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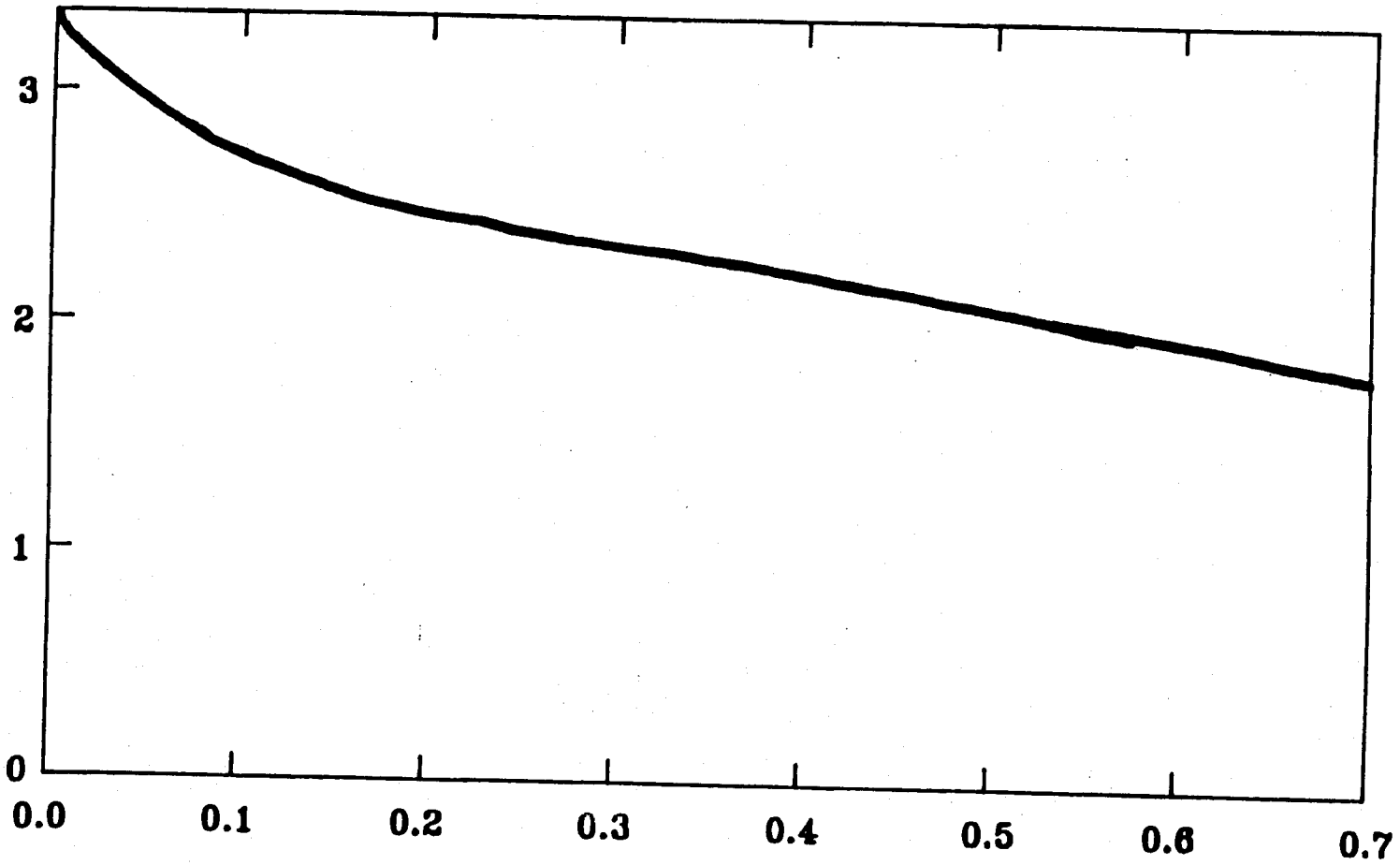
MOVIE OF

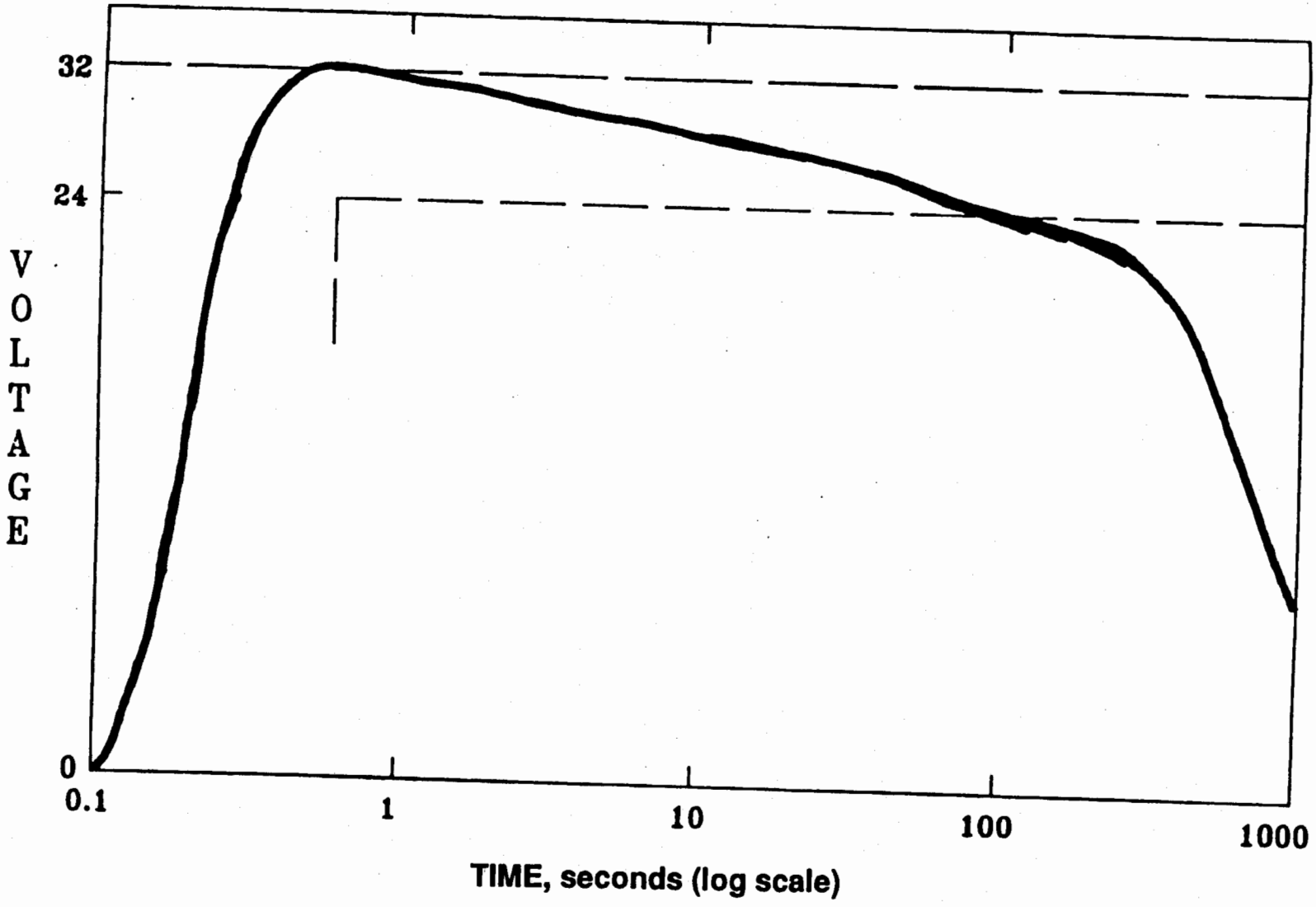
THERMAL BATTERY INITIATION

Cell Voltage vs Current Density
Typical Thermal Battery



UNCLASSIFIED

Typical Thermal Battery Performance--
Constant Load



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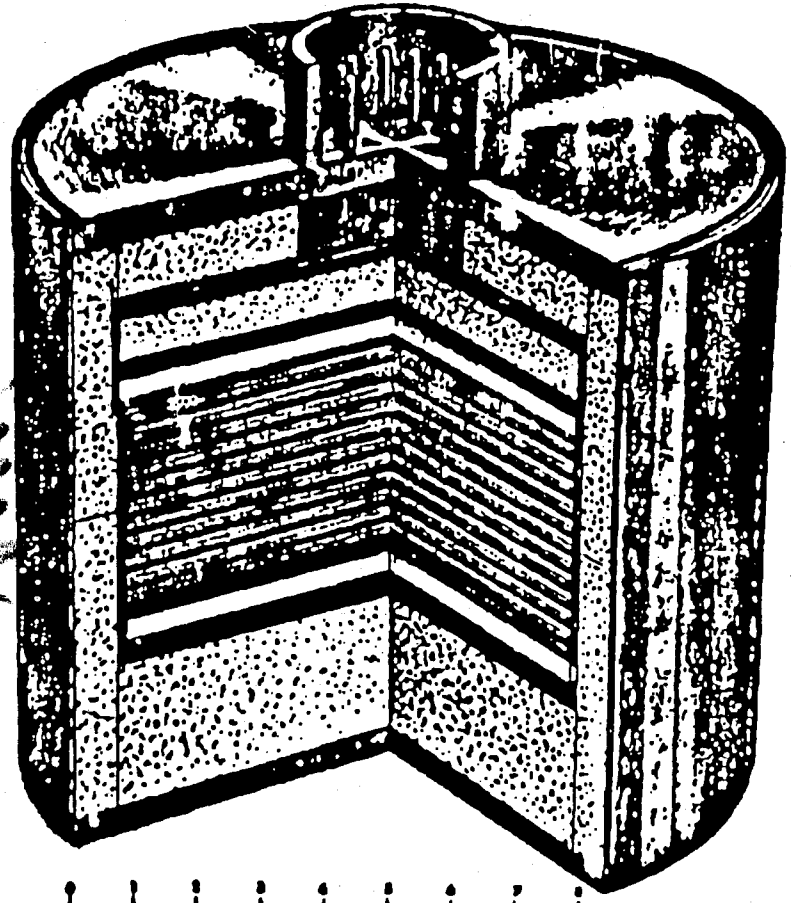


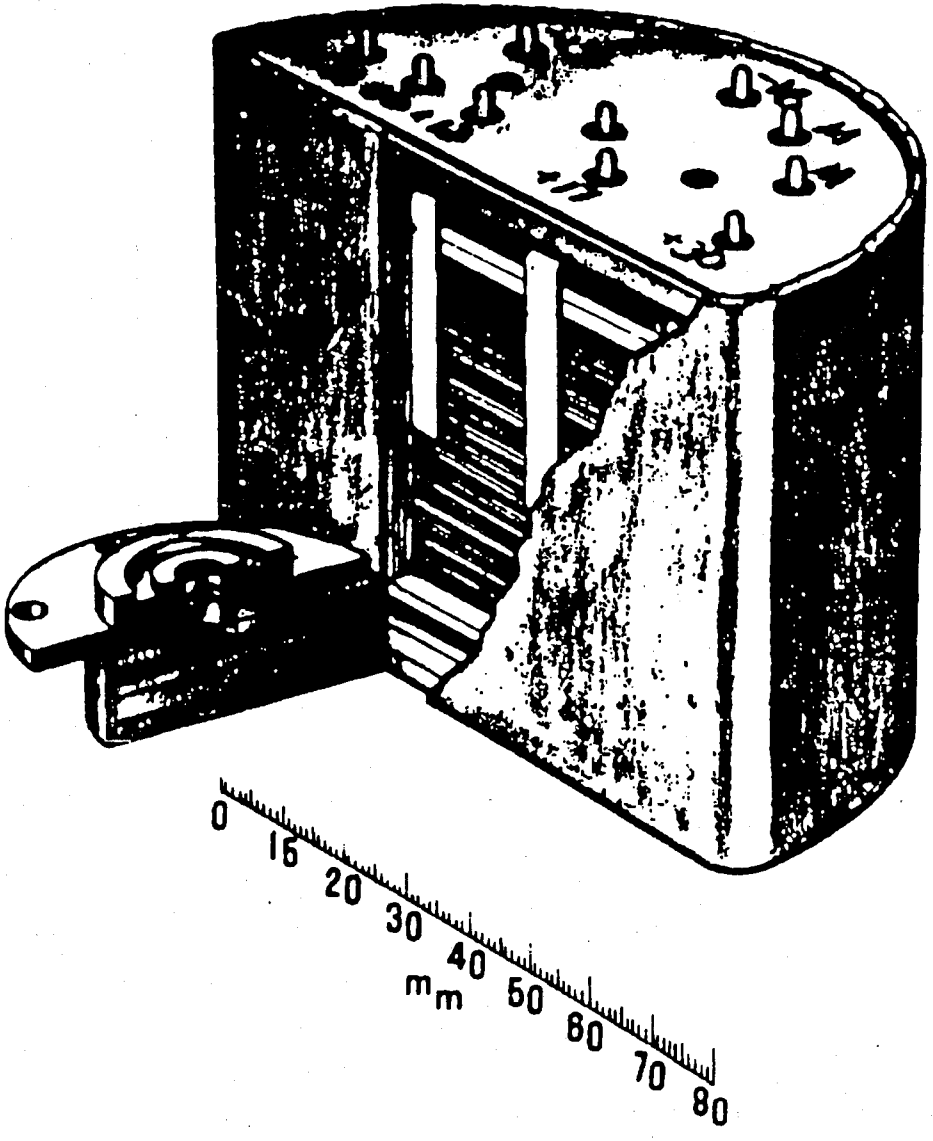
CENTIMETER SCALE

- THERMAL INSULATION (Min-K)
- HEAT SOURCE ($Fe+KClO_4$)
- HEAT OF FUSION HEAT SINK ($NaCl-Li_2SO_4$)
- CALCIUM ANODE
- DEB — DEPOLARIZER ($CaCrO_4$), ELECTROLYTE (LiCl, KCl), BINDER (SiO_2)
- HEAT PAPER ($Zr+BaCrO_4$)

THERMALLY ACTIVATED BATTERY

UNCLASSIFIED
UNCLASSIFIED

MC2936 THERMAL BATTERY



DEPOLARIZER-ELECTROLYTE-BINDER (DEB)

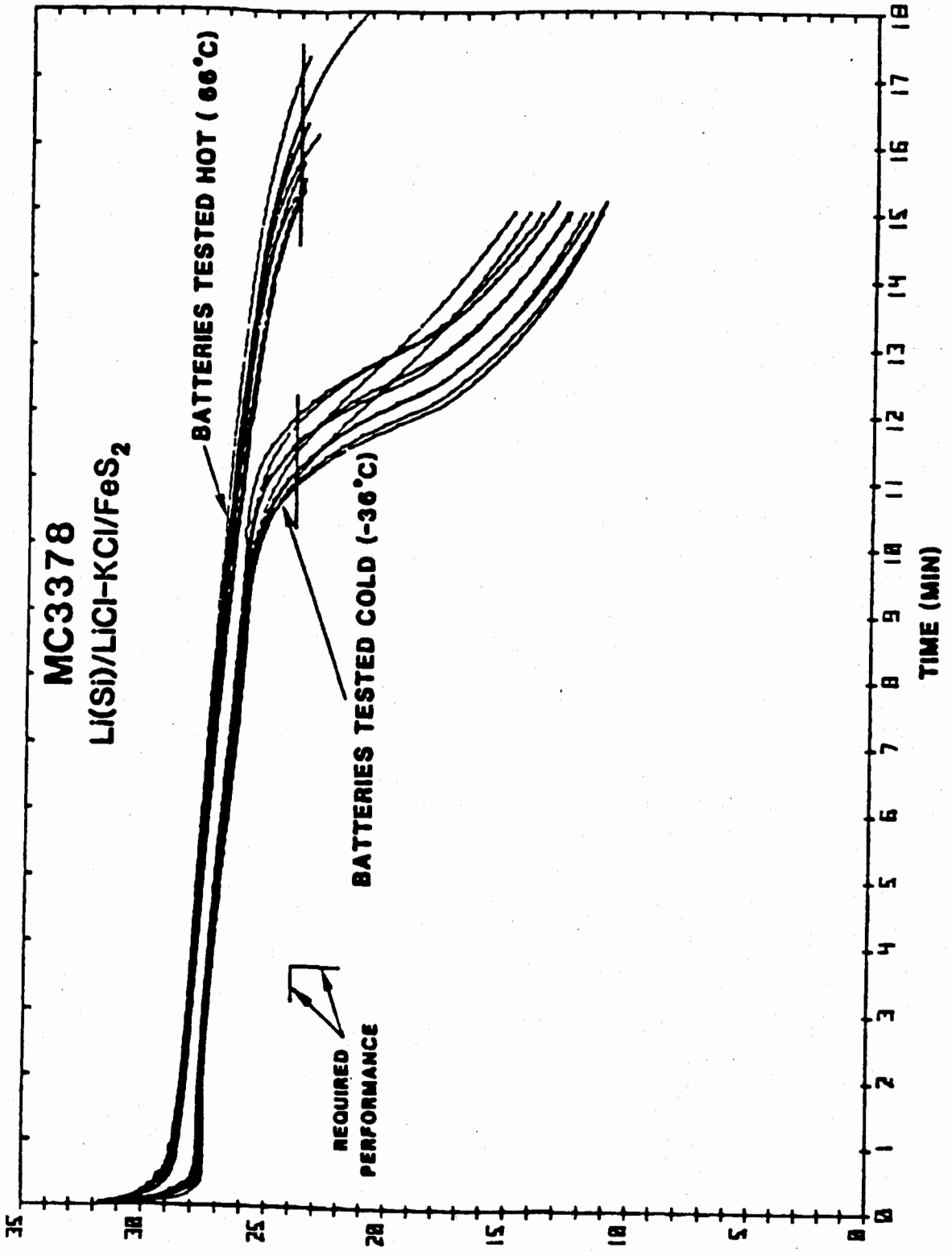
HEAT PELLET & INTER CELL CONNECTOR (Fe-KCl O_4)

NEGATIVE ELECTRODE (Ca)

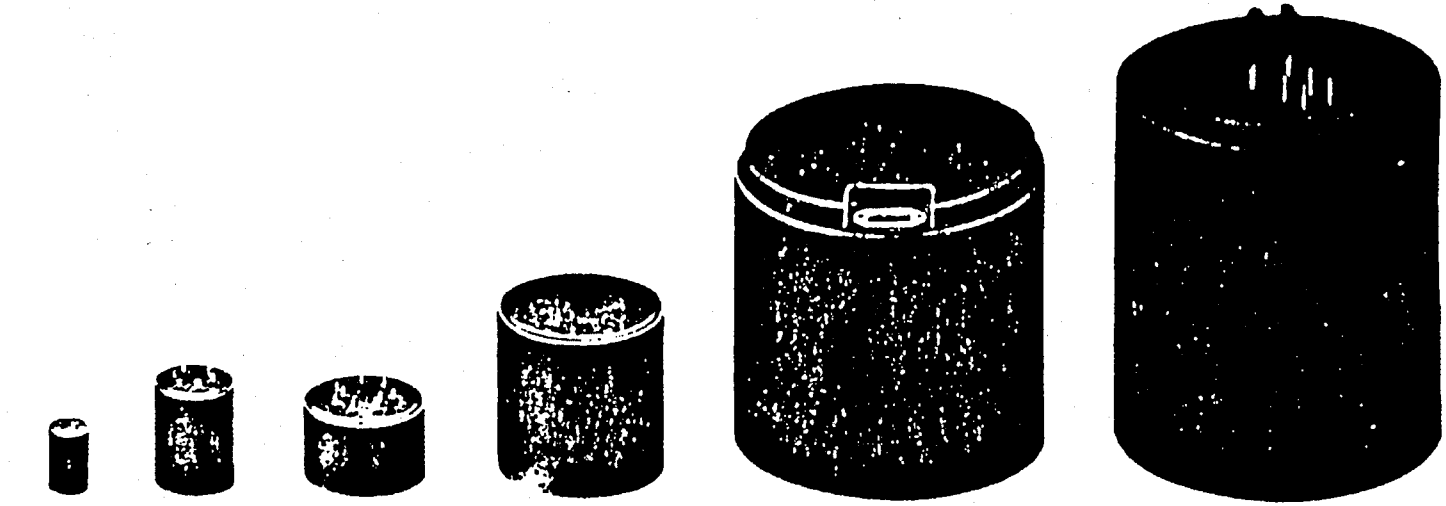
HEAT PAPER

UNCLASSIFIED

UNCLASSIFIED


MC3378
Li(Si)/LiCl-KCl/FeS2
BATTERIES TESTED HOT (66°C)
BATTERIES TESTED COLD (-36°C)
REQUIRED PERFORMANCE
TIME (MIN)
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

