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WORKING PAPER

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APPROACHES FOR ACHIEVING NUCLEAR WEAPON ELECTRICAL SYSTEM SAFETY IN ABNORMAL ENVIRONMENTS (U)

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ABSTRACT

This paper discusses approaches that protect against premature electrical initiation of detonators of nuclear weapons subjected to abnormal environments.

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SUMMARY

The system concepts presented in this paper can be used to achieve nuclear safety in regard to premature initiation of weapon detonators during normal and, particularly, abnormal environments. A reduction in the total region and number of components of the weapon system that are involved in nuclear safety is obtained. A salient feature of the concepts is that a special region of the weapon system which contains safety-critical components is designed to respond to abnormal environments in a predictably safe manner. Nuclear safety in the abnormal environments is achieved even though premature signals appear at the input of the special region and without a precise definition of the abnormal environment. The approaches permit verification of system safety by analysis and test at reasonable resource expenditure levels. The following characteristics are integral parts of the system concepts:

1. Isolation. Electrical isolation is maintained between all sources of electrical energy in the weapon system and the firing set/weapon detonator system by a combination of two features:

   a. Exclusion Region. This special region contains the firing set/weapon detonator system and the necessary packaging and safety devices to exclude electrical energy from the firing set/weapon detonator system except in an intended use situation.

   b. Strong Links. Access to the firing set for the arming and firing signals is through safety devices, called "strong links." These strong links are designed to provide electrical isolation in abnormal environments and to actuate in their normal mode only when an intended use situation exists. The family of strong links includes system enabled ("intent") switches and environmental sensing devices.

2. Unique Signals. These signals actuate specific safety-critical loads in the weapon system. By "unique" is meant that there exists only one signal source within the weapon system capable of actuating the corresponding load. Unique signals may be used for a number of loads, but this characteristic is specifically applicable to the intent switch. In this application of a unique signal to actuate an intent switch, the signal source (remote from the weapon) should be the only source within the weapon system that could actuate the intent switch out of its safe condition in an intended use situation. The signal format is chosen to allow the intent switch to discriminate the unique signal from all other signals that may exist within the weapon system. The source of the unique signal is designed to preclude inadvertent or accidental generation of the unique signal in abnormal environments.

3. Inoperability. The abnormal environmental region over which the strong links must predictably exclude signals can be limited to less than the credible extremes. This can be accomplished by designing the firing set/weapon detonator system to become inoperable, and hence safe, before the strong links fail to maintain electrical isolation. A combination of two features is used.

   a. Weak Links. Selected elements, called "weak links," (e.g., capacitor, transformer) vital to the operation of the firing set/weapon detonator system are designed to respond predictably to certain levels and types of abnormal environments by becoming irreversibly inoperable (and thus rendering the system inoperable) at levels less than those at which the strong links fail to maintain electrical isolation.

   b. Co-Location. The weak links and strong links are located within the exclusion region, and are arranged so that the links will respond sequentially in a predictable manner to assure a safe weapon response if the weapon system is subjected to abnormal environments. Specifically, the weak links will become inoperable and render the electrical system inoperable before the strong links fail to maintain electrical isolation.

4. Incompatibility. The format of the driving signal and the response characteristics of the load are designed to insure that unintended signals inadvertently connected to the load will not produce an undesired response. Incompatibility may be achieved in a number of ways including the format (e.g., a square wave voltage pulse train versus a DC voltage) and the form of energy (e.g., optical versus electrical). The use of incompatible signals in a weapon in normal operation or in abnormal environments can reduce the concern for circuitry interaction.

Implementing these concepts involves the selection of the types of strong links, weak links, strong link actuation inputs, and arming signals used in the weapon system. These design selections and the design of the exclusion region are highly dependent on characteristics of each specific weapon system. As a system design goal, the level of nuclear safety contributed by the parts of the weapon system external to the basic HE/nuclear physics package should be commensurate with the safety requirements placed on the basic HE/nuclear physics package.

APPROACHES FOR ACHIEVING NUCLEAR WEAPON ELECTRICAL SYSTEM SAFETY IN ABNORMAL ENVIRONMENTS (U)

SECTION I -- INTRODUCTION

Nuclear safety encompasses the means and techniques required to prevent the occurrence of significant nuclear yield (normally stated as greater than 4 pounds TNT equivalent) from nuclear weapons except under prescribed circumstances of intended use. Nuclear safety applies from the time during assembly at which a nuclear package becomes capable of producing yield, throughout all phases of weapon life, and to the point of disassembly after weapon retirement. During its lifetime, a weapon may be subjected to various physical environments which impose severe conditions on the weapon. The parameters for many of these environments, specified in the stockpile-to-target sequence (STS) for the weapon, lead to design criteria for the weapon. Recent weapon development guidance documents have included nuclear safety specifications for abnormal weapon conditions such as exposure to fire, crushing, severe shock, lightning, flooding, and fragments. One recognition to be gained from such documents is that of the degree of uncertainty associated with the environments and the difficulty in providing precise and accurate definitions for abnormal or accident situations. Implicit in these listings is the exten of analyses and tests that could be required to verify that weapon safety is achieved under each set of input conditions.

The task of assessing or estimating the level of nuclear safety achieved in an existing or proposed weapon system, which may be subjected to abnormal environments, is significantly complicated when the response of the weapon system to those abnormal environments is difficult to predict. There is a general trend toward a complex interrelationship among major portions of a weapon which results in more of the system being indirectly involved in nuclear safety because of its association with critical circuits or components. The level of effort needed to provide the necessary assurance of safety is increased; more elaborate evaluation techniques are required. System concepts which can reduce the portion of the system which needs to be involved in nuclear safety and lessen the need for precise definition of the abnormal environments while still meeting the safety goals of the system appear to be desirable.

