Spigot Intrusion

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Introduction

The Chief inspector of Naval Ordnance (CINO) is the Safety Approving Authority for all munitions which are embarked on HM ships. CINO therefore has to be satisfied that embarked stores are adequately safe. This is largely a question of having sufficient confidence in how a store will behave in a range of normal and abnormal environments. Simplistically the process which is gone through to acquire much of this confidence is shown at figure I.

Figure 1 - Schematic of weapon safety assessment

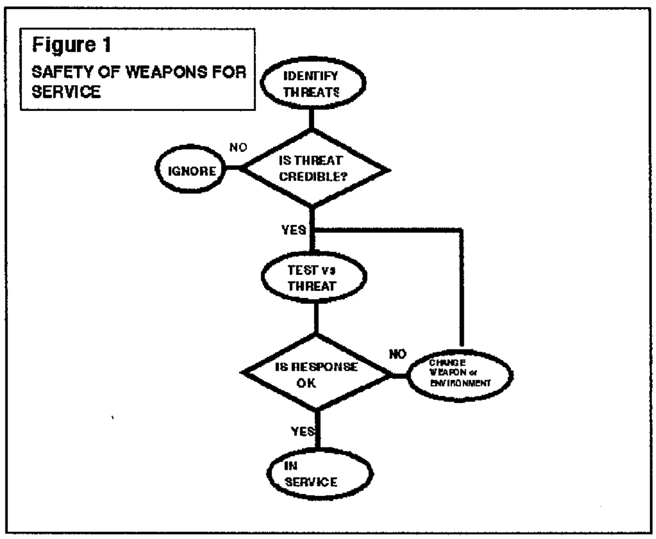

Figure 1 - Shematic of weapon safety assessment

Essentially it requires that all the threats which a munition could see throughout it's life are identified. Some will be disregarded as being incredible whilst for others the likely response will need to be ascertained. A range of tests will often be applied to establish whether the response is acceptable. If the response to the test is acceptable then all is well. If not then the store may need to be modified or redesigned to make the response acceptable. Alternatively the environment may need to be altered to eliminate or reduce the threat.

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Credible Threats

For the most part the Royal Navy utilizes the same tests used internationally in munitions safety assessments. These tests include a safety drop test which traditionally is on to a flat surface. However if we look at the way in which munitions are actually handled and stored in service the chance of an accidental drop being on to a nice clean flat surface is remote. Figure 2 shows some of the potential spigots on an ammunition lighter.

Figure 2 - Ship Ammunitioning showing ammunition lighters

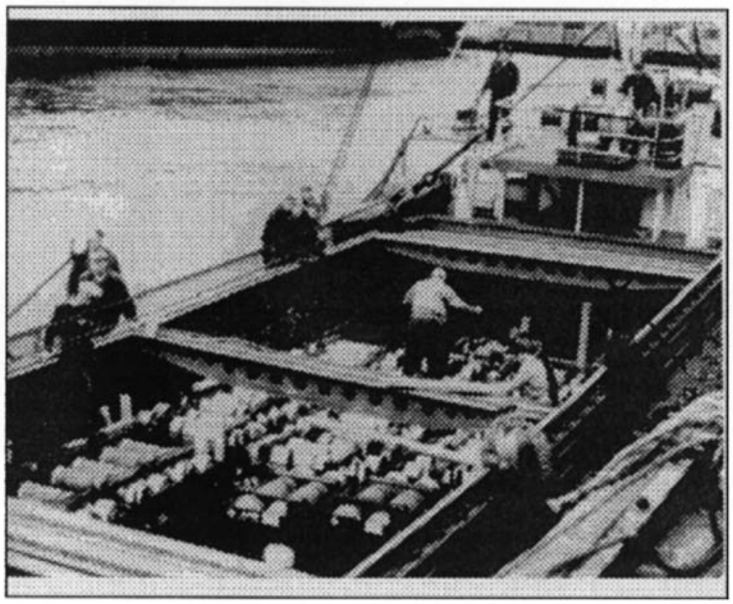

Figure 2 - Ship Ammunitioning showing ammunition lighters

These operations involve the transfer of ordnance stores from the storage depot to lighters. From the lighters stores are transferred to ships which are moored away from populated areas at buoys. Hence there are a significant number of operations involving the transfer of ordnance over dockside and ships structures. Furthermore loads involved are often pelletized loads of ammunition. Hence should a failure of lifting equipment occur the chances are that the dropping load which may have the full weight of a pallet behind it, will impact a surface which has protrusions, corners, edges but which is unlikely to be flat.

One could argue that such drops are unlikely to occur but accidents do occur. The RN accident data base reveals that over the last 15 years there have been numerous ordnance related incidents of which 40% have involved impact and drops (Figure 3). The principal causes are shown in figure 4. Many of these incidents have resulted in intrusion into the explosive filling.

