Munitions Safety - How Safe

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Introduction

The purpose of this paper is to describe some of the factors which been influencing the way in which the UK Navy safety authorities judge the safety of Naval armament Stores. This judgement has been, and will remain, largely a question of the safety authorities acquiring sufficient confidence that the store is and will remain safe throughout its life in a specified environment.

This confidence is derived from a variety of different sources (figure I). Knowing that the store has been designed and built to agreed standards and to satis~ specific requirements provides a large measure of this confidence. These requirements speci~ amongst other things that only propellants and explosives with acceptable properties can be used. A understanding of how the store is to be handled is a ~rther confidence builder. Finally confirmation that the all-up store is safe is provided by a series of munitions safety tests which provide a comfortable margin of safety.

This process is a qualitative one but nevertheless involves the safety authority comparing the perceived confidence against a imaginary threshold. Provided confidence is above this threshold then stores will be brought into service. If ever they drop below the threshold then they may be withdrawn until confidence is restored. By this means the UK Navy have been assured that the weapons they carry will not endanger their ships.

Changing Environment

However it is not only ships and their crew which may be endangered by embarked munitions. When ships enter dockyards or come into port then the whole facility and possibly the surrounding area and its population are put at a small but finite risk. The situation is fiirther complicated if the facility has nuclear installations such as a reactor refit complex. In the case of an accident involving the explosion of ship's munitions these nuclear facilities could be put at risk with the eventual release of radioactive materials into the environment.

Nuclear facilities in the UK whether military or civil are careft~lly regulated. Pennission to operate demands the nuclear safety authorities being satisfied that operations are tolerably safe. The operator of any nuclear facility therefore has to demonstrate through a safety case that all possible accidents have been considered and that those considered credible are so unlikely that the risk to the facility is acceptable.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 1994**	2. REPORT TYPE	3. DATES COVERED **00-00-1994 to 00-00-1994**

4. TITLE AND SUBTITLE **Munitions Safety - How Safe**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Ministry of Defence,MOD(Navy), DES(OAE)/CINO,Ensleigh, Bath, BAI 5AB. UK,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Sixth DoD Explosives Safety Seminar Held in Miami, FL on 16-18 August 1994.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**10**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

In a Naval facility one of these credible accidents is an explosion of munitions in storage or during handing operations. Blast, fragment, thermal radiation and debris damage may all cause damage to nuclear installations. Increasingly we in the ordnance safety community are not being asked for an assurance that weapons are safe but for a quantitative assessment on how safe they are.

Safety Goals

Before considering how we go about answering such questions it worth examining how safe do munitions need to be and how are the safety criteria are expressed. As a working hypothesis we in the Navy department work on the basis that Naval installations should be no more hazardous to people working in them or near to them that corresponding civil ones. In other words people should be at no greater risk living near a Naval base or refit complex than they would be living near a nuclear power station or petrochemical works.

For such civil installations tolerability and acceptance goals are often expressed quantitatively in the form of a graph. This shows the number of people who would be harmed annually by an event against the likelihood of an event occurring Figure 2.

These show three distinct areas:

Acceptable
a) one shows the acceptable area where the risks are so low that no fiirther measures need to be taken to further reduce them. Typically individuals a willing to accept a risk of being killed by lightning of one in a million so any man made risk which is lower than this is considered acceptable. The line which bounds this region is the Basic Safety Objective (BSO).

Intolerable
b) two shows the area of intolerability where the risks are so high that they would be deemed intolerable. If the risk of a nuclear release from power station was this high then the plant would not be allowed to operate. The line which bounds this area is the Basic Safety Limit (BSL).

ALARP
c) the third area lies in between. If the risks lie in this area then fiirther effort should be made to reduce them so that they are as Low As Reasonably Practicable. It would not be considered reasonably practicable to spend millions of pounds or dollars to gain only marginal improvements in safety.

In addition to these three areas the criteria applied to members of the public will usually be more rigorous than those applied to site workers. Furthermore there will often be an aversion to major accidents which affect a lot of people at once.

These goals are already acknowledged in the regulation of civil hazardous facilities and are increasingly forming an important basis for judging the safety of Naval installations.

Meeting the Goals

Demonstrating that the goals are met will normally require a thorough quantitative risk assessment (QRA) of all the risks which an installation or facility faces. In so doing the main factors which contribute to the risk need to be identified. Each is then allocated a share of the total site risk budget as shown in Figure 3.