In nuclear weapons that are inherently one-point safe,* nuclear safety is dependent not only on the nuclear system but also on isolating the nuclear system detonators from all sources of electrical energy that could conceivably lead to a premature detonation. A combination of safety features must be utilized to achieve this latter goal.

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*A characteristic of a nuclear weapon which upon undergoing one-point detonation anywhere in the HE system has an extremely small probability of producing a nuclear yield in excess of 4 pounds TNT equivalent.

The purpose of this report is to present and discuss approaches that protect against premature electrical initiation of the weapon detonators during normal and particularly abnormal environments. They incorporate some techniques used in past weapons, extend some others, and introduce a number of new ideas.

SECTION II -- SYSTEM CONCEPT GOALS

In developing system concepts for achieving nuclear safety, it is useful to establish basic goals which identify desirable system characteristics and yet avoid unnecessary constraint of design options. The following goals were used in developing these concepts:

1. The level of nuclear safety contributed by the parts of the weapon system external to the basic HE/physics package should be commensurate with the safety requirements placed on the basic HE/physics package. This goal recognizes that the basic level of system nuclear safety is bounded by the inherent safety of the HE/nuclear physics package.

2. The nuclear safety-critical elements of a weapon system should be designed to respond to the normal and to the abnormal environments in a predictable manner. Characteristics of these features must be identified and controlled.

3. The assessment methodology for estimating the level of nuclear safety achieved in an existing or proposed weapon system should be clearly defined and compatible with the design concepts.

SECTION III -- CONCEPT CHARACTERISTICS

System design approaches by means of which system concept goals could be achieved can be conveniently divided into three major topics: isolation, inoperability, and incompatibility.

Isolation

Electrical isolation is maintained between all sources of electrical energy in the weapon system and the firing set/weapon detonator system by a combination of two features: an "exclusion region" and "strong link" safety devices.

An electrical energy "exclusion region" is a special region of the weapon system containing the firing set/weapon detonator system and the necessary packaging and safety devices to exclude electrical energy from the firing set/weapon detonator system except in an intended use situation for the weapon. The exclusion region is designed to respond to abnormal environments in a predictably safe manner. An important characteristic of this approach is the reduction in the regions and components of the weapon system that are involved in nuclear safety.

Access to the firing set/weapon detonator system for the arming and firing signals is through the series safety devices, called "strong links." These strong links are designed to resist abnormal environments and to actuate in their normal mode only when an intended use situation exists.

The basic plan for the exclusion region and strong links is shown conceptually in Figure 1. Note that all conductors entering the exclusion region are interrupted by the safety devices to avoid inadvertent electrical bypass. In this concept, nuclear safety in the abnormal environments is achieved even though premature signals appear at the inputs of the exclusion region.

The family of strong links includes "intent" switches and environmental sensing devices. An indication of intended use can be obtained by incorporating an intent switch which responds to signals that result from human action. A second method to indicate intended use is to incorporate an environmental sensing device (ESD) that responds to intended use environments which are results of actions of the carrier--bomb/aircraft, missile, etc. These two types of devices can be utilized to discriminate between intended and unintended use.

The selection of the proper combination of intent switches and ESD's is highly dependent upon the characteristics of the specific weapon system. Obviously a demolition-type weapon that experiences, during normal intended use, an environment no different than storage environment will not be able to incorporate an ESD; full reliance must be placed on intent functions performed by humans to enable the weapon. Intent switches alone may be required in this case to isolate voltages from the firing set. At the other extreme, the uniqueness of the firing environment in an artillery-fired projectile provides an opportunity to utilize the physical act of placing the projectile in the breech