Li(Si)/FeS_2 SYSTEM BATTERIES



PULSE	SPIN	MULTIVOLTAGE	LONGLIFE	INSTRUMENTATION	HIGH CURRENT
fast rise 40 amps for 600 mst	operates at 18,000 rpm	5 voltages over a 5.1 current density range	.35 amps for 1 hour in 400 cm^3 volume	3.2 amps for 1½ hours	30 amps for 30 minutes

UNCLASSIFIED

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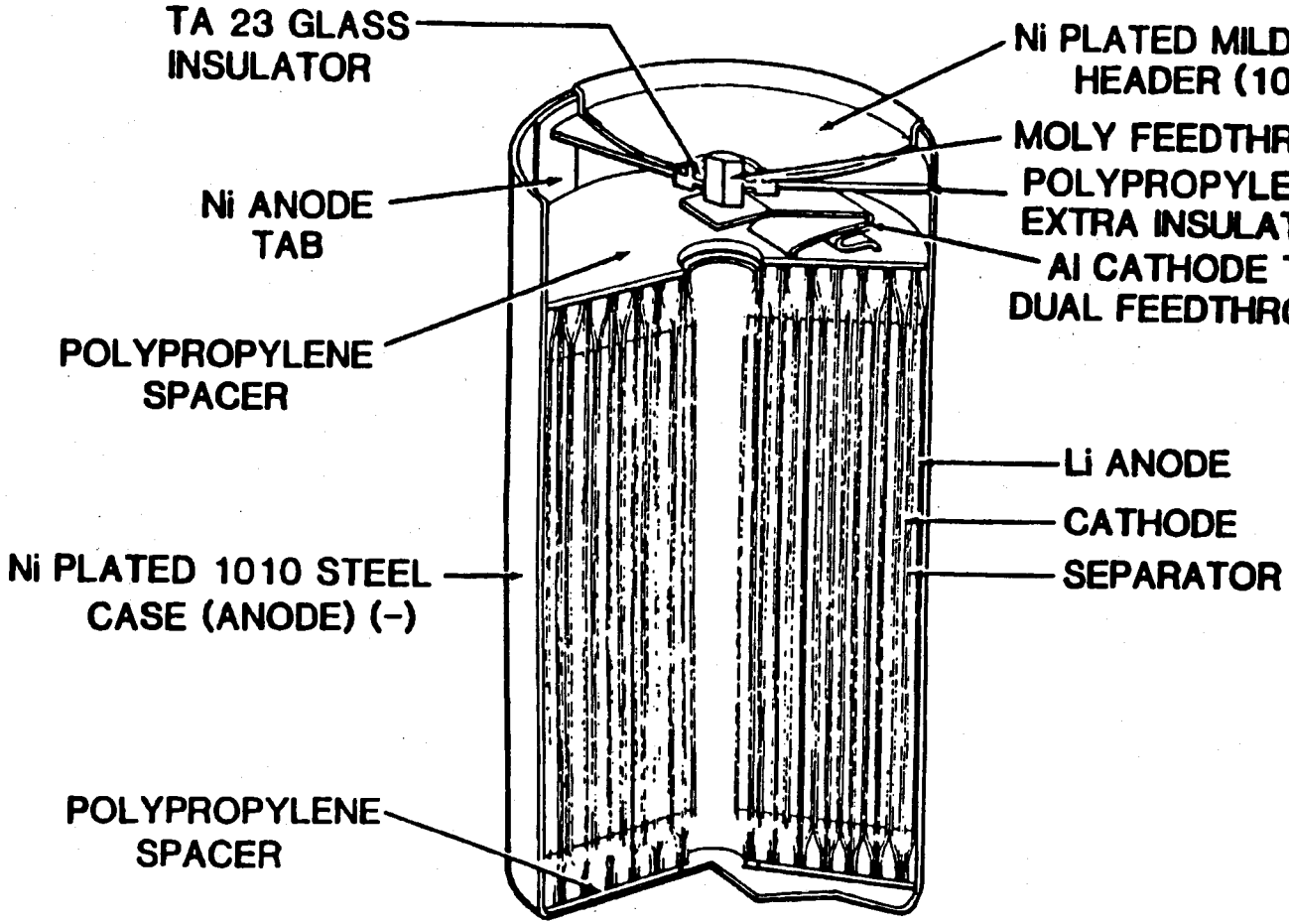

SANDIA MODIFIED
DURACELL INTERNATIONAL
Li/SO_2 'D'CELL

UNCLASSIFIED

UNCLASSIFIED

A REVIEW OF THERMAL BATTERY TECHNOLOGY

B. H. Van Domelen and R. D. Wehrle
Sandia Laboratories
Albuquerque, New Mexico

ABSTRACT

This report reviews the evolution of thermal battery technology from World War II to the present. It discusses the first applied work with thermal cells, the transfer of this laboratory technology to the United States, the development of the initial cup technology by the U. S., and the evolution of this technology to the later pellet technology. The paper by P. Tepper will then discuss the performance of thermal batteries and compare this performance with that of other ordnance batteries.

INTRODUCTION

The electrochemical power sources used in nuclear weapons to date have been lead-acid, nickel-cadmium, silver-zinc, and thermal batteries. The lead-acid battery was used in the first atomic bomb and in later weapon systems until 1953, when it was replaced by the nickel-cadmium battery, followed shortly by the silver-zinc battery. These aqueous electrolyte batteries all had a critical deficiency: their wet stand time was so short that either the battery had to be frequently recharged or the electrolyte had to be carried separately and injected into the battery just before its use. The thermally activated battery, introduced in 1955, solved the wet stand problem. Since then, it has been the sole power source used by Sandia Laboratories for nuclear weapon systems.

The thermal battery is so called because it contains a pyrotechnic heat source that, when ignited, thermally activates the battery by melting the electrolyte, which is a salt mixture. Salt mixtures are solid and chemically inert at room temperature, but when fused become fluid and highly conductive. These properties of the electrolyte provide the long shelf life and good electrical performance of the thermal battery (1,2).

The origin of the thermal battery dates back to World War II when Dr. Ing. Georg Otto Erb, working in Germany, developed the first practical cells, using a salt mixture as an electrolyte. Dr. Erb investigated the performance of several couples and electrolytes, the effects of salts with water of hydration, and the effects of water in unhydrated electrolyte salts. He also conceived and developed batteries for several ordnance applications, including the V-I and V-II rockets and artillery fusing systems; however, none of these batteries was produced for field use. Dr. Erb was interrogated by British Intelligence at the end of the war and his studies were reported to them in a paper entitled "The Theory and Practice of Thermal Cells" (3,4). This information was conveyed by the British, and possibly through other channels, to the United States Ordnance Development Division of the National Bureau of Standards, which later became Harry Diamond Laboratories (HDL). In this paper the authors will discuss only the channel for which documentation is presently available.

Prior to August 1946 (5) Mr. Grenville Ellis, U. S. Signal Corps (now the U. S. Army Electronics Command) brought copies of Dr. Erb's report to a meeting of the Joint Battery Advisory Committee. This committee of about ten people representing the Navy, Army, Air Force, and Industry met informally to exchange ordnance battery information. Dr. A. G. Hellfritzsch, of the Naval Ordnance Laboratory and a member of this committee, recognized the relevance of Dr. Erb's work to the battery needs of the VT (Variable Time) Fuze Panel under the National Research and Development Board. Dr. Hellfritzsch conveyed this report to Roger W. Curtis, who was chairman of the VT Fuze Panel and was also in the Ordnance Development Division of the National Bureau of Standards (6). Within a few weeks Curtis and his co-workers had demonstrated the capabilities of thermal cells for ordnance applications. Combining this with the work under contract to Catalyst Research Corporation to develop gasless pyrotechnics, they developed a self-contained thermal battery (6).

In the late forties the Wurlitzer Corporation began production of HDL's first thermal battery. This battery was used in a mortar round and the total production reached over a million batteries (7).

In 1952 Curtis reported on thermal battery technology at a symposium attended by various ordnance groups (8). Because of its desirable ordnance characteristics, the thermal battery system was adopted by the military for ordnance applications and by the U. S. AEC for nuclear weapon systems.

The early thermal battery designs are frequently referred to as "cup," "pad," "cup and cover," "closed-cup," and "conventional" batteries. These early batteries had three distinguishing characteristics: heat-paper pads, electrolyte and depolarizer pads, and intercell electrical connectors, which are discussed in more detail later. These three characteristics distinguish the earlier batteries from the later pellet-type batteries

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which use heat powder pellets, electrolyte-depolarizer pellets, and an intercell connectors. The evolution from the earlier batteries to the present pellet-type batteries was gradual, and there were several hybrid batteries which included both technologies, such as the Naval Ordnance Laboratory/Eureka-Williams battery which was the first to use a pellet.

This review describes the early cup technology (9,10,11), one of the later hybrid systems (2,10,12), and the present pellet technology (11,13,14). Performance characteristics of the thermal battery are discussed with reference to the Ca/LiCl-KCl/$CaCrO_4$ electrochemical system and the pellet technology which is the principal system used by this Laboratory. Discussion of other electrochemical systems and references to these systems are given by Jeanloge (15).

THE CUP TECHNOLOGY

Figure 1 shows the typical structure of a single cell in the cup design. In the cell are the anode, the electrolyte pads, the depolarizer pads, the cup in which these are enclosed, and a heat pad to thermally activate the cell.

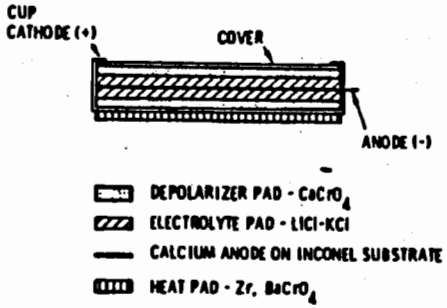

Fig. 1. - Single thermal cell - cup technology

The anode consists of calcium affixed to both sides of a metallic substrate[1] that serves both as the anode current collector and as the negative terminal by virtue of a tab extending through a slit in the side of the cell case. Although not shown in the figure, the anode is electrically insulated from the cathode cup.

The electrolyte pads are adjacent to the calcium surfaces and contain the electrolyte, the eutectic mixture of the lithium-chloride/potassium-chloride system (59 mole % LiCl-41 mole % KCl), which has a melting point of 352 C. The pads are formed by passing a fiberglass tape through a vat of molten electrolyte and punching pads from the tape after it has cooled and the electrolyte has solidified.

1. Inconel, iron, stainless steel, and nickel are the metals most often used.

The depolarizer[2] pads, adjacent to the electrolyte pads, complete the active cell stack. These pads are punched from a paper-like sheet formed by pressing and drying a slurry containing the calcium chromate depolarizer along with glass and ceramic fibers.

The active cell stack is then placed in a metallic cup, covered with a metallic disc, and the sides of the cup are crimped over the disc as a seal. The cup and disc thus hold the cell components in place and serve as the cathode current collector and positive terminal of the cell.

The last component of the single cell is the heat pad, which activates the cell by raising its temperature to the operating range of 500 to 600 C. The pad is punched from heat paper sheets formed by a process similar to that used for the depolarizer pads, but involving a slurry containing zirconium fuel and barium-chromate oxidizer instead of the depolarizer. (The slurry also contained asbestos fibers. Later, Sandia eliminated the asbestos because it releases water of hydration when heated.)

For simplicity, only the basic components of the cup cell have been described. When one includes intercell connecting tabs, wire-mesh current collectors, electrical insulators, etc., there can be as many as 27 individual parts in a cup cell as compared to the 3 parts of the later pellet cells.

It should also be noted that with the cup technology, as well as with the pellet technology, most of the battery materials either absorb or react with water, particularly the electrolyte which is very hygroscopic. Since battery performance is severely degraded if the components are exposed to water vapor concentrations greater than 1500 ppm[3], all processes are carried out in dry rooms. At this Laboratory for example, the dry rooms are maintained at less than 300 ppm; and in addition, all battery components are vacuum dried at 100 C prior to assembly.

Figure 2 illustrates thermal battery construction using the single cell described above. The active battery stack is formed by first welding the appropriate number of cells together, the negative tab of one to the positive case of the next, and then inserting a heat pad between each pair of cells to heat them and to insulate them from each other electrically. Electrical leads are attached and a zerrow fuse strip of heat paper is laid up the side of the stack and across the top cell. The stack is then capped on each end

2. Depolarizer is an historic battery term used to identify the active cathode material which is reduced electrochemically during battery discharge.

3. At 25 C, 1500 ppm is 5% relative humidity.

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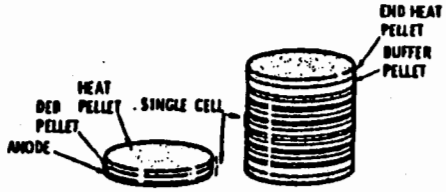

Fig. 5. - Single cell and battery stack - pellet technology

lithium-sulfate/sodium-chloride eutectic, which melts at 493 C and has a heat-of-fusion of about 84 calories per gram. Part of the heat from the end heat pellets is used to melt the eutectic salt in the buffer pellet. When the end of the battery stack cools to 493 C, the eutectic solidifies and releases its heat-of-fusion to maintain the battery temperature for a longer time.

As shown in Figure 6, the assembly of a pellet thermal battery is completed with the addition of electrical leads, match, fuse train, insulation, and battery case. The thermal insulation used is Fiberfrax for regular applications and Johns-Manville's Min-K 2002 for long-life applications. The Min-K 2002 was originally developed under AEC contract for thermoelectric generators and selected for thermal batteries after an extensive evaluation program (13,14). It is composed of silica, quartz fibers, and titanium dioxide.

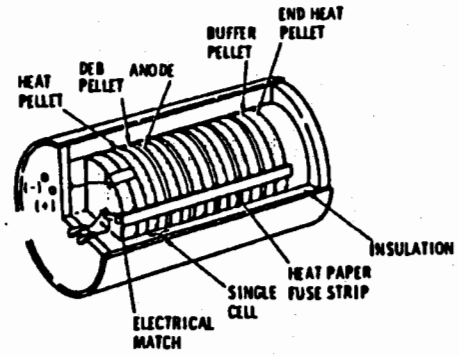

Fig. 6 - Thermal battery construction - pellet technology

Figure 7 shows the steps of battery construction and the use of center bolt construction to ensure concentricity of the plates. In this construction, a quartz-covered steel bolt is passed through center holes in the battery stack and two steel end plates. The result is a concentric, integral, rugged subassembly that can be easily handled and inspected.

Fig. 7 - Thermal battery - pellet technology

The pellet battery offers several improvements over the cup battery: longer activated life, more reproducible performance, greater ruggedness, no intercell connectors, lighter battery cases, better control of materials and processing, simplified fabrication, reduction of inspection and testing, elimination of hazardous heat pads, and lower cost. In addition, the pellet battery design is simpler and thus more amenable to investigation. This in turn has led to improved performance and further advancements, particularly with respect to longer life. Production has been completed on a thermal battery having an activated life of 15 minutes (21) and exploratory thermal batteries under development at Sandia have demonstrated activated lives of over 60 minutes (22).

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of the individuals who provided much of the information concerning the early history of thermal batteries: A. Attewell of the Royal Air Force Establishment in the British Ministry of Defense, E. V. Foreman and C. W. Jennings of Sandia Laboratories, B. Kaplan of Harry Diamond Laboratories, R. T. Mead of Wilson Greatbatch, Ltd., R. D. Walker of the University of Florida, I. D. Yalen of the Naval Ordnance Laboratory, and particularly A. G. Hellfritsch of the Naval Ordnance Laboratory.

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Firing Sets

- Firing Set Technologies
- Evolution of Firing Set Development

Firing Sets Outline

- **Types of Firing Systems**
  CDU, FE, SFE, FM, LOBO
- **History**
- **Present Designs**
- **Future Trends**

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Definitions

X-Unit: Any device in which electrical energy is stored at the proper voltage level for subsequent delivery to a detonator load by the closing of a switch.

Firing Set: Any device which can receive a fuze arming signal and a fuze firing signal and,subsequently, yield the necessary electrical energy for firing detonators. The firing set contains parts necessary for converting energy to the form required by the X—unit, and it may contain pulse shaping apparatus (trigger circuits) necessary for preparing the trigger signal for acceptance by the switch.

Firing System: Any firing set which is packaged as a stand-alone integrated collection of functional circuitry. The firing system contains a firing set and can also include: PAL, Strong Links, Command Destruct, Monitors, etc.

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Design Considerations

* Main HE Detonators
* Neutron Generator Detonators
* Environments
* Nuclear Safety — Weak Links
* Circuit Parameters
* Packaging

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DETONATORS

- EXPLOSIVE/BRIDGEWIRE (EBW)
- SLAPPER — LOS ALAMOS
- SLAPPER — SANDIA
- SLAPPER — LAWRENCE
- CODED EXPLOSIVE LOGIC SYSTEM (CELS)
- MECHANICAL SAFING ARMING DETONATOR (MSAD)
- DETONATOR SAFING STRONG LINK (DSSL)

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Typical Range of Controlling Parameters for Firing System Design

Characteristic	Minimum	Maximum
Electrical		
Input Voltage	24V	36V
Output Voltage (Operating)	400V	6000V
Output Current	600 Amps	640,000 Amps
Voltage Regulation	± 2%	± 10%
Loads	Single	Multiple
Charge Time	300 ms	5 seconds
Arm Time	1 second	20 years
Output Energy	.5 joule	5790 joules
Reliability	.992	.9995
Normal Environment		
Operating Temperature	-65°F	+170°F
Exposure Temperature	-80°F	+200°F
Shock	100g	18,000g
Vibration	.05 g^2/Hz	2 g^2/Hz
Angular Acceleration	—	289,000 rad/sec^2
Spin Rate	—	16,350 rpm

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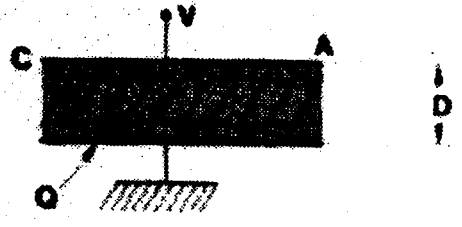
BASIC LINEAR CIRCUITS FOR ELECTROMECHANICAL ENERGY CONVERSION

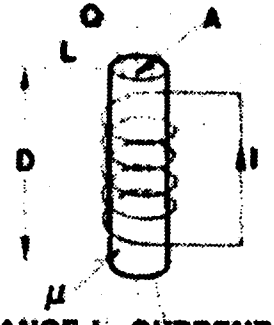
OPEN CIRCUITED CAPACITOR



CAPACITANCE C, VOLTAGE V, AND CHARGE Q ARE CONNECTED BY

$$Q = C \times V$$

FOR LOSSLESS CHANGES, CHARGE Q IS CONSERVED--A WELL KNOWN FACT



INDUCTANCE L, CURRENT I, AND FLUX LINKAGE θ ARE CONNECTED BY

$$\theta = L \times I$$

FOR LOSSLESS CHANGES, FLUX θ IS CONSERVED, WHICH IS NOT WIDELY KNOWN

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The Energy Stored in the Systems

$$E = \frac{CV^2}{2} = \frac{Q^2}{2C}$$

$$E = \frac{LI^2}{2} = \frac{\phi^2}{2L}$$

With Q and ϕ Constant, We Gain Energy, If

$$C = \frac{\varepsilon A}{D}$$

$$L = \frac{\mu A}{D}$$

Are Decreased By:

- Pulling Plates Apart (Van de Graph)
- Pulling Dielectric Out
- Decreasing Dielectric Constant by Lattice Destruction (Ferroelectric Pulse Generator)
- Pushing Wires Apart
- Pulling Core Out
- Continuously Shorting Out Turns (Wire Coil Flux Compressor)
- Collapsing System (General Flux Compression)

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Firing Set Types (U)

CDU — Capacitor Discharge Unit

In its simplest form, the CDU consists of a device for supplying the energy to charge a capacitor upon receipt of arming signals and also a switch of some sort for discharging this energy through the detonators upon receipt of a firing signal.

