



Shipboard Submunition Fuze Safety and Reliability Improvement

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Shipboard Submunition Fuze Safety and Reliability Enhancement

- Sponsored by ONR 353
- Outgrowth of FY04 effort:
 - Assessment of Technologies for USMC
HIMARS Submunition Fuze Design
- Evolved Into Broad Based Multi-Year
Technology Effort Looking at all
Applicable Munitions



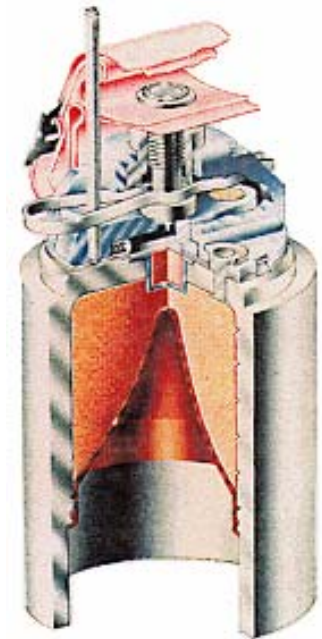
Shipboard Submunition Fuze Safety and Reliability Enhancement

- ISSUE - A number of existing, widely used submunitions do not currently meet either the Navy WSESRB established shipboard safety requirement or the SECDEF policy for Submunition Reliability.
- A low-cost solution is needed to both allow submunitions to be safe enough to be used in future shipboard carried weapons systems and reliable enough to be employed in the field.



DRIVING FACTORS

- **OSD Policy:** field future submunitions with a 99% or higher functioning rate*
- **WSESRB Position:** Shipboard Submunitions must have a probability of less than one in a million for either of the following cases:
 - Arming when inadvertently dispensed from the munition.
 - Inadvertently being dispensed from the munition.**



* SECDEF Memorandum, 10 JAN 2001
Subj: DoD Policy on Submunition Reliability (U)

** NAVSEASYS COM Letter 8020 Ser N314-H-22-001/373, 28 APR 04
Subj: WEAPON SYSTEM EXPLOSIVES SAFETY REVIEW BOARD
EXECUTIVE SESSION MEETING ON SAFETY REQUIREMENTS FOR
WEAPONS CONTAINING SUBMUNITIONS



Safety and Reliability

- Current Army efforts focus on adding Self-Destruct Feature to existing fuze structure to meet 99% functional reliability.
- This approach “places the ship at increased risk since the submunitions will now be designed to reliably function regardless of how they are expelled from the carrier munition, intentionally or inadvertently.”*

*NAVSEASYSKOM Letter 8020 Ser N314-H-22-001/373, 28 APR 04

Subj: WEAPON SYSTEM EXPLOSIVES SAFETY REVIEW BOARD EXECUTIVE SESSION
MEETING ON SAFETY REQUIREMENTS FOR WEAPONS CONTAINING SUBMUNITIONS



Safety and Reliability

Safety is related to the ability to prevent undesired hazardous events. Safety is typically quantified as rate of Failure:

e.g. Failure of 1 in $1 \times 10^6 = 1/10^6 = 1 \times 10^{-6}$

Safety can also be expressed as Safety-Related Reliability:

e.g. $R_S = 1 - F = (1 - 1 \times 10^{-6}) = .999999$

Reliability commonly refers to the ability to perform the desired function at the desired time, i.e. Functional Reliability. Typically quantified as rate of Function:

e.g. Function of 99 out of 100 = $99/100 = .99$



Safety and Reliability Change Through Design

Safety and Reliability can be altered by:

- Fault Avoidance - Keep Problems from Occurring
 - Component Quality
- Fault Tolerance – Some Problems OK
 - Component Redundancy



Safety and Reliability Change Through Design

Fault Avoidance:

High Quality Components = Fewer Problems

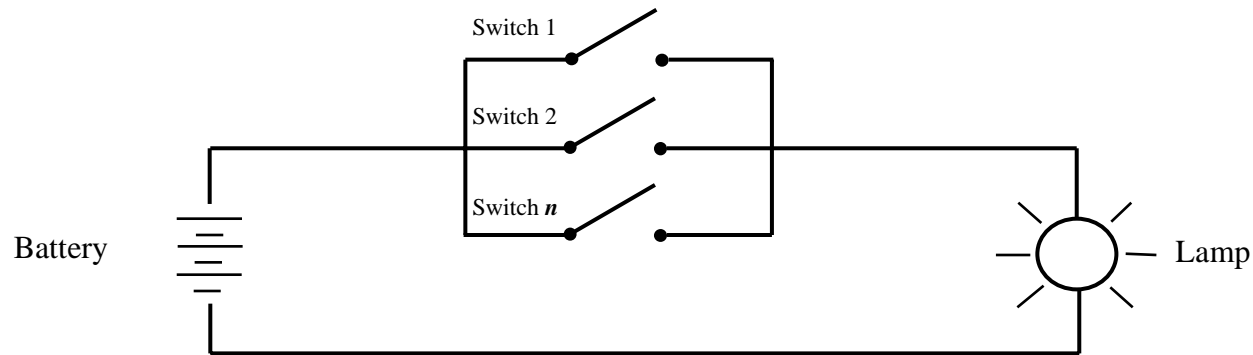
- Quality can be hard to quantify (what makes a part “better” in a given situation)
- Higher quality typically means higher cost
- Very high quality can be hard to achieve and demonstrate



Safety and Reliability

Change Through Design

Reliability Related Fault Tolerance: Parallel Components



$$P_p = 1 - \prod_{i=1}^n (1 - P_i)$$

where,

P_p = the probability of event in the parallel system

P_i = the probability of the event in the subsystem

n = the number of subsystems

Example: if probability of an event for a component is 1 in 10 (10%) the system probability for 3 of these components in parallel would be:

$$P_p = 1 - (1 - 0.1)(1 - 0.1)(1 - 0.1) = 0.271 \text{ or } 27.1\%$$

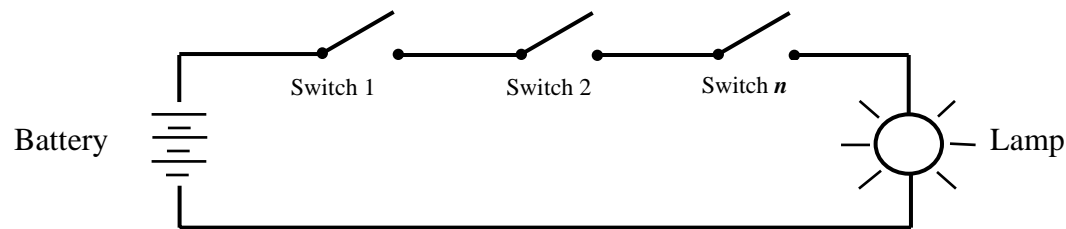
Parallel Systems Increase Event Probability



Safety and Reliability

Change Through Design

Safety Related Fault Tolerance: Series Components



$$P_s = \prod_{i=1}^n P_i$$

where,

P_s = the probability of event in the series system

P_i = the probability of the event in the subsystem

n = the number of subsystems

Example: if probability of an event for a component is 1 in 10 (10%) the system probability for 3 of these components in series would be:

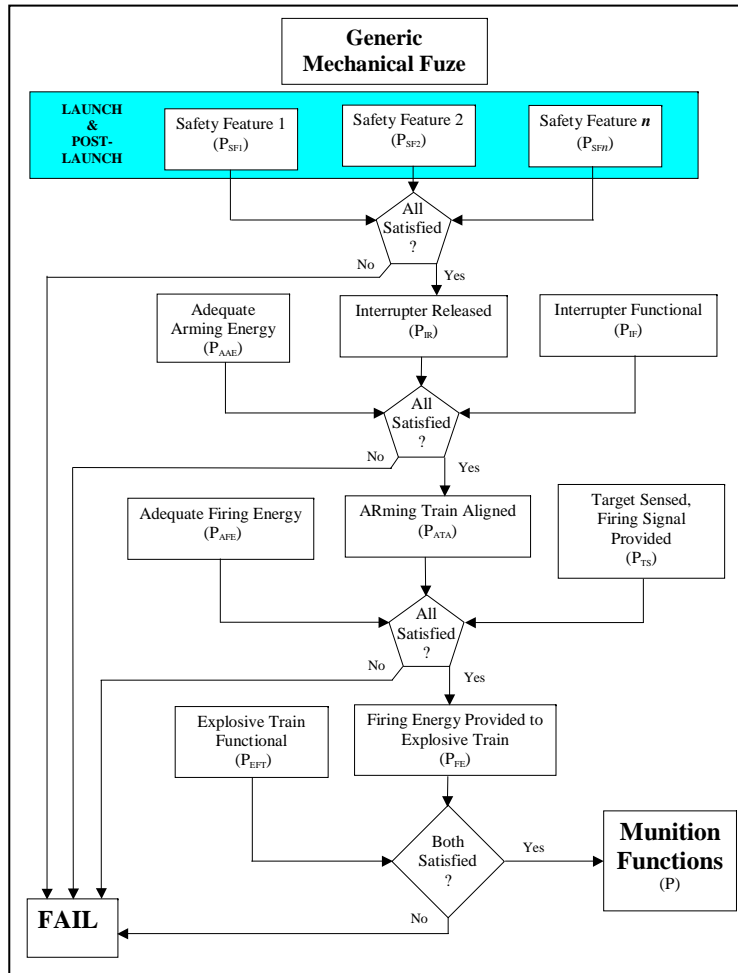
$$P_s = (0.1)(0.1)(0.1) = 0.001 \text{ or } 0.1\%$$

Series Systems Decrease Event Probability



Safety and Reliability

Generic Fuze Functional Reliability



With single fuze

$$\begin{aligned}
 P &= (P_{fe})(P_{eft}) \\
 &= ((P_{ata})(P_{afe})(P_{ts}))(P_{eft}) \\
 &= (((P_{ir})(P_{aae})(P_{if}))(P_{afe})(P_{ts}))(P_{eft}) \\
 &= (((((P_{sf1})(P_{sf2})(P_{sfn}))(P_{aae})(P_{if}))(P_{afe})(P_{ts}))(P_{eft})
 \end{aligned}$$

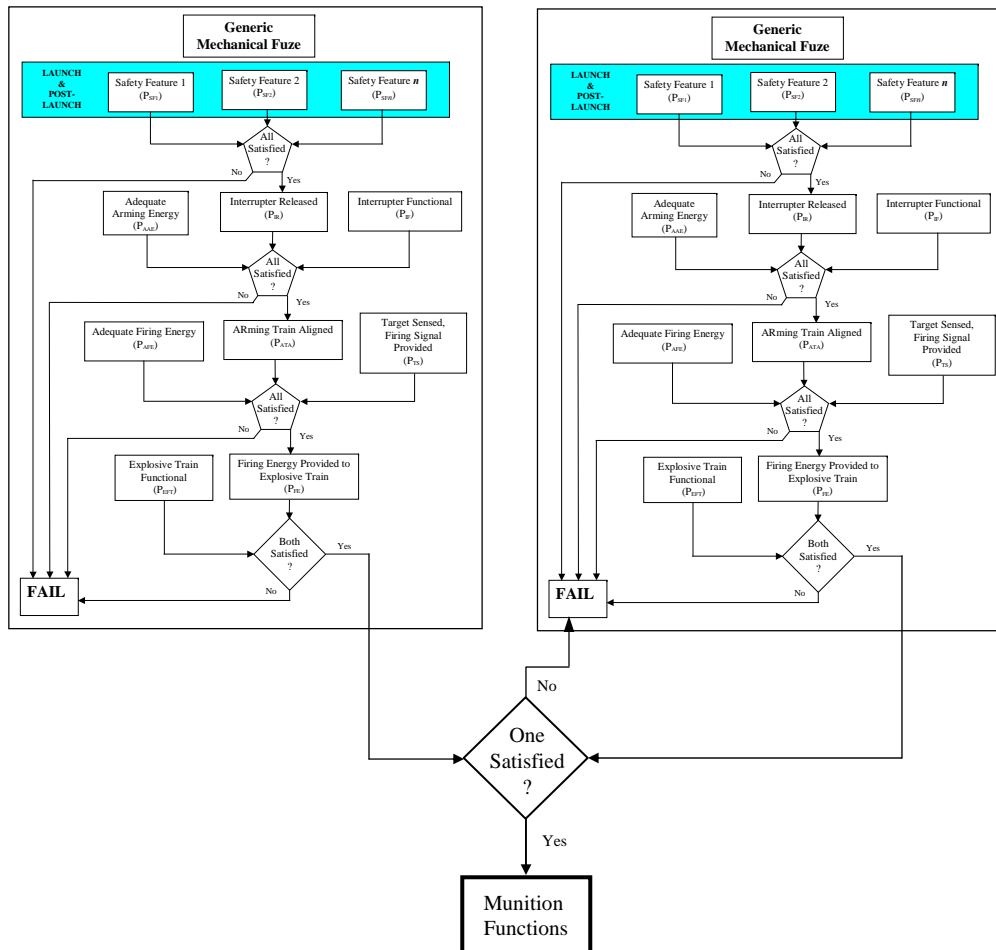
**Required
Submunition
Reliability ≥ 99%**