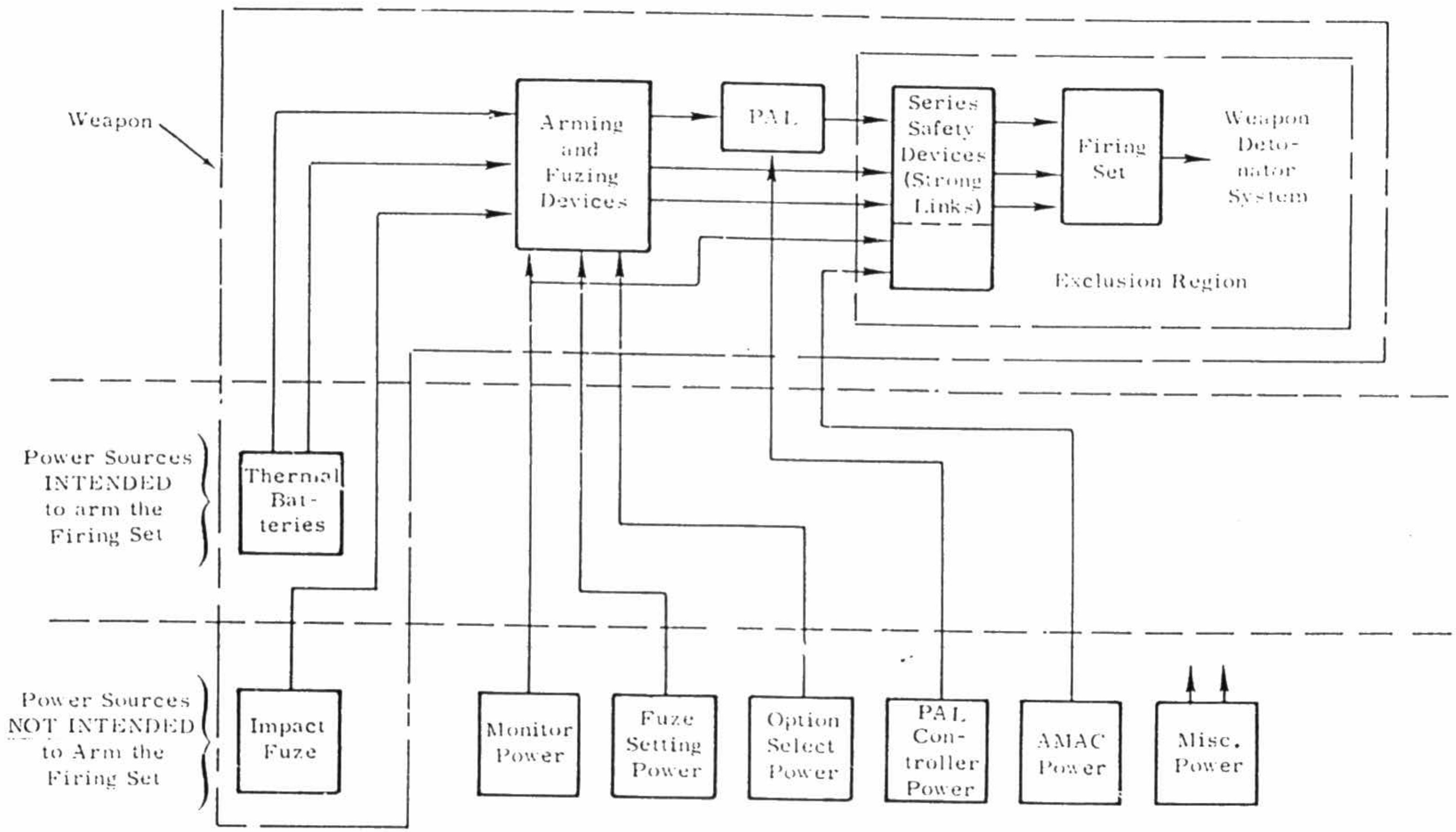

Figure 1. Isolation Using Strong Links and an Exclusion Region

of a gun as the human intent act; this action serves as an alternate to sending an intent-to-use signal to an intent switch in the exclusion region. More typically, in many weapon systems intent switches and ESD's may both be used to discriminate between an intended use of the weapon and an accident situation.

Intent Switches

The intent switch is a principal strong link safety device that indicates an intent to use a weapon.

The internal structure of the intent switch must withstand abnormal environments such as shock, severe vibration, and high temperatures wit ut allowing the functional contacts to physically close or insulation resistance to degrade to the point that undesired levels of current can be conducted from input to output terminals. The external structure of the intent switch is designed to resist abnormal environments such as crushing and high temperatures without allowing short circuits or low insulation resistance between input and output terminals. The design of the materials surrounding the intent switch in the exclusion region will also influence this ability to isolate.

One concept for a strong link intent switch in a bomb is the ready/safe switch developed as part of the Crescent program.* Each contact circuit was designed as a separate ceramic wafer. Each functional input circuit is diametrically separated from the output circuit. A full 90-degree rotation of the rotor portion of the switch mechanism is required to close the contact circuits. As a result of the selection of materials and structure, the switch contacts are highly resistant to inadvertent closure or bypass in abnormal environments.

The "intent-to-use" signal to the intent switch would normally be expected to be derived from some portion of the weapon system under direct human control. The switch should respond toward actuation only upon application of a unique signal input for which it is designed. By "unique" is meant there exists only one signal source within the weapon system capable of actuating the intent switch. The source of the unique signal is designed to preclude inadvertent or accidental generation of the unique signal in normal and abnormal environments. In this manner inadvertent or accidental switch actuation as a result of power from the unique signal generator and from all other power sources within the weapon system is avoided.

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*McGovern, D. C., Project Crescent: A Study of Salient Features for an Airborne Alert (Supersafe) Bomb (U), Sandia Laboratories, SC-SR-70-879, RS 3410/2097, SRD, April 1971.

The unique characteristic of the intent-to-use signal supplied to the intent switch would normally be in the format of the signal such as a sequence of electrical pulses which adds information to the basic form of energy. One concept for a unique electrical signal generated in an aircraft to actuate an intent switch in a bomb is the system developed as part of the Crescent program mentioned earlier. The intent switch requires not only DC voltage for operation but also a series of electrical pulses. The weaponeer in the aircraft, upon intended use of the weapon, would manually turn a knob on a special aircraft monitor and control (AMAC) console to store mechanical energy in a spring; upon release of the knob, the spring would unwind and generate a series of 28-V 5-Hz square wave pulses. The AMAC system would provide both the pulse train and the DC voltage over a period of time. Other signal formats and switch designs could be considered The Crescent-type components could serve as a strong link intent switch and unique signal generator and thus reduce the hazard of aircraft wiring faults or abnormal environment-induced actuation of a weapon-located switch.

The uniqueness of the operating signals for the intent switch in relationship to other signals in the system is discussed more fully in a later section concerning incompatibility.

If electrical inputs are used to drive the intent switch to the ready condition in normal operation and electrical safing circuits plus electrical monitoring are required, special care must be given to these electrical conductors to prevent their becoming an inadvertent electrical access to critical portions of the exclusion region.

Environmental Sensing Devices

The environmental sensing device (ESD) is a second type of strong link safety device that can discriminate between an intent to use a weapon and other situations. The ESD role is to provide isolation of input and output circuits until the ESD has experienced one or more environments unique to the intended use trajectory of the weapon.

As in the case of the intent switch, the ESD must be designed to resist abnormal environments such as high temperatures, shock, and crush without allowing short circuits or low insulation resistance between functional input and output circuits.

In many cases, the ESD can properly differentiate between a normal flight trajectory and many classes of normal environments (e.g., aircraft arrested landings) and abnormal environments (e.g., fire, low-speed crashes). However, certain limitations in the ability of an ESD to discriminate must be considered. For instance, the ESD may not differentiate properly between an intended missile launch (or bomb drop) and certain classes of abnormal environments (e.g., a tumbling environment that simulates linear acceleration in a launch accelerometer). Furthermore, the ESD cannot clearly differentiate between an intended and inadvertent or accidental launch (or drop). These ESD limitations must be considered for each specific weapon system, both in design and analysis.

