be employed to improve weapon safety; the immediate practical problems are in process of design solution.

a. The one-point-safe, sealed-pit nuclear design is the safest implosion assembly presently attained for immediate readiness applications.

b. Means of nuclear safing which require a manual arming action can provide effective safety only up to the point of weapon preparation for immediate readiness.

c. Where readiness requirements dictate that nuclear arming must be performed by an automatic mechanism (in response to an arming signal), it is feasible to design a system which is at least equivalent in safety to one-point-safe, sealed-pit systems.

d. In the event a unique arming signal from a source independent of the weapon delivery system (e.g., a coded "war-strike" signal from some form of master command transmitter) could be made available, the use of such a signal to operate a nuclear unsafing function—independently of the detonator arming and firing circuits—would allow a first order improvement in inherent peacetime safety.

Recommendations: Technical

Based on the present state of knowledge and experience, it is recommended that:

1. Safety measures to reduce the probability of inadvertent drop or launch of armed weapons should be increased.

   a. The T-249A aircraft monitor and control box should be universally adopted.

   b. An additional independent bomb arming action should be agreed upon and implemented in all aircraft/bomb systems not presently so equipped.

   c. Comparable electrical and/or mechanical safety measures should be implemented in all nuclear warhead/missile systems.

2. Safety measures in AEC bomb and warhead designs should continue to be directed at minimizing the human error problem and, in addition, should emphasize, to a greater degree, inherent resistance to saboteur/psychotic action.

   a. The "wooden" concept of a sealed, no-test, no-maintenance warhead should be retained as the optimum design approach to this end.

b. Trajectory environment sensing should be incorporated in all warheads to the extent now possible and to the extent found feasible in the future.

c. All warheads should be equipped with a sealed or locked connector cap by a method or methods having a suitable degree of sophistication.

3. Research and development on methods of safing the basic nuclear system should continue.

a. Nuclear system safing should be considered an alternative and not a supplement to one-point-safety in implosion designs.

b. Improvements in other operational characteristics (reduction in weapon size or weight and increases in specific yield) should be recognized as potential advantages to nuclear safing in future systems.

Recommendations: General

Pertaining to the general problem of increased safety in AEC designs, it is further recommended that:

4. A uniform DOD policy, consistent among the military services, be adopted which treats the safety problem in its entirety in terms of all hazards, their causes, their relative likelihood, and the severity of their consequences. Safety requirements on warhead and bomb designs should be expressed in terms of this over-all policy and not in terms of design detail preferences.

5. A means should be formally established by which the details of all DOD incidents and accidents involving nuclear weapons, however minor in nature, are made known promptly to the AEC and its weapon contractors for possible guidance in design and development.

NOTE

The discussions to follow in the body of this report describe comprehensively the many areas of study on safety problems and possible solutions (1) to indicate the scope of AEC investigations and (2) to outline those areas in which the AEC may present future proposals if such appear warranted by the results of continued study. Except for the additional safing measures specifically singled out in the conclusions and recommendations, none of the design techniques discussed can be interpreted as proposals or system choices for current or future developments. Should some of these ideas and efforts survive the tests of ultimate feasibility and practicality, they will appear in the future, for DOD review, in appropriate proposed ordnance characteristics reports as measures for meeting the <u>general</u> safety objectives of the corresponding military characteristics.

BACKGROUND

A letter to Mr. L. L. Strauss, Chairman, USAEC, dated 29 July 1957 (Reference 1), from the Deputy Secretary of Defense, Mr. D. A. Quarles, requested that a study be undertaken by the AEC on the possibilities for increasing the safety of nuclear weapons. In conference with Brigadier General A. D. Starbird, Director of the Division of Military Application, USAEC, the directors of the nuclear laboratories and the president of the Sandia Corporation agreed that Sandia would assume primary responsibility for such a study and for the ultimate preparation of a coordinated report on the general subject of nuclear weapon safety.

Subsequently, it was agreed among the DMA, ALOO, and Sandia Corporation that this general investigation should constitute a second phase safety study to follow a series of detailed reports covering the existing degree of design safety in those sealed-pit weapon systems treated in Reference 2, "Proceedings of the Atomic Weapon Safety Board," by FC/AFSWP. These safety reports, References 3, 4, 5, and 6, have been completed and distributed.

In the interim, the more general problem has been studied in consultation with the nuclear laboratories, FC/AFSWP, AFSWC, and with the several development agencies of the military services. During this period also, the Sandia Corporation has provided technical representation on the U.S. Air Force Nuclear Weapon System Safety Group and on each of the various Army and Navy safety subcommittees which have been formed under the auspices of the respective joint working group or coordinating committee monitoring the development of individual warhead applications.

Drawing upon this broad background, this report is a summary of deliberations and investigations within the AEC which have attempted to define more closely the general safety problem—placing it in perspective—as well as to outline the approaches to increased safety in nuclear ordnance design of special weapons which have come under study during the past year.

INTRODUCTION

Safety as a design problem has not suddenly loomed before nuclear weapon designers. In the past, safety has maintained a position of primary importance in the written Military Characteristics (MC's) which guide each development program. The writing of these MC's by the Department of Defense and the subsequent interpretation by the Atomic Energy Commission and its prime contractors have always served, in the past, to strike what has been considered an acceptable balance among the safety, reliability, and operational characteristics desired of each weapon application. During the course of a development program, the MC's are elaborated in continuous formal and informal liaison between the DOD and the AEC as required at all levels of authority. Such liaison continues on all factors affecting the safety, reliability, operational requirement balance at least until formal release by the AEC and formal acceptance by the DOD of the particular design.

The redoubled concern over nuclear weapon safety is then truly a call for a re-examination of what might be termed the historical trade-offs among the safety, reliability, and operational factors.

There are a variety of reasons supporting a reappraisal, for example:

a. The absolute number of nuclear weapons in production, in transport, in storage, and in military custody has become larger and is increasing at an accelerated rate.

b. The numbers of people required to shepherd and to maneuver with nuclear weapons must increase apace while there is every reason to believe the general level of ability of this force will not, as a result, be improved.

c. It is conceivable that a nuclear accident within the territory of the U.S. or its allies might produce public and diplomatic reactions leading to disastrous curtailment of military readiness and nuclear capability. Further, it is not inconceivable that such an accident might be mistaken for the opening round of an unannounced nuclear war.

d. Increased military emphasis on operational readiness and training with live weapons constitutes a major change in design ground rules. New weapon systems such as POLARIS, the IRBM and ICBM families, the NIKE series, the MB-1, MINUTEMAN, and the strategic bombs affected by the SAC reflex and alert concepts are all examples of capabilities in which immediate readiness and maximum safety are extremely critical requirements.

e. The advent of sealed-pit weapon designs has contributed to increased military concern on the safety question.

f. The point at which reliability can be traded for safety has probably arrived. The emphasis within the Air Force on low-level deliveries and standoff missiles reflects a strengthening of enemy defensive capability and a growing concern over expected high attrition rates. The far greater complexity of high performance missile systems causes an 80 percent reliability off the launcher to be held outstanding.

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The terms "balance" and "trade-off," used above in discussion of competing weapon characteristics, deserve concentrated attention. While outwardly the sealed-pit weapon design may have appeared as little more than a mutation in the evolutionary process, it was in reality a new species. From the outset, it was obvious that every safety advantage which did not compromise the traditional operational requirements of the Military Characteristics had to be taken by the AEC designers. Whatever reservoir of "free safety" may have at any time existed has already been exhausted in present day sealed-pit designs. Additional safety must be paid for in reliability, in size and weight, in readiness, in simplicity, in flexibility of application, in nuclear cost, or in some combination of these characteristics.

On the other hand, the nuclear weapon safety problem needlessly includes elements of fear, superstition, and misapprehension. These elements need to be removed to prevent the (in)judicious placing of hindrances on the design and operation of nuclear weapon systems which, above all, are in themselves safety devices protecting the national security.

This report places primary emphasis on the problems and feasibility of modifying existing sealed-pit bomb and warhead designs by measures which promise additional over-all safety at nominal cost in other operational parameters. This is the emphasis inferred from Secretary Quarles' letter (Reference 1) which requests an AEC study of

> "...all reasonable means of providing a higher degree of nuclear safing for present and future designs. Such safing should, of course, cause minimum interference with readiness and reliability. In order to achieve more positive safing, however, some handicaps might be acceptable as long as they do not jeopardize our operational capability."

There is, nonetheless, a second approach to safer weapon design. This is a fresh and basic attack which ignores the evolutional history of existing designs and all operational restrictions which have influenced this evolution. Beginning perhaps even with new nuclear devices and inventive techniques, it appears possible to pursue the safety problem from the opposite pole, developing weapon-like systems which achieve, first of all, maximum safety. Operationally suitable systems can then perhaps be reached by trading—bit by bit—safety for reliability, simplicity, flexibility, and readiness until an "optimum" balance has been reached. It is conceivable that this optimum balance may ultimately be little different from that reached by proceeding from today's designs; the impossibility of predicting the outcome of basic research and inventive effort, however, precludes more than a brief general discussion in this report. It is obvious also that a prolonged nuclear test moratorium will handicap this basic area of activity. This approach, however, is under study and should serve to emphasize that the AEC has no intention of standing pat on current technology.

