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from: N. R. Hansen, 5165

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subject: Nuclear Safety Themes for Earth Penetrating Weapons, *Issue C*

A meeting of the people listed as Distribution A was held on January 12, 1993 to discuss potential nuclear safety themes with specific application to earth penetrating weapon systems. Based on the discussions in this meeting a report has been generated which reviews previous and proposes new safety themes; a copy of which is attached. The objective of this work is to develop safety themes for a potential future application to earth penetrating systems. These safety themes would be used to motivate exploratory development of appropriate system components.

The intent is to refine this report based on a series of reviews. Please review the attached report and make comments regarding correctness, observations, and suggestions for improving the content or style. Please return to Ned Hansen, 5165 by the requested date, according to the table below. A final issue (D) will be distributed to all on the previous distributions in April. Thank you for your participation.

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Report Issue A	Report Issue B	Report Issue C
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Nuclear Safety Themes for Earth Penetrating Weapons

1.0 Introduction

To enhance the prospects of survival many high-valued enemy targets are being located underground. The effects of above-ground detonations against buried targets is greatly reduced because the ground tends to mitigate the shock and other effects. Effectiveness is enhanced if the weapon is buried in proximity to the target. Earth penetrating weapons (EPW) are designed to accomplish this mission. Although modern systems can deliver penetrating weapons with great precision, many of the enemy targets are sufficiently hardened against the effects of existing penetrating munitions using conventional high-explosives, while most are vulnerable to the effects of a buried nuclear yield. The utility of a nuclear earth penetrating weapon has been promoted for some time. In fact two different systems were fielded in the 1950's (Mk 8 and 11). Several systems have been developed since these but, because the number of targets was relatively small and the costs high, these programs were cancelled before production began. Since the number of targets that require a earth penetrating weapons will only increase in the future; conventional penetrators are inadequate against many targets; and a nuclear penetrator is not currently a stockpile asset, it appears reasonable to assume that a nuclear penetrator may be required in the future.

Sandia has been involved in EPW research for over twenty years. The perception of a future penetrating weapon development has justified the continuation of penetrator research under a project called the Exploratory Penetrator Systems. The intent of the project is to develop technologies that have application to future EPW systems. The safety of nuclear weapons is a critical element in the development of any new system. Therefore, an important element to the Exploratory Penetrator Systems Project is the development of improved or enhanced nuclear safety themes for future systems. This report reviews the concepts of nuclear safety in general and then outlines some of the safety features used in previous EPW systems before two recommended safety themes are presented. The intent of this document is to summarize the issues and present some concepts that might generate suggestions for even further enhancement with respect to the safety of earth penetrating weapons systems.

2.0 Nuclear Safety

The following is a brief review of the concepts associated with a nuclear safety theme. The attempt is to keep the definitions and concepts as general as possible, but include implementation features used in the past as illustrations.

2.1 Objectives

Without the inclusion of any nuclear safety devices, a nuclear weapon can be generalized by the flow chart given in Figure 1. The problem with a device such as this, and the motivation for nuclear safety, is that under certain conditions the human intent can be circumvented and an accidental nuclear yield could result.

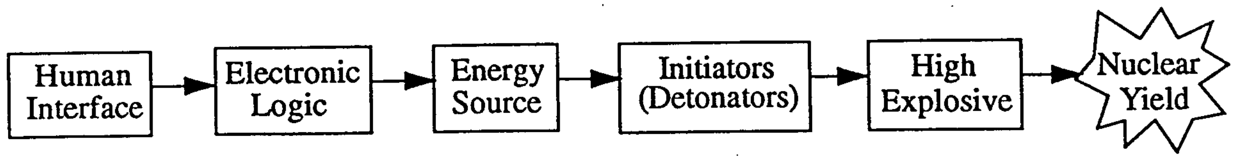

Figure 1. Flow Chart for Intended Nuclear Detonation.

Nuclear safety is *the protection of the system by design to prevent against an inadvertent nuclear detonation in the absence of specific safety-critical inputs.* Special design features and components are required to satisfy this objective. Implicit in the preceding definition of nuclear safety is that the weapon system design must satisfy the following

- Respond to normal and abnormal environments (defined later) in a predictably safe manner.
- Ensure that the predictably safe behavior is maintained until the weapon receives appropriate unambiguous commands required to initiate the safety-critical components.
- Meet safety requirements without requiring detailed definitions of the abnormal environments.
- Facilitate a safety analysis which can be confirmed by a modest number of tests.
- Minimize the number of components that are safety critical throughout the weapon.

2.2 Requirements

2.2.1 Definitions

Normal Environments are the expected logistic and operational environments that the weapon is required to survive without degradation in operational reliability. All of these environments are defined specifically for the individual weapon system. Types of normal environments include temperature, vibration, and shock based on the handling, transportation, and delivery to the target of the system.

Abnormal Environments are those environments to which the weapon may be exposed after which it is not required to retain operational reliability. Some of these environments are defined for the specific weapon and others are postulated scenarios. Types of abnormal environments include fire, crush, and lightning.

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2.2.2 Operational Sequence

A weapon system proceeds through the following operations sequence

1 Initial Enabling Stimuli or Prearm: A human action(s) is taken, thereby indicating to the weapon by a specific signal that use is intended. This operation is reversible prior to launch.

2 Final Enabling Stimuli: Unique sequence of environments are detected indicating to the weapon that the operational sequence should continue and the path for energy transfer be opened to the detonators.

3 Final Arming: Final procedure which readies the system for transfer of energy to the detonators when the fire command is issued.

4 Fire: The release of energy which sets off the detonators for the high-explosive and causes the nuclear yield.

2.2.3 Numerical Requirements

For each weapon over its stockpile lifetime, the minimum probability of premature nuclear detonation for both normal and abnormal environments is summarized in Figure 2. A one in 10^9 probability is equivalent to the value of 10^{-9}.