The environment to be sensed by an ESD depends upon the weapon's normal delivery environment. An ESD that senses g and g-second product should be designed to actuate at levels which discriminate against abnormal environments including tumbling type accidents. A lock that holds the ESD mass until an unlocking signal is supplied may also help reduce system sensitivity to an accident environment. If an electrical signal is utilized for this purpose, the lock input must be well isolated from all threat voltages or perhaps require a unique signal to achieve incompatibility with unintended signal sources. Requiring continuous unlocking power during the g-second sensing period may be advantageous in some applications.

Combined environments can also be used in some weapon systems to help the ESD differentiate between normal and abnormal environments. For instance, combined setback and spin could be utilized in an artillery fired atomic projectile to cause normal functioning of an ESD strong link.

Aircraft-released cruise missiles offer a technical challenge in designing a discriminating ESD because of very low g-acceleration profiles. As an example of an ESD for this type application, a missile-skin fence could be popped out upon weapon release from the aircraft to supply a differential air pressure over an extended period of time as a function of altitude and velocity. An ESD in the exclusion region could either be actuated or perhaps unlocked by the pressure differential. As an alternative, the pressure differential could be used to generate a unique electrical signal (e.g., a chopped DC voltage) which could operate a strong link stepping switch in the exclusion region.

An example will illustrate a proposed method to reduce the probability of short circuits bypassing the contacts of an ESD. Figure 2 illustrates a combined ESD and output transformer of a transverter in one integral package. For normal operation, the ESD must first respond to an intended use environment of g and g-seconds to close the circuit to the three terminals of the transformer, in this case a vital element in the operation of the firing set transverter. Short circuits from input to output of the package will not permit the transverter to function, and the strong housing of the package reduces the probability of stray AC voltages inadvertently shorting to the input terminals of the transformer in normal and abnormal environments. Further possible advantages of this approach toward isolation and inoperability by removal of a vital element from the firing set until ESD operation are discussed later.

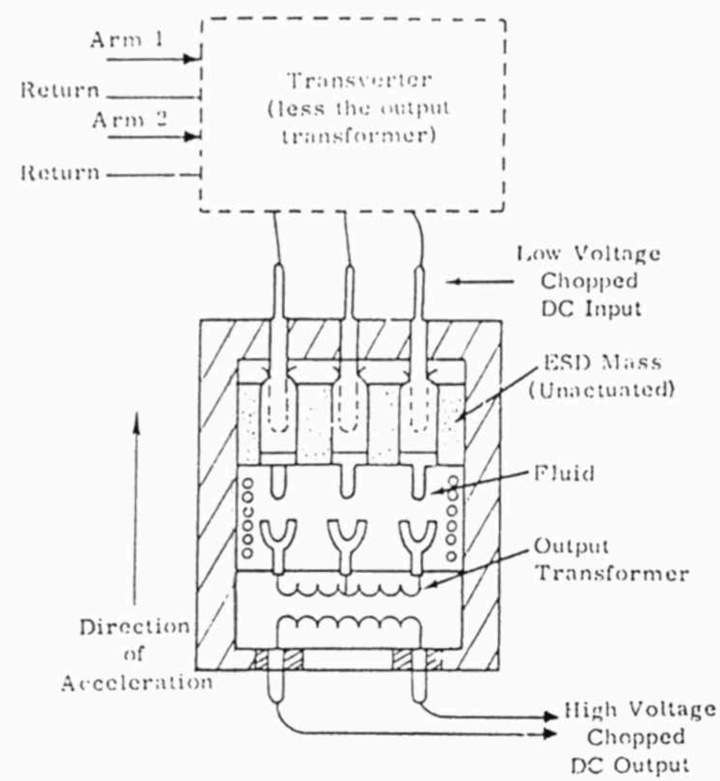

Figure 2. Vital Element Removal Device

Summary

The firing set/weapon detonator system is isolated in an electrical energy exclusion region from all sources of electrical energy that could credibly be applied to the firing set/weapon detonator system. The only credible electrical access to the firing set/weapon detonator system is through a set of series safety devices called strong links. These strong links, which are designed to resist abnormal environments, will actuate in their normal mode only when an intended use situation of the weapon exists. An intent switch is the principal type strong link that indicates intended use by responding to unique signals which result from human action. An environmental sensing device is a strong link that in many systems can provide a means of indicating intended use by responding to an environment unique to the weapon delivery mode. The selection of the proper combination of intent switches and ESD's is highly dependent upon the characteristics of the specific weapon system.

In this concept, only the small portion of the weapon system contained in the exclusion region need be predictable in the abnormal environment. Nuclear safety is achieved in the abnormal environments even though premature signals appear at the inputs of the exclusion region.

Inoperability

A second aspect of the safety concepts discussed in this report concerns inoperability.

Weak Links

If it were possible and practical to design the series safety device strong links and the exclusion region isolating medium strong enough to isolate all electrical signals from the firing set/weapon detonator system through all credible abnormal environments, nuclear safety could be achieved by this means alone. However, in many systems where severe environments (e.g., very high temperatures and large crushing forces) may be encountered in accidents, and where practical component sizes limit the physical spacing of conductors and strength of components, it is reasonable to assume that electrical isolation cannot be predictably maintained throughout all environmental extremes.

As examples, the contact circuit insulation of strong links may become electrically conductive at very high temperatures induced by fires; electrical contacts may be forced together in extreme weapon crushing environments; verge escapement mechanisms in ESD's may break because of high shock levels, or ESD silicone fluid may leak out because of deformation or high temperatures. The cost in size or other parameters to improve the resistance to increasing environmental severity may result in undesirable system penalties.