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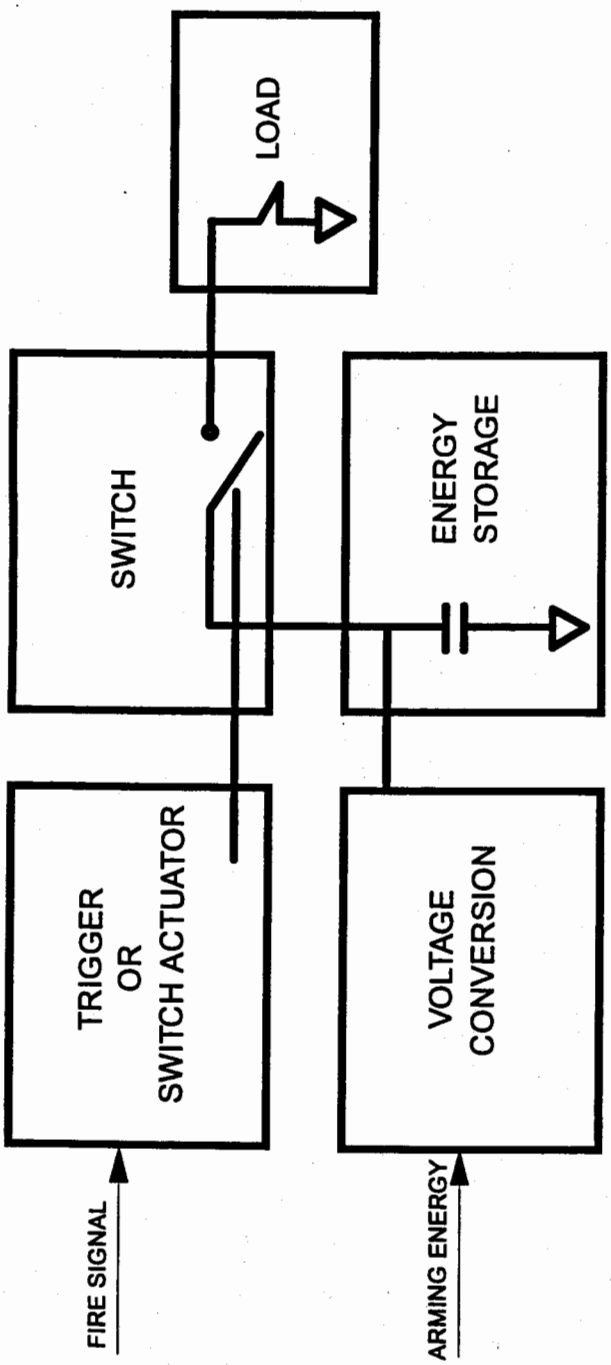
LOAD
SWITCH
ENERGY STORAGE
TRIGGER OR SWITCH ACTUATOR
VOLTAGE CONVERSION
FIRE SIGNAL
ARMING ENERGY

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DOE
b(3)

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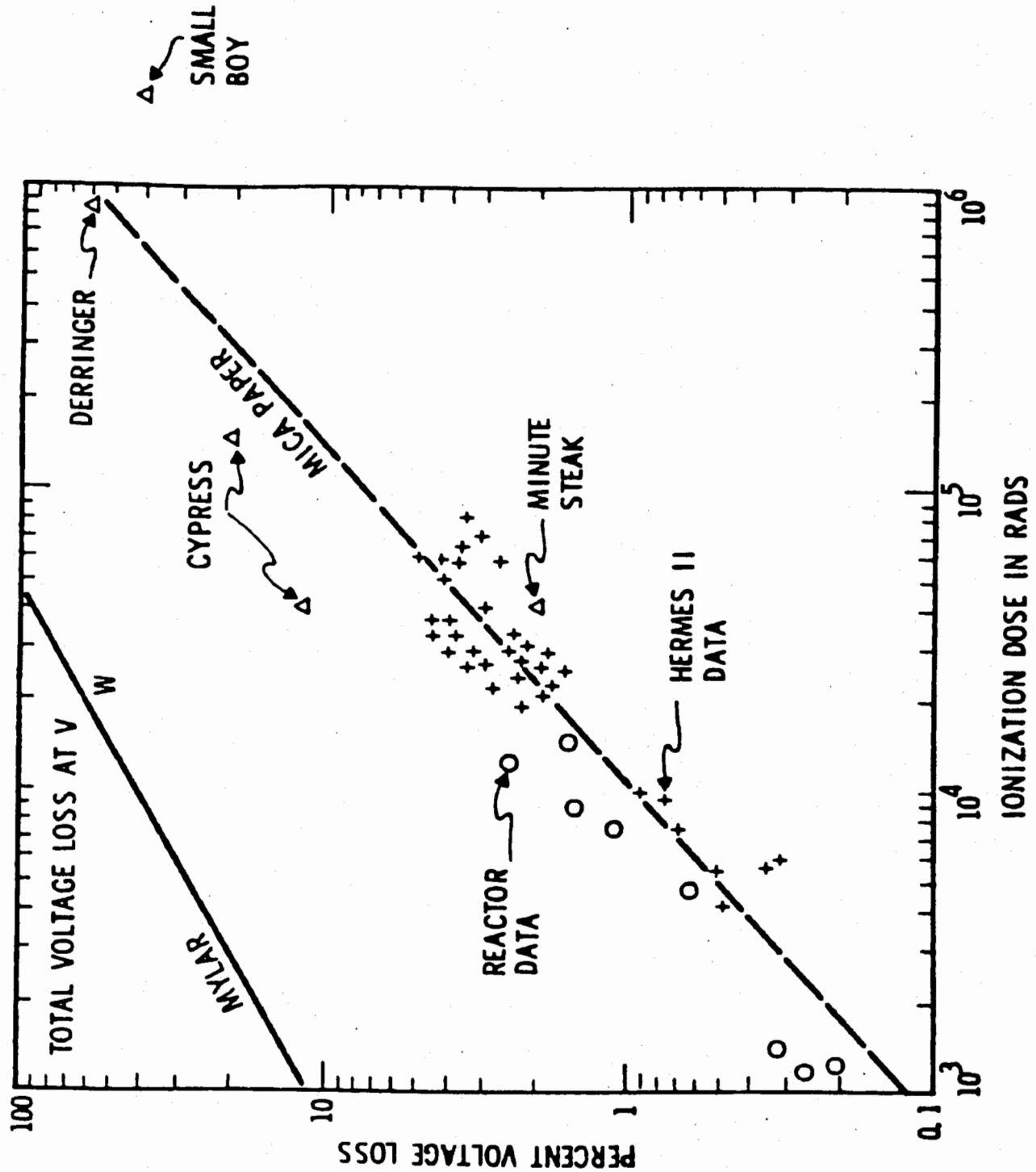
SMALL BOY
DERRINGER
CYPRESS
MICA PAPER
MINUTE STEAK
HERMES II DATA
REACTOR DATA
W
MYLAR
TOTAL VOLTAGE LOSS AT V
PERCENT VOLTAGE LOSS
IONIZATION DOSE IN RADS
100
10
1
0.1
10^3
10^4
10^5
10^6

Firing Set Types (U)

FE — Ferroelectric

The FE firing set consists of an explosive plane wave generator and a poled ferroelectric ceramic element. A pressure pulse produced by detonation of the explosive in the plane wave generator causes the release of bound charge from the ceramic element in the detonator load. This technology is also used as the power source in explosive neutron generators.

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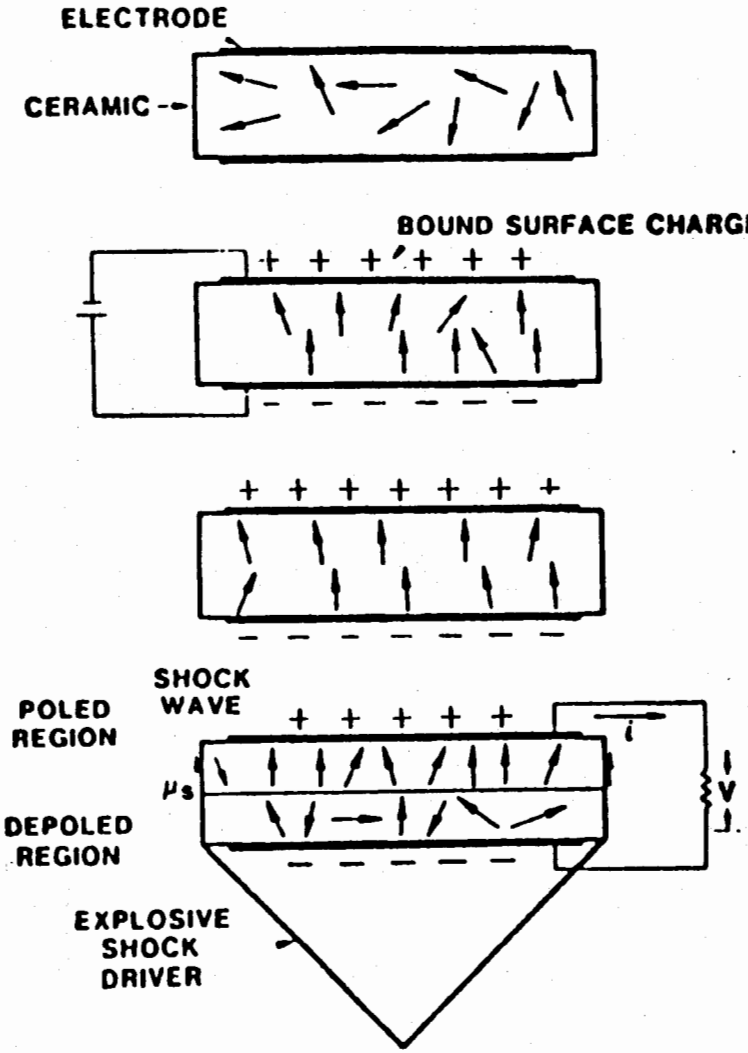
THEORY OF OPERATION PRE-ARMED FE



UNPOLED

Polycrystalline Multidomain Ferroelectric Ceramic

POLING PROCESS

Domains aligned (as allowed by crystallographic directions) by impressing external electric field

POLED CERAMIC

Dipoles remain aligned in absence of disturbing independent variable. Bound surface charge remains due to internal electric field

SHOCK DEPOLING PROCESS

Shock wave randomizes dipoles (domains) eliminating internal field, thus freeing bound charge to external circuit.

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Firing Set Types (U)

SFE — Slim Loop FE

The SFE firing set is similar to the FE, but its poling voltage is provided by an external power source in a manner similar to the CDU energy storage capacitor. This technology is used on the Mk3, Mk4, and Mk12A.

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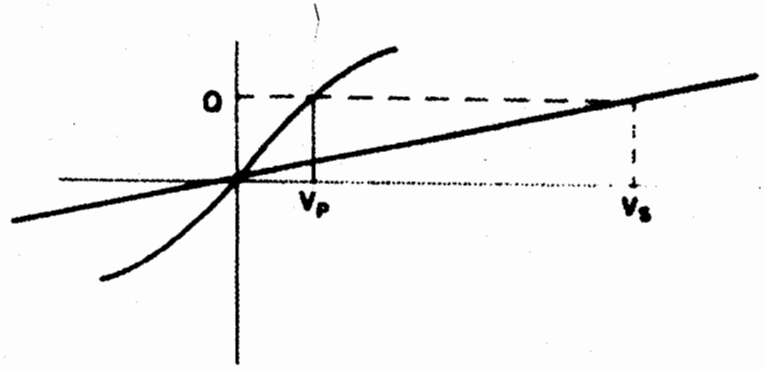
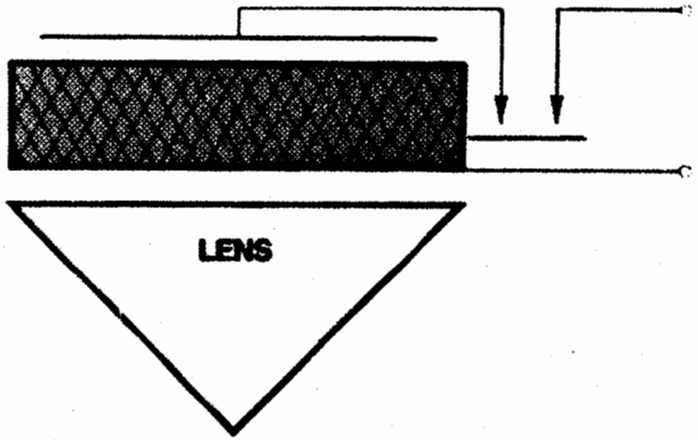
THEORY OF OPERATION ARMABLE SFE

$$Q = \text{CONSTANT}$$

$$E = \frac{QV}{2}$$

$$Eg = \frac{Q(V_S - V_P)}{2}$$





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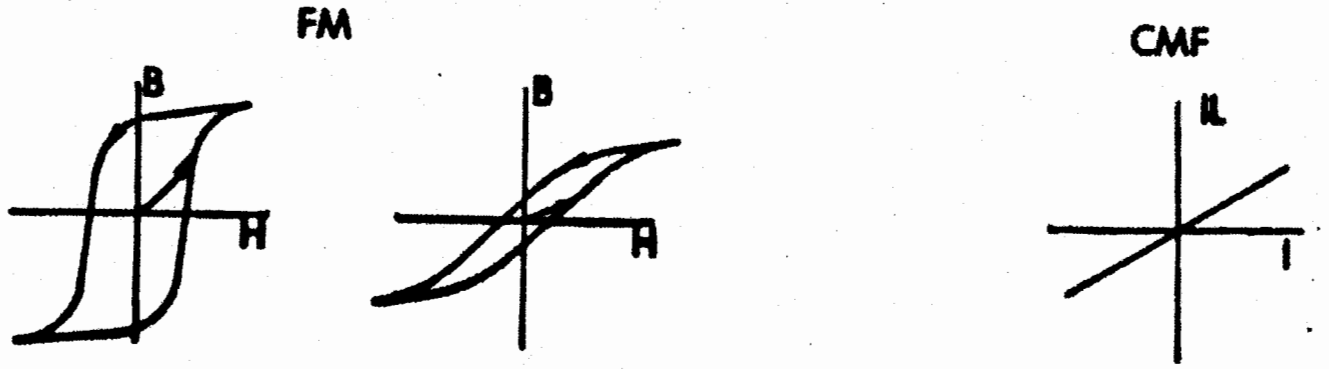
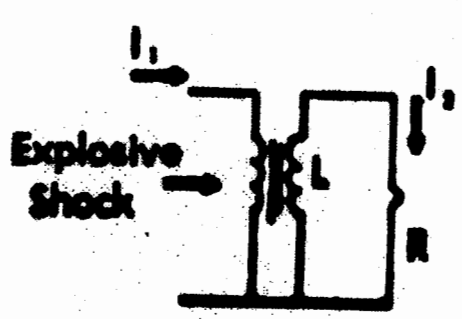
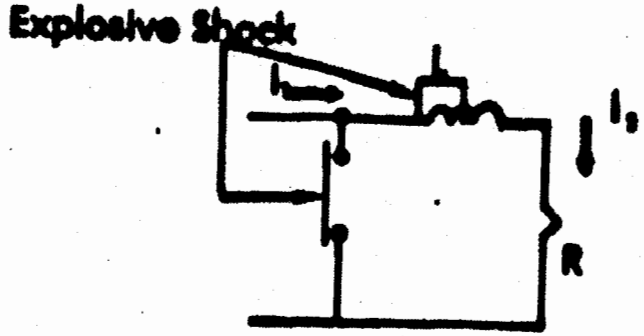
MAGNETIC ENERGY CONVERSION







Conservation of Flux-Linkage (φ)

$$\left.\begin{array}{l}\varphi_1 = L_1 I_1 \\ \varphi_2 = L_2 I_2\end{array}\right\} \quad \left.\begin{array}{l}\varphi_1 = \varphi_2 \\ L_1 I_1 = \downarrow L_2 I_2 \uparrow\end{array}\right\} \quad I_2 = I_1 \frac{L_1}{L_2}$$

$$\uparrow \text{Energy} = 1/2\, L I^2 = 1/2\, \frac{\varphi^2}{L I}$$

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Firing Set Types (U)

FM — Ferromagnetic

The FM firing set basically consists of an explosive charge, a ring of ferromagnetic cores and excitation and load windings. Mechanical energy in an explosively driven pressure pulse is transduced into electrical energy in the load winding as the magnetic cores are demagnetized by the shock wave.

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Firing Set Types (U)

CMF — Compressed Magnetic Field

The CMF or "Lobo" firing set converts chemical energy stored in explosive to electro-magnetic energy through magnetic flux compression. A CMF firing system also includes an injector to introduce an initial magnetic flux into the compression volume just prior to the compression event. This injector can be a CDU, FE, FM, or SFE.

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DoE
1(3)

[redacted] UNCLASSIFIED

[redacted] UNCLASSIFIED

416

UNCLASSIFIED

[redacted]

DOE b(3)

Recent Production Firing Sets

B28	Bomb Stockpile Improvement	CDU
W31	Nike Hercules Stockpile Improvement	CDU
B53	Bomb Stockpile Improvement	CDU
B51	Bombs	CDU
W78	MK4 Reentry Vehicle	SFE
W79	8-inch Projectile	FM
W80	Cruise Missiles	CDU
B83	Bomb	CDU
W84	Ground Launched CM	CDU
W87	MX (Peacekeeper)	CDU
W88	Mk5 Reentry Vehicle	CDU

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Current Production Set

B83 Redesign CDU

UNCLASSIFIED

DOE 4(3)

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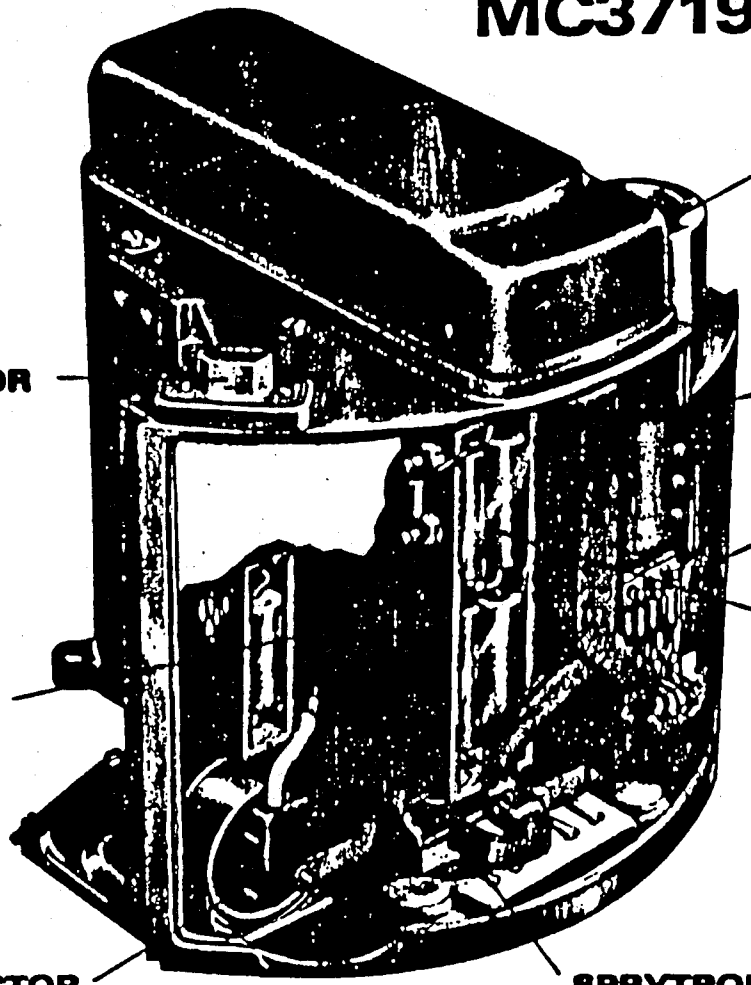
DOE
b(3)

[redacted]

DoE
b(3)

[redacted]

MC3719 FSA



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430

[redacted] UNCLASSIFIED

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SECRET

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432

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Current Development Firing Set