In a hypothetical case a naval vessel may well be berthed in close proximity to a nuclear installation such that a weapon explosion would inevitably lead to an off site release of radioactive material. If the tolerability of such a release were IE-06 per annum from all possible causes and weapons threats are allocated one tenth of the risk budget it follows that the tolerability of a weapon explosion is lE-07. However if there are many weapon movements (say l00) per year the risk of a weapon accident per movement will be lE-09 per movement. Showing that the risk for each weapon movement is beffer than one in a thousand million is a major challenge.

Facing The Challenge

Over the past year the UK munitions safety authorities have been endeavouring to answer the question - how safe?.

The factors which provide confidence for safety assurance are also those which need to be quantified. The safety authorities need to establish how safe is the design, the explosives, the handling and the weapon. The following examples illustrate how for a particular weapon system the safety of the design and the weapon handling operations have been quantified.

Design Safety

In one torpedo example the major risk of a weapon explosion was ascertained to be the undetected mixing of the fuel and oxidant in the propulsion system. It was therefore necessary to establish the likelihood of this occurring.

A joint team comprising the weapon designers, the MOD project manager and the safety authorities examined all aspects of the design to establish all possible modes of failure. A logical fault tree was agreed and drawn up with some 650 events. The probabilities of these events occurnng was established by consultation with established data bases or though expert judgement. A page from the fault tree is reproduced at Figure 4. It shows the sort of events which had to be considered. By this process the safety critical areas were identified and the design weaknesses established.

The safety goal for the design in this case was that there should be three independent and unlikely modes of failure. Unlikely was defined as between 10E-2 and 10E-3 depending on confidence of the results. This gives an overall failure frequency of between 10E-6 and 10E-9. Although it could be shown that this overall figure could be achieved it could not always be achieved by three independent failures. A major output from the analysis was a series of recommendations which will restore the three fault safe criteria.

It was also possible to demonstrate in a auditable way that the design was tolerably safe and when installed in a submarine created an acceptable risk to the submarine's crew propulsion plant and shore facilities.

Handling Safety

In a second example all up weapons tests were unable to demonstrate that a weapon would behave in an acceptable way when dropped or otherwise mishandled. In this case the quantitative risk analysis concentrated on looking at all phases of the weapon's deployment to acquire confidence that it would not be dropped or mishandled.

Again a joint team was assembled bringing together explosives experts, operators, crane experts, safety advisors, designers and project staff Every stage of the weapon system's deployment was analysed in detail. All transport, storage and handling operations were meticulously analysed. The team witnessed movements and viewed videos of handling. All procedures and steps were documented and for every stage in the operation the risks were assessed. Many hundreds of steps were identified and these were brought together in fault trees which enabled one to identi~ the safety critical activities and those which had little impact on safety. Figure 5 shows some of the activities identified and quantified. In every case the source of the data was referenced and expert opinion sought to verity the figures used.

The safety critical ones were analysed even more rigorously and in several cases operating procedures and engineering modifications were introduced to provide adequate margins of safety. In this case pessimistic assumptions had to be made about how a weapon would respond in an accident however it was possible to show that a weapon accident was so unlikely as not to hazard other facilities.

Munitions Tests

The two studies cited have been undertaken because the traditional means of assessing weapon safety through all up weapons testing have not provided the required confidence. For that reason even greater reliance has been placed on demonstrating that the design is intrinsically safe and that handling operations are sufficiently safe. In these cases the confidence level required is not an intellectual one but a numerical one.

Traditional weapons testing is designed to provide confidence that in the worst case scenario the weapon will behave in an acceptable way. The 40ft drop test, bullet attack tests fast cook off are all intended as worst case tests. However as we have discovered in our spigot attack work detonations have occurred at 5ft on stores which have survived 40ft drops. We have also seen higher order events when a store is struck by lower velocity bullets.

The greatest shortcoming is that they provide little information which is usetul in the quantitative assessments. Knowing that one store survives a 40ft drop does not enable us to predict the likelihood of a detonation when it is dropped from the back of a truck. In part their inadequacy is due to our poor understanding of the mechanisms involved and the links between all up weapon behaviour and small scale testing.

Conclusions

From CINOs experience over the past few years we have drawn the following conclusions.

There is an increasing and inescapable need to quantify the risks of munitions accidents.

Where quantitative analysis is undertaken on the design and handling this should be conducted at the beginning of the project rather than at the end. At that stages design weaknesses or shortcomings in handling procedures can be identified and rectified.