Fortunately a mitigating factor can occur: vital elements of the firing set/weapon detonator system may inherently (or by design) become inoperable when subjected to the same classes of abnormal environments that tend to make the strong links unpredictable. These vital elements are called "weak links."

Consider a CDU firing set. The transverter section and high voltage storage capacitor are vital to the capability of providing energy of the proper format to the weapon detonators. A means of creating a predictable configurational change which would render the firing set inoperable under abnormal environmental inputs is to intentionally design specific weak link characteristics into some or all of these vital elements necessary to the chain of events leading to a nuclear detonation. The function of the weak link(s) would be to become predictably inoperable when subjected to environmental inputs which exceed those levels of the weapon's normal STS environment regime. The weak link should exhibit inherent properties for failure, preferably without depending upon external passive or active devices to cause the desired level of inoperability, and should depend upon the "physics of failure" of its own properties to predictably produce the response mode expected and desired under the proper input conditions. To be credible in a safety sense, these responses must be irreversible, i.e., the weak link must not recover a significant portion of its former capability subsequent to removal of the environment.

As an example of a weak link element in the firing system, the high voltage storage capacitor of the CDU firing set could fail completely and catastrophically (fail to hold a charge) at elevated temperatures because of the materials and construction methods used in its manufacture. To cover the whole range of potential abnormal environmental inputs for weak link elements may require the use of more than one weak link in a system, but this need is dependent on the strong link characteristics.

Other vital elements of a CDU firing set may serve as useful weak links: the oscillator and power amplifier components are potential candidates.

One more important characteristic of a suitable weak link is that its physical/chemical/electrical features which determine its predictable response to abnormal environments must be identified and controlled during manufacture.

In summary, a weak link should possess three important characteristics:

1. Its operation is necessary for the firing set/weapon detonator system to function.
2. It will predictably become irreversibly inoperable at the intended environment level.
3. Parameters which insure its weak link characteristics are identified and controlled.

Co-Location

The strong link isolating devices discussed previously must be able to isolate voltage sources from the firing set/weapon detonator system until after the weak links become inoperable in the abnormal environments. Because the strong links and weak links would be required to function in a critical relationship with each other (energy holdoff until disablement), a physical relationship between the two types of elements becomes a part of the design concept. The logical relationship is one of close proximity or co-location of the links to facilitate the sensing of identical or nearly identical environmental inputs. An environmentally shielded weak link and exposed strong link design configuration would tend to defeat the purpose of the safety element pair; therefore, co-location insofar as environmental exposure for both types of elements is equally as important as the use of the elements themselves.

The strength required of the strong links is directly related to the weakness of the weak links and to the physical relationship of the strong and weak links. Ideally, the weak links would be designed to perform the normal weapon function reliably throughout the ranges of normal environments defined in the STS, but to perform their safety function by becoming irreversibly inoperable at levels of abnormal environment just beyond those of the normal environment. If the strong link could experience the exact environment experienced by the weak link, then the strong link would have to perform its holdoff safety function also only barely into the abnormal environment regime. In a practical sense, the weak links will not become inoperable until they experience an environment much more severe than the maximum normal environment. The margin above the maximum normal environment levels results from several factors:

Material properties of the weak links often cannot be selected to achieve the ideal situation.

Response characteristics of the weak links will be somewhat variable because of normal manufacturing tolerances.

An environmental gradient may exist between a strong link and a weak link due to their location within the exclusion region.

Integration of a strong link ESD and a vital element to improve electrical isolation in abnormal environments was discussed previously. Figure 2 shown earlier illustrates the use of a power transformer as the vital element. If the transformer can be designed as a suitable weak link and paired with the ESD in the integrated package, then the resulting device might have a highly predictable safe response in a wide range of abnormal environments.

The use of weak link/strong link components, whether contained in a single integrated package or simply placed near each other, offers the weapon designer the capability to determine and set a level of safety protection against environmental inputs above those experienced in the normal STS. Judicious selection of weak link response modes and levels coupled with co-location and selection of an environmental differential as large as practical between weak link disablement and strong link holdoff offer safety protection with a large degree of independence from precise level definitions of abnormal environments. The use of weak link/strong link/co-location design features also can provide the designer with the ability to analyze and test a system, and thus verify its safety within reasonable limits of resource and effort expenditures.

Care in packaging components (including strong links and weak links) and their interconnections must be exercised so that the electrical energy exclusion features of the region are not violated under conditions of normal or abnormal environments. It is important to have determined the appropriate weak link/strong link/co-location theme as an initial input along with component size and shape so that these safety related factors are considered concurrently with packaging efficiency.

Summary

Weak links and strong links are co-located in an electrical energy exclusion region so that the links will respond sequentially in a predictable manner to assure a safe weapon response if the weapon system is subjected to abnormal environments. Specifically, the weak links will become irreversibly inoperable and render the electrical system inoperable before the strong links fail to maintain electrical isolation.

Incompatibility

Another facet of the safety concepts discussed in this report concerns incompatibility. Incompatibility of signal sources and loads as used here means that the unintended signal source is incapable of actuating a particular safety-critical component or subassembly in the weapon, if the unintended signal source and load are inadvertently connected together. The incompatibility characteristic allows faults (e.g., loss of isolation between critical circuits) to occur without loss of safety; this approach contrasts with a common voltage approach (e.g., all 28-VDC circuits) in which isolation must be carefully maintained between compatible sources and safety-critical loads that are not intended to be interconnected.

Incompatibility between signal and load can be in the form of signal level such as 28-VDC source versus a 500-VDC load, or 100-milliampere source versus a 2-ampere load. It can be in the form of energy such as electrical, fluidic, and optical; incompatibility can be in the format, such as a 28-VDC signal versus a 2-kHz AC load. It is usually desirable from a nuclear safety standpoint that some of these signals are unique within the weapon system.