Phase 3

None

Pseudo Phase 3

PRESS CM
MAST 1

Cruise Missile
B61 Type

CDU
CDU

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UNCLASSIFIED

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Trends

* Volume

* Detonator/X—Unit Energy

* Complexity

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[redacted] UNCLASSIFIED

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[redacted] UNCLASSIFIED

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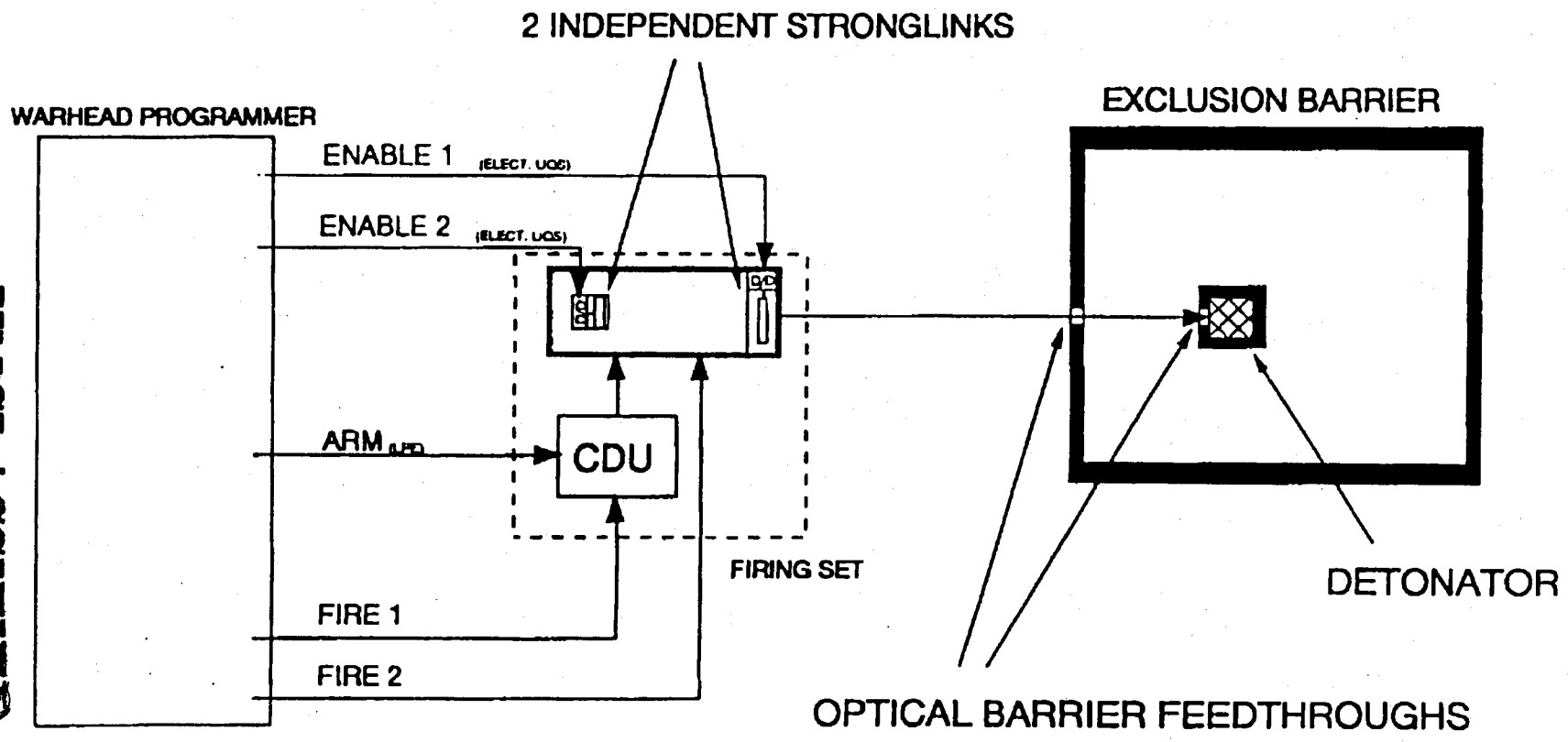
444

OPTICAL FIRING SET

BASELINE SAF ARCHITECTURE



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Neutron Sources

- Internal
- External
  - Technology Involved
  - Evolution of Neutron Generator Development

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NEUTRON MULTIPLICATION RATE

$$\frac{dN}{dt} = \frac{XN}{T}$$

$$\frac{dN}{dt} = \alpha N$$

$$N = N_0 e^{\alpha t}$$

$\alpha < 0$ subcritical

$\alpha = 0$ critical

$\alpha > 0$ supercritical

N = number of neutrons

X = excess number of neutrons per fission

(0.5 - 1.0 assumed to equal **1.0)**

T = time per fission generation

(10^{-8} sec)

= multiplication rate

(10^{8} generations/sec)

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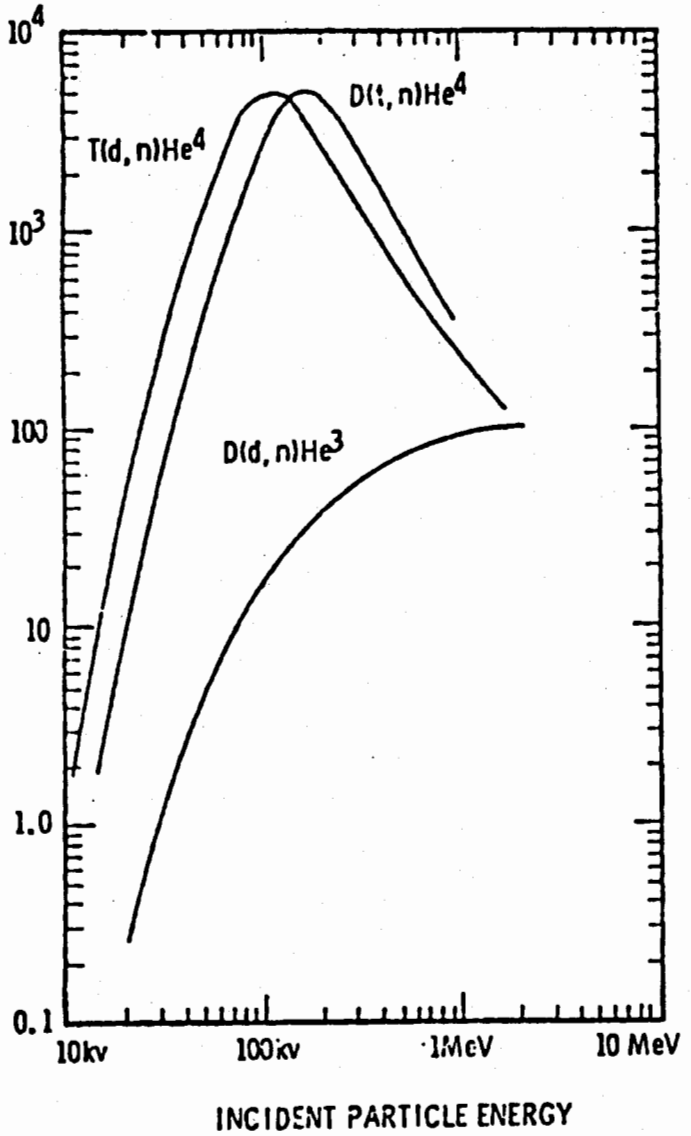

Figure 1. Reaction Cross Section Versus Incident Particle Energy

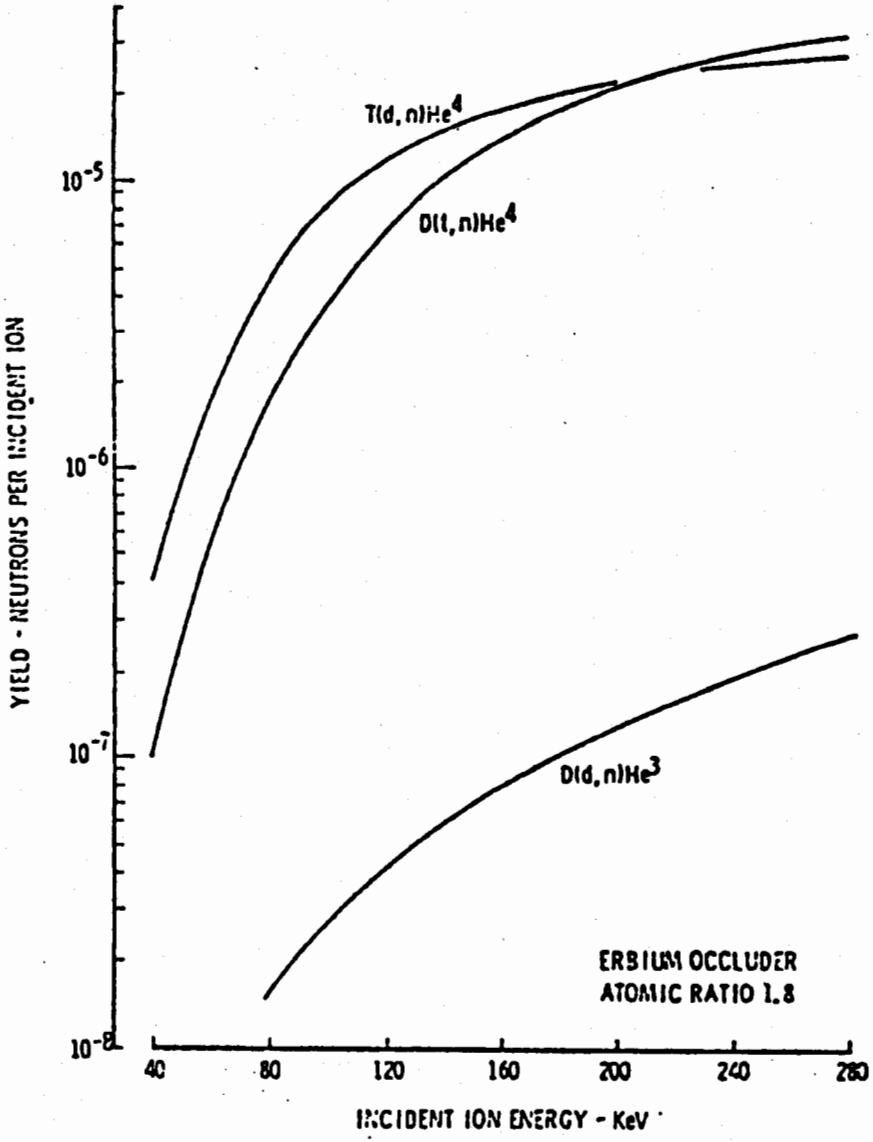

Figure 2. Theoretical Thick Target Yield

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION XII

•NUCLEAR TESTING

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PHYSICS PACKAGE DEVELOPMENT TOOLS

- THEORY
- NON-NUCLEAR TESTING
- NUCLEAR TESTING

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NON-NUCLEAR IMPLOSION DIAGNOSTICS

- PHERMEX (RADIOGRAPHY)
- PIN DOME
- HIGH SPEED PHOTOGRAPHY

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NUCLEAR TESTING

- WEAPON DEVELOPMENT
- EFFECTS
- VULNERABILITY AND HARDENING
- STOCKPILE RELIABILITY
- PEACEFUL NUCLEAR EXPLOSIVES

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DIAGNOSTICS

- YIELD
- "ALPHA"
- CHANNEL TEMPERATURES
- INTERSTAGE TIME
- OTHER

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DIAGNOSTICS

- YIELD
- "ALPHA"
- CHANNEL TEMPERATURES
- INTERSTAGE TIME
- OTHER

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY WR708

SESSION XIII

- TRANSFER SYSTEMS

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GAS TRANSFER SYSTEM TECHNOLOGY

STEVEN ROBINSON, 8412

COMPONENT DEVELOPMENT DEPARTMENT

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WEAPON BOOSTING REQUIRES THE ABILITY TO STORE MIXTURES OF HYDROGEN ISOTOPES AND TO DELIVER THE APPROPRIATE MIXTURE ON DEMAND

THIS REQUIRES

- Containment reservoirs
- Flow Systems
- Explosive Valves

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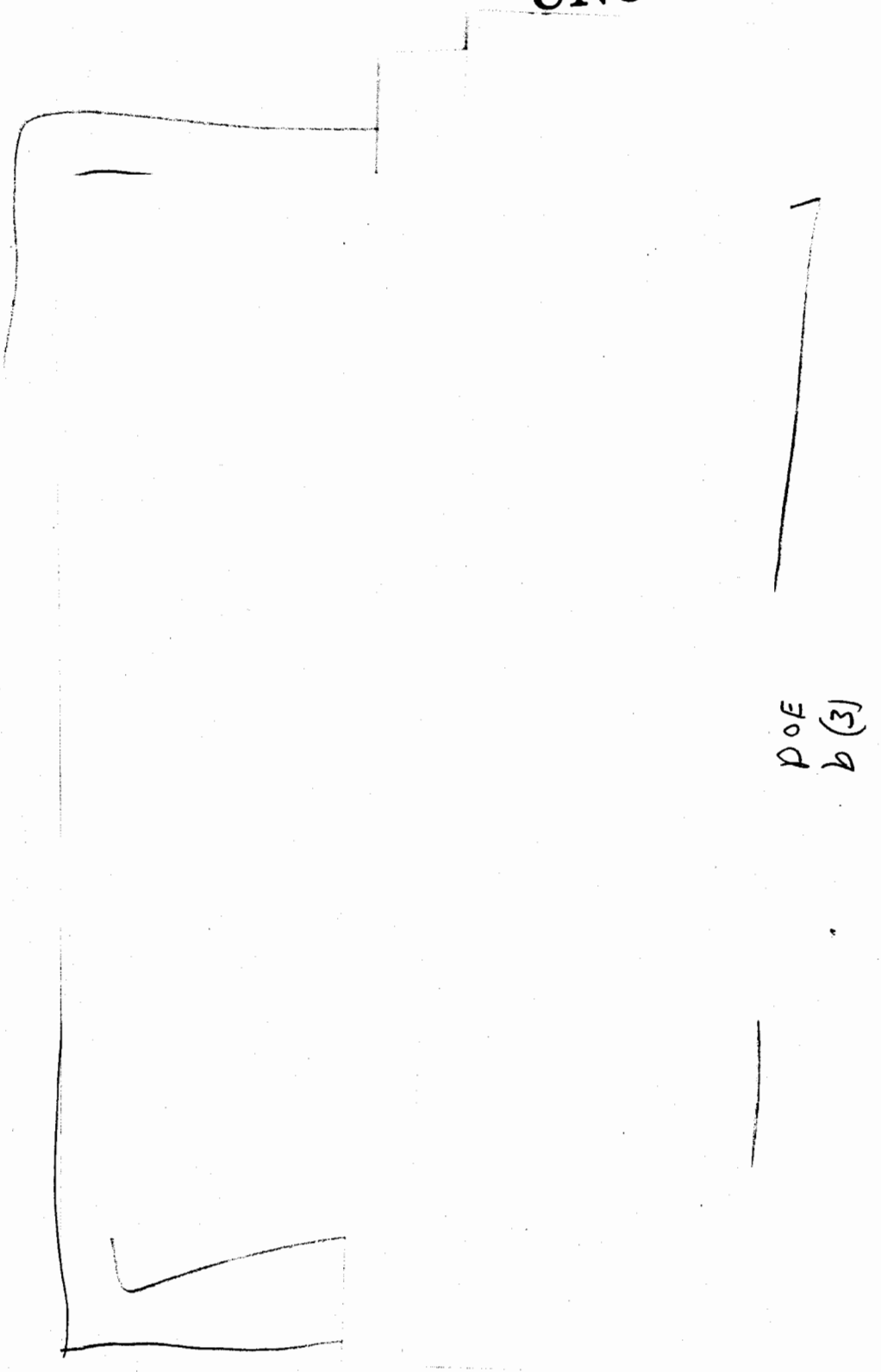

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CHALLENGES WITH GAS TRANSFER SYSTEMS

- Long Term Degradation
- Constancy of Delivery
- Complex Plumbing
- Minimization of Weight and Volume
- Cost

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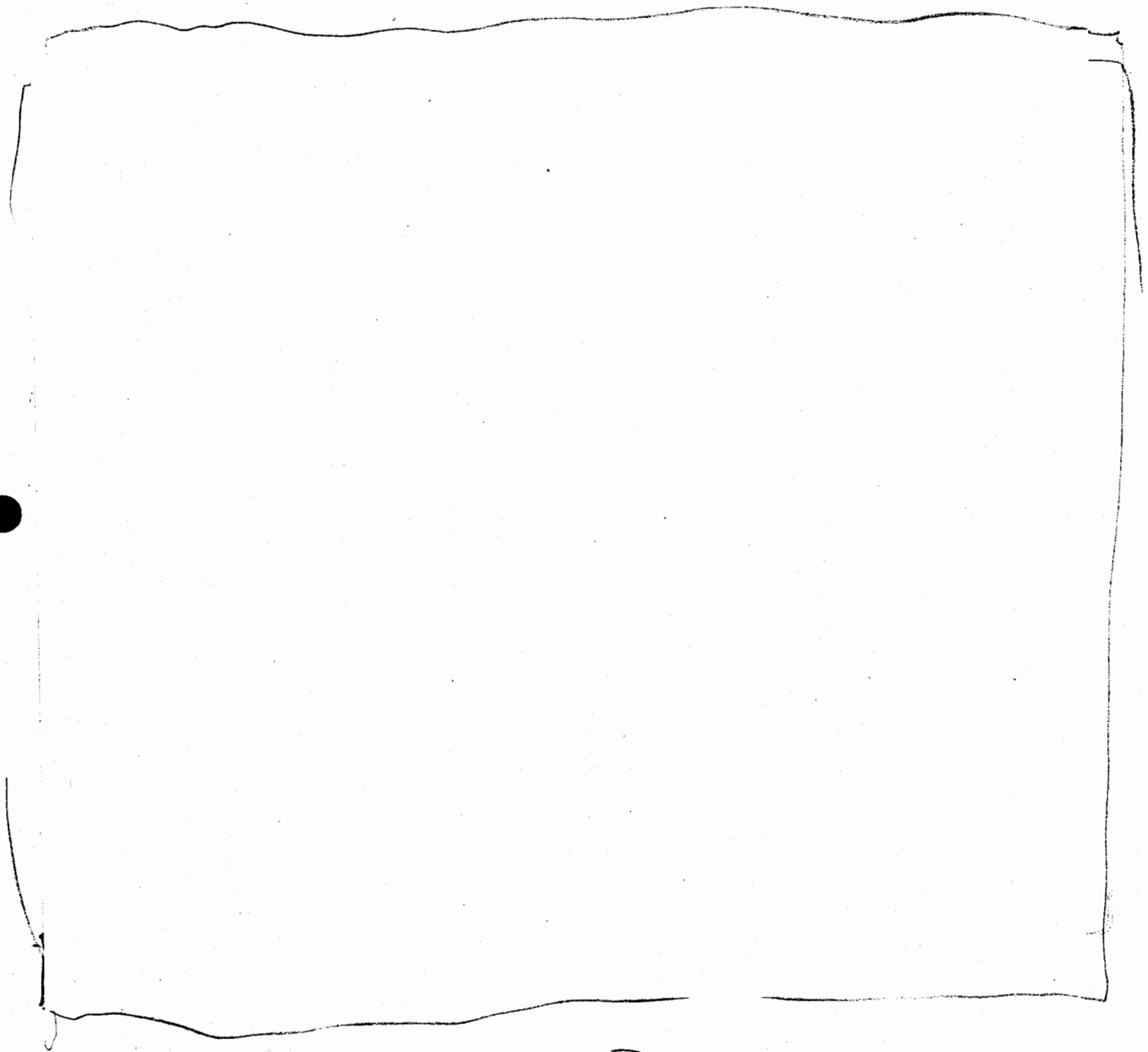

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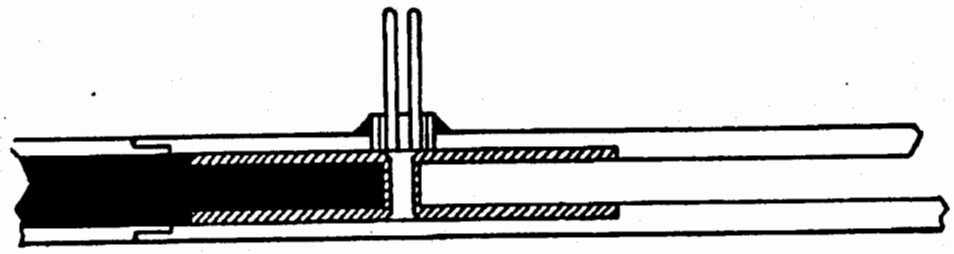
EXPLODING DISK VALVE OPERATIONAL SEQUENCE



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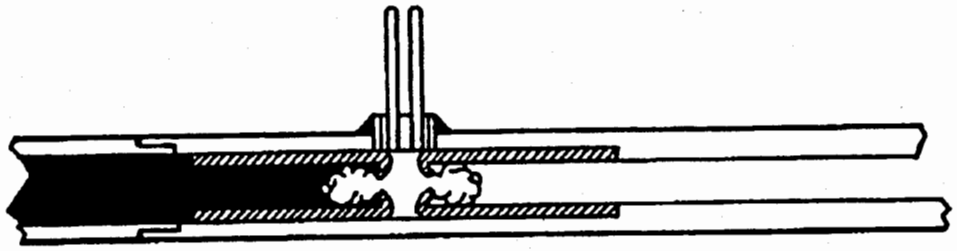

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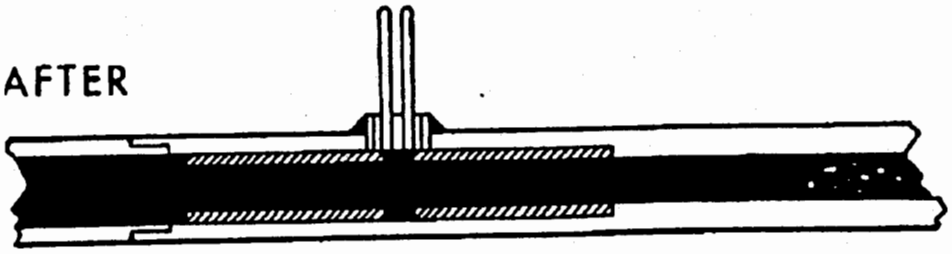