The resources, skills, time and data required to undertake an analysis should not be underestimated. This is a major undertaking.

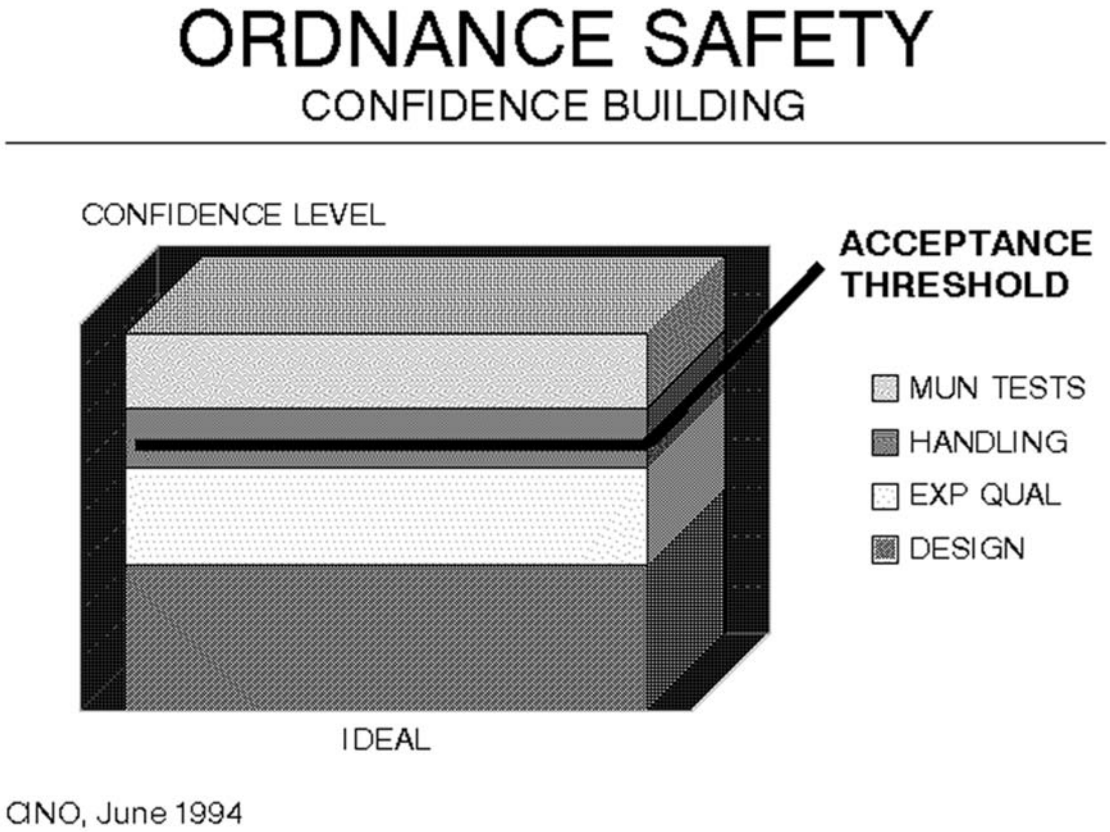
Traditional munitions tests are unable to provide sound a sound basis for quantitative assessment. Furthermore our understanding of the mechanisms leading to initiation in these tests is inadequate.

Recommendations

An improved understanding needs to be established on the link between all up weapons tests and small scale predictive tests.

Quantitative data bases need to be established to support quantitative assessments. Agreed methodologies should be established for assessing the risks from weapons. Quantitative goals for weapons safety should be agreed and declared as a design requirement.

FIGURE 1



ORDNANCE SAFETY
CONFIDENCE BUILDING
CONFIDENCE LEVEL
ACCEPTANCE THRESHOLD
MUN TESTS
HANDLING
EXP QUAL
DESIGN
IDEAL
CINO, June 1994