Safety and Reliability

Generic Fuze Functional Reliability

With 2 parallel fuzes



$$P = 1 - (1 - P_{FA1})(1 - P_{FA2})$$

P = Probability of Munition Function
 P_{FA1} = Probability of Fuze 1 Function
 P_{FA2} = Probability of Fuze 2 Function

Assuming that the fuzes have equal probability of arming ($P_{FA1} = P_{FA2}$), and $P \geq 99\%$ to meet the OSD requirement, then the equation reduces to:

$$P = 1 - (1 - P_{FA1})(1 - P_{FA1})$$

$$P = 1 - (1 - P_{FA1})^2$$

$$P = 1 - (1 - 2P_{FA1} + (P_{FA1})^2)$$

$$P = 2P_{FA1} - (P_{FA1})^2$$

$$0 = 0.99 - 2P_{FA1} + (P_{FA1})^2$$

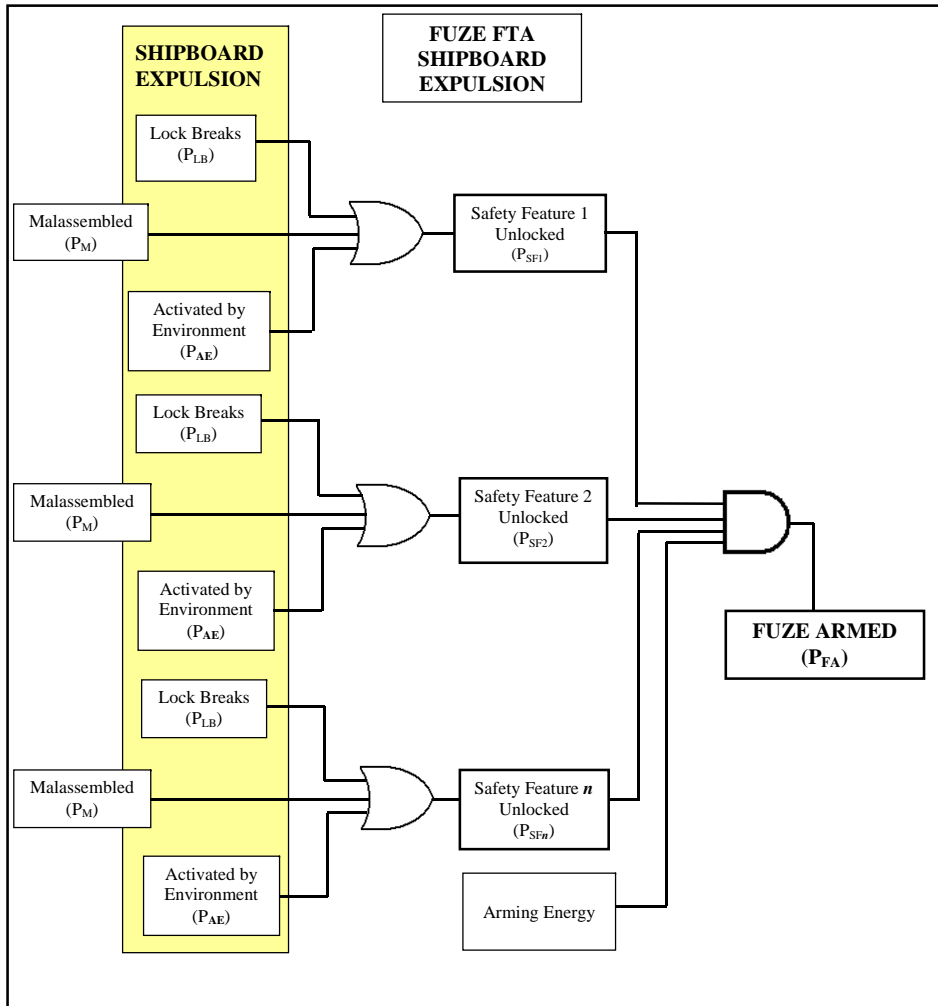
Solving the quadratic yields

$$P_{FA1} \geq 90\%$$



Safety and Reliability

Generic Fuze Safety



With single fuze

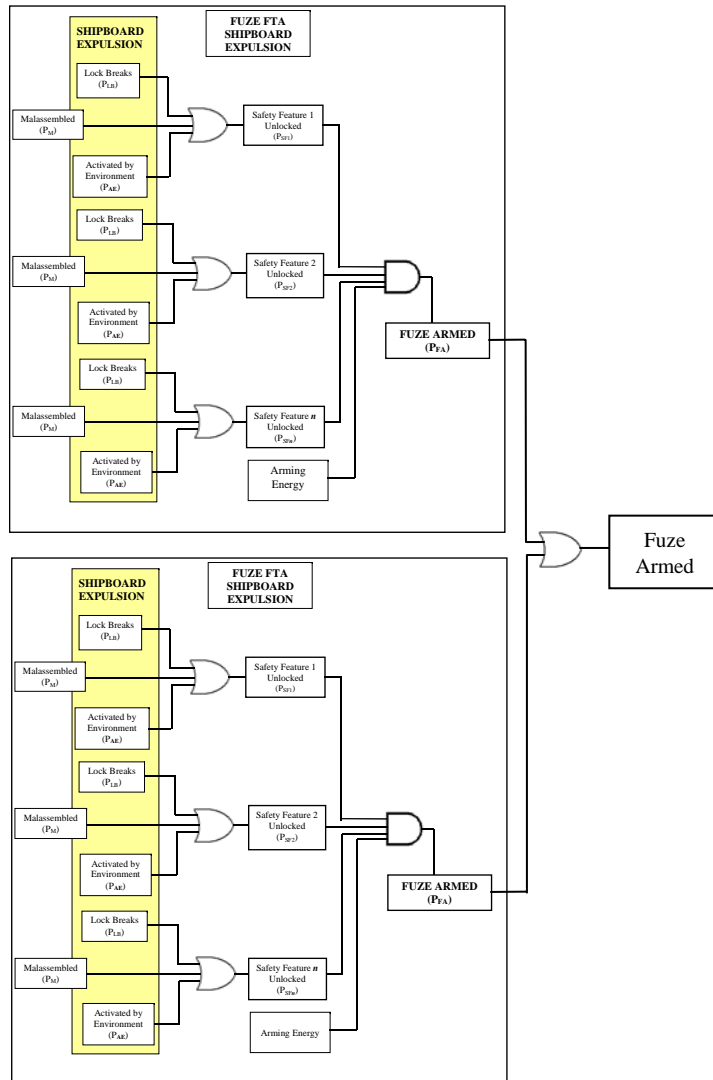
$$P_{FA} = (P_{SF1})(P_{SF2})(P_{SFn})$$
$$P_{FA} \leq 1 \times 10^{-6}$$