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UNIQUE DESIGN PROBLEMS IN TRITIUM RESERVOIRS (U)

- *System*
  - Must Deliver In Specified Time
  - Must Be Consistent
  - Satisfy Weight And Space Requirements
  - Fire And Accident Considerations

- *Long Term Degradation*
  - Subject To Hydrogen Embrittlement
  - Subject To Helium Embrittlement
  - Withstand Pressure Increase With Time
  - Subject to Radiation Induced Effects (Loss of Permeability, Stoichiometry)

- *Safety*
  - Must Be Super Safe Against
    - Burst
    - Permeation (Walls, Welds, Stringers)

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Consequences of a stockpile tritium release:

a. Weapon reliability

b. Personnel safety

c. Political/environmental ramifications

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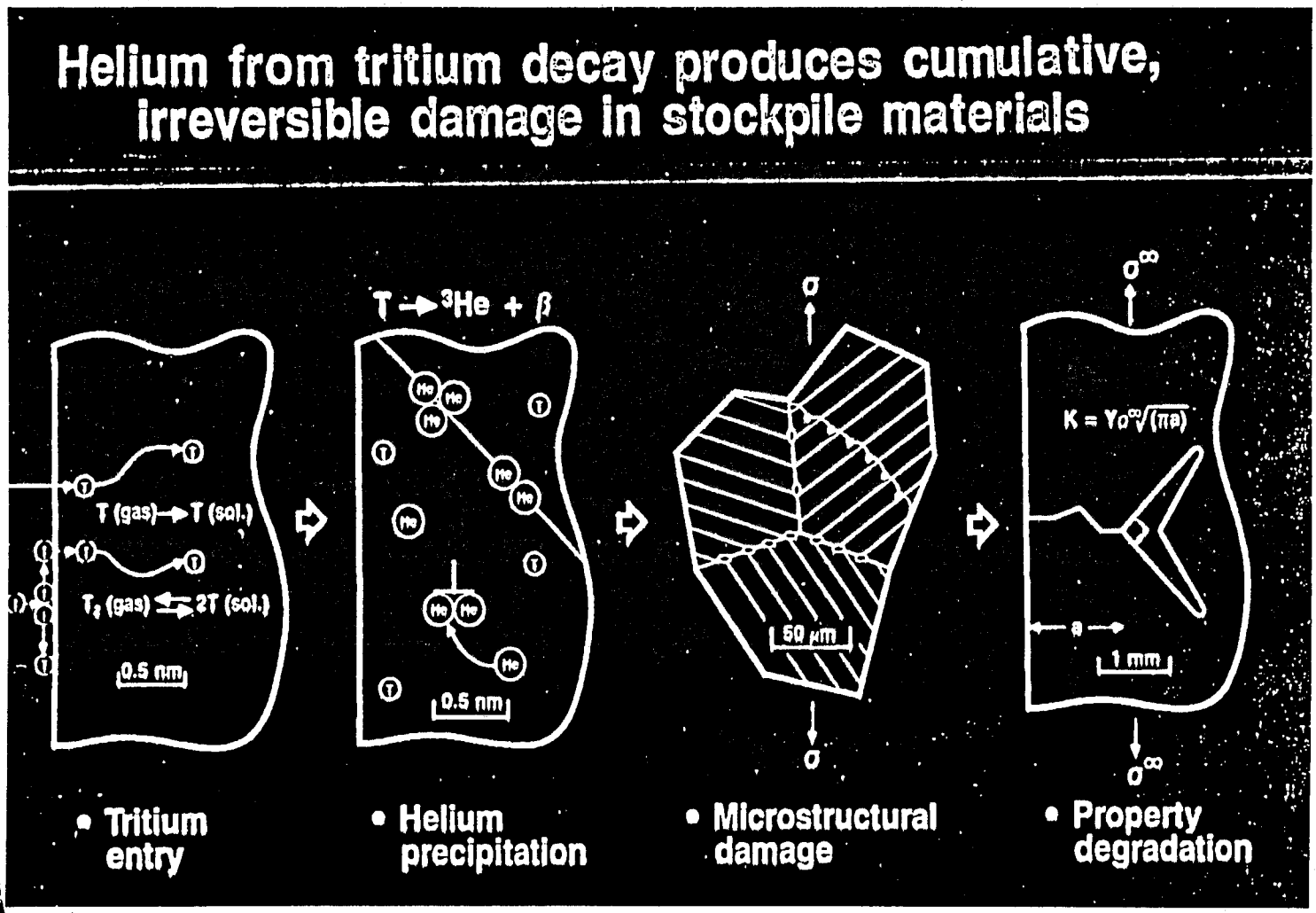

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Specifications

- •Narrow chemistry——promotes weldability
- •Grain size——less than ASTM 5
- •Vacuum—arc—remelt (VAR) material
  - Inclusions——ultraclean
  - Ferrete distribution—— < 3% minimize stringers

Acceptance

- •Chemistry
- •Metallography
  - Grain size
  - Ferrite distribution
  - Inclusion
- •Ultrasonics——porosity

For tritium reservoirs, it is necessary to improve the material properties

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It is most important to clean all surfaces of undesirables

CLEANING

Why

- To remove residues and oxides which could interface with welding, plating, or heat treating processes
- To remove any metallic materials imbedded into the surfaces permitting the formation of a continuous protective oxide film
- To prevent sources of rusting and corrosion on the surfaces
- To remove contaminants which could react with tritium

How

- Detergent solutions agitated ultrasonically
- Nitric acid solutions for dissolving imbedded copper and iron particles
- Nitric—hydrofluoric acid solutions for dissolving oxide films and imbedded particulate matter, and to etch certain stainless steel alloys
- Freon and alcohol rinsing for removing organic contaminants
- High purity water for rinsing
- High temperature vacuum bake

We take extreme care to verify cleanliness

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CLEANLINESS VERIFICATION

- Monitor the resistivity of the rinse water to verify the absence of ionizable material
- Use analytical rinses to check for organic and inorganic contaminants with infrared spectrophotometer and ion chromotagraphy
- Perform particulate analysis on each reservoir
- Check for imbedded iron particles with a copper sulfate test
- Borescopic examination where applicable
- Visual examination for discoloration, staining, or superficial corrosive attack

Both piece parts and assemblies are cleaned prior to inspection

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Inspection and gaging costs approximate one-third of th

INSPECTION AND GAGIN

To assure:

- Interchangeability of piece parts
- Fit with next assembly
- Conformation with engineering drawings

We inspect and gage using:

- In process monitoring—feedback
- Open——set up inspection
- Dedicated gages
- Contour gages
- Air gages——non-contact
- Statistical sampling
- Control of numerical machine tapes
- Coordinate measuring machines

To minimize scrap and rework costs, we inspect early in th

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Mechanical joints are not used for storage of tritium

ASSEMBLY AND JOINING

Joining:

- Weldments
  - Gas-tungsten are——autogenous and wire feed
  - Electron beam——autogenous and wire feed
  - Laser
  - Friction
  - Inertia
  - Resistance forge weld
- Brazes
  - Copper
  - Copper-silver-tin

Inspection and Control:

- Process monitor
- Radiographic
- Ultrasonic
- Dye Penetrant

All pressure rated components are pressure tested

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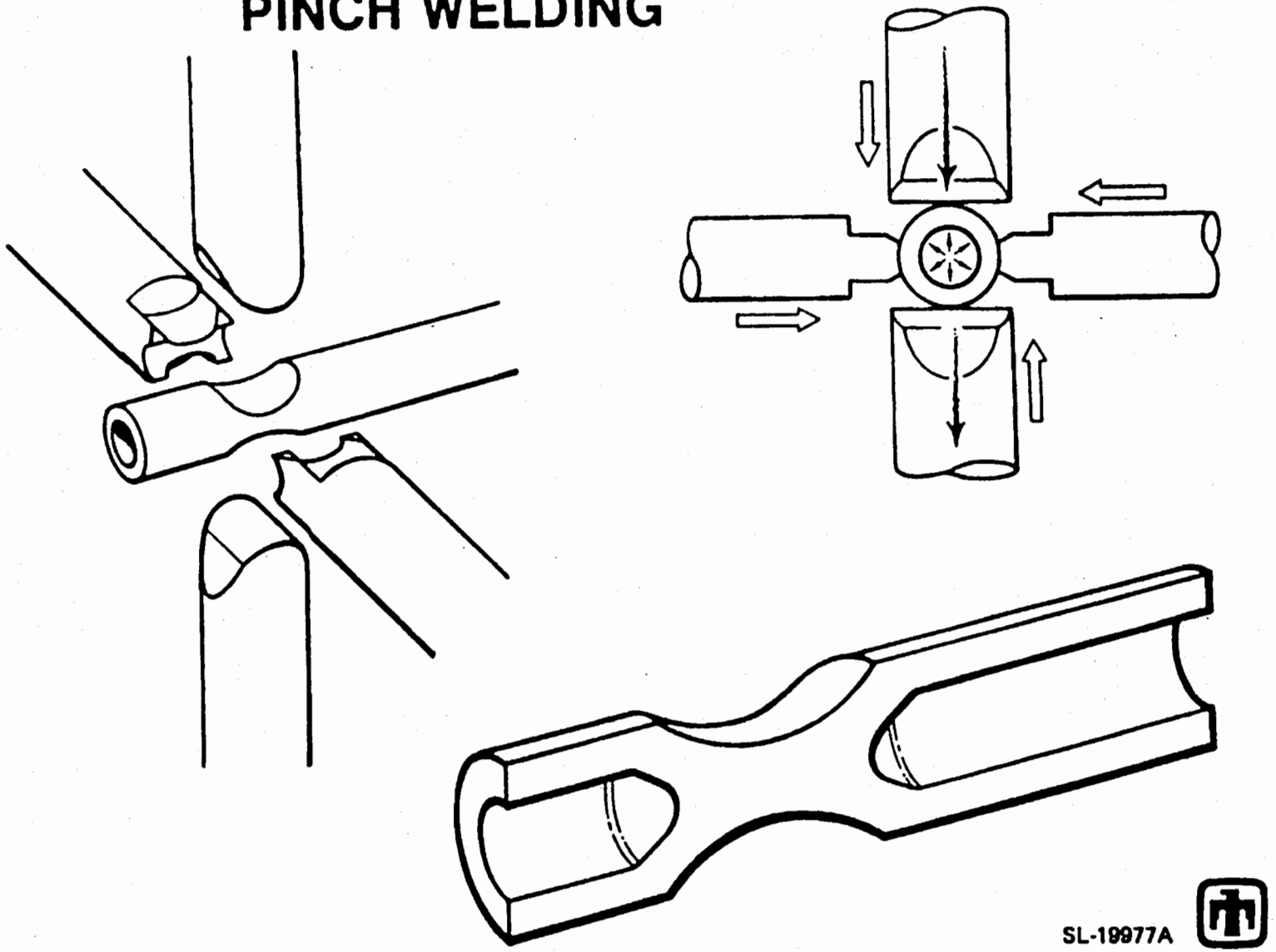
PINCH WELDING



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PRODUCT DEVELOPMENT (U)

AT SANDIA - R&D

- MATERIALS SELECTION AND TESTING
  SPECIMEN AND STRUCTURAL ANALYSIS
- COMPONENT DESIGN
  DRAWING AND SPECIFICATIONS
- PROTOTYPE DEVELOPMENT
  FABRICATION AND JOINING
- COMPONENT EVALUATION
  STORAGE AND STRUCTURAL TESTING
- SYSTEMS TESTING
  LABORATORY AND FLIGHT TESTS
- PRODUCT DEFINITION

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PRODUCT DEVELOPMENT (U)

AT INTEGRATED CONTRACTORS

- EG&G - ROCKY FLATS (COLORADO)
  FABRICATES PRESSURE VESSELS

- ALLIED SIGNAL - BENDIX (MISSOURI)
  FABRICATES VALVES

- EG&G MOUND (OHIO)
  FABRICATES VALVE ACTUATORS
  CONDUCTS STOCKPILE TESTING

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- WESTINGHOUSE - SAVANNAH RIVER (SOUTH CAROLINA)
  FILLS WITH DT GAS

- MASON & HANGER - PANTEX (TEXAS)
  INSTALLS INTO WARHEADS

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WE HAVE NO REASON TO ASSUME WE FOUND ALL THE TRITIUM SURPRISES

It is not possible to extrapolate with

adequate confidence, tritium effects on components

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION XIV

- RADAR FUZING TECHNOLOGY
- OTHER FUZING MODES
- ADVANCED FUZING CONCEPTS

Nuclear Weapon Fuzing Technology

- Introduction to Fuzing Components & Systems
- Timers & Inertial Devices
- Contact Fuzing
- Radar Fuzing
- Fuzing Systems

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Fuzing System Hierarchy

Components:

Radars
(Antennas)

Clocks

G-Switches

Pressure Sensors
(Baro/Hydro)

Accelerometers

Programmers

Crush Sensors

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Fuzing System Hierarchy

Components:	Sub-Systems:
Radars (Antennas)	Airburst Radars
	Proximity Radars (Prox Time-Down)
Clocks	Timers
G-Switches	G-Started Timers
Pressure Sensors (Baro/Hydro)	Pressure-Started Timers
Accelerometers	G-Started Integrating Accelerometers (FBIAs)
	Path Length
Programmers	Radar Updated Path Length
Crush Sensors	Impact Fuzes

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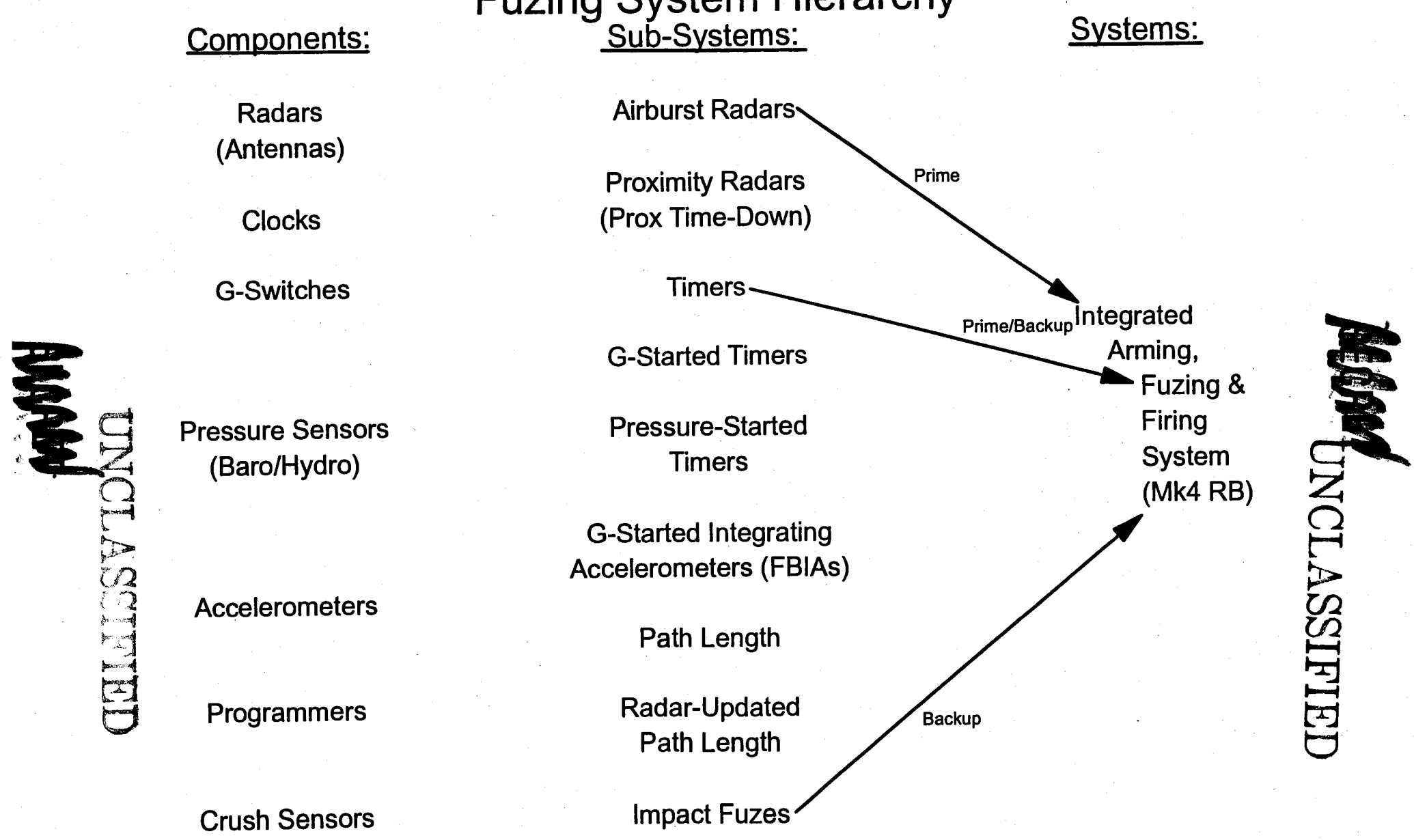
Fuzing System Hierarchy



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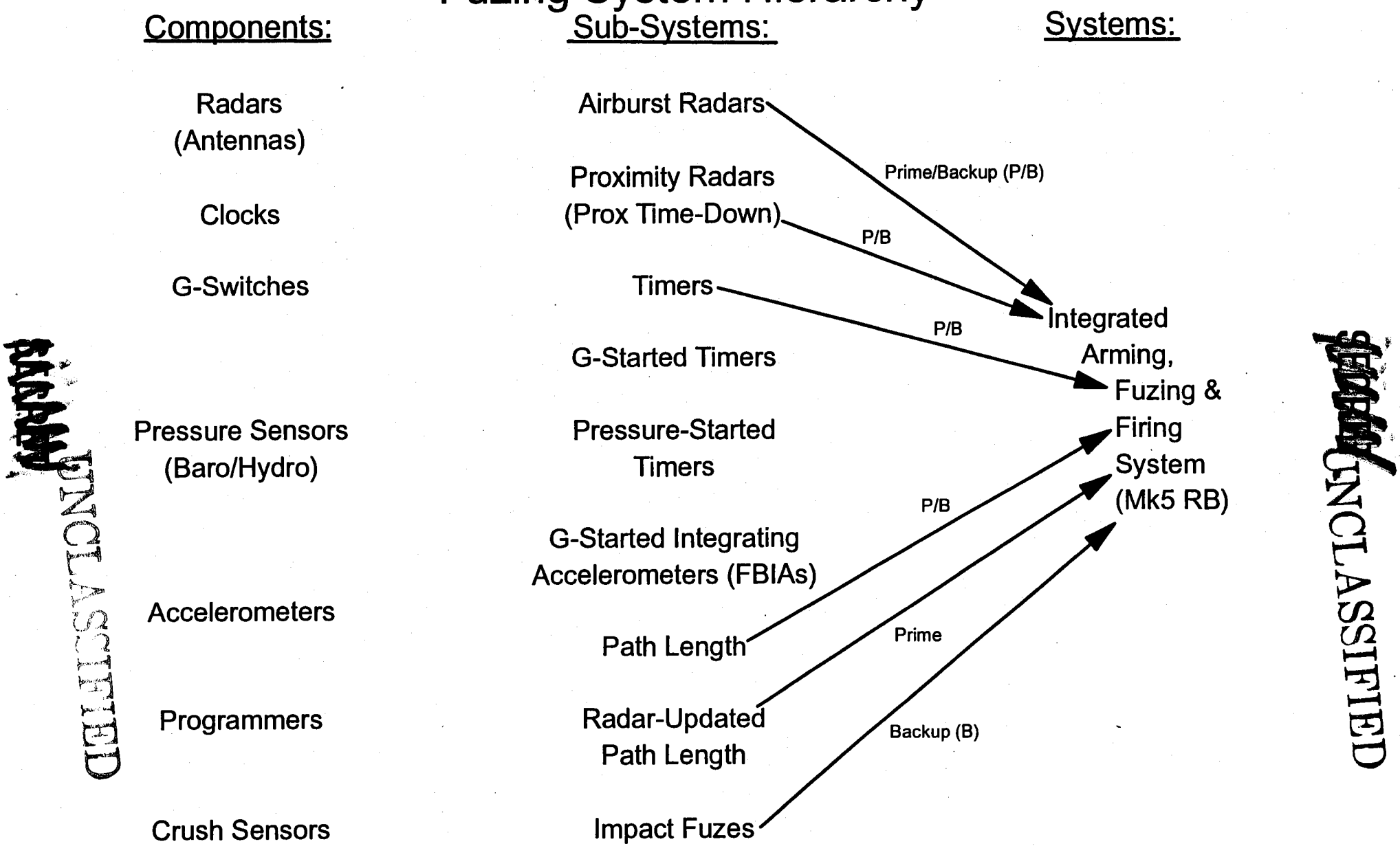
Fuzing System Hierarchy



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HOW IS A FUZE SELECTED?