THE ASSESSMENT OF SAFETY HAZARDS

The lack of operational experience with sealed-pit weapons has aggravated the natural, intuitive apprehension concerning the inherent safety of inseparable HE/nuclear assemblies: at the same time it precludes an objective analysis of the true safety question in terms of statistical data on the likelihood of exposure to potentially hazardous situations in each of the weapon states of being, i.e., the number of handlings, number of tests, hours of flight, etc., per weapon per year.

It may <u>seem</u> uncomfortable, but maintaining a nuclear capability in some state of readiness is fundamentally a matter of playing percentages. In absolute value these percentages are never accurately known; <u>a priori</u> probability estimates concerning a hypothetical design change may indicate a decrease in premature probability for a specifically defined situation from one in one billion to one in ten billion. The improvement ratio of 10 to 1 influences the design choice; the true probabilities may be considerably in error and hence are meaningless except for the important fact that, in their calculation, intentional pessimism has hopefully been compounded.

It is axiomatic that a practical nuclear weapon which is designed to detonate with high reliability following a prescribed stockpile-to-target sequence can <u>possibly</u> premature or be detonated in error. The problem of safe weapon design therefore requires the application of science, art, and intuition to the goal of minimizing the over-all probability of a nuclear disaster, considering all conceivably important production line to target situations. This is not a problem to be attacked piecemeal, for there are situations where a design change which obviously improves safety in one weapon state of being, very likely compromises safety in another more important aspect. This "mousetrap" effect must be guarded against.

Recorded Accident Experience

In an attempt to place the total safety picture in perspective, it is necessary to review the record to date of nuclear weapon accidents and incidents. This record is far from complete, difficult to compile, and, of course, is still quite meager in content—particularly so concerning experience with sealed-pit weapon systems. For the purposes of this report,

Table I is a summary of 94 of the weapon incidents in U.S. Air Force experience. The basic list includes a record of 87 compiled by the USAF Safety Board in Reference 7 plus seven other accidents of record which did not there appear. Army and Navy incidents are not represented here although attempts are under way to collect all available data. There is no reason to suspect, however, that other service experience will differ markedly from that of the Air Force; in fact, Air Force experience is perhaps broader at the present time, particularly in operational phases with live weapons.

For the summary of Table I, the weapon "state of being" breakdown was changed somewhat from the format of Reference 7 to the following four categories:

1. <u>Weapons on Board Aircraft</u>

   This includes all ground and flight situations except air ferry (which is placed under Transport below).

2. <u>Handling and Testing</u>

   This category includes all assembly, testing, loading and unloading operations.

3. <u>Transport</u>

   This category includes all means of transport—road, rail, ship, air ferry, and short hauls on dollies or weapon trailers.

4. <u>Storage</u>

   This includes static storage in bunkers, igloos, or open areas of weapons in any state of readiness.

Only a few comments on Table I are required. Category 1 is obviously the phase of operations where weapons are most frequently severely damaged, totally destroyed by fire or impact, or one-point detonated; the mechanical damage of Category 2 is with few exceptions limited to dented cases or crushed fins. Almost all damage in transport, Category 3, has occurred with weapons on dollies or trailers—one incident reports unexplained case damage to a weapon in air shipment. The single incident of Category 4, storage, involved an aircraft crash into a bunker; none of the three weapons damaged were detonated. It is to be noted that the seven electrical incidents which involved firing of detonator bridge wires all occurred on training weapons of the capsule type; had these occurred on weapons of this type containing explosive, a full order HE explosion would, of course, have taken place. In sealed-pit designs, however, elaborate, anti-error precautions have naturally been taken to prevent such an occurrence; these are discussed in References 3, 4, 5, and 6.

TABLE I

Summary of 94 Known Air Force Accidents and Incidents Involving Nuclear Weapons

Category	War Reserve Weapons Number	War Reserve Weapons Remarks	Training Weapons Number	Training Weapons Remarks
1. Weapons Aboard Aircraft*				
a. A/C crash	7	3 HE detonations, 4 weapons burned	3	
b. Weapon jettison	2	Both weapons lost in water	2	
c. Inadvertent release (from flying or taxiing A/C)	4	Two of these resulted in HE detonations	7	
d. Inadvertent release (from parked A/C)	2	No detonations	3	
2. Handling and Test				
a. Mechanical accident	11	Mechanical damage only or no damage	24	Mechanical damage only or no damage
b. Electrical accident	1	Minor electrical damage	14	7 serious electrical damage—dummy detonators fired; 7 minor electrical damage
3. Transport	6	Mechanical damage only or no damage	7	Mechanical damage only or no damage
4. Storage	1	Three weapons badly damaged in A/C crash into storage bunker	0	None reported
Totals	34		60	

*None of these weapons are known to have been pre-armed from the aircraft.

While this list of accidents and incidents applies strictly to the aircraft/bomb weapon systems, missile testing experience and reports of nonnuclear missile accidents certainly suggest that Category 1 above can be expanded to include missiles with warheads on the launcher. Also, Categories 2, 3, and 4 can logically be applied to warheads in or out of missile warhead installations. There is every evidence and expectation that, once operational deployments of missile systems become comparable in scope to those of manned weapon systems, the rates of occurrence of analogous accidents will likely also converge.

Normal Hazards

In ordering the operational areas of safety concern to arrive at a "first things first" design guide, it is even more important to consider the severity of possible consequences of an accident and/or gross human error. On this basis the order of the four categories above remains unchanged.

1. <u>Ready Weapons Aboard Aircraft and in Missiles on the Launcher</u>

   Inadvertent release of an armed bomb or inadvertent launch of an armed missile means, with near certainty, a full-scale nuclear yield. (This must be qualified in the case of those missiles employing ground control and automatic self-destruct features.) In this area of complete readiness, the inherent safety of bomb and/or warhead design is not an important safeguard; the readiness requirement itself shifts safety responsibility to the controlling elements of the weapon delivery system. In the case of bombs, the Sandia Corporation does possess responsibility for the circuitry design and component specifications of the T-249 aircraft monitor and control box. Efforts toward improving T-249 design to minimize the risk of inadvertent bomb arming will be discussed below. In the case of missiles, the AEC has but little influence on the arming and fuzing functions of missile adaption kits and none at all in missile firing and control equipment.

2. <u>Testing and Handling of Bombs and Warheads</u>

   In this phase must be admitted the probability of gross human errors in which the weapon electrical system might be fully operated, leading to a multipoint detonation of the HE assembly. This situation could result from the inadvertent or ill-advised application of particular voltage and current signals to warhead components. Because at least four individual signals with

some sequencing are typically required for full arming and firing, the full-scale yield disaster probabilities are remote.

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3. Transport of Bombs and Warheads

In road, rail, and air transport, both impact shock and fire are the chief hazards; in some cases the two environments may follow in one or the other sequence. A limited number of weapons would be involved; however, the effects of blast and contamination are more likely than not to affect real estate not controlled by the AEC or DOD. The hazard is chiefly one of HE blast and possible plutonium contamination from single point weapon detonations. In ship transport the primary hazard would seem to be fire, with perhaps the advantage, on the open ocean at least, that only the ship itself would be affected.

4. Storage of Bombs and Warheads

Again fire and explosion leading to warhead HE detonations are the primary hazards; severe physical impact is perhaps less likely in this phase. The total number of weapons involved in an incident could be larger than in transport operations; however, the storage sites are located on controlled real estate.

While some degree of artificiality is inevitably involved in assigning these operational categories, the purpose is not to isolate either the geographical or chronological loci of weapons in the stockpile-to-target sequence, but to delineate the operational areas where human error and physical environment are, respectively, the salient potential causes of disaster. It is recognized that weapon testing, handling, and assembly, for example, may take place aboard ship or at a storage site. The intention is that such operations automatically then come under Category 2, rather than 3 or 4.

Abnormal Hazards

There remain three situations still untreated. The first of these involves the possibility of an undisturbed weapon spontaneously detonating as a result of the most pessimistic chain of internal failures and malfunctions conceivable. It is this prospect that reaches to the heart of the design problem and is the basic reason for the employment of such measures as lower sensitivity explosives, high energy detonators, multiple arming and safing functions, fail-safe components, and the utmost care in design, manufacture, and quality control. It is this prospect that a priori premature probability analyses treat most adequately, and which typical premature probability estimates like 10^{-12} and smaller describe. Such numbers can be made still smaller, but clearly there is a point of diminishing returns because of the penalties involved. The human error problem so strongly overshadows that of the "malevolent weapon" that efforts to preclude absolutely the latter can gravely aggravate the former—the "mousetrap" effect. For example, storage of a weapon in certain partially disassembled conditions to preclude the most minute risk of spontaneous detonation necessitates additional handling, assembly, and testing operations with the then larger attendant risk of gross human error.

Recognizing this larger human error hazard, a Field Command, AFSWP report (Reference 8) recommended universal adoption in Military Characteristics for nuclear weapons of an a priori premature probability—exclusive of human error—of 10^{-8} during the nonready phases of weapon operations. This requirement is now appearing in the more recent MC's. While the details of derivation of this number will always be open to debate, the argument of Reference 8 that such a number—describing premature probability owing to random component failures alone—reduces the "malevolent" weapon hazard at least to one order of magnitude below the human error hazard is certainly a realistic approach. A priori premature analyses of sealed-pit systems invariably lead to numbers which surpass this requirement. Granted that such infinitesimals can never be tested for absolute significance, they nevertheless represent "indices of confidence" in the benevolence of system designs which at the least determine that measurable safety gains are not to be made by concentrating, for example, on increased series redundancy in hardware design.