Figure 3 - RN Ordnance Incidents
and
Figure 4 - RN Incident Causes

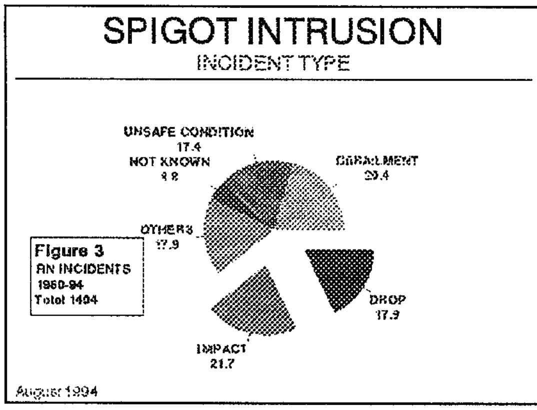

Figure 3 - RN Ordnance Incidents

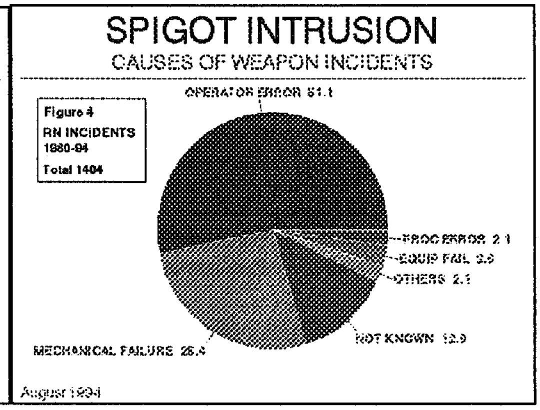

Figure 4 - RN Incident Causes

The most dramatic of these incidents involved the collision of HMS Southampton whilst engaged in operations in the Gulf Figure 5 shows the damage to the ship and to the Sea Dart missiles. The holes in the rocket motor and warhead casing show that they have been penetrated. Fortunately in this case no ignitions or explosions occurred.

Figure 5 - Damage to HMS Southampton showing missile being removed through hole in hull.

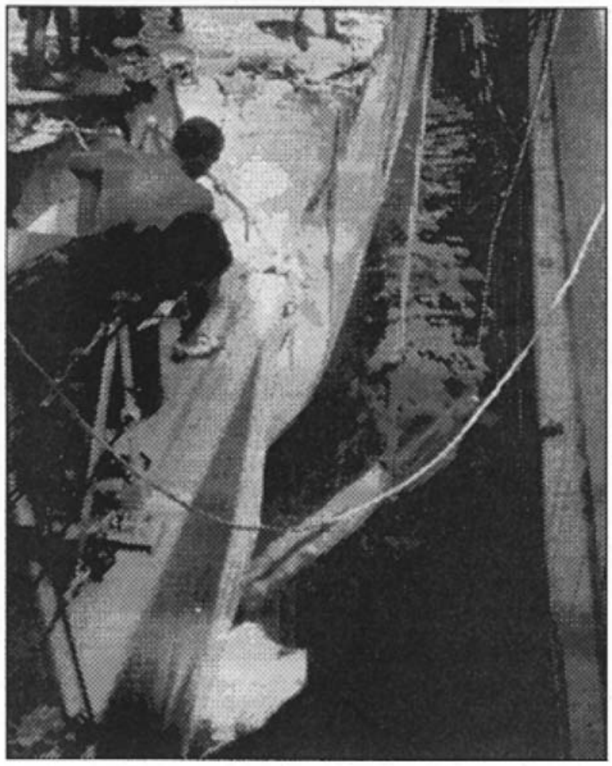

Figure 5 - Damage to HMS Southampton showing missile being removed through hole in hull.

To confidently accept stores into service we need to know in advance how explosive stores will respond in this type of credible accident. For this reason we in the Royal Navy have developed a variant of the drop test which involves intrusion of a spigot into the explosive filling.

Spigot Intrusion Trials

Because of the difficulties inherent in dropping cumbersome stores onto a spigot in a reproducible way the test geometry is reversed (Figure 6). A weighted spigot is dropped onto a static store from a series of heights to determine the response. In some cases the weight will match the weight of the bare store whilst in others it will match a ally pelletized load. More than a thousand trials have been conducted on a wide range of different stores and components including pyrotechnics, rocket motors and warheads.

The first point to make is that we see ignitions and explosions for stores which have successfully undergone conventional drop test. The second is that in some cases even modest drops produce very violent outcomes. From consideration of the drop weight and height the trials sponsors have developed empirical relationships which predict the likelihood of initiation but not the violence of the response.