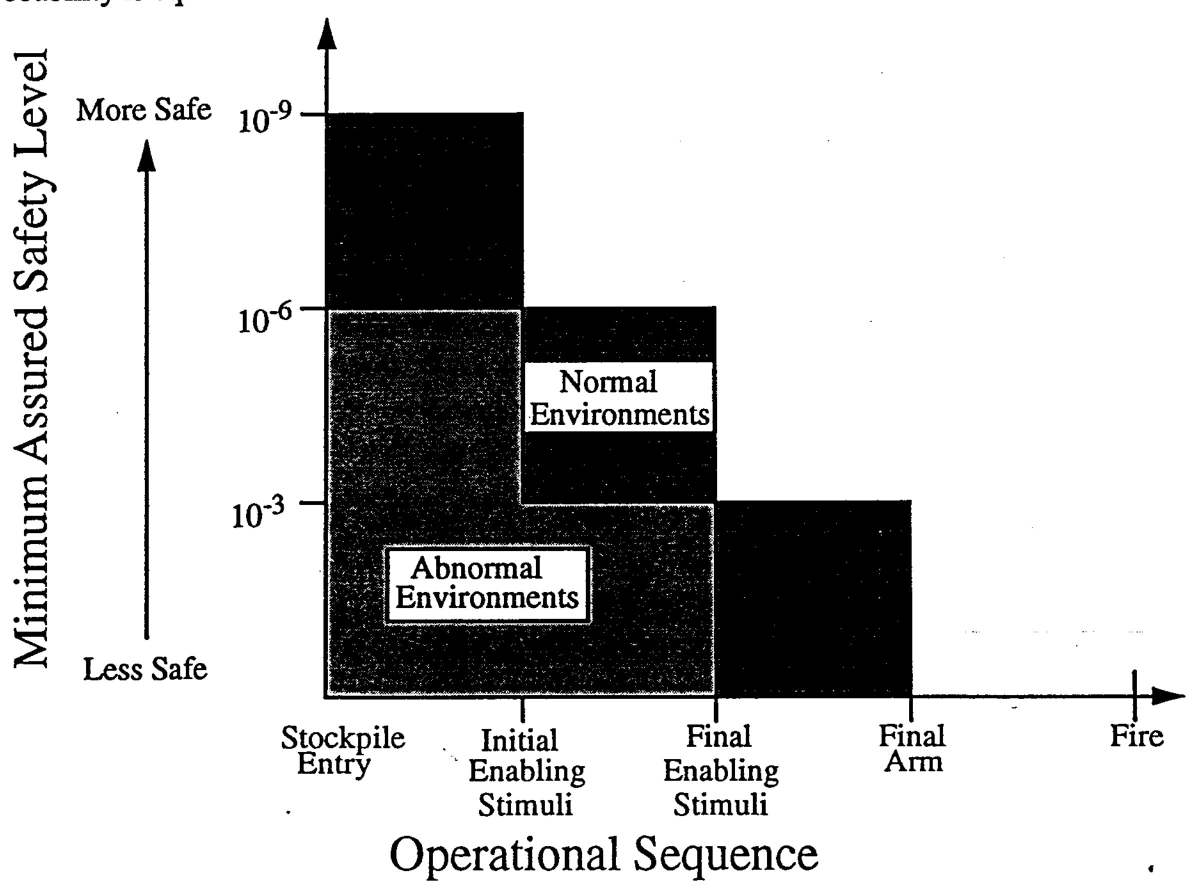

Figure 2. Minimum Safety Requirements.

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2.3 Principles of a Nuclear Safety Theme

Four principles must be satisfied to implement a credible nuclear safety theme. These principles are isolation, incompatibility, inoperability, and independence. These are further expanded, including implementation examples, in the following subsections.

2.3.1 *Principle of Isolation* implies that the safety-critical components isolate a portion of the weapon system from an inadvertent action that would allow a detonation. The typical method for satisfying this principle is to establish an exclusion region and by design control the entry of energy into this region through safety-critical components, such as stronglinks. This can be illustrated conceptually by surrounding the detonators, high-explosive and nuclear components shown in Figure 1 with a barrier that will not allow energy to be transferred to the detonators without passing through a special "door" called a stronglink. The motivation for the name stronglink is because these components are to be sufficiently strong as to not fail and allow the energy to pass before a companion component or subcomponent, called a weaklink, fails.

2.3.2 *Principle of Incompatibility* requires that the signals to enable, or operate safety critical components, are unique such that the probability of these signals being generated except by the designed or intended scenario is less than an acceptable threshold. A discriminating device is typically incorporated in the stronglink assembly. This discriminator requires 24 bits of unique binary information in order to operate the stronglink. The sensing of unique sequences of environments is also incorporated into safety themes.

2.3.3 *Principle of Inoperability* extends beyond maintaining the weapon system in a safe or unarmed state until the required sequence of operations occurs. If an incorrect signal is received this principle requires that the safety-critical devices lock or irreversibly disallow arming of the weapon. In addition, in abnormal environments the weaklink fails before the stronglink such that the weapon is inoperable.

2.3.4 *Principle of Independence* is employed to prevent common mode failures of the safety-critical components. More than one safety-critical component is necessary to achieve the outlined requirements. This principle implies that the duplicate components would not satisfy the principle of independence because they both would fail in the same manner. Instead independent components responding to independent unique signals are required.

3.0 Previous EPW Systems

Several nuclear penetrator programs have been initiated over the years, but three of recent have matured to significant levels before their cancelation. These three programs are the W86/Pershing II, Strategic Earth Penetrating Weapons (SEPW) and the W61. For historical background, the nuclear safety themes employed by these systems will be reviewed in the following subsections.

3.1 W86

The W86 began in February of 1972 as a Phase I study of a tactical earth penetrating warhead for the Pershing II missile. In May of 1979 it received a Phase III authorization for full-scale development. In September 1980 the program was cancelled. Further details on the W86 program can be found in references [1,2]. The nuclear safety theme as summarized in this section is described in these references. This safety theme is shown in schematic form in Figure 3. Because this is the first of five safety themes to be presented, the description of the W86 nuclear safety theme is rather detailed so that many of the concepts and definitions need not be repeated in the subsequent sections.