The second special situation involves the overzealous commander who, without proper authority, causes a weapon to be armed or even to be delivered in anger. This problem is of an administrative nature, and design can only aid a solution if operational readiness were allowed to be significantly reduced. In any event where a ready weapon must be entrusted to a single responsible individual, there can be no additional control by means of ordnance design. Some far reaching schemes for delaying the readiness capability by technical means will be mentioned in a later section.

The third special situation concerns the saboteur/knowledgeable psychotic problem in which a full-scale nuclear yield results from deliberate action. This subject is treated comprehensively in a recent Rand Corporation report, Reference 9. The hazard is common to all four categories of operational phases ordered above. Administrative security measures must remain the first line of defense, abetted by design measures which increase the amount of time and/or equipment needed to cause a detonation.

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It is axiomatic that weapons alone can not be made saboteur- and psychotic-proof; their physical resistance can be increased, principally by the same measures which reduce the problem of human error—the denial of mechanical and electrical access to warhead interiors.

Consistent with this appraisal of the general problem and the weighting of its several aspects, the remainder of this report will discuss the physical means for design implementation of greater over-all weapon safety.

ELECTRICAL SYSTEM SAFING AGAINST ACCIDENTAL ARMING AND RELEASE

It is certainly true that the safety of earlier implosion weapons in stockpile, the capsule types, rested primarily upon tight administrative control of the nuclear materials; the nuclear capsules were handled, stored, and transported separately from the bomb and warhead assemblies. It is also true that the major part of this nuclear safety was lost upon installation of the capsule into the insertion mechanism of the weapon assembly. The capsule-type weapons, which were never designed for deployment under conditions of immediate readiness, are today less suitable for ready deployment in all respects—especially in safety—than their one-point-safe, sealed-pit descendants. In a later section of this report it will be shown that, on basic principles, known techniques of nuclear safing are not, a priori, a preferable method of increasing the inherent safety of immediate-readiness weapons.

Therefore, in treating the most pressing safety problem first, the following discussion presents methods for reducing the likelihood of inadvertent release of an armed bomb by electrical/mechanical design at the AEC/DOD system interface. Analogous safety measures to lessen the probability of inadvertent launch of an armed missile are entirely a DOD responsibility and, for several systems, have been treated elsewhere in respective missile system safety reports published by various DOD study groups.

Possibilities for Increasing the Safety of Bomb/Aircraft Weapon Systems

For bomb systems, the Sandia Corporation possesses responsibility for the component specifications and circuitry design of the aircraft monitor and control system. The discussion below considers additional design measures to protect against inadvertent arming of ready bombs loaded aboard aircraft.

T-249 Redesign

The T-249, Figure 1, is an almost universal aircraft monitor and control box for nuclear weapons. In its present configuration, it mounts a toggle-type ON-OFF power switch and a three-position SAFE-GROUND-AIR arming selector switch. The T-249 may be considered as having two inherent deficiencies: first, it is a very easy procedure to arm a bomb carried

Fig. 1 -- The T-249 aircraft monitor and control box

ready in an aircraft, since only two switching operations are required. Second, if the bomb has for some reason been armed (i. e., the selector switch moved to the ground burst or air burst option with the power switch "ON") and the power switch is then thrown to "OFF," the bomb can not be resafed until the power switch is reactivated. This difficulty can also occur if the power switch is thrown off too quickly, before the electromechanical arming system in the bomb has had time to operate fully. A monitor lamp is provided to signal this hazard, but it is, of course, a passive warning only.

The Air Force is presently modifying T-249 boxes in the field as shown in Figure 2. This modification leaves the power switch unencumbered but provides a wire-sealed, hinge-plate lock on the arming selector switch. Full arming is thus a more difficult, more deliberate action, but no additional assurance is provided that, once the bomb has been armed, the power switch will not inadvertently be turned off prematurely. Alternate types of simple mechanical interlocks have been devised to prevent power toggle operation before the selector switch is returned to SAFE, but none provide absolute protection against nimble operation in a time interval too short to insure full bomb safing.

The final T-249 redesign proposal, the T-249A shown in Figure 3, omits the toggle switch entirely and employs a four position selector with OFF, SAFE, GROUND, and AIR positions. The wire-sealed lock is retained and, in the space formerly occupied by the power toggle, a power hold-on relay is incorporated to retain power on the system until the bomb itself has signalled that its internal circuits have in fact returned to the "SAFE" position. In this mode there is no hazard involved in the rapid manipulation of the selector switch to OFF. The final design of the T-249A has been released; it is now the prerogative of the services to adopt, procure, and install the T-249A equipment.

Provision for Additional Arming Actions

Aircraft Equipment

There is expressed concern that the method of arming a nuclear bomb for release by means of the T-249, with or without a mechanical lock, is perhaps too simple a procedure and that at least a second discrete and deliberate act should be required. The Air Force, on its strategic bombing aircraft, has one such feature: the U-2 lock on bomb racks in the bomb bay. This lock is set at all times until released manually from the cockpit by a lanyard-operated mechanical linkage. On Navy aircraft, however, and on Air Force tactical

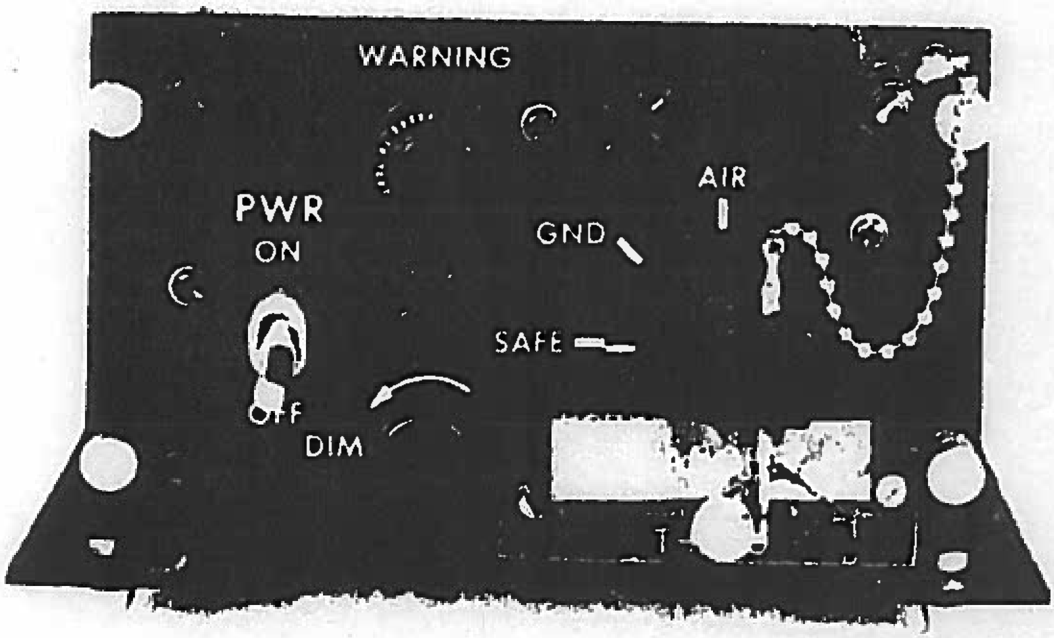

Fig. 2 -- Air Force modification of T-249 aircraft monitor and control box

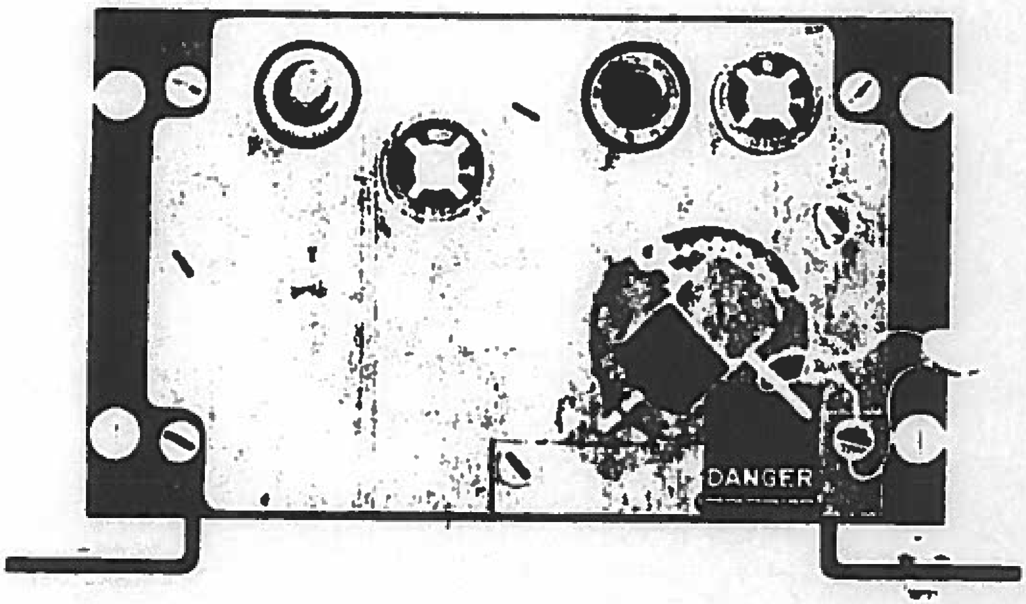

Fig. 3 -- T-249A aircraft monitor and control box

carriers, there is currently no second function. The Air Force is proceeding with investigations into the modification of tactical aircraft to include some form of positive rack lock. It is understood that the Navy is studying a proposal to wire the T-249 arm-line through the bomb-release (pickle) switch in order that arming of the pickle switch by a circuit breaker on the cockpit panel would then constitute a second arming action before live release.