FIGURE 2

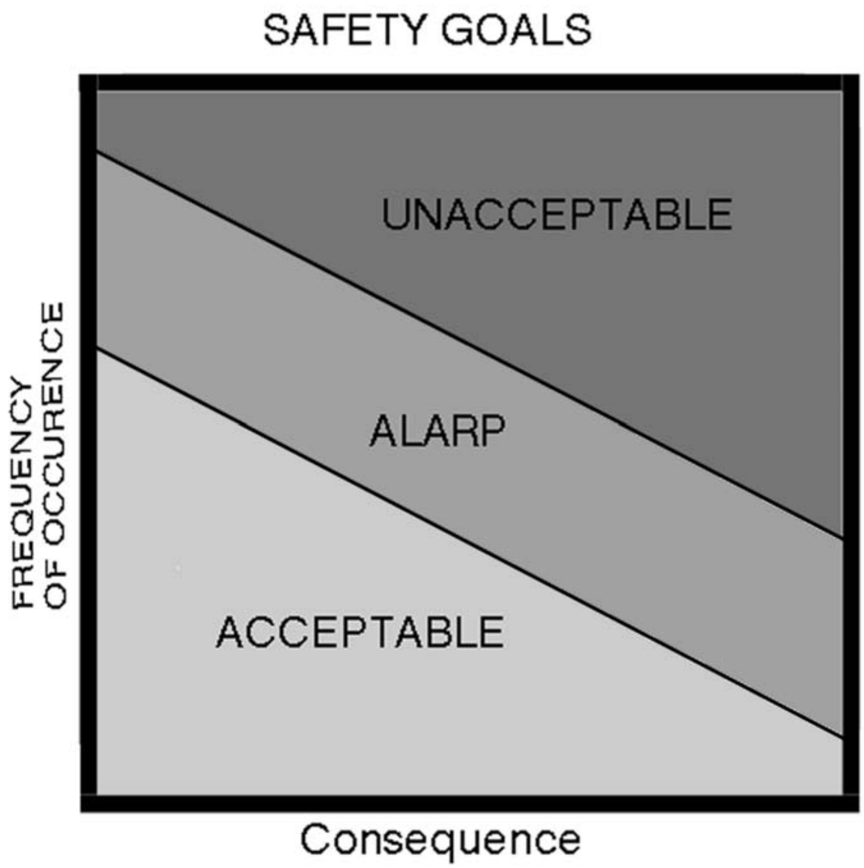

SAFETY GOALS
UNACCEPTABLE
ALARP
ACCEPTABLE
FREQUENCY
OF OCCURENCE
Consequence