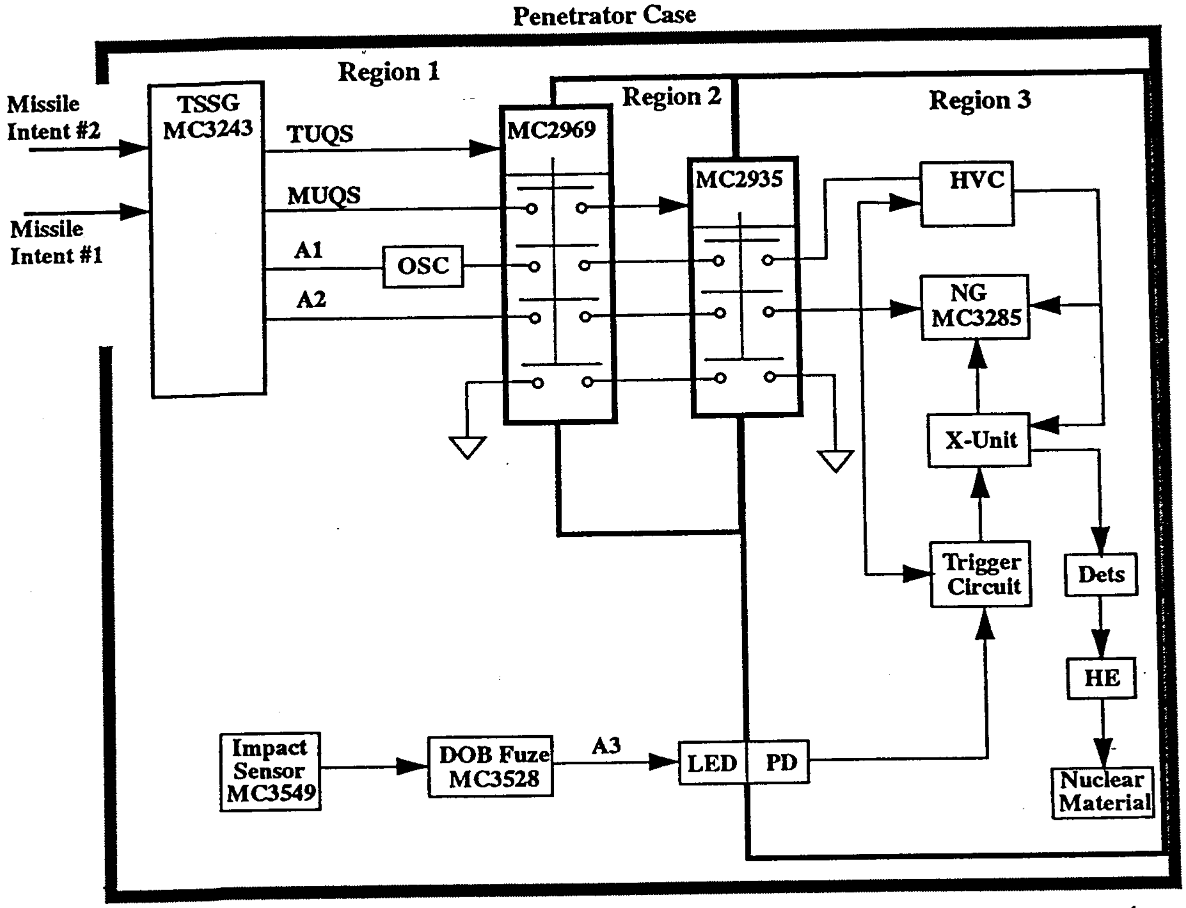

Figure 3. Schematic of the W86 Nuclear Safety Theme.

An exclusion region (#3) is established using steel material to encase a subset of the components. The purpose of this region is to exclude energy (electrical in this case) from reaching the detonators. In reference to Figure 1, the exclusion region is inserted between the energy source and the initiators and it surrounds the explosive and nuclear materials. The exclusion region satisfies the principle of isolation. Information used in the fuzing of the weapon is passed through the exclusion region barrier by light emitting diode (LED) and a photo-detector (PD).

Two stronglinks (MC2969 and MC2935) are introduced to allow energy to enter the exclusion region when intended and block energy transfer otherwise. Each stronglink has a discriminator mechanism that requires a unique pulse signal (47-bit and 20-bit, respectively) in order to close the stronglink switches. The unique nature of the signal satisfies the principle of incompatibility. The MC2969 is denoted as the trajectory stronglink because a trajectory unique signal (TUQS) is required to operate the discriminator. Likewise, the MC2935 is the good guidance stronglink because the Missile Unique Signal (MUQS) is required. The origin of these unique signals will be discussed below. The difference in the signals and the construction of the stronglinks satisfies the principles of incompatibility and independence. The default position for the electrical contacts in the stronglinks is opened or disabled and as implied by their name the stronglinks are sufficiently robust such that they will not fail in an abnormal environment to close the electrical switches before a weaklink fails. The weaklinks for this system is the discriminator mechanism which jams in a crush environment and the high explosive decomposes in a thermal environment.

The MC3243 or the Trajectory Sensing Signal Generator (TSSG) is the brains of the weapon. In subsequent weapons presented in this report many of the functions of this component are handled by a Warhead Programmer, a Trajectory Sensing Signal Processor (TSSP), or a Warhead Interface Module. The TSSG communicates with the missile, senses environments, sequences operation of the safety-critical components, and arms the weapon. Two missile intent words are past to the TSSG just prior to launch. The operational sequence for the W86 is as follows:

Prior to Launch

- TSSG initiated
- Missile Intent Words passed
- Depth-of-Burst (DOB) information passed and stored

Launch

- TSSG senses missile/trajectory environments and if correct enables MC2969 (based on missile intent word #2)
- Missile passes good guidance or Missile Unique Signal (MUQS)
- First missile intent word is combined with MUQS to enable the MC2935.

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- From the TSSG, the A1 arm power is passed through the Oscillator, through both stronglinks, to the high-voltage converter (HVC) and the A2 final arm signal initiates the charging of the X-Unit and the Neutron Generator (NG)

Impact

- Impact sensed by the Impact Sensor (MC3549)
- Initiate the DOB Fuze (MC3528)
- Generate the LED signal
- Sensed by the PD which signals the trigger circuit
- At the appropriate time the Trigger Circuit fires the Neutron Generator and signals the discharge of the X-unit to the Detonators, which initiates the high-explosive and finally creates the critical mass of nuclear material.

The attempt has been to highlight the operational sequence of the W86 and the implementation of the nuclear safety theme. Obviously not all of the details of the warhead electrical system have been explained in detail and references [1,2] contain a more detailed description of these features. Some components must be developed specifically for an earth penetrating mission because of severe shock requirements. These components, that must function after penetration, are the Impact Sensor, DOB fuze, LED/PD, Trigger Circuit, Neutron Generators, X-unit, Detonators, HE, and the nuclear material. The remaining components are not required to function but must be sufficiently robust so to not damage the other components during penetration.

Consider how the W86 operation sequence compares to the generic operational sequence description presented in Section 2.2.2. The initial enabling stimuli is the sensing of the environments that enables the MC2969 stronglink, the final enabling stimuli is the comparison of the good guidance word with the first missile intent word to enable the MC2935 stronglink, and the final arm occurs when the electronics charges the X-unit and prepares the system for detonation. The term X-unit is interchangeable with Capacitive Discharge Unit (CDU). With regards to the numerical requirements for minimum assured safety as given in Section 2.2.3, each stronglink provides a level of safety protection of 10^{-3} and the fuzing electronics provide an additional 10^{-3} for normal environments. Therefore for both normal and abnormal environments, the implemented safety satisfies the requirements shown in the Figure 2.