Bomb Safing Pins

It is possible in most cases to equip a bomb with a set of nonshear safing pins in the pullout switch assembly, such pins to be left in place at all times until removed manually by means of a lanyard from the aircraft cockpit. In the TX-41 design such a proposal has been made as a modification of the pullout switch assembly. Provision of the lanyard linkage in general requires an aircraft modification; this system is operationally unacceptable to the Air Force as a long range solution.

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Intentional Dudding

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If the bomb were then armed by the T-249, and only that arming action were performed, any release would cause the guillotine cutters to part the detonator cables and produce an intentional dud. The second arming action required would, in this system, be the manual operation of a mechanical or electrical linkage to sterilize the guillotine cutters before a release in anger. Again, aircraft modification is required.

Prerequisite Aircraft Maneuver

A third possibility which has evolved in the course of safety studies involves requiring the delivery aircraft to perform a deliberate, specified maneuver on the way to the target. An example maneuver considered is a long, two-g turn. An inertial device to sense this maneuver would be mounted within the bomb in series with the arm-line (only) from the T-249 aircraft monitor and control box so that no arming would be accomplished within the weapon unless the aircraft were performing a two-g turn during the few seconds in which the bomb circuits were responding to the T-249. The safing line would remain unencumbered so that resafing would be possible by the T-249 alone. The possible operational handicaps are recognized, but this proposal is indicative of a separate arming technique which requires no aircraft modification.

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War-Peace Switch

In this proposal an electrical switch, mounted in the aircraft cockpit in a location remote from the T-249, would be placed in series with the T-249 arm line. The switch would be conspicuously marked and, for purposes of example, placed within a "break-glass-in-case-of-fire" type mount. Operation of this switch in addition to the T-249 (and by a second responsible crew member in multi-place aircraft) would obviously be required for full arming. Some aircraft modification would be required.

Remote Control Arming

The principle involved in the Strategic Air Command "fail-safe" alert concept, in which a coded "go" signal is transmitted to the aircraft crew, might be extended to the bomb arming system. It has been suggested that this "go" signal include an otherwise unknown code or combination necessary to unlock an appropriately designed bomb-arming system.

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ELECTRICAL SYSTEM SAFING TO REDUCE THE HUMAN PROBLEM

The presence of large numbers of human beings along the nuclear weapon pipeline from manufacturing facility to the site of readiness preparation causes the second major safety concern. Gross human error, sabotage, and impulsive or psychotic actions are the specific hazards (Reference 9). This section describes the design techniques which have already been implemented in ABC bomb and warhead systems to counter these dangers, and describes additional measures to improve the "people-resistance" of ABC weapon packages.

The Electrical Key to Disaster Prevention

The many subtle particulars in nuclear weapon design—the chosen balance between specific energy and sensitivity of the high explosive, the multiple use of high energy-threshold bridge wire detonators, the DELETED detonator simultaneity requirements, the unprecedented manufacturing tolerances on implosion assembly components, and so forth—emphasize the fact that proper, multipoint implosion is completely contingent upon proper operation of a warhead firing set. Therefore, electrical safing is the real key to the prevention of accidental multipoint initiation of HE assemblies with simultaneity adequate for weapon purposes. Without further assumption, this statement means (in sealed-pit weapon systems employing more than DELETED that no nuclear yield greater than a few tons of tons can occur without operation of the electrical firing set. Assuming that the design goal of inherent one-point nuclear safety under all conditions in multidetonator sealed-pit systems has been reached, then no noticeable nuclear yield will ever result from accidental detonation of such a warhead unless the electrical system has functioned.

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A Brief Review of "Wooden Bomb" Electrical Design

The fundamental guiding precept in the evolution of nuclear ordnance electrical design stems from the early recognition that a sealed, no-maintenance, no-test warhead provides the ultimate in both safety and reliability by virtue of reducing the greatest hazard—human error. This "wooden-bomb" concept is, of course, not unqualified; implementation must include all

possible measures to keep the system "benevolent." These measures can be and are recognized and incorporated to the extent that the contribution to the gross disaster hazard over the entire stockpile history of a sealed system can, with confidence, be certified as far less than the analogous contribution of an alternate system in which human factors must be taken into account. The crucial point to be stressed is that the safety comparison between System A, having a sealed electrical assembly, and System B, which is in some sense electrically incomplete, can not be considered solely during dead, "untouched by human hands" storage. Over an entire operational history, System B will require additional handling, assembly, and testing that inevitably adds an undesirable human error term in the disaster probability function. Obviously, the case of an incomplete nuclear assembly is another matter and will be taken into account in later discussion.

General Makeup of a Warhead Electrical System

Sealed-pit nuclear assemblies provided the first opportunity to advance significantly the state-of-the-art of warhead design toward the "wooden" goal. Details of present generation electrical systems used in current development programs can be found in safety References 2, 3, 4, 5, and 6. However, to generalize, a boosted, externally initiated, sealed-pit warhead contains—in addition to the implosion assembly—a separately armed valve on the boosting gas reservoir, a pair of external neutron sources for initiation (Zippers), a high-voltage power supply, a high-voltage energy storage bank, and a trigger circuit plus gap switch which accepts a fire signal and directs the firing set charge into a high power distribution circuit to the detonators and Zippers. Through a connector on the warhead package are introduced the gas-boost arm signal, two distinct and independent X-unit arm signals, and the fire signal. None of these signals are derived in the warhead, but originate from bomb or missile fuzing circuits.

High-Voltage Thermal Battery System

The first step in "wooden" electrical design was taken with the use of high-voltage thermal batteries to supply the firing set (X-unit) and Zipper power. The benefits in design and in operational capability over the older chemical battery/rotary inverter systems were outstanding. Although electrically inert until activated by an arming signal, high-voltage thermal batteries are basically a warhead-contained power source. When employed in design, therefore, all input and output lines to the batteries are kept open within the warhead; for fire safety, thermal fuses are installed at the surface of the battery packs to break the electrical circuit should environmental temperatures increase suspiciously above maximum design ambient. The battery ground is, in most cases, supplied subsequent to mating a fuze or

adaption kit with the warhead. Two distinct electrical arming signals are required: one to close a high-voltage switch between the battery and the X-unit, the second to cause battery activation.

The Mk 25, TX-27, Mk 28, XW-30, XW-31, XW-34, and XW-40 are examples of sealed-pit weapons with warhead high voltage supplied from high-voltage thermal batteries.

Despite the fact that the inherent safety of the thermal battery together with the system precautions could be certified to meet the MC premature requirements, it became evident that there existed some DOD distrust of such a package on the grounds that a self-contained power source contributed to the "malevolence" of a nuclear warhead. The AEC was faced with specific requirements for the capability to remove high-voltage thermal battery packs.

The Chopper/Converter System

The problems of miniaturization and the penalties of providing for removability in certain applications were severe enough to prompt the development of electrical systems which did not employ power sources—permanent removal, in a sense. Such a system is the chopper/convertor assembly, analogous to the vibrator power supply of an automobile radio. This power supply is completely inert and merely transforms low-voltage power to high-voltage power for X-unit and Zipper charging. All electrical power must be supplied from outside the warhead package, i.e., from the bomb fuze assembly or the missile adaption kit. Two distinct arming signals are still required to charge the X-unit: one to start and run the chopper motor, a second to supply the low-voltage power to be transformed. Note that both these arming functions require continuous arming power and not short duration electrical signals. With this system also, the need for a high-voltage switch logically disappears; with all power derived from outside the warhead, low-voltage switching is fully equivalent to high-voltage switching.

The chopper/converter type firing set is being employed in the TX-41, XW-42, TX-43, XW-44, XW-45, XW-46, XW-47, and XW-49 programs.

Possibilities for Increasing the Inherent Electrical Safety of Warheads

By virtue of its inertness, the chopper/converter system should reduce the suspicion of warhead "malevolence" to its minimum. Further, since a reliable system can be supplied in a sealed, no-test, no-maintenance assembly, the human error contribution to disaster probability can by this means be reduced.

But human error has not yet been minimized; the weakest safety link remaining is the warhead connector. Power supplied foolishly or accidentally at this point could be dangerous; therefore a substantial increase in safety can be realized by isolating the warhead connector.

Trajectory Environment Sensing

The most promising technique for electrically isolating the warhead connector interposes, between the connector and the warhead electrical system, an open circuit in the form of a switching device which prevents arming until this component has sensed the existence of a physical environment implying that the warhead has been committed to a delivery-like trajectory. This concept has been termed trajectory-environment-sensing, and is being accomplished in the ICBM/IRBM warhead designs. Increased safety thus appears in three areas:

1. In all phases of operational life up to the time it is placed in a delivery-like environment, a warhead so equipped is protected from accidental arming as a result of human errors and/or faulty test, monitor and control equipment.

2. A warhead so equipped is significantly more difficult to detonate deliberately by sabotage or psychotic action provided that the safety device cannot easily be bypassed.