FIGURE 3

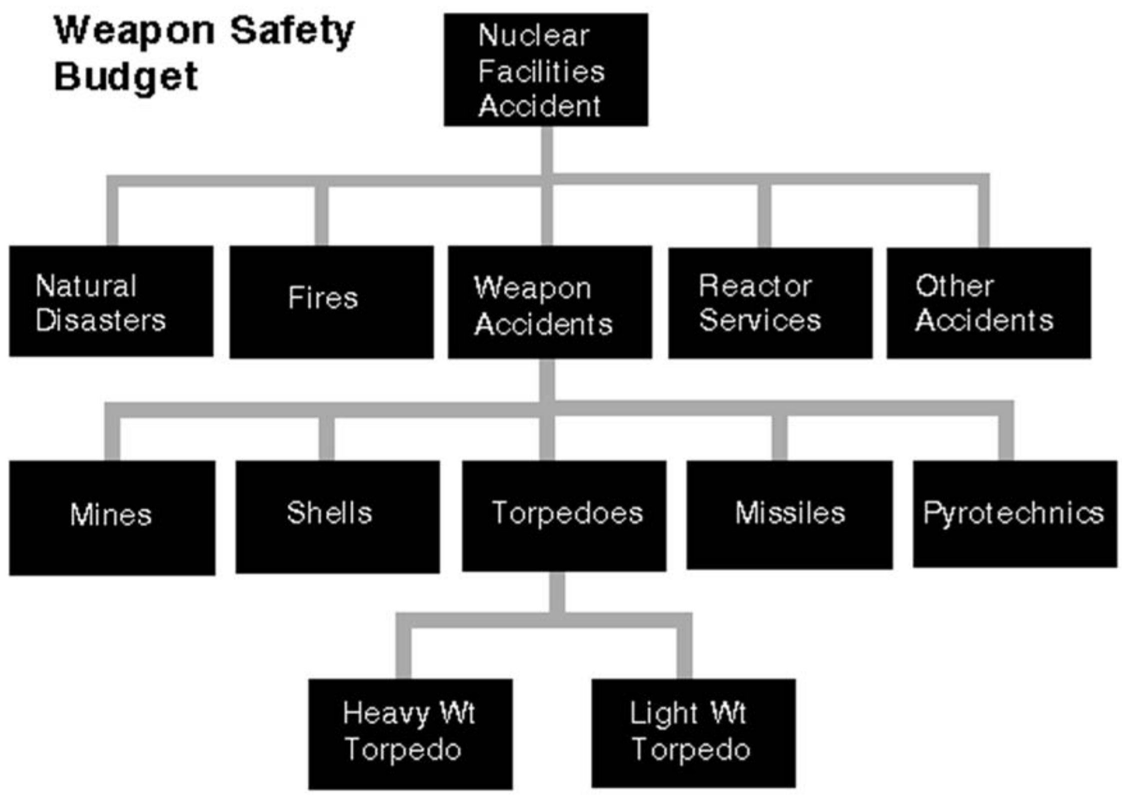
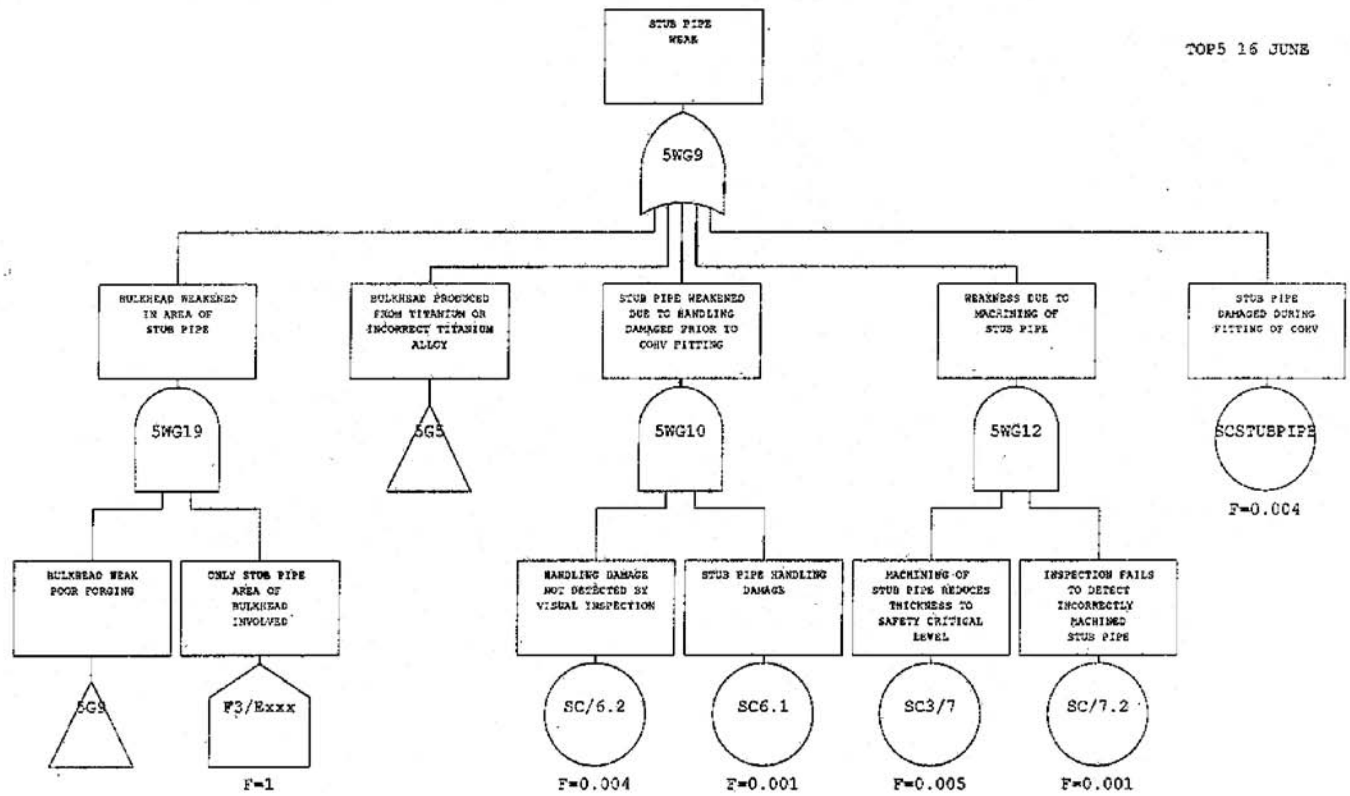
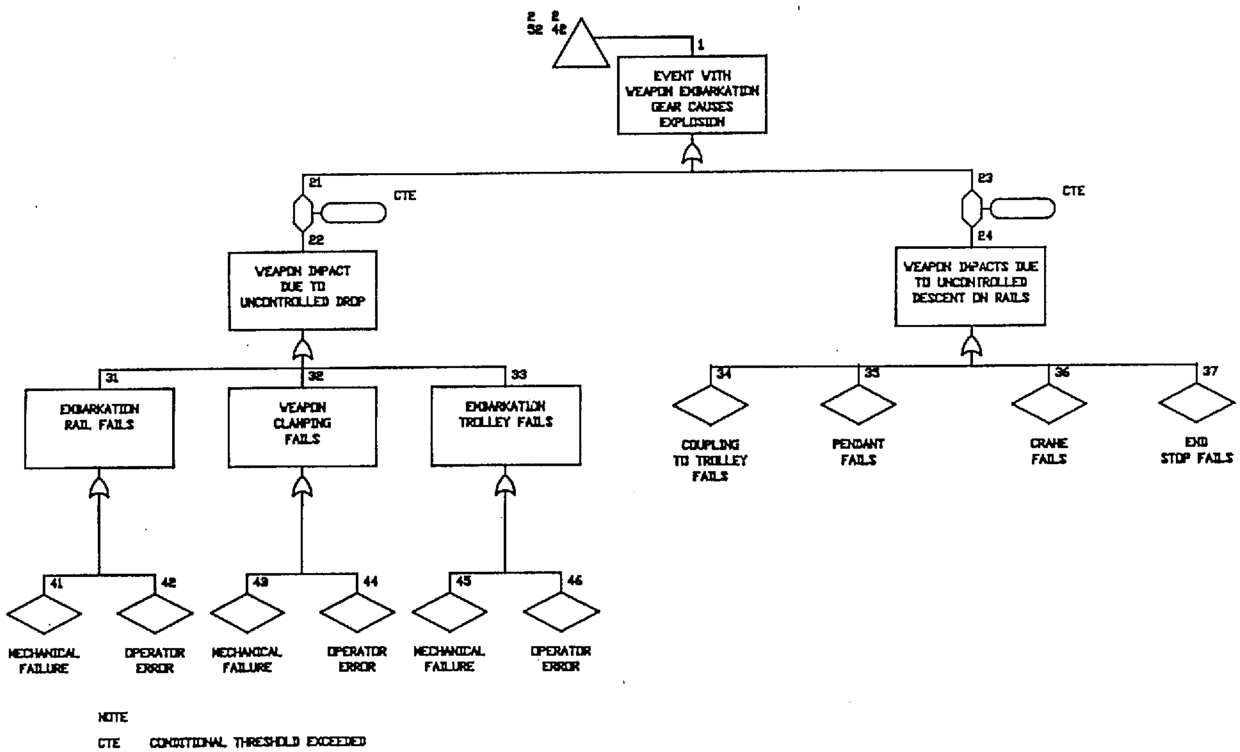