To maintain an incompatible relationship between critical loads and unintended signal sources, the characteristics of critical load responses and signal source outputs must remain invariable within predictable limits when the critical loads and signal sources are subjected to normal and abnormal environments. The use of an incompatibility concept within a system is therefore selective, and the concept is most applicable where problems in assuring isolation are expected or where uniqueness of a function is desired. Examples of its application are:

1. The main firing set in the exclusion region would be the only signal source within the weapon system capable of supplying a signal of characteristics that would fire the most sensitive critical cable configuration of weapon detonators.* For instance, neither the main trigger circuit, an impact fuze, a command destruct circuit, a neutron generator, a radar power supply, a guidance and control system, nor any other subsystem, power supply, or component would be capable of supplying such a signal.

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*The most sensitive critical cable configuration is that set of one, two, or more detonator cables that requires the least amount of energy to produce an unacceptable yield (greater than 4 pounds TNT equivalent).

2. The two (or more) arming signals required by the main firing set would be of different characteristics so that neither signal applied to any set of points within the exclusion region would be capable of causing arming of the firing set or firing of the most sensitive critical cable configuration of weapon detonators.

3. In a CDU firing set system, the power amplifiers would be unique signal sources within the weapon system capable of charging the main CDU to a level sufficient to fire the most sensitive critical cable configuration of weapon detonators.

4. The drive mechanism of a strong link intent switch would be designed to remain inoperable if any extraneous voltage is applied. As discussed earlier, the Crescent-type intent switch requires two simultaneous input signals to drive it. One is a continuous 28-VDC signal to engage a clutch and the second a series of 28-VDC pulses to drive the switch to the ready position. If the second signal is indeed unique within the weapon system, then this approach would provide a high degree of assurance that the intent switch will be operated only when intended and not inadvertently through circuit faults in normal and abnormal environments. Other forms of a unique drive signal to the intent switch could be more complex such as a fixed nonuniform pulse width format. A coded pulse train similar to that needed to unlock a PAL device could be used, but in general this appears more complex than necessary for nuclear safety. The concern here is protection against inadvertent operation of the intent switch by some naturally occurring signal format in normal or accident environments. The particular selection of signal format is highly dependent on overall weapon system considerations.

5. Monitoring currents and voltages that are allowed into a weapon system would be incapable of operating critical elements.

As mentioned earlier, incompatibility can be achieved by using fiber optic and fluidic systems which can offer the additional advantage of transmitting information and energy into and out of the exclusion region without causing electrical bypass of safety devices. Incorporation of these type systems could eliminate certain electrical bypass problems and reduce constraints on safety devices.

In summary, an incompatibility concept can be implemented by using several dissimilar signals to actuate various safety-critical components or assure nonactuation of safety-critical components, where "incompatibility" means that, if an unintended signal source is inadvertently connected to a critical load, the load will not respond in an unsafe manner.

SECTION IV -- SYSTEM DESIGN CONSIDERATIONS

Implementing the system concepts discussed in this paper involves the selection of the type and quantity of strong links, weak links, strong link actuation inputs, and arming signals used in the weapon system. These design selections and the design of the exclusion region are highly dependent on characteristics of each specific weapon system. The nuclear safety inherent in a design is influenced by:

1. The number and types of strong links
2. The number and diversity of weak links
3. The number of actuation inputs required by each strong link
4. The number and diversity of arming signals required to arm the firing set.

However, just adding "more" features doesn't necessarily result in a net safety gain within a particular system since interaction may be more likely or safety devices may be more complex and have less resistance to abnormal environments. When selecting the appropriate type and quantity of these entities to meet particular goals, each weapon system must be considered on an individual basis during the design phase. These factors cannot easily be considered independently of each other. Many of the system implementation considerations were discussed earlier because of the strong interrelation with a particular topic. Additional considerations are discussed in the following sections.

Strong Link Selection

An examination of the various ways in which a strong link may fail to provide electrical isolation is required to help with the selection of the quantity of strong links appropriate for a particular weapon system.

First, a strong link may be electrically bypassed by multiple short circuits. By choosing a sufficient number of arming signals of the proper characteristics and interrupting all circuits with the strong link contacts, the bypass possibility can be reduced to low enough significance such that the strong link itself and the availability of the actuation energy are the dominant areas of consideration.

A second manner for the strong link to fail to isolate electrical signals is for the actuation energy inputs to be available, thereby causing inadvertent actuation.

Third, the strong link could be inadvertently left in the actuated condition in stockpile because of tester failure or human error.

Finally, the energy available from abnormal environments, such as thermal and mechanical energy, could cause the strong link contacts to close or internal electrical insulation to fail at levels below the intended levels.

Because of the difficulty and cost of gathering vast quantities of data to establish the actual probability of occurrence of these types of failures (which could be extremely small), the probability of failure of a single strong link to provide electrical isolation is often estimated to be about 10^{-3} to 10^{-4}. The safety requirements placed on the basic HE/nuclear physics package in abnormal environments is generally stated as a probability of less than 10^{-6} of a significant nuclear yield.

Thus, for the level of nuclear safety contributed by the parts of the weapon system external to the basic HE/physics package to be commensurate with the safety requirements placed on the basic HE/physics package in abnormal environments, it appears necessary to use a minimum of two strong links in series to isolate arming voltages from the firing set. Implicit are the assumptions that

1. Failure of the two series safety devices are independent
2. Threat signals are available at the exclusion region interface, with the exception of the unique actuation signal(s) to the intent switch
3. The operating environment is not available to the environmental sensing device(s).