3. Some bonus protection is afforded in such weapon system accidents as missiles falling from the launcher and in instances of improper system operation such as a below-tolerance missile booster thrust. The term "bonus" is emphasized because such trajectory protection is of a gross nature and should not be regarded as a substitute for any trajectory recognition function normally included in a missile adaption kit.

This trajectory-arm concept is basically an extension to warheads of present practice in bomb design which incorporates a trajectory-arm device in the fuze package with the primary objective of providing safety in ground handling. In fact, the warhead contained trajectory switch has come to be termed a handling safety device (HSD).

Trajectory Sensing Devices

The HSD (trajectory-sensing component) can practically take many forms depending upon its parent warhead application. Delivery environments suitable for the derivation of arming intelligence include the high-temperature high-energy heat pulse of nose cone reentry, the long-term high-level acoustic environment of high performance aircraft and missile flight, the near-vacuum of extra-atmospheric flight, the free-fall weightlessness

experienced in certain ballistic trajectories, and the accelerations and velocities of the delivery vehicle. For the present, however, hardware design is being concentrated on inertial switches which integrate accelerations (or decelerations) over a time interval. The advantages in such "g-second" switches are that:

a. The devices can be extremely small, simple, and reliable.

b. Sensing inertial forces requires no external sensory elements or connections such as the barometric ports and hoses of differential pressure switches.

c. Acceleration-time is a less specialized environment; its adoption as an arming criterion permits maximum standardization of trajectory-arm components and of warheads in which they are employed.

d. Inertial devices will be available on shorter time scales for this safety purpose.

The g-second switch designs employ the specific characteristics of an acceleration history for trajectory recognition. There is first a lower threshold acceleration below which no functioning occurs; this property discriminates against normal handling and transportation shocks. Second, the integrating properties of the device discriminate against the severe short duration shocks of impact, collision or explosions. Third, the device must "see" a predetermined g-second product before operation occurs; this characteristic permits the recognition of a missile boost interval and allows discrimination against other possible force-time signatures—for example, catapult launch or arrested landing of aircraft. Because of these behavioral characteristics, these devices are properly termed g-second switches or g-second integrators; they are not true velocity switches, the latter being somewhat less desirable as HSD elements.

Implementation in Design

Over the past year considerable work has been done on this safing concept. Priority has been given to incorporation of these devices in the ICBM/IRBM warheads and to the air defense warheads since these will be peacetime deployed in rather large numbers in proximity to friendly population centers. A handling safety device has already been tested successfully on re-entry in JUPITER nose cones. Investigation, however, is being done on all sealed-pit warhead applications—new programs, current developments and retrofit of systems already in production. A comprehensive proposal of intended program procedure will shortly be submitted to DMA.

Trajectory environment sensing is an attractive means of increasing safety since, for each specific application, there is no sacrifice of operational readiness, and the penalty in reliability is system-wise negligible. It is believed that the <u>a priori</u> increase in dud rate can be held to 5 parts in 10,000 or less. There are limitations to the applicability of this safing method as well as broader penalties, in terms of the over-all stockpile, involved in its adoption. These aspects are reviewed below.

<u>Limitations of Trajectory Environment Sensing</u>

Although each potential application must be studied specifically, in general inertial safing can be provided in the warhead of any missile which employs a rocket engine or booster. There are many warhead programs where a definitive delivery environment either is completely lacking or is at such a low level that it cannot reliably be sensed to the complete discrimination of accidental inertial loads. An example of the first case is the atomic demolition munition. Examples of the second kind are low thrust missiles such as CORVUS, RASCAL, and HOUNDDOG and the nuclear torpedo ASTOR which, in its wire guided mode, is not fired from a torpedo tube but "swims" out under its own power.

Nuclear bombs comprise an additional special case. It has already been mentioned that trajectory-arming in the form of an altitude or velocity sensing differential baroswitch is employed in free-fall bombs. In addition, in the parachute retarded TX-43 and TX-28X1 bombs, inertial devices are used to make parachute deployment a prerequisite to arming. Indeed, the first g-second switches to be available for warhead safing will be derived from these deployment sensing switches.

It would obviously be more desirable in nuclear bombs to move the trajectory arm function into the warhead proper, again with the purpose of isolating the warhead connector. To this end, feasibility investigations are under way in at least four areas:

1. <u>Intentional Spinning of Free-Fall Bombs in Trajectory</u>. -- This would allow a handling safety device within the warhead to sense radial accelerations. Spinning can be accomplished through aerodynamic forces on canted fins or by the use of spin rockets. The first method limits low-level delivery capability, the latter system involves a space and weight penalty, as well as some penalty in reliability.

2. <u>Attitude Sensing in Bomb Trajectories</u>. -- This technique would sense the changing attitude of a bomb in trajectory, for example, nose down with a slow clockwise roll. The dynamic limitations over the wide variety of trajectories typically required of a nuclear bomb appear greater than those for

intentional spinning. The required attitude pattern might also be intentionally or inadvertently reproduced in handling.

3. Radiation Field Protection. -- This proposal makes use of a miniature proximity-fuze-type transmitter/receiver system. The appearance of power or an electrical signal at the warhead connector would activate the protector system, surrounding the bomb with a radiation field. The presence of any hoist, shackle, structure, ground plane, etc., within several feet of the weapon would then give rise to a signal which would prevent arming. Thus, the weapon essentially must be in free space for arming to occur. The proposal has interesting features worth study; it is at once obvious, however, that this system cannot be warhead contained. Further, it is an active system and necessarily must be fail-safe; this feature might introduce an unacceptable reliability penalty.

4. Ballistic Weightlessness in Trajectory. -- It might be expected that within a free-falling bomb there exists an interval between release and the attainment of terminal velocity during which the gravitational field is to some extent neutralized. Sensing a less-than-one-g acceleration over a period of a few seconds would insure a sufficiently unique trajectory-arm signal. In reality, however, there are operationally important bomb trajectories in which the force field "seen" by internal components is never less than one g, or is less than one g only for a very short interval—for example, dive releases and high-speed level releases. In these cases the decelerations resulting from aerodynamic drag produce the perturbation. Vectorial discrimination between the gravity and drag forces may be possible, but this problem reduces in many respects to that of Number 2 above, attitude sensing.

A simpler alternative method for increasing the inherent safety of warheads in bomb applications consists of designing the entire bomb (minus afterbody sections, perhaps) as a sealed package. This proposal further reduces the human error factor contingent upon internal access, electrically isolates the warhead by virtue of the three or four series open circuits provided in the fuze package, and imputes to existing barometric trajectory-arm devices and parachute retardation sensing switches more of the desirable properties of an inaccessible handling safety element. In future designs more flexibility would be afforded in the development of additional or alternative trajectory arming techniques, some of which are outlined above. This potentiality needs to be given serious consideration.

Gross Penalties of Trajectory Environment Sensing,

It has already been pointed out that the a priori degradation of functional reliability introduced by a trajectory environment sensing function promises to be 0.0005 or less and that the operational readiness of a specific application so equipped remains unaffected. The flexibility of application of an inertially safed warhead, however, will be to some extent restricted. Specific, illustrative examples of this effect are as follows:

1. The XW-40 warhead is currently employed in three carriers, the BOMARC, the LACROSSE, and the CORVUS missiles. In CORVUS, the warhead is mounted in a direction displaced 180° from LACROSSE; in BOMARC, the warhead is mounted across the axis, or 90° in displacement from either of the other applications. In addition, the CORVUS (air launched and liquid propelled) is a low thrust missile. It is obvious that both the scalar and vector properties of the acceleration history to be sensed for arming differs markedly among these three applications, and hence, a warhead suitably safed by an acceleration device for LACROSSE would not be readily interchangeable in the other applications. This difficulty arises similarly in the XW-28/MACE and XW-28/REGULUS systems, as well as in others.

2. A similar problem arises with warheads used in bomb applications. Safing the warhead by means of acceleration-time sensing for use in a given missile will disallow a ready conversion to a bomb weapon; trajectory safing the bomb warhead may prevent the reverse conversion in certain instances.

3. Current Army philosophy on the atomic demolition munition supports the development of a Universal Firing Device to be used in the adaption of several varieties of tactical warheads to the ADM mission. Presumably such weapons as the XW-40, XW-31 and XW-45 are primary candidates; inertial safing in those applications, in the strictest sense, would prohibit their compatibility with a ready conversion into preplaced munitions.

System and component design analyses are underway to uncover all possible means of reducing these penalties. It appears feasible, for example, in those cases where a warhead orientation is reversed in two missile applications having similar thrust programs, to incorporate a trajectory sensing assembly which will operate in response to g-second inputs from either fore or aft. Broad discrepancies in thrust between two common-warhead applications

(when the lower thrust missile does not afford a g-second signature of adequate magnitude) leave no alternative in the timely incorporation of inertial safing other than tailoring one warhead version and thereby sacrificing interchangeability.

By its very definition of purpose, a handling safety device is necessarily an inaccessible component of the warhead interior. A removable HSD is a paradox. Provision of ready access to remove, exchange, or bypass the safing element destroys all but a minor portion of its design safety. The penalty in flexibility can not yet be absolutely assayed since it requires a detailed warhead-by-warhead investigation which can never truly be complete since it reaches into future applications as well. Specific problem areas will be outlined in detail as implementation proposals by warhead program are proposed. Some compromise may be required; for example, it would be possible to provide—for a given warhead with HSD's—a spare electrical assembly without these safety elements to be used for wartime conversion as, perhaps, a major depot operation.