The W86 nuclear safety theme was state-of-the-art in the mid-1970's. Some of the implementation components and concepts would still be applicable today, while others would not be adequate. For example, vulnerabilities with the stronglinks have been discovered. Other stronglinks have since been developed that are preferred and would be incorporated in future systems.

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3.2 Strategic Earth Penetrating Weapon (SEPW)

The SEPW program advanced through Phase II before it was cancelled in 1990. A spectrum of penetrator designs, with relatively large nuclear yields, were considered. All designs used a common safety theme. This safety theme (see references [3,4]) is shown schematically in Figure 4.

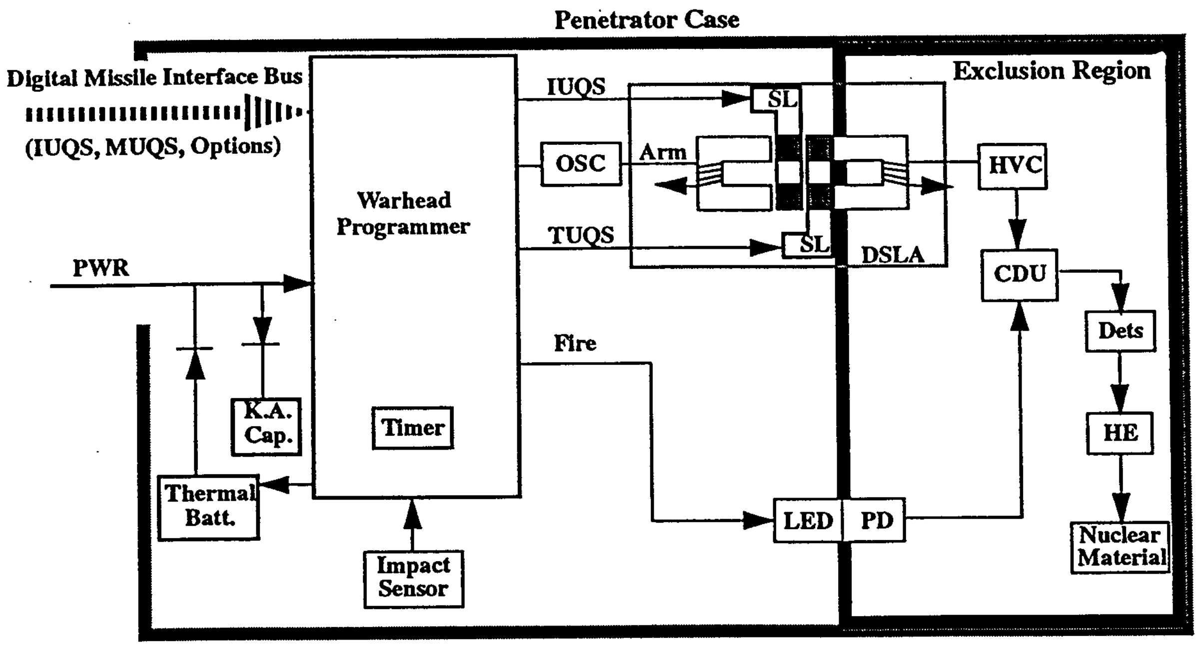

Figure 4. Schematic of the SEPW Nuclear Safety Theme.

The safety theme is similar to that used in the W86 in that an exclusion region is established with associated stronglinks and weaklinks to protect against inadvertent electrical energy getting to the detonators. The more common notation for unique signals is introduced here. The unique signals that indicate human intent are denoted IUQS, those transferred by the missile indicating correct performance are MUQS and environments sensed by the warhead indicating a proper "trajectory" are denoted by TUQS. Sometime the MUQS is combined with a TUQS and denoted as TUQS as implemented by SEPW. Some unique features of this system are a digital interface with the carrier vehicle, a Warhead Programmer for controlling the function/interface, a Keep-Alive Capacitor (Supercap) for maintaining power to the circuitry during penetration, and a Dual Stronglink Assembly (DSLA) using an interrupted-transformer as the means for transferring energy into the exclusion. The stronglinks are enabled before impact but the energy is transferred after the penetrator has come to rest. This implies that the transformer portion of the DSLA must still function after impact but the discriminator and drive mechanisms are not required to survive. Some advanced development on shock-hardened Stronglinks, Thermal Batteries, Supercaps, and Programmer components were completed during Phase II of the SEPW program.

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3.3 W61

The W61 program received Phase III authorization in 1990 as an interim solution to SEPW target set as a retrofit of the B61-7 laydown bomb. The proposed carrier vehicle was cancelled approximately 18 months later, thereby cancelling the W61. The laydown bomb was retrofitted with a minimum number of modifications for delivery in a missile. Therefore, the safety theme including most of the electrical hardware was inherited from the B61-7. The W61 safety theme is shown schematically in Figure 5. A more detailed description of the W61 is found in [7].