Safety and Reliability

Generic Fuze Safety

With 2 parallel fuzes



$$P = 1 - (1 - P_{FA1})(1 - P_{FA2})$$

P = Probability of Either Fuze Arming

P_{FA1} = Probability of Fuze 1 Arming

P_{FA2} = Probability of Fuze 2 Arming

Assuming that the fuzes have equal probability of arming

($P_{FA1} = P_{FA2}$), and $P_{FA} \leq 1 \times 10^{-6}$ to meet the WSESRB

requirement, then the equation reduces to:

$$P_{FA} = 1 - (1 - P_{FA1})(1 - P_{FA1})$$

$$P_{FA} = 1 - (1 - P_{FA1})^2$$

$$P_{FA} = 1 - 1 + 2P_{FA1} - (P_{FA1})^2$$

$$0 = P_{FA} - 2P_{FA1} + (P_{FA1})^2$$

$$0 = 1 \times 10^{-6} - 2P_{FA1} + (P_{FA1})^2$$

$$P_{FA1} = 5 \times 10^{-7}$$

Or less than 1 in 2 million



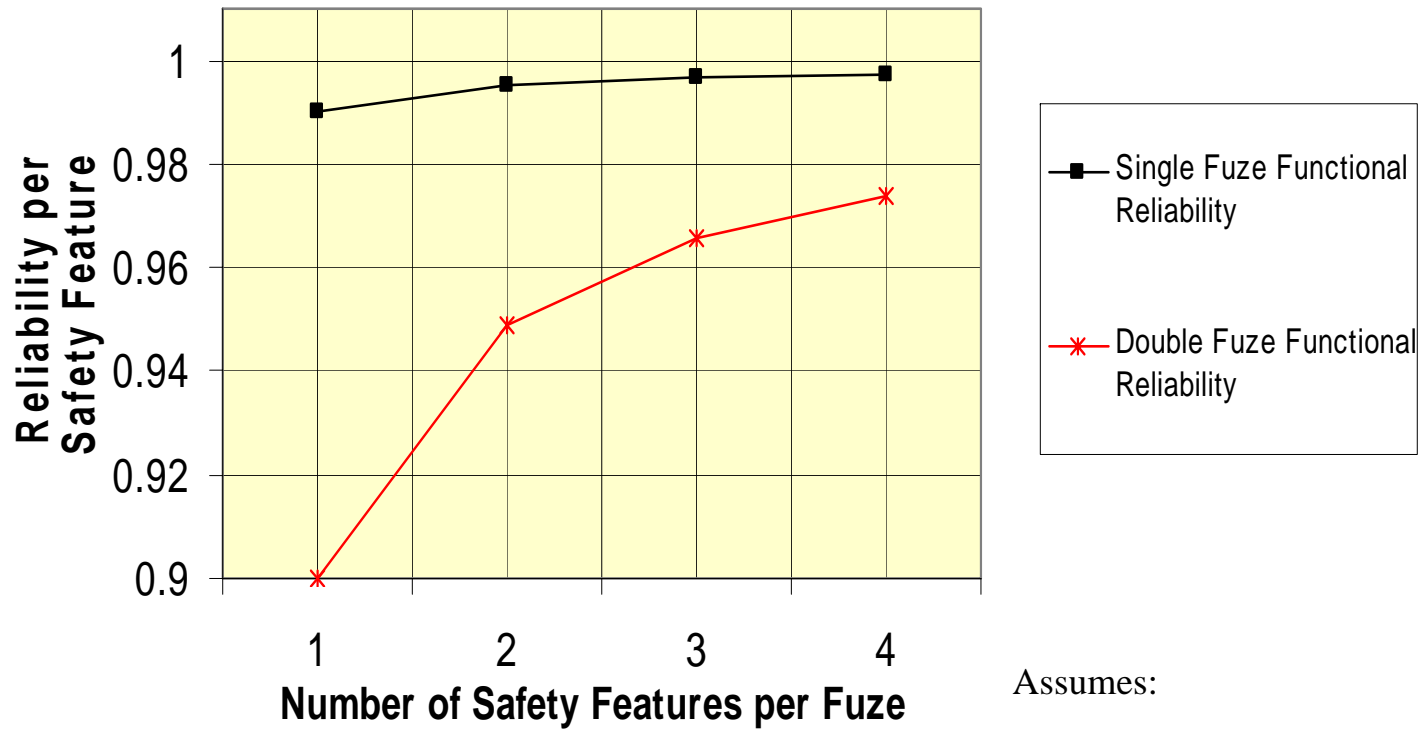
Safety and Reliability

Number of Safety Features	Functional Reliability Requirements per Individual Safety Feature		Safety-Related Reliability Requirements per Individual Safety Feature	
	Single Fuze	Dual Fuze	Single Fuze	Dual Fuze
	1	0.99	0.9	0.999999
2	0.994987437	0.9486833	0.999	0.9992929
3	0.996655493	0.9654894	0.99	0.992063
4	0.99749057	0.9740037	0.968377223	0.9734085
5	0.997991952	0.9791484	0.936904266	0.945072