It might also be possible to employ a key or combination lock switch bypass of the safing element which could be operated in emergency situations by a responsible team to whom the closely controlled keys or lock combinations would be supplied or entrusted.

<u>The Locked Warhead Connector</u>

At least for those warhead applications where electrical isolation of the warhead connector can not be accomplished by HSD's, the next best step is mechanical isolation. To this end is proposed a warhead locking cap with key. The degree of sophistication in such a design is completely open to service preferences; a separate and unduplicated key for each individual warhead in stockpile is possible, with each key nonmanufacturable from standard blanks. Such a cap not only isolates the warhead circuits but, through control of the key, provides also a measure of administrative safety which has been of some service interest. To force special handling, the key might well be loaded with Cobalt 60 or some similar radioactive material. Indeed, the connector lock may be a desirable feature even on inertially safed warheads, particularly so if even a slight compromise is made in the design inaccessibility of the safing device to permit wartime interchangeability as discussed above.

Used alone, the connector lock is inferior to trajectory safing in several respects:

a. Where HSD's provide increased safety at least until missile launch, the additional safety of the connector lock is lost earlier in the time frame of weapon preparation when the bomb fuze or missile adaption kit must be mated with the warhead.

b. Unlike the handling safety device, the key-lock requires human action and therefore makes a larger contribution to system unreliability.

c. The true degree of safety and sabotage protection of the key-lock system rests heavily upon administrative key control.

On the other hand, the connector lock itself does not compromise to any degree the flexibility of application of stockpile warheads. A locking plate covering the warhead connector was being carried in the design of the TX-46 up to the time of program cancellation.

ELECTRICAL SYSTEM SAFING MEASURES NOT RECOMMENDED

It is easy to attack piecemeal the problem of nuclear weapon safety and to propose and require seemingly small details of weapon design which, on the surface, have the appearance of increasing over-all safety. Unfortunately, shortcuts and excesses in the name of safety have their unfavorable consequences. Illustrative examples of potentially troublesome measures are discussed below.

Removability of Warhead Electrical Components

Intuitively, it appears that a warhead having a self-contained power source must incontrovertibly be safer in storage and transportation when that power source can be space-wise isolated to some further degree than the conservatively specified voltage standoff provided by the open contacts of electrical switches.

Critically examined, this concern fundamentally involves only the spontaneous detonation probability of the warhead—its "malevolence." In the total safety problem, this possibility is of least importance. To the contrary, removability of battery packs or of power supply components provides free access into warhead interiors and exposes critical electrical circuits to (1) inadvertently applied electrical signals as a result of gross error and (2) intentionally applied electrical signals as a result of saboteur/psychotic action.

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It seems clear that removability in this sense is a "mousetrap" measure in that it improves safety only in an area of least need and is an antithetical measure when the larger hazards are heeded. In consequence, the attendant penalties to design are exorbitant: DOE 6.2(a)

a. Both the reliability and the environmental resistance of high-voltage subassemblies are maximized by keeping components and connectors to a minimum, holding electrical leads short, and potting entire assemblies. These goals are not consistent with removability; it is basically poor engineering practice to tamper unnecessarily in design with high-voltage circuits.

b. Provision for removal of bulky components compromises the efficient use of space, weight, and volume, all of which are critical in meeting the operational requirements for light, compact warhead packages.

c. In weapons like the TX-43 and XW-44, which must survive severe impact shocks, provision for easy removability introduces unacceptable structural discontinuities in areas where case integrity must be maintained.

d. When removability can be provided in the warhead, missile designers in one or more of the weapon applications are forced to locate counterpart access doors in the missile skin at a location which, only by slimmest coincidence, is optimum or even acceptable.

Warheads employing the chopper/converter system are electrically inert, and removability of components need not be considered. Design efforts in the direction of effective and uncompromising removability are being exerted in connection with component research on certain new species of miniature firing sets employing explosively driven transducers or nuclear "battery" energy storage units. The goal is to provide removability—when necessary—of a critical element which is small, is sufficiently unique that easy substitution or duplication is prevented, and is of such a nature that open access to electrical leads or connectors is never provided by removal.

Increased Series Redundancy of Warhead Arming Functions

To detonate at full yield, a boosted sealed-pit warhead requires four signals.

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j Again the fourth signal required is the fire signal.

Ideally these four signals would be separate and distinct, independently derived from four phenomenological events in the history of a weapon system trajectory. To illustrate this point, two sequential signals from a fusing package timer assembly are not distinct; premature reception of one signal in many cases means the second will also be premature. On the other hand, a timer signal plus a baroswitch signal are phenomenologically independent. Realistically, however, four, or even three, separate and distinct signals are rarely available. In general, it has been necessary to relax the "separate and distinct" condition, in application, to the two primary electrical arming functions. The remaining signals required are separate as they enter the warhead but, in general, are not distinctly derived.

It is therefore obvious that an additional electrical arming function would, system-wise, have to operate in parallel with an existing arming function. The increase in safety is then only illusory, since a premature of the common signal will simultaneously perform both functions. An additional arming function in the warhead can be fully exploited for safety if, and only if, the delivery trajectory and/or the fuze or adaption kit package permit the derivation of an additional independent signal. It should be noted here that a warhead-contained inertial switch (HSD) is in addition a redundant series safing element; it will, however, derive its own operate signal.

Separate Arming of Zipper Initiators

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At first glance, therefore, it might seem [redacted] arming of Zipper initiators would provide this measure of increased safety against unboosted or full nuclear yields. (Note: the fact that this extra measure of safety does exist in one-point detonation situations is an extremely important point often overlooked.) Zipper initiators as currently employed are, however, armed from the high-voltage supply of the firing set and fired from the X-unit. As a result, all series safing devices which presently safe against firing set arming are equally as effective in safing Zippers. There is no additional advantage to be gained from a separate device which solely isolates the initiator assembly; if an additional arming function (consistent with the requirements for justifiable use as outlined in the preceding section) can be warhead-employed, there is no more proper circuit position than one which safes both the X-unit and the Zippers.

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NUCLEAR SYSTEM SAFING

The term nuclear safing as used in this report refers to safing features which are part of, or which operate on, the basic implosion assembly. This section compares the safety of the one-point-safe, sealed-pit-type system with that of the separable capsule-type assemblies. Methods of nuclear safing which have been used or studied are summarized. On general principles, it is shown that in one-point-safe, sealed-pit weapons representative of the current state-of-the-art, nuclear safing is not a peerless approach to increasing the safety of ready weapons.

One-Point Detonations

It is necessary to preface this discussion with some clarifying remarks on the subject of one-point nuclear safety and the manner in which it gives rise to concern.

While Military Characteristics have in some instances specified a maximum of four pounds of HE equivalent nuclear energy yield from a one-point detonation, the nuclear laboratories have adopted criteria which correspond more nearly to about one or two pounds of HE equivalent in defining a one-point safe design. Zero nuclear yield is physically an unreasonable objective. Both nuclear laboratories have undertaken extensive theoretical and experimental programs toward an understanding as complete as possible of the one-point problem and toward design release of only those multidetonator, sealed-pit nuclear systems which exhibit satisfactory one-point nuclear safety.

To demonstrate one-point safety, the test device is normally set up and fired with more than adequate neutron initiation

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The fact that positive neutron initiation is provided is extremely important; in the absence of intentional initiation (in an accidental, one-point detonation, external ZIPPER initiators DELETED would not function), the probability of any nuclear yield resulting from a weapon critical assembly, i.e., a non-one-point-safe detonation, is

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There are three questions which can be asked concerning tests of one-point safety. First, does a single, successful one-point test (or at most a very few such tests) furnish assurance that a system is indeed safe under the given conditions, or is a larger statistical sample necessary? The answer is that the hydrodynamic repeatability of a given test is sufficiently precise that a single test is adequate. The nuclear repeatability is also assured by the provision for certain initiation of the nuclear assembly. The second order question is: Are there any possible physical conditions, different from those of the experimental test, under which the safety of the same system geometry might still be questioned? The answer is: Yes, for some systems the hydrodynamic behavior can be influenced by the presence of external tamping—for example, a weapon submerged in water, partially buried, or in contact with heavy objects. No direct experimental study of such effects has been made. It is possible that a combination of experimental studies of the perturbation of implosion by environment plus calculations can indicate the magnitude of these effects. The third order question asks: Given assurance of safety under the two conditions above, can one-point safety be guaranteed under all conceivable operational situations? It is not possible to guarantee absolutely that there can be no uniquely severe accident situation in which the geometry of the weapon is so changed prior to detonation of the HE that an appreciable nuclear yield is caused—"appreciable" here meaning a yield of the order of ten tons. In aircraft crashes and certain missile accidents, the possibility must be admitted. In a fire, part of the high explosive may burn away before detonation; in a severe crash or impact, the HE-nuclear geometry may be deformed prior to exploding. In either case, the weapon configuration resulting is obviously an unpredictable geometry on which no calculations can be made and on which no testing has been done. Truly hazardous situations must indeed be unlikely; this unlikelihood, plus the low probability of initiation, plus the smallness of any resulting yield, should reasonably be construed as constituting a negligible safety problem.