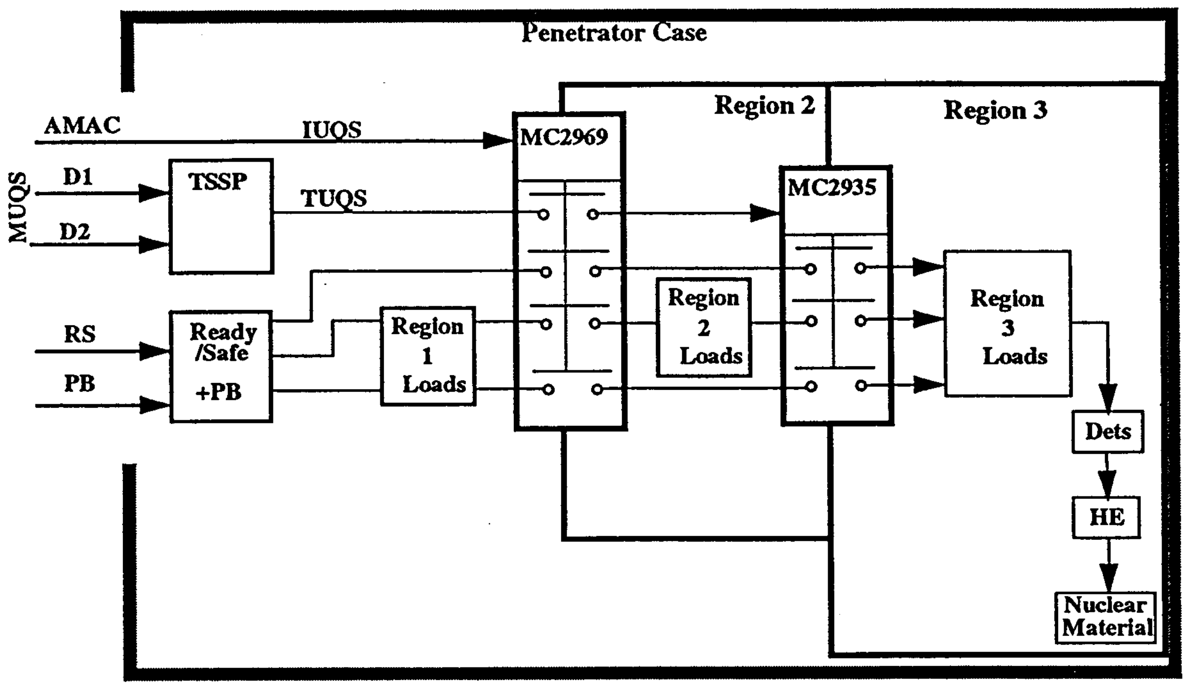

Figure 5. Schematic of the W61 Nuclear Safety Theme.

Similar to the W86, the W61 used the MC2969 as the intent stronglink and the MC2935 as the trajectory stronglink, both of which interrupt the transfer of electrical energy into the exclusion regions. Not all of the communication with the missile came through a Trajectory Sensing Signal Processor (TSSP), which was one of the new components. This safety theme is similar to that used in the W86 and the previous comments are still applicable.

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4.0 Two Suggested EPW Safety Themes

An understanding of the peculiarities of designing earth penetrating weapons is important in order to develop improved safety theme concepts, and will be briefly discussed. The single most important requirement for earth penetrator designs is the extreme normal environments. These environments, which vary with impact conditions, target properties, and penetration configuration, can easily exceed 5000-10,000 g's. This is two or three orders of magnitude greater than required of other nuclear weapons systems. The required survival loads influence every aspect of the system design.

The penetrator case is constructed of very high-strength steel with high fracture toughness. The geometry of the case, in particular the diameter, has a dramatic affect on the induced loadings. Smaller diameter and greater penetrator weight tend to reduce the loadings. Joints in the case itself present serious design obstacles. The nuclear package and the warhead electrical system reside within the case. Only a minimized subset of the components should be required to survive and function after penetration. These components must be specifically developed for earth penetration application because components from other systems do not have sufficient shock hardening. Even those components not required to function after penetration must have sufficient structural support so as not to damage other components. Unlike other nuclear system, penetrators are rather simple, that is features such as complex mechanical yield selection, elaborate fuzing options, or other complex subsystems are unlikely to be included in an earth penetrator due to the extreme environments. The direct optical initiation (DOI) of explosive is a concept being investigated as an enhancement to nuclear safety. A rugged laser is the critical component that would be difficult to harden to the penetration environments. A this point DOI is not considered as penetration system option. The internal components are packaged in a robust steel assemblies where the gaps between parts are minimized to eliminate the rattling. Because of the difficulties associated with joints in the penetrator case and the strict packaging requirements, concepts such as insertable nuclear components would be extremely difficult to implement in an earth penetrator. The difficulties of supporting the fissile material during penetration make impractical the concept of pumping paste explosive around the fissile material in EPW environments. In this report, the safety concepts of an insertable nuclear component and paste high explosive will not be considered viable options for earth penetrating applications.

As discussed, the environments of penetration make difficult some of the complex nuclear safety concepts and tends to limit the choices for developing reliable safety themes. These same environments may be used to an advantage in the development of a nuclear safety theme because they are very unique and are orders of magnitude greater than the environments that the weapon can experience except when used in the intended mode. A specifically developed component that detects this environment can be used to discriminate from other conditions and allow the weapon to operate only in the intended mode.

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Given the limitations presented, safety themes based on two different principles of nuclear explosion generation that have application for earth penetrating missions are introduced. These principles are implosion weapons and gun-assembled weapons. Each has unique challenges and advantages that will be discussed. Only the portions of the safety theme imbedded in penetrator case will be discussed. It will be assumed that this is independent of the warhead delivery mode, that is air dropped, guided bomb, missile, or reentry vehicle, but the system employed is sufficient to generate a unique environment for a MUQS or a TUQS. A double human intent (IUQS1 and IUQS2) scheme is also proposed for both systems. The presented safety themes do not represent an ultimate or final implementation but instead are achievable and reasonable implementations based on an understanding of unique problems associated with the development of an earth penetrating weapon and the development of some advanced technologies.

4.1 Implosion Systems

A high explosive charge surrounding a subcritical nuclear mass upon detonation compresses the mass into a supercritical state, and hence the name implosion system. All new systems in the last thirty years have been the imploding type, including the three penetrating systems presented in the previous section. It is reasonable to assume that an implosion system would be a candidate for a future system. Given the unique requirements of an earth penetrating system and in light of current safety critical technologies, the purpose of this section is to propose a candidate nuclear safety theme that might be implemented in a future penetrating system.

As discussed previously, insertable nuclear components and paste high explosive are not considered here, therefore, in reference to Figure 1 interrupting the detonators would be the next best location for the safety critical components. Three concepts have been proposed as means of safing the detonators. These concepts are (1) Detonator Safing Stronglink (DSSL) in which high explosive booster pellet is rotated out of position and protected with a stronglink mechanism; (2) Paste-Explosive Stronglink where this booster explosive is pumped as a paste with associated stronglink protection; and (3) Slide Actuated Laser Armed Detonator (SALAD) that uses a laser ignited actuator to slide the detonator booster into position with associated stronglink protection. A potential disadvantage to these protection concepts is the environments may prove too extreme. Of the three concepts, SALAD may have the higher potential for designs that can withstand the penetration environments. For all options, evaluation for high-g applications is warranted. Until further investigations are completed on these concepts, the conservative approach is followed here, which assume that these concepts cannot be strengthened for the penetration environments. Hence, protecting against inadvertent electrical energy reaching the detonators is the objective of the safety theme as is shown in Figure 6. If after further evaluation it is determined that any of these concepts can survive the environments then one of the interrupted transformer stronglinks in the proposed system should be replaced with a detonator stronglink, and the exclusion region shown in Figure 6 can be moved to the right such that the detonators are at the barrier.