A FUZE (OR FUZES) FOR A PARTICULAR WEAPON SHOULD BE:

- ACCURATE
- RELIABLE
- FLEXIBLE
- SMALL
- LIGHT WEIGHT
- INEXPENSIVE
- PRODUCIBLE
- TESTABLE

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TIMERS

- REENTRY BODY FUZING
  - PRIMARY FUZE ON OLDER SYSTEMS
  - HIGH ALTITUDE FUZE AND/OR BACKUP TO RADAR ON RECENT SYSTEMS
  - CANDIDATE FUZE FOR EARTH PENETRATING WEAPONS
- BOMB FUZING
  - ALSO USES TIMER FOR SAFE ESCAPE IN LAYDOWN ROLE
- ARTILLERY PROJECTILES AND SPECIAL MUNITIONS
- DEPTH BOMBS
  - TIMER INITIATED BY WATER IMPACT OR HYDROSTATIC PRESSURE

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TIMERS (CONT'D)

- MECHANISM FOR INITIATING ARMING FUNCTIONS, I.E., BATTERIES

- CRITICAL ELEMENT OF ANY PROGRAMMER AND/OR COMPUTER FOR WARHEADS, BOMBS, GUIDANCE PLATFORMS, ETC.

- TECHNOLOGY EVOLUTION
  - MECHANICAL — APPROXIMATELY 5% ACCURACY
  - ELECTRONIC (LC) — SMALLER WITH APPROXIMATELY 2% ACCURACY
  - CRYSTAL — SMALLEST WITH ACCURACY MEASURED IN PARTS PER MILLION

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INERTIAL DEVICES

- MECHANICAL G-SWITCHES AND INTEGRATING ACCELEROMETERS
  - •USED TO INITIATE TIMER FUZES
  - •PHYSICAL DISPLACEMENT OF A SENSING MASS PROVIDES CLOSURE OF ELECTRICAL CONTACTS
  - •INSTRUMENT ACCURACY APPROXIMATELY 1%
  - •ALSO PERFORMS ARMING FUNCTIONS
- ELECTRONIC INTEGRATING ACCELEROMETERS
  - •STAND-ALONE FUZE
  - •ESSENTIAL ELEMENT OF PATH LENGTH MECHANIZATION FOUND ON NEWER SYSTEMS
  - •VELOCITY CHANGE PROPORTIONAL TO VOLTAGE REQUIRED FOR FIELD-INDUCED ALIGNMENT OF SENSING MASS
  - •INSTRUMENT ACCURACY APPROXIMATELY 0.1%
  - •ALSO PERFORMS ARMING FUNCTIONS

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CONTACT FUZING

OBJECTIVE:

TO PROVIDE AN ELECTRICAL FUZING SIGNAL WHEN A REENTRY BODY IMPACTS THE TARGET SURFACE

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CONTACT FUZE CHARACTERISTICS

CRYSTAL WITH PIEZOELECTRIC PROPERTIES PRODUCES AN ELECTRICAL POTENTIAL WHEN SHOCKED

FUNCTION BY SENSING DEFORMATION OR VERY HIGH DECELERATIONS AT FUZE LOCATION

USED ON BOTH REENTRY BODIES AND BOMBS

SELECTABLE AS EITHER PRIMARY OR BACKUP FUZING MODE

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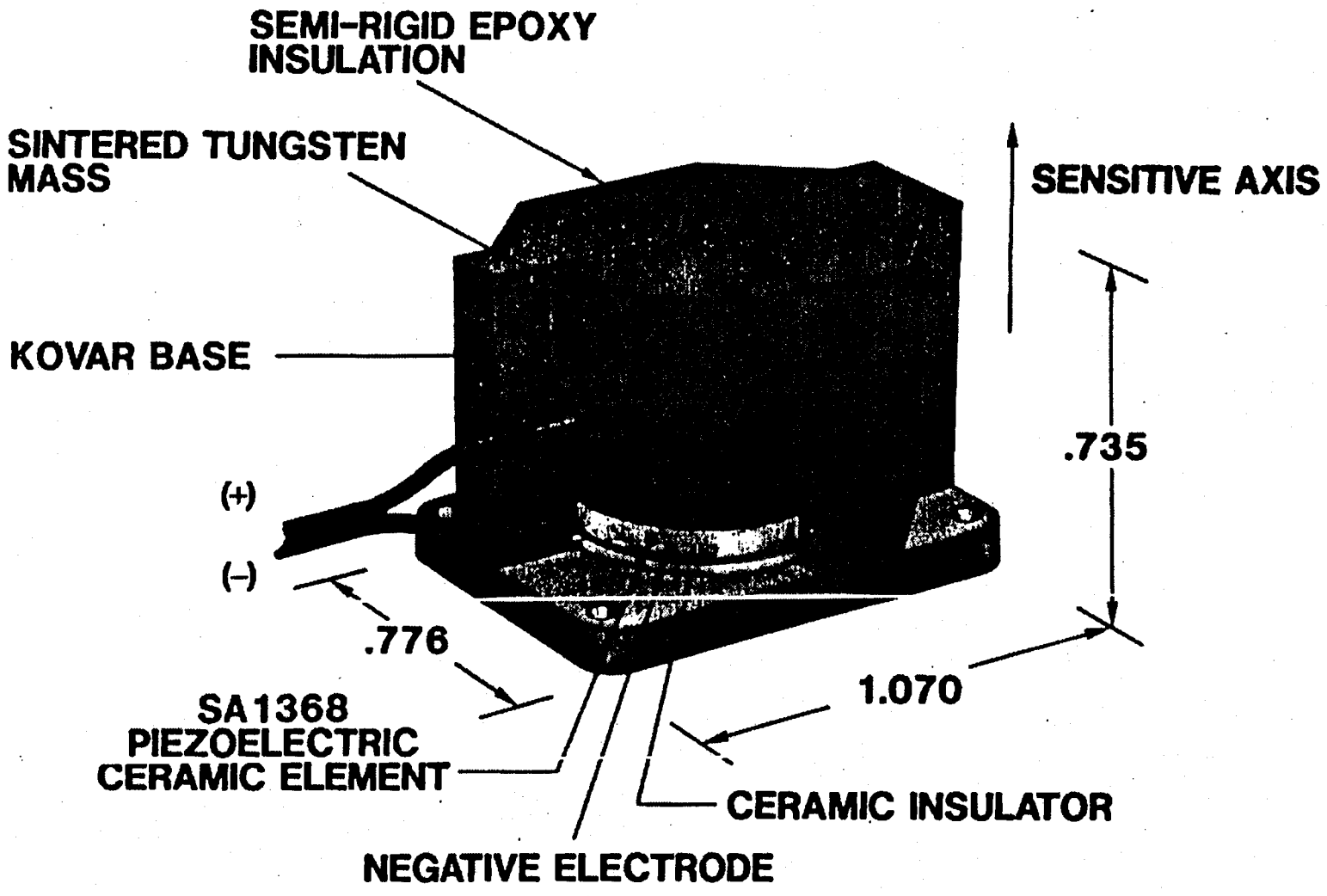
MC3549 IMPACT SENSOR



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CONTACT FUZE CHARACTERISTICS

- ADVANTAGES
  - VERY LITTLE PENALTY IN WEIGHT, COST OR VOLUME
  - DESIRABLE AS BACKUP FOR AIR BURST FUZING
  - RADIATION HARDENED AND IMMUNE TO JAMMING
  - VERY RELIABLE AS A COMPONENT
  - MAXIMIZES CRATER VOLUME AND GROUND MOTION IN COMPARISON TO OTHER AIR BURST OPTIONS
- DISADVANTAGES
  - REDUCED "EFFECTS RADIUS" FOR AIR BLAST TARGETS
  - RANGE OFFSET ASSOCIATED WITH BACKUP ROLE
  - QUALIFICATION / TESTING HAS BEEN COSTLY
  - DEPENDABILITY CONCERNS (SYSTEM RELIABILITY)

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IMPROVED SURFACE FUZING

- "ZERO TIME" IMPACT SENSORS
  - PROVIDE ADEQUATE TIME MARGIN AGAINST FLAT, UNOBSTRUCTED TARGETS
  - PROVIDE LITTLE OR NO ADDITIONAL PROTECTION AGAINST TARGET IRREGULARITIES
- PROXIMITY FUZING
  - PROVIDES ADEQUATE TIME RACE MARGIN AGAINST ALL TARGETS
  - ADDITIONAL BURST HEIGHT MAY RESULT IN AN UNDESIRABLE REDUCTION IN WEAPON EFFECTS BENEATH THE SURFACE
  - THESE FEATURES MAY BE BALANCED BY A TIME-DELAYED DETONATION

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RADAR FUZING

- The Role of Radar Fuzing
- Basic Radar Operation
- Radar Design Issues
- Current Technology
- Imaging Radar Technology

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WHY USE A RADAR?

- TO PROVIDE BURST HEIGHT PRECISION FOR MAXIMIZING LOW LEVELS OF AIR BLAST OVERPRESSURE

  - PRECISION IMPLIES BOTH RESOLUTION AND ACCURACY

- TO PROVIDE DEPENDABLE SURFACE FUZING

- TO PROVIDE AN ACCURATE ALTITUDE REFERENCE FOR IMPROVING INERTIAL FUZE ACCURACY

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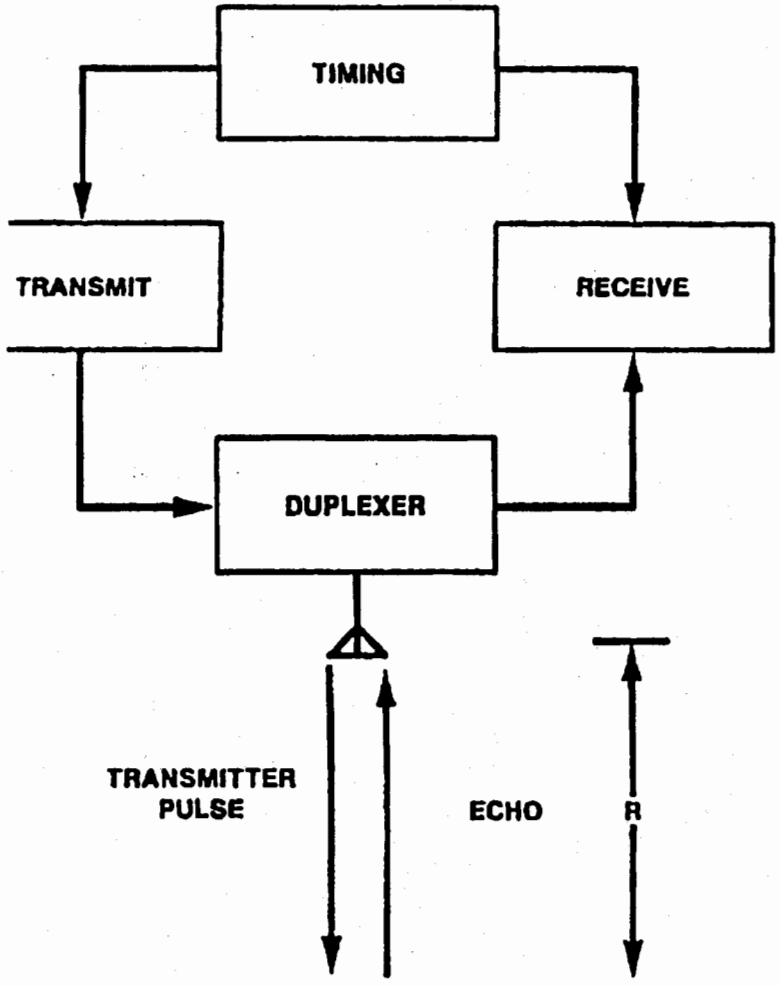
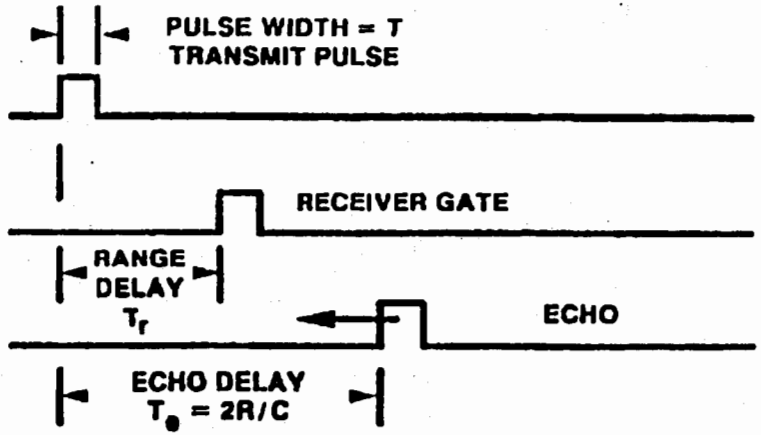
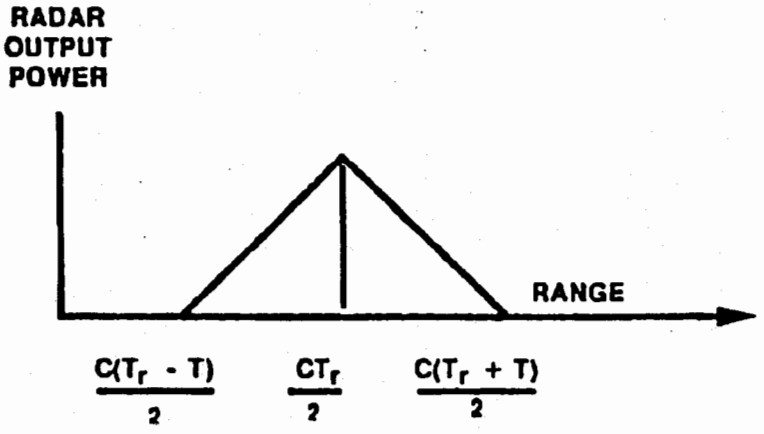
BASIC RADAR OPERATION







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RADAR FUZE DESIGN PROBLEMS

- RESISTANT TO JAMMING
  - IMPOSSIBLE TO FOOL INTO FUNCTIONING EARLY
  - VERY DIFFICULT TO PREVENT FUNCTIONING
- PLASMA LOSS
- RADIATION RESISTANT
- HIGH RELIABILITY
- STOCKPILE LIFE
- SMALL SIZE

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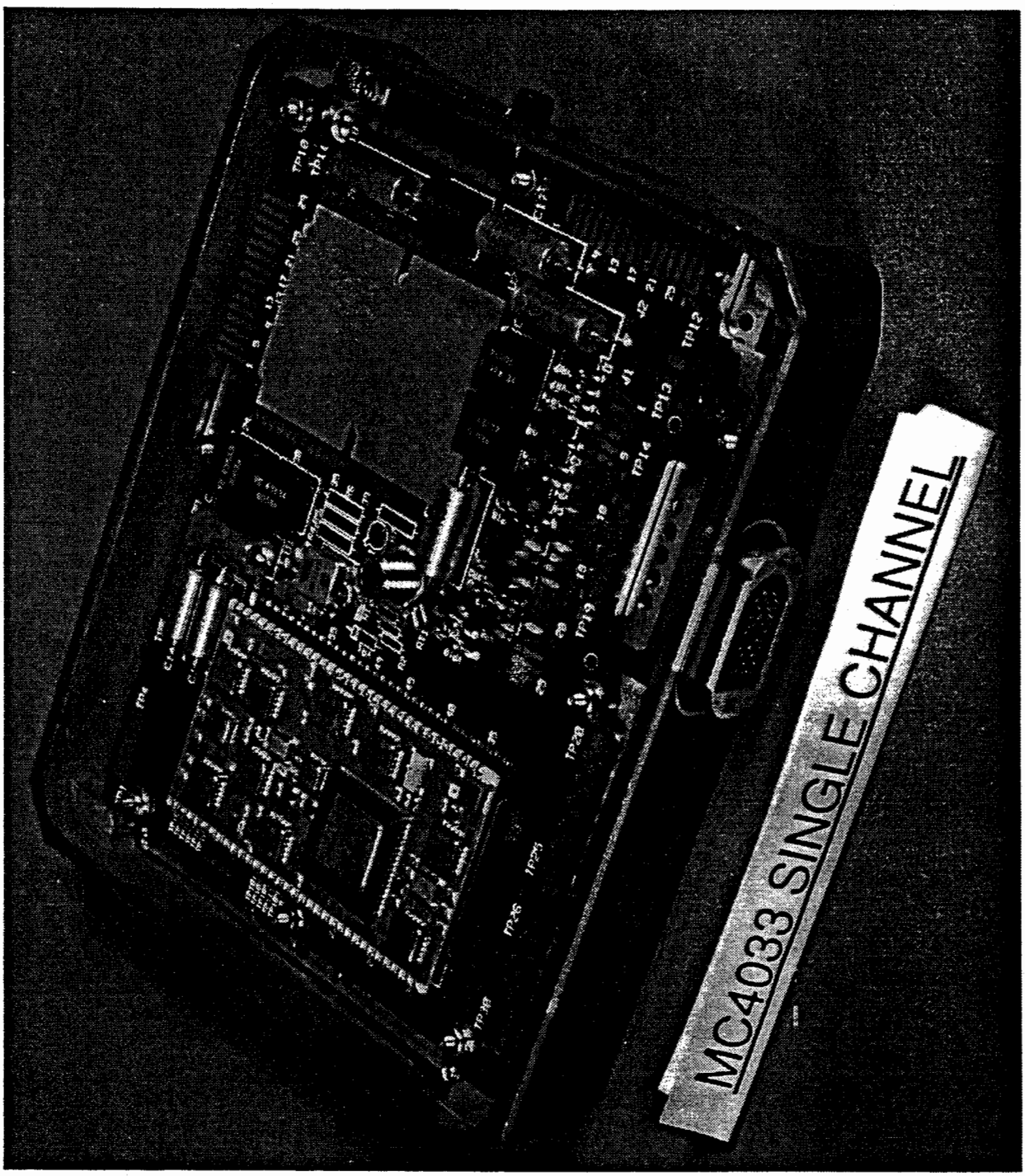
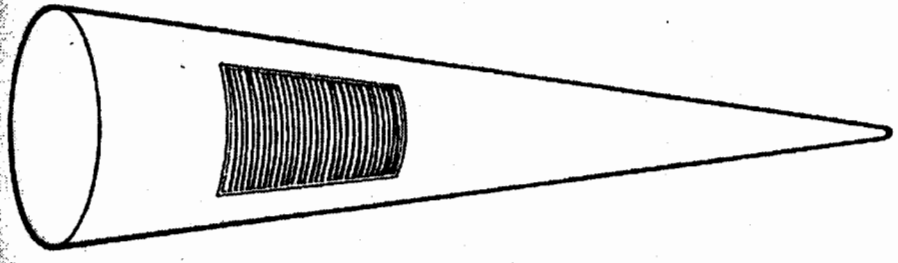
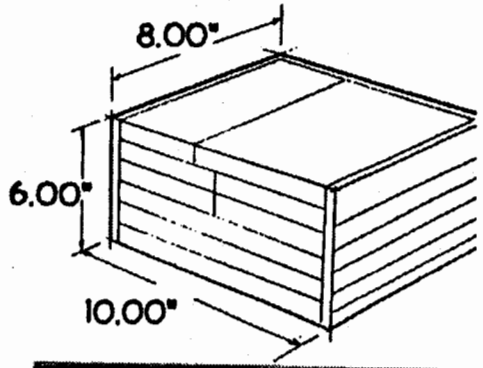
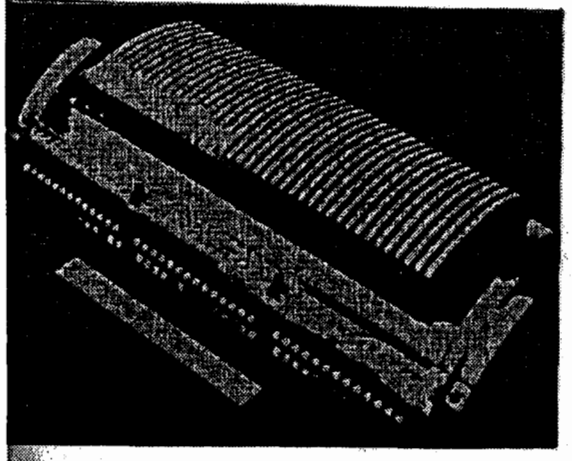
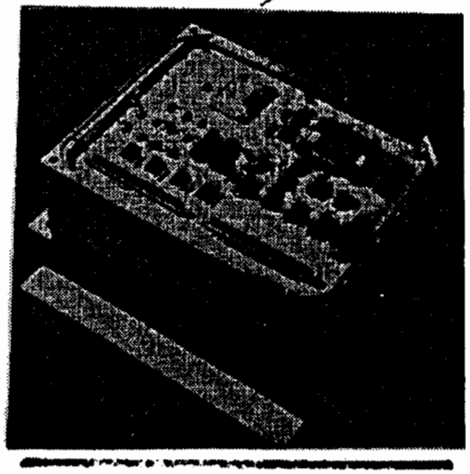

MC4033 SINGLE CHANNEL

Miniature SAR









Phased array antenna
30 lb.
460 cu. in.