*The probability of about 200 grams HE equivalent yield in an accidental <u>one-point implosion</u> of the example systems described in the footnote on p. 47 were calculated to be as follows:

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Possibilities for Increasing Nuclear Safety

Absolute Nuclear Safety

It is unfortunate that the term "absolute safety" is so often used in connection with safing schemes which involve mechanical separability of the high explosive and nuclear components of the basic implosion assembly. The connotation is fallacious in any practical application.

Consider first a weapon system exhibiting truly "ideal" or "absolute" nuclear safety. In such a system the main weapon package contains no fissionable material until the intended zero time (or very shortly before) it is to be burst in anger over an enemy target. At no time previous to this is even the remotest possibility to be allowed for the basic weapon plus its nuclear components to become simultaneously involved in any conceivable accident or incident. There is but one design solution: separate delivery of the weapon and its nuclear components with assembly being made in the vicinity of the target when the weapon is irrevocably committed. Feasibility of this ideal system is not foreseeable.

In the interests of feasibility and practicality, it is thus necessary to back off from the ideal, giving ground safety-wise in order to obtain useful weapons. A missile must be materially complete when it leaves the launcher; therefore, in a missile system the nuclear components must be mated in some degree with the warhead package prior to launch. A bomb must be complete at release from the aircraft; therefore, the nuclear components must at least be taken aboard the aircraft just prior to takeoff. (It is perhaps technically feasible to supply the nuclear components over enemy territory from a second aircraft by a technique resembling in-flight refueling, but the operational practicality is certainly questionable.) At this point, then, warhead safety is perhaps maximum, but the corresponding weapon system is operationally primitive.

General Discussion of In-Flight-Insertion (IFI) Type Safing Mechanisms

There can be no question that separation of the nuclear material from the warhead is the most effective means of safing, but it is also true that its effectiveness diminishes as the opportunities for accidental or premature reassembly increase. In this respect, the best of the IFI systems are manual, as represented in the old Mk 4 and Mk 6 bombs. The IFI procedure required that the nuclear capsule be assembled into the bomb in the bomb bay of the delivery aircraft. Even in the Mk 6 this is a sufficiently ponderous task in several respects that nuclear arming can not be accidentally performed.

However, as the size and weight of nuclear warheads decreased, it became possible to serve more applications than the strategic bomb. Nuclear warheads for missiles entered development, as did smaller bombs for carriage on light tactical- and fighter-bombers. But it became obvious that the accessibility of implosion assembly interiors was extremely limited in missiles on launchers and in bombs in the bays of light bombing aircraft. For externally carried bombs, of course, access to the weapon for manual arming is impossible in flight.

These operational requirements prompted a further back-off in nuclear safety, and the IFI necessarily became automatic in the Mk 5, Mk 7, and Mk 12 systems. With the automatic IFI (AIFI), the nuclear capsule is installed in the weapon but outside of the implosion assembly; a motor driven mechanism performs the final insertion function in response to an electrical arming signal.

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With the AIFI, nuclear safety therefore depends almost entirely upon the administrative denial of permission to install nuclear components in the mechanism.

This denial, until hostilities begin, is professed to be an unacceptable operational restriction in certain systems—notably air defense weapons and strategic bombs; it is certainly a safe prediction that it would be found so on such systems as NIKE ZEUS and MINUTEMAN. The implication is that, were AIFI designs provided for these systems, the nuclear components would necessarily be installed at all times in the ready weapons. This is certainly the case today in the capsule versions of the Mk 15, Mk 39, and Mk 36 bombs, and the W-7/NIKE HERCULES.

Let it be assumed, however, that a "modern" AIFI system can be designed which is one-point-safe in the disarmed configuration. Following is a comparison of the safety aspects of such an AIFI with the sealed-pit (SP) system in the more important situations of hazard.

CATEGORY 1 - Inadvertent missile launch or bomb release: If armed, in either case the almost certain result is full nuclear yield. If unarmed, or incompletely armed, the SP system is conditionally safe subject

to the possibility of a "peculiar" one-point detonation resulting in a yield of the order of ten tons. The "modern" AIFI system is assumed safe with one exception; in those instances where incomplete arming consists of the AIFI mechanism having been operated through a gross error, a malfunction, or as a result of an accident, the one-point safety of the AIFI weapon on impact or in fire is at least as much in question as that of the SP system. Neither the ready AIFI nor the SP systems eliminate the plutonium contamination problem; to do this in the AIFI system, it is necessary to withdraw the nuclear capsule into a protective compartment to isolate the plutonium from the high temperatures of the HE detonation. However, with experimental knowledge, plutonium contamination has come to be regarded as a "problem" rather than a severe hazard.

CATEGORY 2 - Handling and Testing: Assuming that weapon procedures are effective in prohibiting all human activity on an AIFI warhead with nuclear capsule installed in the mechanism, nuclear safety follows. In the SP systems, the prevention of simultaneous detonator firing is entrusted to the warhead electrical system which, as has been shown, can reduce the disaster probability from all causes to as low a level as may be required to match logically defined requirements.

CATEGORY 3 and 4 - Transport and Storage: In these areas, the AIFI systems are without nuclear components and therefore exhibit positive nuclear safety. The SP systems are again conditionally safe owing to the possibility of ten ton-like yields in unusual one-point accidents.

To summarize, in the most important area—ready weapons—the AIFI and SP systems are for all practical purposes safety-wise equivalent; a slight advantage of one system over the other could only be determined after the detailed characteristics of a modern AIFI system had been explored in design and development. In the area of next importance, handling and testing, the comparison is subjective: The positive nuclear safety of the AIFI system rests on administrative control; the nuclear safety of the SP system depends on the "benevolence" of the warhead electrical system. In transportation and storage, the AIFI system is slightly more safe in the light of the remote possibility of a small nuclear yield from an otherwise one-point-safe SP design.

Penalties in AIFI Systems

Thus far, the only design constraint admitted in discussion has been operational readiness, but there are other weapon characteristics which must be compared.

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It will be assumed that modern AIFI designs could retain the economy and radiation resistance of counterpart sealed-pit systems; yet, unequivocally, the other parameters must be degraded.

AIFI's Applied to Those Sealed-Pit Designs in An Advanced State of Development

Beginning first with an attempt to provide complete separation of the high explosive and nuclear material, mechanical studies have been performed in an attempt to measure warhead parametric changes. From results, the following may be predicted:

a. A weight increase of approximately 50 per cent of the particular implosion assembly weight, considering only the AIFI mechanism itself.

b. A length increase of about 40 per cent of the total sealed-pit warhead length. The swept volume over this length approaches full warhead diameter and must be kept free of other components.

c. A reduced intrinsic ruggedness expected to be considerably lower than the nominal 100-g longitudinal and 40-g transverse tolerances of the W-7 (AIFI) system. Ruggedness could be somewhat improved by substantial increases in structural weight, but laydown and unretarded water entry applications would almost certainly be infeasible.

A particularly illustrative example is a comparison of the W-7 capsule warhead with the somewhat smaller sealed-pit VIPER assembly. In the W-7, the HE core charge removed from behind the DELETED capsule in nuclear extraction weighs DOE 6.2(a) diameter pit from the VIPER, about must also be displaced. Based on the criterion used in the W-7, i.e., capsule extraction to a point of external tangency to the HE sphere, a total mass of approximately 150 pounds would have to be translated to the order of DELETED although there is a possibility the distance required for positive nuclear safety might be appreciably less. The weight, bulk, and structural complexity of such an AIFI system are obvious. DOE 6.2(a)

In present sealed pit systems, these are indications of the costs involved in methods of total HE/nuclear material separation to achieve perhaps some additional protection against the suspected possibility of one-point yields of the order of ten tons in some small fraction of severe weapon accidents.

Partial Separation Mechanisms for Future Designs

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It is possible, of course, that something less than full separation of the explosive and fissionable material would suffice.

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This motion could be effected by smaller and lighter mechanisms with proportionately smaller increases in warhead weight and size.

The LRL is also studying the possibility of a more simple mechanical means of safing by displacing a cylindrical or conical segment of the implosion assembly so that a portion of the high explosive is projected into the pit; this charge would be retracted for arming by a simple screw action.

Proof of the safing effectiveness of such systems under a wide variety of conceivable accident situations may entail the same difficulties encountered in proving one-point safety; however, these problems would certainly be determined to a large extent by the details of any proposed design.

On a long range basis, LRL is conducting a research program (WOODCOCK) to study the possibilities for nuclear assembly designs exhibiting a maximum degree of inherent safety. Under investigation are means of separating either the fissile material or, alternatively, all or a major portion of the high explosive from the warhead package. To extend this safety advantage as far as possible into the stockpile-to-target sequence, last-minute manual replacement of the separated component(s), as well as a two-action assembly function in which the final arming motion is mechanically driven, are under study. Related investigations of HE and detonator materials considerably less sensitive to impact or fire than those now employed are also under way; if feasible, such materials in new designs would reduce the probability of nuclear contamination following accidents severe enough to detonate present explosive elements.

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Relative to removability of nuclear components, the Livermore laboratories have been attempting to solve the reliability and procedural problems attending the capability for field interchangeability of boosting-gas reservoirs.

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kiloton in most systems). If the boosting reservoir could be tightly controlled as a separate component and readily installed as a last-minute arming action, it would provide some measure of additional safety by virtue of the fact that the warhead state of less-than-full-yield-readiness could be prolonged.