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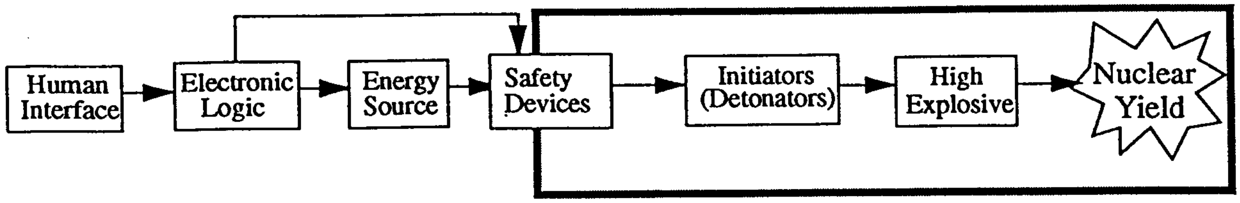

Figure 6. Flow Chart for Intended Nuclear Detonation With Proposed Safety Theme for Implosion Type Earth Penetrating Weapons.

The schematic for the proposed nuclear safety theme for earth penetration applications is given in Figure 7. This scheme is more evolutionary than revolutionary but the differences and possible improvements are discussed below.

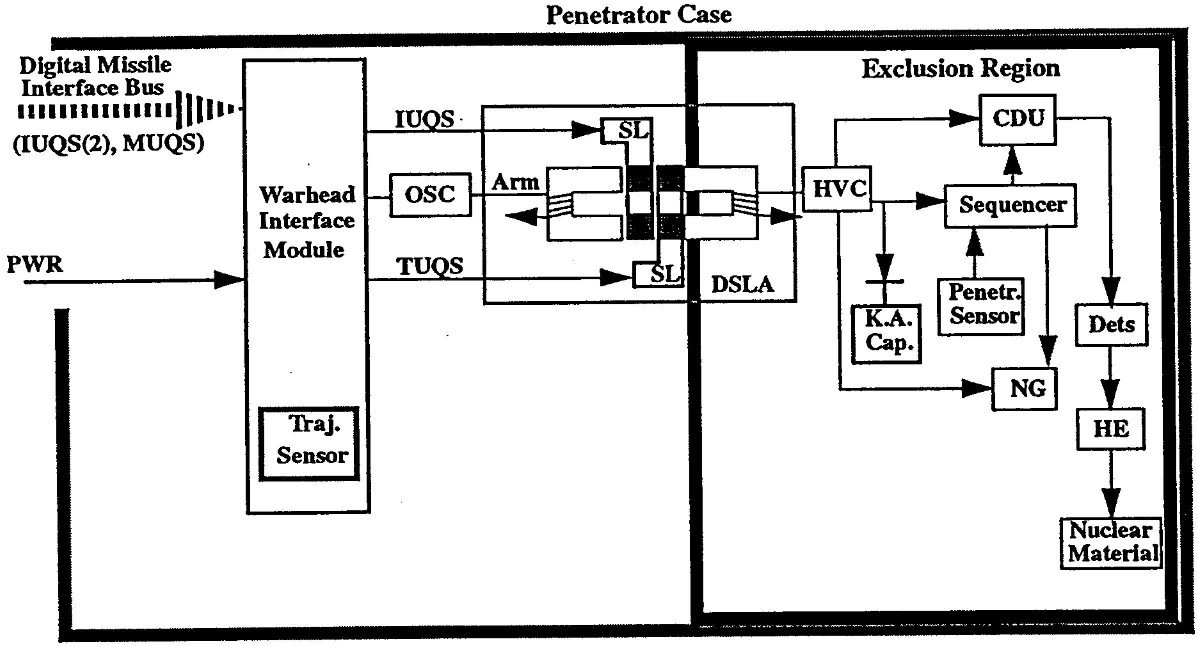

Figure 7. Schematic of the Proposed Implosion System Nuclear Safety Theme.

This theme is founded on the SEPW approach with some ideas used in the W86. The penetrator case plus a robust bulkhead is used to establish an exclusion region for the denial of electrical energy. There are no violations of this barrier, other than a pit tube if required. The energy transfer is facilitated through a magnetically coupled transformer. This transformer is normally blocked by discriminator protected stronglinks. The IUQS and the TUQS are required to enable or open the energy transfer path. This stronglink technology has been demonstrated on other programs and for this concept the dual stronglink assembly (DSA) is not required to function after penetration. As employed in the W86, the CDU is charged prior to impact. The power to perform the fuzing functions is stored in a keep-alive capacitor or Supercap, which is charged when the CDU is charged. A Penetration Sensor and a Sequencer are used to fuze the system. Because of the similarity with

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the W86 safety theme, this theme satisfies the numerical requirements given in Section 2.2.3 and the principles of Section 2.3. The important features of this safety theme are:

- No physical violations of the exclusion region barrier.
- None of the components outside the exclusion region are required to survive the penetration loads. This includes the stronglinks.
- No stored energy sources within the exclusion region prior to final arming. The energy is passed during the arming sequence and stored in the CDU and Supercap.
- Number of components required to survive penetration is maintained at a minimum and those required to survive are simple (no stronglinks). Desirable features for a penetrating weapon.
- The components required to survive penetration are the CDU, Supercap, Penetration Sensor, Sequencer, and the Neutron Generators. Because similar component technologies have been demonstrated on other programs, these components can be developed with low risk.
- The fuzing scheme is very flexible. The complexity of the fuzing is determined by the complexity of the Penetration Sensor and the logic in the Sequencer. The simplest scheme is an Impact Sensor and a Timer, while more complex systems could include sensors that would determine if the penetrator achieved a minimum depth requirement before it would detonate.
- The proposed safety theme is not restricted to an interrupted transformer type of stronglink. Other types such as optical charging of the CDU could replace that proposed but further exploratory development for this component is required. The approach taken is lower risk from a technology development standpoint.

In summary, a generic nuclear safety theme has been proposed for implosion type weapons with an earth penetrating mission. This system is not drastically different from that employed by previous penetrating weapons but has employed some evolutionary improvements. As discussed, additional improvements, such as a stronglink protected paste detonator explosive and optical charging of the CDU, may be incorporated given further developments of these components. The development of appropriate fuzing schemes and investigations in the shock hardening of penetration critical components is recommended.

4.2 Gun-Assembled Systems

A gun-assembled system involves two subcritical masses of nuclear material which are assembled together in a barrel using a propellant to produce a supercritical mass. Enriched uranium is the nuclear material used in gun-assembled weapons. Compared to an implosion system the physics required to produce a nuclear yield is much simpler. Several gun-assembled systems have been introduced into the stockpile over the years but currently all gun-assembled systems have been removed from the stockpile. With respect to comparable implosion systems gun-assembled weapons are not as weight efficient, cannot achieve as high of yields, and past safety themes cannot be considered modern. These reasons have contributed to their absence in the current stockpile.