Safety and Reliability

Safety Feature Reliability Requirements



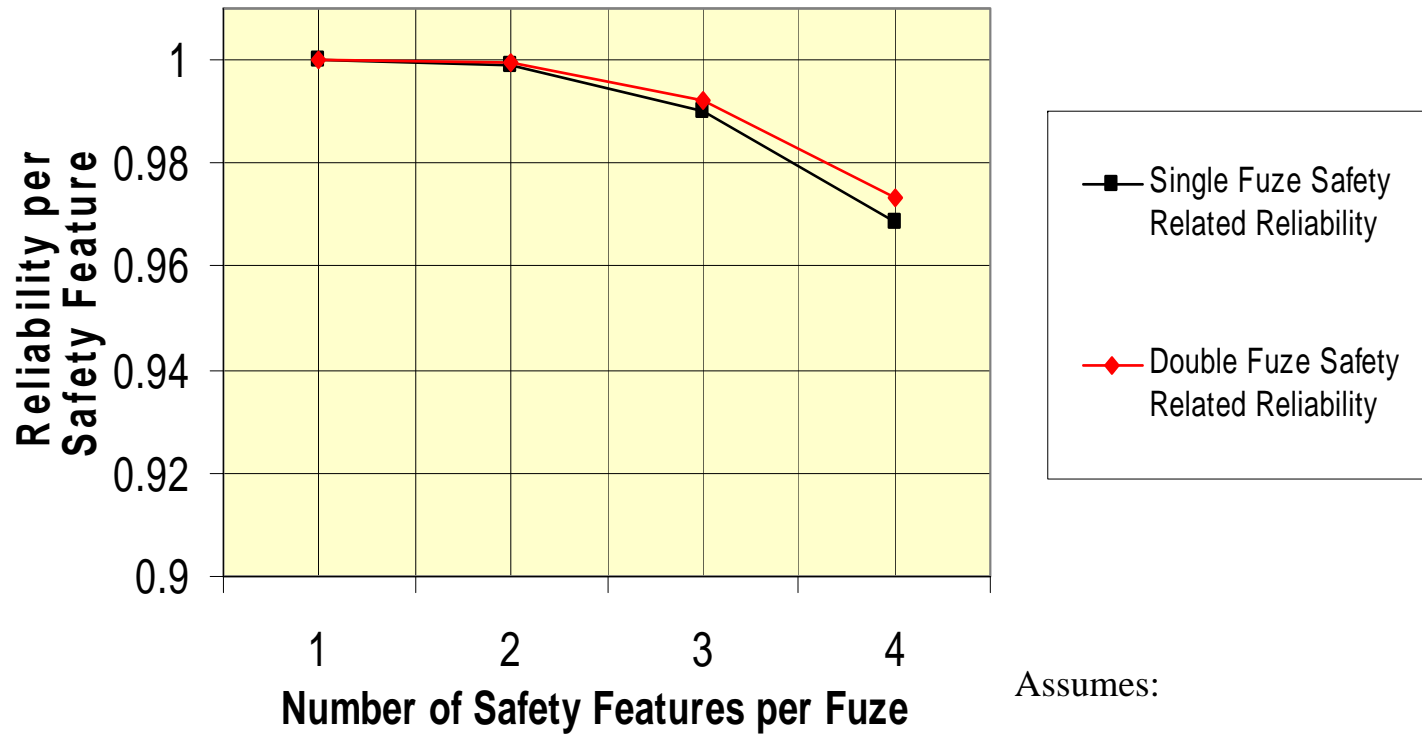
Assumes:

All other event driving probabilities = 1



Safety and Reliability

Safety Feature Reliability Requirements



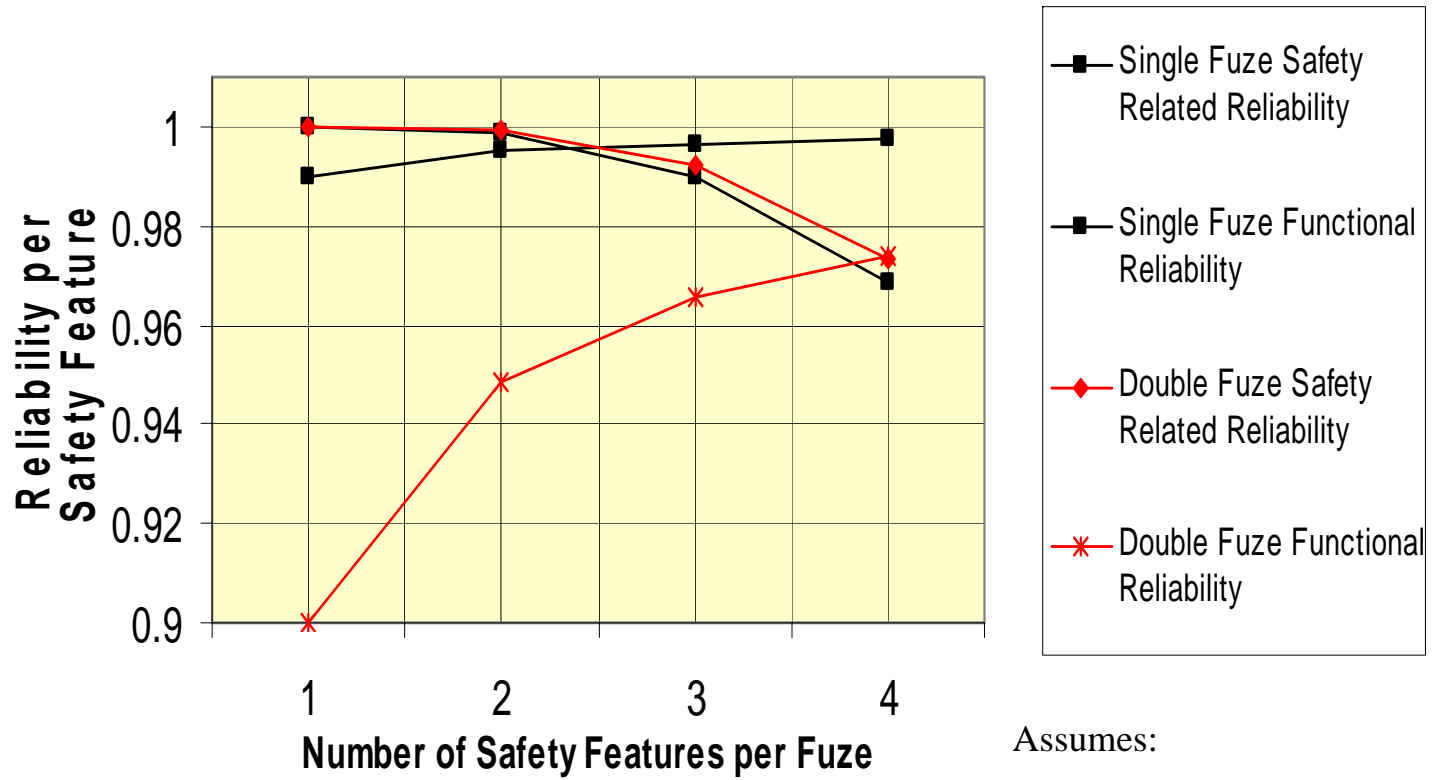
Assumes:

All other event driving probabilities = 1



Safety and Reliability

Safety Feature Reliability Requirements



Assumes:

All other event driving probabilities = 1



Safety and Reliability

Using two parallel fuzes each with three safety features in series allows meeting of the reliability and safety requirements using components having more easily obtainable reliability.



MEMS as a Means to Achieve Dual Fuzing

- Readily manufactured at numerous commercial facilities.
- At the chip level there is no assembly required regardless of the number of features.
- Much like photocopying, increasing MEMS features does not significantly affect cost.

ABC

Costs about the same as