The use of two or more series safety devices does not eliminate the possibility of short circuits that bypass all safety devices. Careful design and control of the circuit routing and insulating materials in the exclusion region may reduce the probability of this type of bypass to the desired level. However, a different approach may also be used to advantage: a vital portion (e.g., oscillator) of the firing set system may be isolated from the transverter by a strong link. If it is located electrically between the two strong links, it creates an energy conversion or transformation region. This creates an incompatibility between Arm Signal 1 and Arm Signal 2 in the transverter region, a desirable concept discussed in an earlier section. An oscillator converts a DC current to a unique pulsating DC (perhaps 10-kHz square wave) current external to the firing set. Thus, DC voltage short circuits around both strong links will not allow a suitable arming signal to reach the firing set. Incompatibility is achieved and bypass faults are made highly selective.

Hypothetical System Examples

Figure 3 shows schematically a single channel example of a hypothetical weapon system based on considerations discussed above. As a baseline for a generalized weapon system, the exclusion region contains an intent switch and an ESD for strong links, and several components identified as weak links: a power amplifier with a separate oscillator, and a CDU firing set. The CDU firing set is used as a model in explaining the exclusion region concept. Other firing set technologies could be used to achieve equivalent results. The intent switch requires two simultaneous, incompatible electrical signals (one being unique) and time to actuate to the ready condition where it latches. The ESD requires a minimum g-acceleration for a length of time to measure a minimum velocity change; the ESD latches in the actuated condition. Two arming signals are required to arm the firing set. One of these signals is converted to a 10-kHz square wave signal electrically between the two strong links. All arming and firing signals pass through contacts of both strong

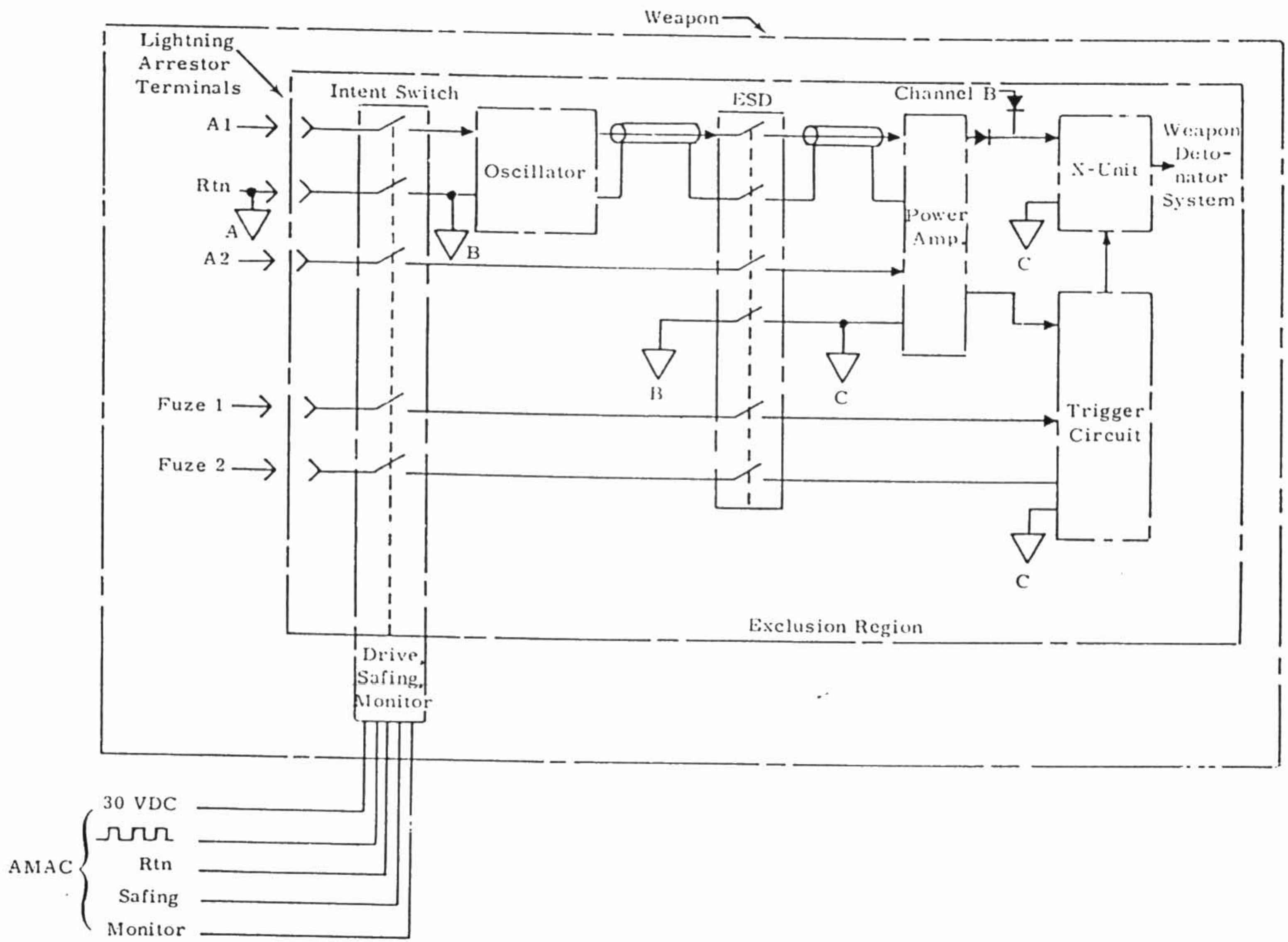

Figure 3. Example of an Exclusion Region Schematic

links. If the ESD required an unlock signal first, this signal must also pass through contacts of the intent switch.

In that all electrical arming and firing signals pass through contacts of the strong links, a large number of contacts may be needed. To reduce the number of contacts and at the same time reduce the amount of electrical wiring which can allow short circuit bypassing of the strong links, fiber optic systems could be considered to transmit information such as firing signals into the exclusion region or to transmit, for example, a trigger signal out of the exclusion region to a neutron generator. As an alternate method for transmitting certain types of energy/information, fluidic systems may also offer certain advantages.