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Gun-assembled systems do have several advantages over comparable implosion systems. The technology being much simpler does not require the developments, both analytically and experimentally, to field a new system. It may be possible to field a new gun-type system without an underground test and given the current political climate this may be a significant advantage. Gun-assembled systems only use enriched uranium, not plutonium, which is easier to configure from an ES&H standpoint and does not pose the threat of plutonium scattering. The nature of an implosion system makes it is very difficult to locate safety critical devices between the explosive and the nuclear material or devices to prevent supercritical mass creation. A gun-assembled system is much more amenable to incorporating safety devices that prevent the unintended assembly of the nuclear material. With respect to the flow chart for intended detonation, this concept for safety theme for a gun-assembled system is illustrated in Figure 8. Because the safety devices are further into the flow, this can be argued as an improved concept compared to the safety which blocks energy flow to the detonators.

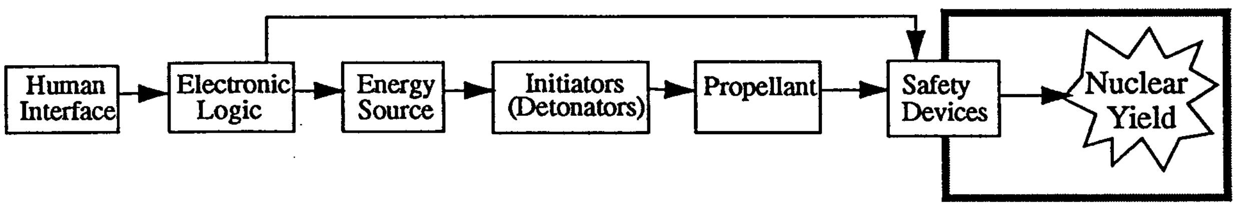
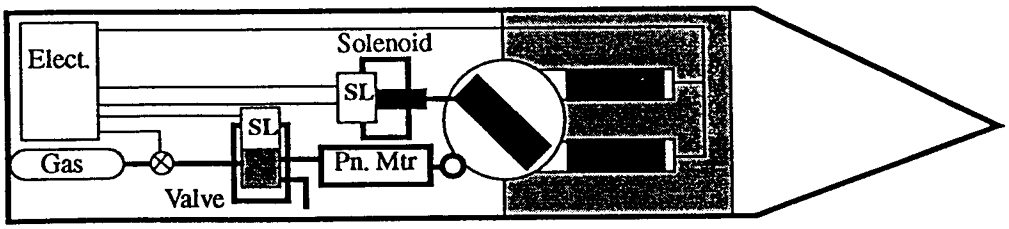


Figure 8. Flow Chart for Intended Nuclear Detonation With Proposed Safety Theme for Gun-Assembled Type Earth Penetrating Weapons.

In addition, gun-assembled systems have several advantages which make them attractive specifically for earth penetrating applications. Unlike most other applications where weight is often minimized, weight actually enhances depth of penetration performance, so gun-assembled systems are not at a disadvantage. The yield limitations would not be restrictive for low collateral damage earth penetrating systems, the yield range for gun-assembled systems is within current anticipated requirements. The most significant advantage may be the inherent ruggedness or shock-hardening capability of the fissile materials. Implosion systems require the nuclear material to be supported by the high-explosives, which is a relatively soft material. Enriched uranium, which is a moderate strength metal, can be supported in the barrel with high strength materials.

The potential for improved nuclear safety because of the additional flexibility and the benefits specifically applicable to earth penetrating systems are sufficient to justify renewed investigations of gun-assembled systems. A proposed nuclear safety theme and implementation for gun-assembled system for earth penetrating application is shown in Figure 9. Since gun-assembled weapons have not been considered for some time, some of the concepts introduced will for the first time be evaluated with respect to modern nuclear safety. These ideas will require a more thorough evaluation which is beyond the scope of this work.