Weapon Safety Budget
Nuclear Facilities Accident
Natural Disasters
Fires
Weapon Accidents
Reactor Services
Other Accidents
Mines
Shells
Torpedoes
Missiles
Pyrotechnics
Heavy Wt Torpedo
Light Wt Torpedo

FIGURE 4



STUB PIPE WEAK
TOP5 16 JUNE
5WG9
BULKHEAD WEAKENED IN AREA OF STUB PIPE
BULKHEAD PRODUCED FROM TITANIUM OR INCORRECT TITANIUM ALLOY
STUB PIPE WEAKENED DUE TO HANDLING DAMAGED PRIOR TO COHV FITTING
WEAKNESS DUE TO MACHINING OF STUB PIPE
STUB PIPE DAMAGED DURING FITTING OF COHV
5WG19
5G5
5WG10
5WG12
SCSTUBPIPE
F=0.004
BULKHEAD WEAK POOR FORGING
ONLY STUB PIPE AREA OF BULKHEAD INVOLVED
HANDLING DAMAGE NOT DETECTED BY VISUAL INSPECTION
STUB PIPE HANDLING DAMAGE
MACHINING OF STUB PIPE REDUCES THICKNESS TO SAFETY CRITICAL LEVEL
INSPECTION FAILS TO DETECT INCORRECTLY MACHINED STUB PIPE
5G9
F3/Exxx
F=1
SC/6.2
F=0.004
SC6.1
F=0.001
SC3/7
F=0.005
SC/7.2
F=0.001

FIGURE 5



SHEET 6 - EVENT WITH WEAPON EMBARKATION GEAR CAUSES EXPLOSION