The system components illustrated in Figure 3 are packaged in an exclusion region adjacent to the nuclear system; the outer layer of this region is electrically conductive for lightning protection. The drive mechanism, electrical monitoring circuits, and safing mechanism of the intent switch are physically and electrically isolated from the functional contacts in such a way that lightning currents introduced in any of these control and monitoring lines will not electromagnetically induce significant currents or voltages into the exclusion region. Lightning currents are shown blocked from entering the exclusion region by the combination of lightning arrestor terminals, a conductive outer layer around the exclusion region, and the open contacts of the intent switch. In any accident situation that tends to separate the exclusion region from the HE/nuclear physics package, the design should ensure that the weapon detonator circuitry is permanently disrupted so that the detonators are disconnected from each other. Thus, electrical access by lightning to the weapon detonators at a single point is denied. Figure 4 illustrates the concept with a "vital element removal" ESD.

Operationally necessary weapon elements, such as fuzing devices, option and yield selection devices, destruct firing sets, or other specific devices required or desired can be located outside the exclusion region. The only safety restraint on these subsystems external to the exclusion region is that various voltages utilized must not duplicate unique voltages used within the exclusion region in either normal or abnormal environment conditions.

Summary

Implementing the system concepts involves the selection of the types of strong links, weak links, strong link actuation inputs, and arming signals used in the weapon system. These design selections and the design of the exclusion region are highly dependent on characteristics of each specific weapon system. As a system design goal, the level of nuclear safety contributed by the parts of the weapon system external to the basic HE/nuclear physics package should be commensurate with the safety requirements placed on the basic HE/nuclear physics package.

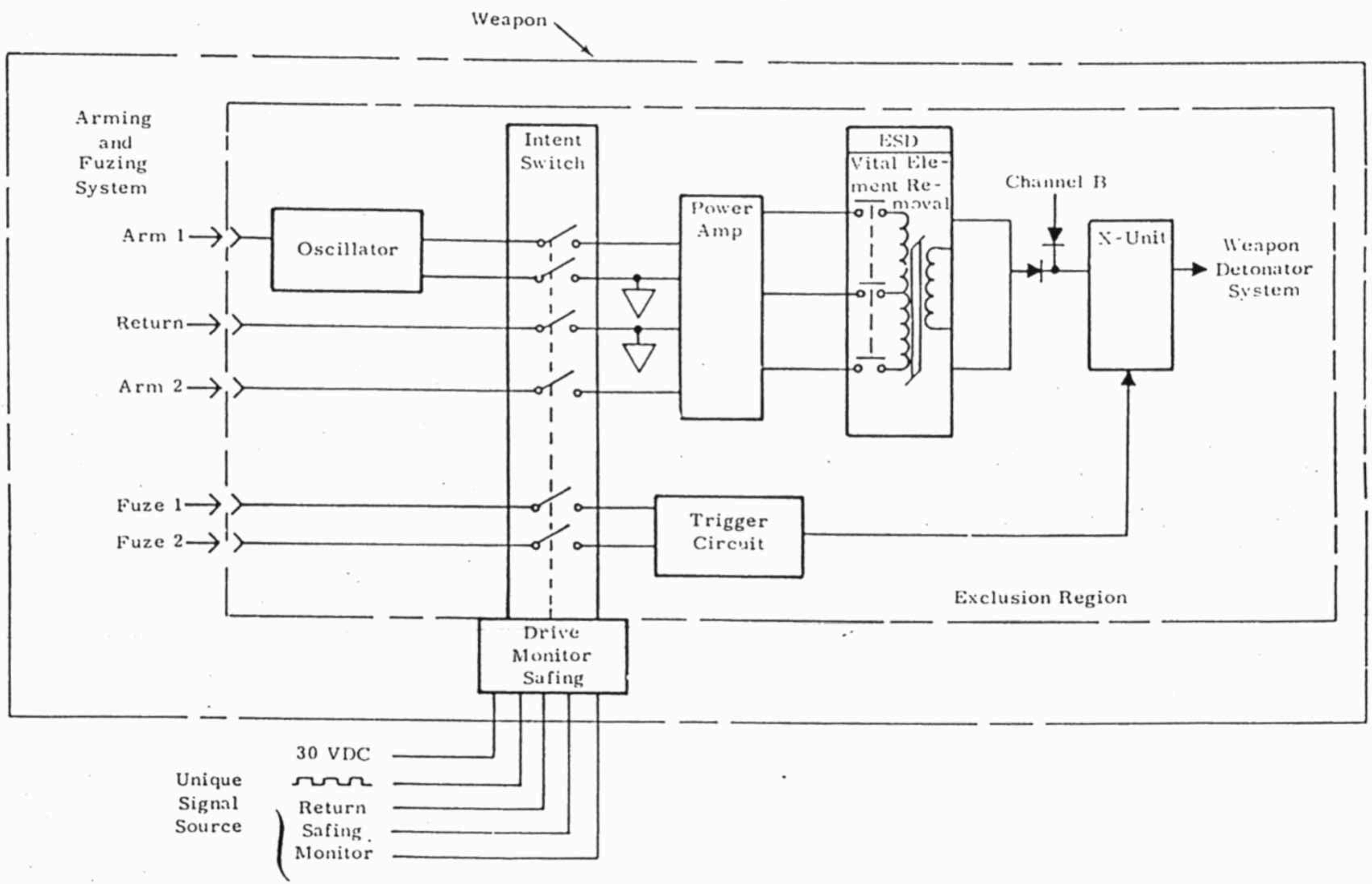

Figure 4. Example Exclusion Region Schematic with Vital Element Removal ESD

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