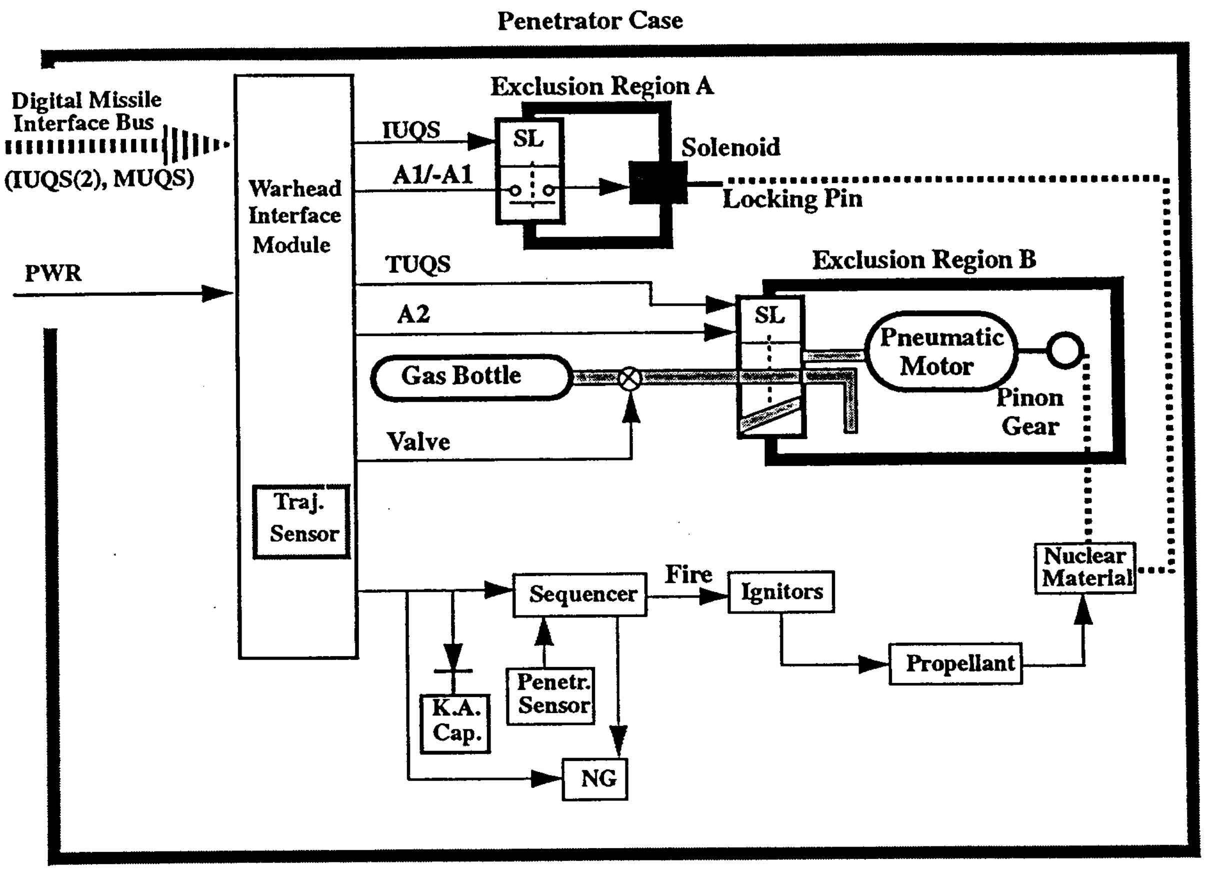


Figure 9. Schematic of the Nuclear Safety Theme for the Gun-Assembled Concept.

For this presentation, assume that the nuclear material is configure in a *slug* shaped as a solid right cylinder and ring which is a hollow cylindrical shape. The rings are driven over the slug by a propellant charge to assemble a supercritical mass. The foundation for the proposed nuclear safety theme is that in the unarmed state the slug is rotated out of position with respect to the ring. Even if the propellant charge were to ignite the ring cannot assemble with the slug. The rotation of the slug is locked with a solenoid actuated pin. If the pin is removed then the rotation is accomplished by a pneumatic motor driving a pinon gear. Unlike the implosion system which protected against electrical energy from reaching the detonators, for the proposed gun-assembled system the protection is against rotation of the slug into position to mate with the ring. The safety critical components are a stronglink protected solenoid pin mechanism that prevents rotation of the slug and a

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stronglink protected valve in the pneumatic line to the motor which rotates the slug. The establishment of a large exclusion region is not required in this theme, instead two small exclusion regions around these two safety critical components is all that is required. An alternative to this scheme could include the electrical stronglink protection of the line to the ignitor, either in addition or instead of one of the two proposed stronglinks. The normal operation of a weapon using this safety concepts is follows:

- Power to the Warhead Interface Module (WIM)
- Transfer of the dual intent unique signals from the aircraft or launch control and store in WIM.
- Launch or release from aircraft.
- Use IUQS1 to unlock solenoid stronglink and retract anti-rotation pin.
- Measure delivery vehicle environments to generate MUQS.
- Combine MUQS with IUQS2 to produce TUQS.
- Use TUQS to unlock second stronglink and operate valve.
- Open valve on gas bottle, which allows gas to operate motor and rotate slug.
- Extend solenoid pin to lock slug in an armed but penetration ready state.
- Impact and penetration.
- Penetration Sensor indicates to the Sequencer to continue with final fuzing of the system and detonate when intended.

With respect to satisfying nuclear safety requirements, each stronglink is required to provide 10^{-3} minimum assured safety for both normal and abnormal environments. The final 10^{-3} assured safety for normal environments, as required in Section 2.2.3, is guaranteed by the fuzing circuitry. The principle of isolation is satisfied by the two stronglink protected exclusion regions, the first isolates electrical energy from operating the solenoid pin and the second isolates the pneumatic motor from pressurized gas sources. The principle of incompatibility is satisfied because the electrical signals required to operate the stronglinks employ different unique signals. In addition, the energy to operate the pneumatic motor (pressurized gas) is incompatible with the electrical energy required to operate the solenoid. This incompatibility of energy sources also satisfies the principle of independence. The principle of inoperability is satisfied by the stronglink protection of the devices that prevent the rotation of the slug into position to accept the ring. If either of the stronglinks receive an incorrect signal then they will lock-up and prevent arming of the system. Further detailed engineering on the safing pin is required to insure that if the intent stronglink is destroyed the anti-rotation pin will fail in such a way as to lock rotation (a weaklink concept). The other weaklinks in the theme are a glass section in the pneumatic line for crush, solenoid wiring melting before pin, pressure relief feature in pneumatic system for high temperatures, and stronglink lock-up under crush.

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Some of the proposed ideas are only conceptual and given some exploratory development, may change the preferred implementations. Such as the safing pin may not be solenoid actuated but hydraulically operated instead and the gas bottle valve may be incorporate in the stronglink valve. In any event, the nature of gun-assembled systems allows for greater flexibility in developing revolutionary nuclear safety themes that are at least as protective as many of the themes employed by implosion systems. Some of the components have application for both type systems but the novel components for gun-assembled systems should be evaluated.

5.0 Summary and Conclusions

In summary, the basic definitions, principles, and requirements for nuclear safety themes have been reviewed. From three previous earth penetrating weapon programs (W86, SEPW, & W61) the implementation of the safety themes have been summarized for historical reference. The unique requirements (simple and robust) for the design of earth penetrating system were reviewed with emphasis regarding implementation of safety critical components. Two nuclear safety themes for earth penetrating weapons were introduced and discussed. These proposals have application to implosion type systems and gun-assembled systems, respectively. For the implosion system, the proposal is an improvement over the previous systems with minimum number of safety critical components required to survive penetration. Gun-assembled systems have been unjustly stereotyped as inherently unsafe, but the proposed scheme illustrates that the system can be protected to levels at least as safe as implosion systems and gun-assembled systems offer additional flexibility in developing improved safety themes. Many of the shock-hardened safety critical components have application to both types of systems but additional components for the gun-assembled should evaluated in exploratory development. The purpose of these proposals is to initiate thinking on the weaponization of future earth penetrating systems, stimulate responses for improvements, and motivate the exploratory development of some of these concepts and safety critical components.

6.0 References

[1] **The W86 Fuzing and Firing System (U)**, Confidential Report SAND83-1640, by Lloyd J. Merrell, 1983.

[2] **W86 Warhead Status Report (U)**, Secret Report SAND83-1642.

[3] "Minutes from March 2, 1987 SEPW Electrical System Meeting," compiled by John Shane, 5161.

[4] "LANL/SNLA Technical Interchange Meeting (TIM) 87-5 Minutes (U)," compiled by L. B. Traylor, 5165, dtd 12/87, RS5165/87/37.

[5] "LANL/SNLA Technical Interchange Meeting (TIM) 88-1 Minutes (U)," compiled by L. B. Traylor, 5165, dtd 4/88, RS5165/88/16.

[6] **W61-0 Weapon Development Report (U)**, Secret Report, SAND91-2243.

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