RF & signal processor
20 lb.
480 cu. in.

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Synthetic Aperture Radar Features/Applications

- **SAR features**
  - Day/night operation
  - All weather (minimal rain attenuation)
  - Minimal surface penetration
- **Nuclear weapons** - Navigation update (landmark recognition) or target identification for MaRBs
- **Conventional weapons** -Target location for precision strike weapons
- **Oceanographic**
  - Oil spill monitoring
  - Sea-state monitoring (wave structure)
  - Ocean floor mapping (surface contour changes)
  - Iceberg and ice flow monitoring
  - Monitor shipping (ship & wake detection)
- **Reconnaisance & verificaion** - "Open skies"
- **Space** - Deep space mapping of planet surfaces (Magellan)

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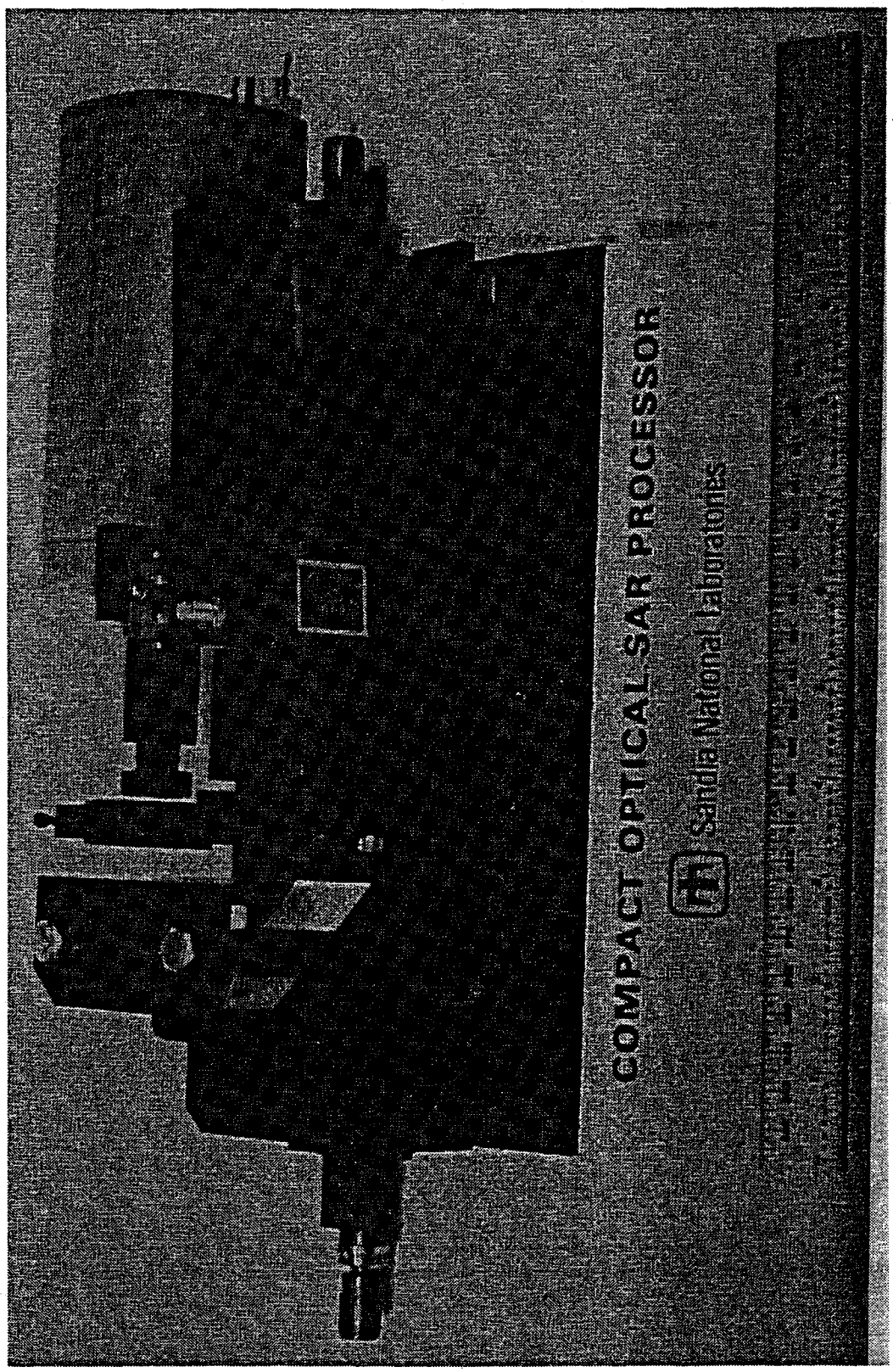
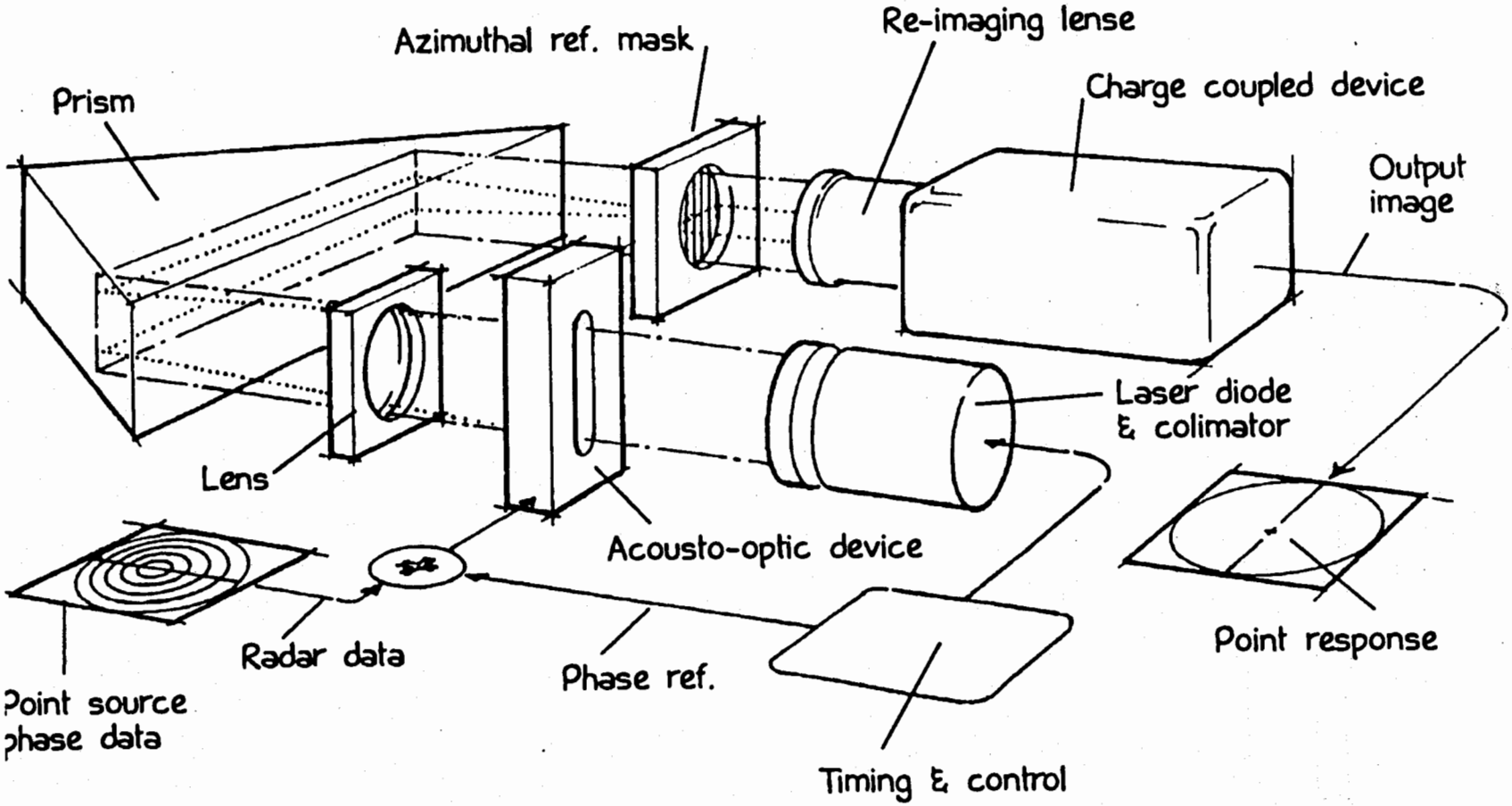

COMPACT OPTICAL SAR PROCESSOR
Sandia National Laboratories

Compact acousto-optic SAR processor



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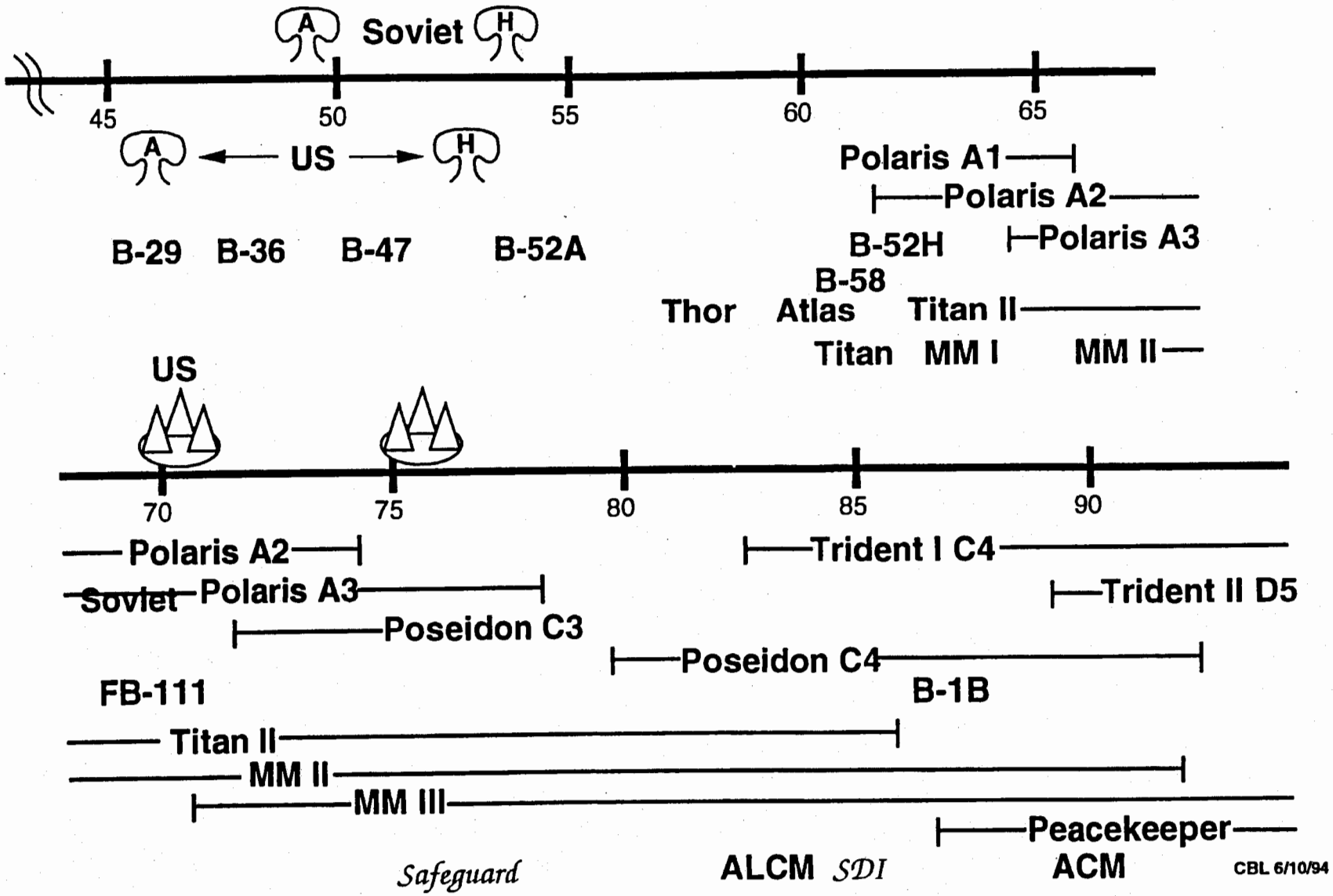
Strategic Delivery Systems



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The Evolution of Response Time

1948	Berlin blockade	2 days to assemble
1957	Suez	few hours to launch
1959	DEFCON established	
1960	JSTPS & SIOP	1/3 of bombers ready for immediate take-off
1962	Cuban missile crisis	1/8 on airborne alert

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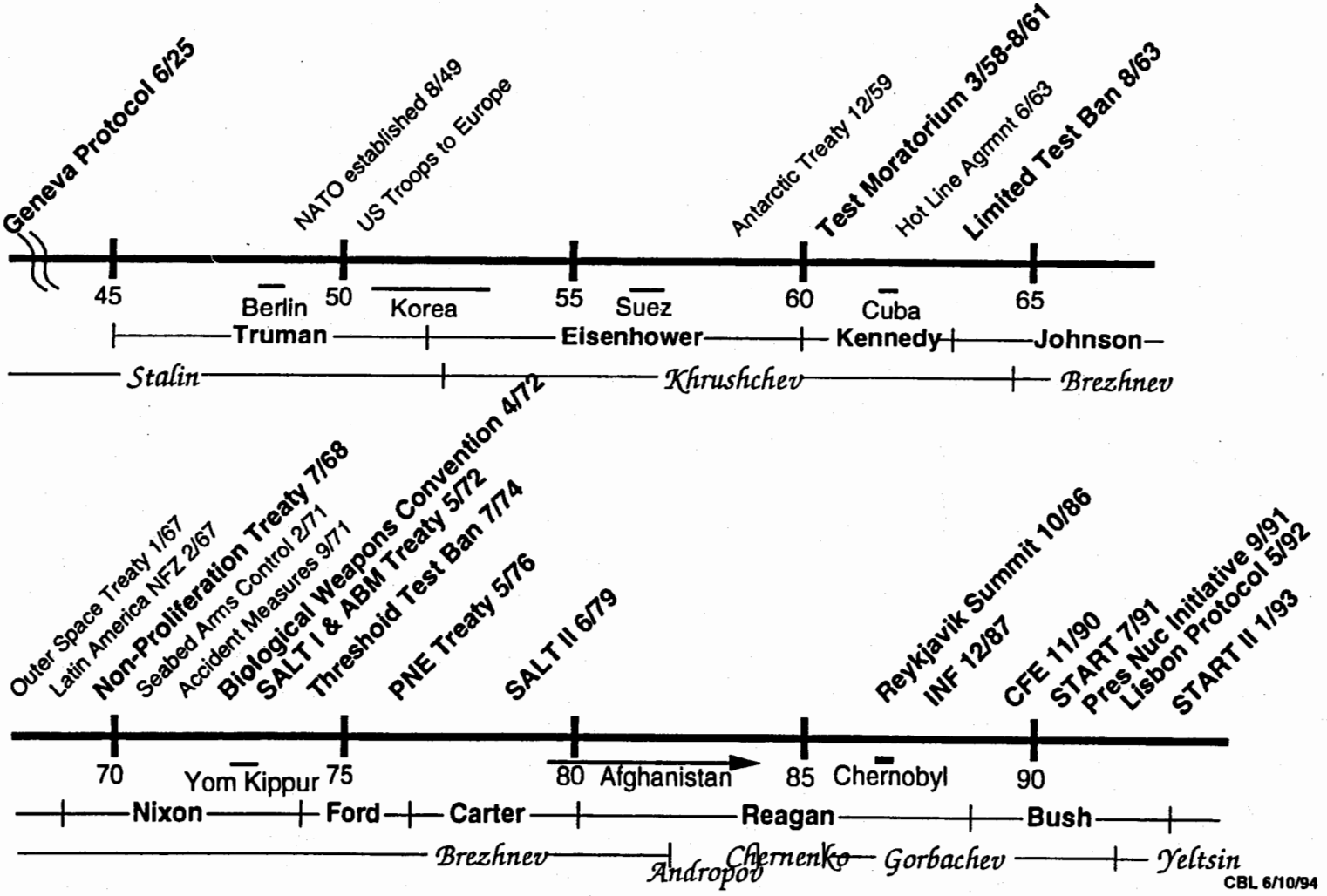
Arms Control Treaties



CBL 6/10/94

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The Geneva Protocol - 1925

Banned the use in war of asphyxiating, poisonous, or other gases and of bacteriological methods of warfare

US ratified in 1975

All major states now parties

UN Conference on Disarmament is working toward a ban on production and stockpiling

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Test Moratorium - 1958 to 1961

In March 1958, Soviets declared moratorium

In October, negotiations on CTBT began & Eisenhower announced 1-yr U. S. moratorium

May 1960 U-2 incident scrubbed planned summit

Kennedy Administration resumed talks

August 1961, citing French test, Soviets resumed testing

Soviets conducted over 50 tests in the last 3 months of 1961

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The Limited Test Ban Treaty - 1963

Limited nuclear tests to underground

Original signatories were US, Soviet Union, and UK

US ratified 10/63

More than 100 parties now

France ceased above ground tests in 1974,
China in 1980

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The Nonproliferation Treaty - 1968

Eisenhower proposed "Atoms for Peace" in 1953

IAEA established in 1957 to promote and monitor

Nuclear Nonproliferation Treaty was negotiated from 1965 and signed in 1968

NPT Review Conferences every 5 years

After 25 years (1995) a majority vote will determine indefinite or another fixed extension

In exchange for peaceful use of atomic energy, signatories agree to safeguards

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Biological and Toxin Weapons Convention

Outlaws development, production, stockpiling of all biological or toxin weapons and requires destruction of existing stocks

No specific verification provisions

Signed in 1972 and ratified by the US in 1975

Nixon ended US program in 1969 and destroyed stocks

Soviet incident at Sverdlovsk in 1979

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SALT I - 1972

Interim Agreement on Strategic Offensive Arms

Limited launchers (silos and sub tubes) to the then current number

US - 1710 SU - 2347

Limit on heavy launchers (SS-9 and later SS-18)

Five year duration

US ratified in Oct 1972

Reagan repudiated SALT I and II in May 1986

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ABM Treaty - 1972

Johnson and McNamara tried to convince Kosygin at Glassboro to limit ABM systems - June 1967

US announced Sentinel program in September1967

ABM talks were postponed by Soviet invasion of Czechoslovakia in 1968

Nixon changed concept to Safeguard, protecting ICBMs and Washington, DC

Treaty prevents defense of territory, limits to 2 sites with 100 interceptors, limits LPARS

Forbids mobile ABMS or sea, air, or space systems

OPP, Krasnoyarsk, SCC, capabilities questions

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Threshold Test Ban Treaty - 1974

Signatories are the US, Soviet Union, and UK

Limits nuclear tests to 150kT

Verification by NTM (seismic)

A two page treaty

Joint Verification Experiment in 1988

US ratified in 1989

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Peaceful Nuclear Explosives Treaty - 1976

Limited peaceful nuclear explosives to 150kT

Permitted maximum aggregate yield of 1.5 MT, with on site monitoring for yields above 150kT

Plugged a loophole in the TTBT

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START Treaty - 1991

Signed July 31, 1991, 5 months before the end of SU

Lisbon Protocol, signed May 1992, committed Russia, Ukraine, Belarus, and Kazakhstan to START (and NPT)

START limits SNDVs and deployed warheads:

	START	US forces*	Soviet forces*
SNDVs	1600	2246	2500
ICBM & SLBM Warheads	4900	8210	9416
Total Warheads	6000	10563	10271
Heavy ICBM Warheads	1540	------	3080
Mobile ICBM Warheads	1100	------	618
Throw-wt ICs & SLs (metric tons)	3600	2631	6626

*as of 9/90

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The President's Nuclear Initiative-1991

Sept 1991

- Eliminate ground launched tactical nuclear weapons
  - Lance and AFAPs
- Withdraw tactical nuclear weapons from surface ships, subs and P-3 bases
  - B-57, SLCM, B-61
- Stand down strategic bombers from alert
- Stand down MMII
- Cancel mobility for PK and SICBM
- Cancel SRAM II
- Propose joint elimination of MIRVed ICBMs

Jan 1992

- Build only 20 B-2s
- Cancel SICBM
- Halt production of ACM
- Halt production of W88 for Trident II

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START II - 1993

Treaty between the Russian Federation and US, signed by Bush and Yeltsin January 3, 1993, codifed agreements of the Washington summit of June 17, 1992.