Foreign Material in the Nuclear Pit

In the DELETED was installed in the oralloy pit during storage and transportation for safety until the bomb was made ready for strike. DOE 6.2(a)

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On the other hand, design studies are proceeding on

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The LASL has also investigated liquids for pit safing. While this technique can probably be made fail-safe, the plumbing and pumping mechanisms, together with the reservoir necessary for a reversible system, are unattractive additions to the complexity, weight, and volume of the warhead package. An internal bladder may also be necessary to prevent contamination of the fissionable material in the pit by the safing liquid; some means of retracting the bladder to clear the pit following removal of the liquid would then be required.

Potential Advantages of Nuclear System Safing

At present it appears that the DELETED technique of nuclear safing mentioned in the preceding section can be designed with the characteristics necessary to make it an DOE 6.2(a)

equivalent, or even attractive alternative to inherent one-point safety. The major characteristics required in addition to preventing nuclear yield in a one-point implosion are:

(1) Inherent fail-safety of the over-all design.

(2) Adequate reliability against premature operation.

(3) Adequate reliability to preclude functional testing.

(4) Sufficiently rapid operation to permit nuclear unsafing to be performed in the weapon trajectory.

The major advantages of a nuclear safing system achieving these objectives are the following:

a. The possibilities are greatly expanded for the design of smaller implosion systems with higher yield-to-weight ratios than can presently be achieved in designs maintaining inherent one-point-safety.

b. The necessity for nuclear safety shots may be eliminated.

While a suitable nuclear safing system can perhaps improve over-all weapon safety—to the extent that even the remote possibility of a small nuclear yield in an unusual accident might be eliminated—it does not appear that this potential gain is significant enough to justify nuclear system safing as a supplement in implosion systems exhibiting one-point-safety as presently defined and tested.

On a longer range basis, a suitable nuclear safing system could be employed in many future systems to provide a first order safety improvement in peacetime operations; namely, protection against the nuclear burst of an armed bomb inadvertently dropped or an armed missile inadvertently launched. To achieve such an objective, there are two major requirements:

1. A nuclear safing system which prevents nuclear yields even in the event of a symmetrical implosion.

2. The availability of a unique "war-strike" arming signal which is independent of the delivery system and is generated from a high level echelon of command. This signal could be used to activate the nuclear system arming mechanism independent of the normal arming and firing signals generated in the delivery system and weapon trajectory. A coded, master-command

transmitter network might be one example of such a war announcement system. Arming commands relayed from satellites, or unique radiation signals from very high altitude large-yield bursts have also been mentioned as possibilities to be considered.

SUPPLEMENTARY REMARKS

A thorough and objective appraisal of the whole safety problem leaves three salient impressions. First, the paramount danger is that of full nuclear yield from an accidentally armed bomb (or warhead) dropped (or launched) inadvertently. Second, the human problem—encompassing gross procedural errors, the saboteur, and the psychotic—constitutes a hazard which is at least as omnipresent as personnel in the weapon system. Third, there is the latent danger that misplaced emphasis in so-called "safer" weapon system designs might unnecessarily compromise military capability while accomplishing little, perhaps even causing a reduction, in over-all safety.

There are, in addition to these universal considerations, other problem areas in individual applications where a general safety philosophy and policy may conflict with highly specialized operational capabilities. Two of the more important examples are discussed below. Finally, the necessity for an expedited means of data feedback from field users to weapon design groups on safety problems is discussed.

The Inadvertent Release Problem

Concerning the first point, the problem of accidental commitment of a fully armed weapon has appeared as a direct consequence of requirements for higher and higher degrees of readiness. The probability of nuclear disaster with an airborne Mk 6 bomb was certainly remote, since the weapon had to be nuclearly armed through the exertion of considerable manual effort in the bomb bay. The Mk 6 arming system was long ago judged operationally unacceptable. Regardless of the fundamental nature of the nuclear system or the detailed design of bomb or warhead, a weapon which requires only the receipt of intelligence from the delivery system for arming will accept and respond to such intelligence whether the signals are intentional or not. The most important step to increasing safety must therefore consist of making this remote control arming less likely to occur in any inadvertent manner. To this end, remote arming actions can be made more difficult, more numerous, more diverse in function, and more inherently discriminating against improper procedure. This is the underlying reason in bomb/aircraft systems for redesign of the aircraft monitor and control equipment, for

locks and seals on critical control elements, and for the proposals for additional arming actions.
It also underlies the call for analogous emphasis in missile arming and control systems.

The Human Problem

Passing to the second most pressing problem, that of gross human misconduct in
handling bombs and warheads in all states of less-than-complete readiness, the adminis-
trative safety provided by personnel screening, operational procedures, and security
measures must—wherever possible—be augmented by technical means. It is fundamental
that the human problem is reduced by reducing the necessity and the opportunity for human
activity in and around the critical portions of bomb and warhead assemblies, not by generally
employing design approaches which require additional handling, assembly, testing, and
monitoring. The "wooden-ness" concept of a sealed, tamper-proof warhead (or bomb) as-
sembly can certainly minimize human activity. A further step, to protect the electrical
connector through which arming and firing signals must pass, can and should be accomplished
in all cases. The best method, where it is feasible, is to isolate the connector by a trajec-
tory environment sensing switch (handling safety device) buried within the AEC warhead
package; at least in those applications where addition of this feature is not possible, a lock
or seal protecting the connector appears worthwhile, though somewhat less effective in
combating the psychotic or the saboteur.

Objective Appraisal of Nuclear System Safing

The third point, admittedly a negative one, has principally to do with what appears to
be a preoccupation with the concept of true nuclear safing; i.e., the removability of a vital
part of the basic nuclear assembly. Complete separation of such a component does indeed
provide "absolute" nuclear safety; however, unless such a component can be tightly and
separately controlled until manually reinserted at the last possible moment, it will not con-
tribute any greater safety margin in the critical readiness phase of weapon operations. To
restate the discussion in the main body of this report, a nuclear arming feature, automatically
operated by signal, is only an alternative means of adding an arming function. It is not nec-
essarily a better means than others discussed which are not basically connected with the
uclear assembly; any absolute comparison must await a careful evaluation of reasonably
irm, future proposals for nuclear safing. Any a priori preference for nuclear safing features,

which perhaps stems from trust in the older capsule-type weapon designs, must be carefully tempered with recognition of the fact that, in general, **DELETED**

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Since weapons of this nature are today deployed in this state of readiness, nuclear safety is not "absolute," it is nonexistent; one-point-safe, sealed-pit assemblies are far superior in safety as well as in readiness. At the same time, there is no objective reason for condemning the inherent safety of one-point-safe, sealed-pit designs in the less hazardous phases of storage, transportation, and handling.

On the positive side, the possibility of breakthroughs and new inventions comparable to the step from capsule-type to sealed-pit designs cannot be discounted. Research and development on new nuclear safing techniques must and will continue.

Safety Problems in Specific Applications

While this report has emphasized the general safety problem and basic AEC design philosophy, there are a multitude of specific subordinate problems which arise in connection with one or another individual application and which must be individually resolved. The following are the more important among current examples:

1. The Atomic Demolition Munition (ADM)

The concept of the auxiliary use of various missile and bomb warheads as demolition munitions by supplying, in the field, a Universal Firing Device (UFD) capable of arming and firing almost any warhead at hand has at least two uncomfortable safety aspects. First, the general requirement for compatibility of tactical and air defense missile warheads with ADM application would disallow the inclusion of trajectory safing devices in most of these warheads unless some compromise method of providing for their bypass were incorporated. Second, the availability in the field of a ready-made UFD kit for producing a full-scale detonation from almost any warhead could severely aggravate the human error, saboteur, and psychotic problems. It appears much more satisfactory to supply carefully designed, demolition-use-only, nuclear munitions. For special purpose devices it would be possible to take maximum safety advantages in over-all design without affecting or being affected by the far different requirements of other weapon applications.

2. The Automatic Bomb Arming System

Under serious DOD consideration is a requirement for an automatic device, sometimes called a "dead-man switch" (DMS), which would arm and/or fuze a nuclear bomb for full yield in the event the carrier and/or crew fell prey to the enemy defense. Methods of accomplishing this salvage feature have been under study within the AEC at Sandia Corporation. Safety implications must be carefully evaluated in connection with this capability; while maintaining adequate safety is not a major problem in the design of a DMS system to operate from medium to high delivery altitudes (e.g., the Special Weapons Emergency Separation System, SWESS, designed by the Air Force Special Weapons Center), it is a paramount obstacle in the design of a DMS system for low-level bombing missions where such a short time is available for bomb arming that many existing bomb safety features would have to be deliberately or automatically bypassed.

These types of problems emphasize the necessity for continuing AEC/DOD assessment of the whole safety picture in order to insure full coordination and proper balance when desired capability and weapon system safety are at cross purposes.

Profiting from Field Experience

There is one other major area in which AEC/DOD coordination can contribute measurably to improving weapon safety; this is the field of nuclear accidents, incidents, and near-accidents and incidents. Several times in past experience, the nuclear and ordnance designs of nuclear weapons have been improved in safety as well as reliability on the basis of reported field experience. At the present time the feedback to the AEC of such information is uncertain and inefficient. It must be considered a vital precautionary measure to improve this reporting system. No mishap, near mishap, or related detail is so minor that some useful information might not be drawn from it. The difficulties of gathering objective detail of this nature are recognized, particularly where human error is involved. This matter is discussed in Reference 9. However, the potential usefulness and importance of this information warrants the effort and special procedures necessary to implement its collection and distribution.

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