START II builds on START - and requires START

	START	START II Ph1	START II Ph2
Start Warheads	6000	3800-4250	3000-3500
ICBM & SLBM Warheads	4900	no sublimit	no sublimit
MIRVed ICBM Warheads	N/A	1200	0
SLBM Warheads	N/A	2160	1700-1750
Heavy ICBM Warheads	1540	650	0
Mobile ICBM Warheads	1100	1100	1100

Phase one to be complete 7 years after entry-into-force, Phase two by 2003

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Books of interest

The Making of the Atomic Bomb, Richard Rhodes, 1986.
Pulitzer prize winner, follows the scientific discoveries that led to the bomb, particularly good at the personalities involved, finishes with vivid descriptions of Hiroshima and Nagasaki. Excellent and entertaining.

At the Highest Levels, Michael R. Beschloss and StrobeTalbott, 1993.
Intimate details of the end of the Cold War, as seen at the top.

Lenin's Tomb, David Remnick, 1993.
Details the end of the Soviet Union from the viewpoint of the Russian people and their legacy. Choppy, but a very human picture of the great event.

The Wizards of Armageddon, Fred Kaplan, 1983.
Follows the policy and strategy decision regarding nuclear weapons, much emphasis on the early RAND personalities. Very good and readable.

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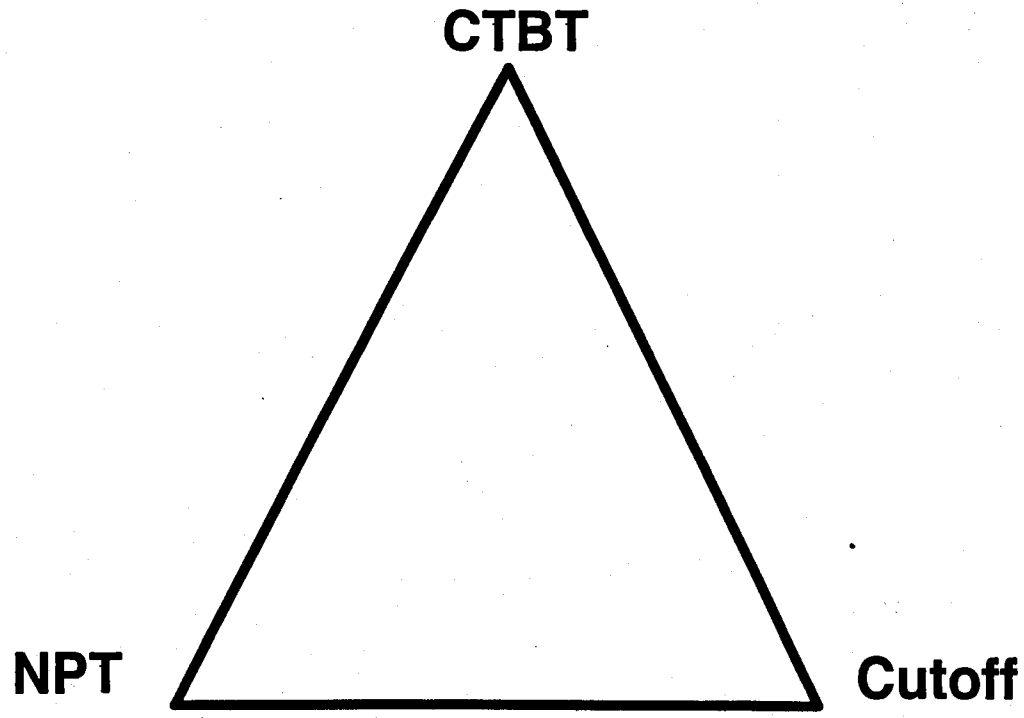
Nonproliferation Initiative

Alva Myrdahl's Historical View of Nuclear Weapon Controls



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Some Definitions

Proliferation is the spread of weapons of mass destruction (WMD)-- typically nuclear, biological, and chemical weapons--and the systems which deliver them.

Nonproliferation is the use of the full range of political, economic and military tools to prevent proliferation, reverse it diplomatically, or protect our interest against an opponent armed with WMD or missiles.

Counterproliferation measures are the activities of the DoD across the full range of U.S. efforts to combat proliferation.

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Nonproliferation Initiative

What Constitutes a Weapon of Mass Destruction

- Indiscriminate nature of use
- Effect not confined to Belligerents
- Excessive injury -- "cruel and unusual"
- Inability to defend against effectively
- Use would overwhelm medical and evacuation resources
- Notion of "terror"

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ARMS CONTROL IN THE ANCIENT WORLD

1269 BC	Earliest known peace treaty (Egypt and the Hittites), cemented by the marriage of Ramses II to a Hittite princess.
1100 BC	Philistines restrict the use of iron by the Israelites (1 Samuel 13:19-20).
700-800 BC	"...and they shall beat their swords into plowshares..neither shall they make war anymore" (Isaiah 2:2-4).
546 BC	Following the first recorded arms control conference, a "cessation of armaments" ends 72 years of hostilities in the Yangtse River Valley in Honan Province, China.

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ARMS CONTROL IN THE ANCIENT WORLD (CONT'D)

400-500 BC	Athens and Sparta agree to dismantle fortifications although during the negotiations the Athenians hedged their bet by continuing to build their ramparts "high enough to be defended" (Peloponnesian War, Thucydides). Note that, according to the Aristophanes, the women of Athens and Sparta, under the leadership of Lysistrata, tried a different approach to forcing an end to hostilities!
450 BC	Socrates to Glaucon -- no use of poisoned weapons or poisoned water (The Republic, Plato).
300-400 BC	No weapons concealed in wood, no barbed or poisoned points, no points "blazing with fire" (India's Book of Man).
202 BC	After the battle of Zama, Carthage is required to surrender all war elephants and all but 10 triremes to Rome (Book XXX, Livy).

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The Changing Context

Old	New
Bipolar Rigidity	Multipolar Complexity
Predictable	Uncertain
Communism	Nationalism/Religious Extremists
U.S. Dominant Western Power	U.S. Militarily No.1 - Not Economical
Fixed Alliances	Ad Hoc Coalitions
"Good Guys and Bad Guys"	"Grey Guys"
U.N. Paralyzed	U.N. Viable

Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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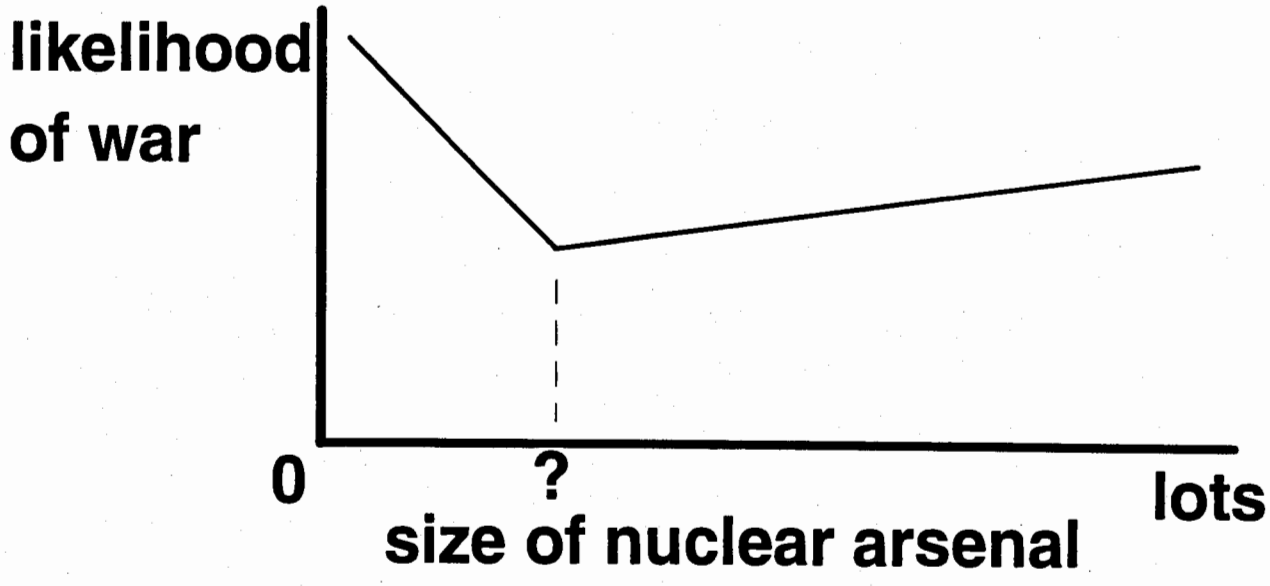
Why Not Zero?

Many nations and individuals want us to completely eliminate weapons -- attractive philosophy but dubious policy:



There may be things worse than nuclear weapons (e.g. biologics)

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There have been some Nonproliferation Successes

-- Sweden abandoned its programs in the 1970s.

-- South Africa stopped its programs in 1992 (6 weapons).

-- Argentina and Brazil renounced their programs.

-- Taiwan and South Korea abandoned their programs in the 1980s.

-- Iraq's program "put on hold" by Desert Storm and UN Resolution 687 and 715.

-- Belarus, Kazakhstan, and Ukraine (?) have agreed to return the FSU weapons to Russia.

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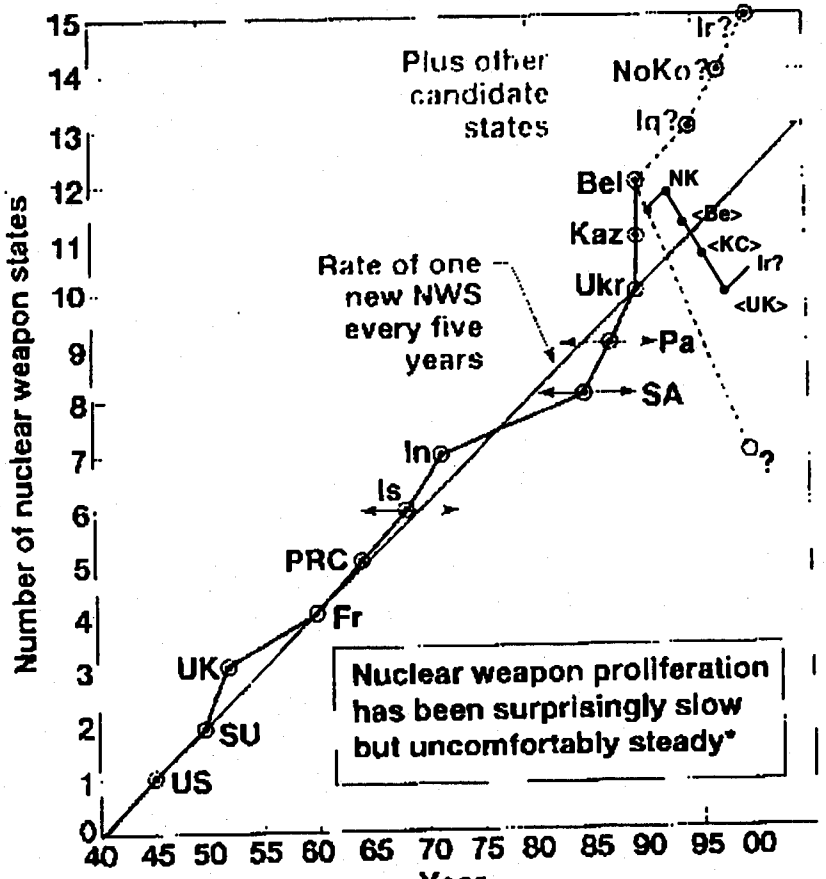
How many nuclear weapons states will there be in the year 2000?



*Data from news and journal articles in 1992

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Nonproliferation Initiative

Nuclear Proliferation: A Current Status

- Acknowledged/Declared Nuclear Weapon States
  -- US, UK, China, France, Russia
- Undeclared but widely suspected Nuclear Weapon States
  -- India, Pakistan, Israel
- "Inheritors" of Soviet weapons
  --Ukraine, Kazakhstan, Belarus
- Virtual Nuclear Weapon States (e.g., weapon capabilities but no weapons)
  --Japan, Germany
- Threshold Nuclear Weapon States
  --North Korea
- Aspiring Proliferators
  --Iraq, Iran, Libya, Algeria, various terrorist organizations
- Rollback cases
  --Argentina, Brazil, Sweden, Taiwan, South Africa

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Nonproliferation Initiative

Goals of Proliferation Controls (non → counter)

-- **REMOVE MOTIVATION** FOR POSSESSION OF NUCLEAR WEAPONS

-- **INTERDICT DEVELOPMENT AND ACQUISITION**

-- **DETER EMPLOYMENT** OF KNOWN OR SUSPECTED STOCKPILES OF NUCLEAR WEAPONS

-- **ELIMINATE INFRASTRUCTURE** BY PERSUASION, INTERNATIONAL SANCTIONS (E.G., Res 687)

-- PROACTIVELY **DESTROY FACILITIES** (E.G., Osirak)

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Incorporation of Nonproliferation into US National Security Policy

A successful nonproliferation strategy must address the underlying security concerns that drive the quest to obtain advanced weapons and must encompass contingency planning to deal with these weapons should prevention fail.

National Security Strategy of the United States
August 1991

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Secondary Impacts of Nonproliferation Initiatives

o NPT//NPT Extension Conference (1995):
- -- New and more intrusive inspections regimes
- -- An increased call for transparency
- -- More downward pressure on the stockpile from the "have nots"
- -- Continued pressure against nuclear testing

o Negotiations on controls on fissile materials:
- -- Codify in-place current US and Russian practices
- -- Inspection regimes and transparency
- -- Possible attempts to restrict tritium production

o Export Controls
- -- Heightened concern over "dual use" systems and commodities

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Nonproliferation Initiative

Options across the Nonproliferation -- Counterproliferation Spectrum

disincentives ⟷ **incentives**

venues

Economics — blockades, sanctions — export controls — foreign aid

Politics — political isolation — int'l organizations — alliances

Military Force — war — peacekeeping — military sales — military asst. — covert operations

confrontation ⟷ **cooperation**

COUNTERPROLIFERATION ⟷ **NONPROLIFERATION**

Issues on the Nonproliferation Platter

- Control over the nuclear arsenal of the FSU.
- North Korea
- The 1995 NPT Extension Conference
- China
- The Israeli nuclear arsenal
- The nuclear relationship between India and Pakistan
- Iran

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION XVII

- STOCKPILE STEWARDSHIP
- SUMMARY/DISCUSSION

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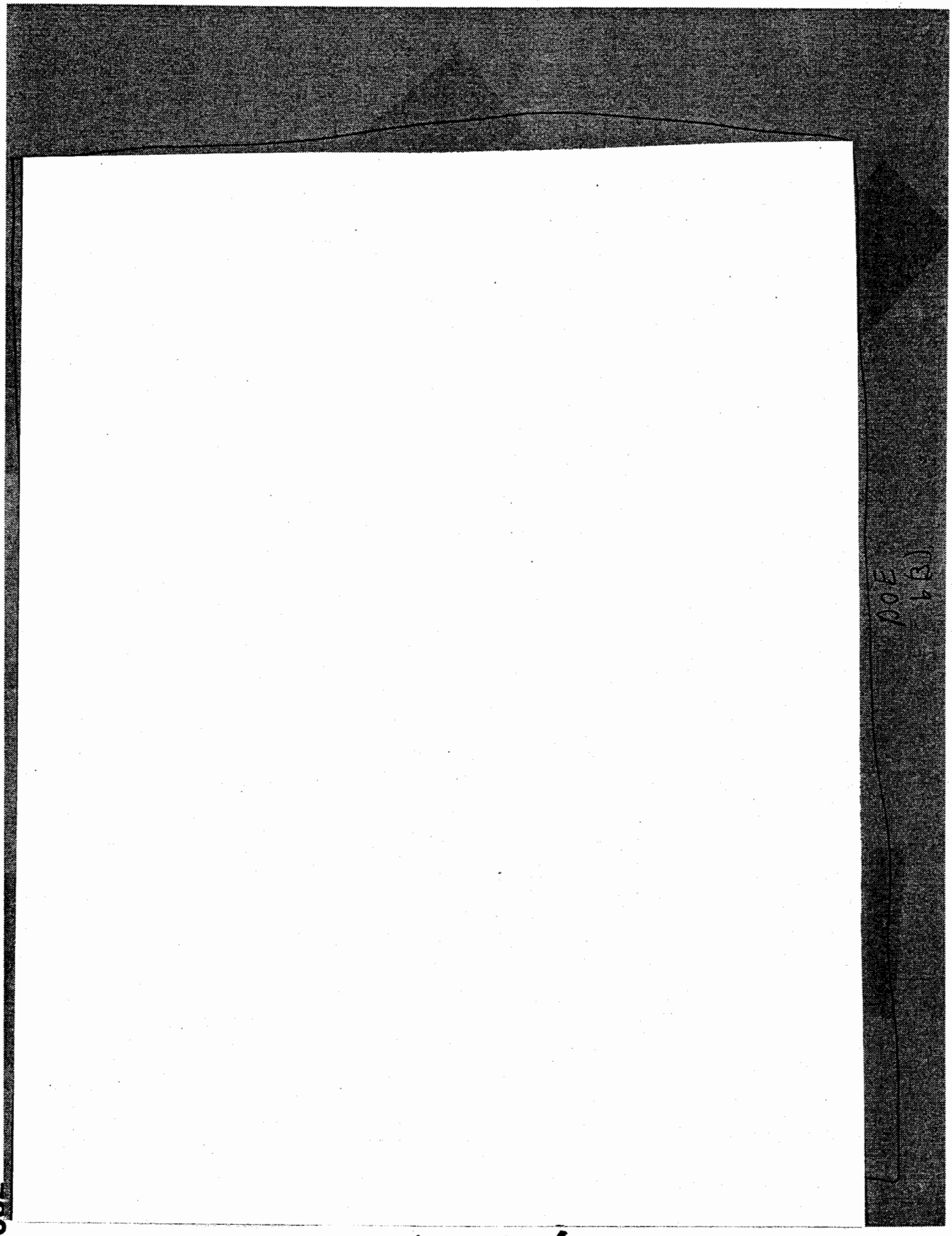

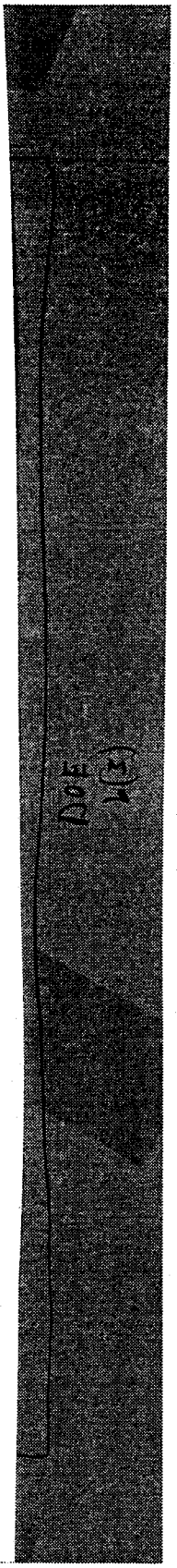

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION XVIII

FIELD TRIP TO THE INTER-SERVICE NUCLEAR WEAPONS SCHOOLS' WEAPON DISPLAY AREA

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682

Total pages 682, June 6, 1995
Subject: Survey of Weapon Development and Technology (WR708) (U)

Distribution:
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NEW DOCUMENTS FROM FOIA

1. A document about A Proposed Zipper System for Small Weapons by B. J. Carr, Document # SAC200119840000, Ref. Sym–7223 (380), dated–April 12, 1957
2. A document about Development Specification for XMC-364 (U) by J. D. Grenko, B. J. Carr, Ellis A. Turner, Jr., and T. S. Church, document # SAC200119030000, SC-5098, dated June 5, 1953
3. A document about XR Systems for Operation Redwing (U) by B. J. Carr, 1414, Document # SAC200119820000, Ref. Sym: 7223 (301), dated March 28, 1956