Figure 6 - Spigot Intrusion

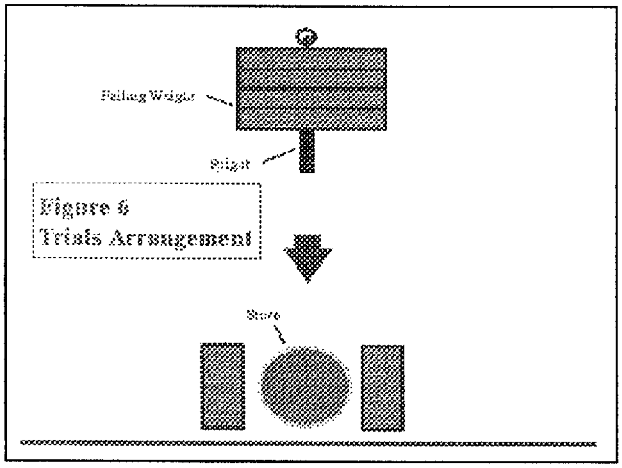

Figure 6 - Spigot Intrusion Test Trials Arrangement

This relationship is shown graphically at figure 7 and applies to a particular weapon system and configuration.

Figure 7 - Spigot Intrusion Test Results

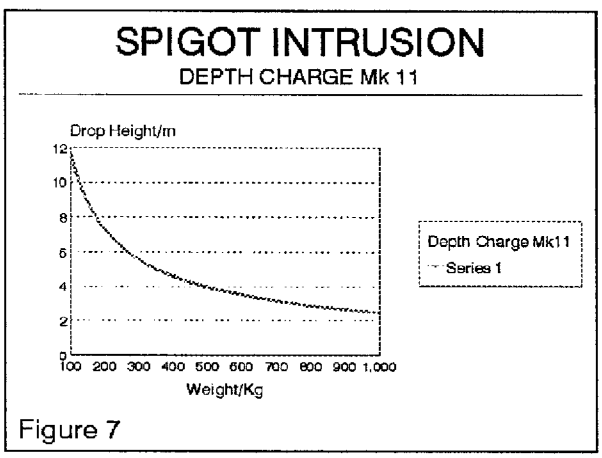

Figure 7 - Spigot Intrusion Test Results

Similar curves have been derived for other systems but generally follow the same pattern. From these weapon and component trials results a number of factors are ○thought to influence the results other than the drop height and weight.

a) Explosive Fillings

The weapons or components tested have contained different explosive fillings. They include:

I) Pyrotechnics

Reconnaissance Flare	Mg/NaNO3

ii) Rocket Motors

Extruded Double Base	NC/NG
Cast Double Base (CDB)	NC/NG
Elastomer Modified CDB	NC/NG/Elastomer
Composite Rubbery	AP/Al/CTPB
Composite Plastic	AP/PIB

iii) Warheads

Torpex	RDX/TNT/Al/Wax
Amatol	Ammonium Nitrate / TNT
EDC	HMX/RDX/TNT/Wax
PBX	HMX/Nylon

Ranking the response of the explosives alone is not possible because for these real weapon trials each change in filling usually means a change in case material. Furthermore the quality of the filling was not always known for these trials and it is believed that the presence of cracks and voids will influence the results. There is some ◦evidence to show that gassing of old fillings makes them more likely to respond violently.

b) Case Material

The nature of the case material is also a major determinant of the response. Stores with steel, titanium, aluminum cases as well as those with GRP and other non metallic stores have been examined. Generally steel cased stores appear to be more responsive compared to aluminum. The displacement of a disk of material into the explosive may contribute to the difference between Aluminum and Steel however even composite cased stores and those where no material has been detached have responded.

The thickness of material obviously has an effect in that it will prevent intrusion if it is thick and strong enough. Where there is no intrusion there is no explosion.

The effect of packaging and other forms of protection have also been explored as have the effects of case liners.

c) Spigot Shape

In real life the shape and material of an item which intrudes into an explosive store could be almost anything. Some work was therefore done to determine how sensitive the response was to the shape of the spigot. Whilst a number of objects will intrude into the store those spigots which successfully punch out a piece of case material have been found to be the most likely to cause ignition. For cylindrical spigots the diameter has been found to be important. As expected as the diameter is increased the likelihood of penetration is decreased and hence the probability of ignition or explosion is reduced. The most effective shape in causing a response is the I inch diameter steel cylinder which is now a standard part of the test.

Recent results have shown that weapons dropped on to some of the typical deck fittings shown in figure 8 ignited. Unlike the ideal test spigot the nature of damage caused to the case varied and in most cases no material was displaced to form a source of ignition.

Figure 8 - Typical Deck Fittings

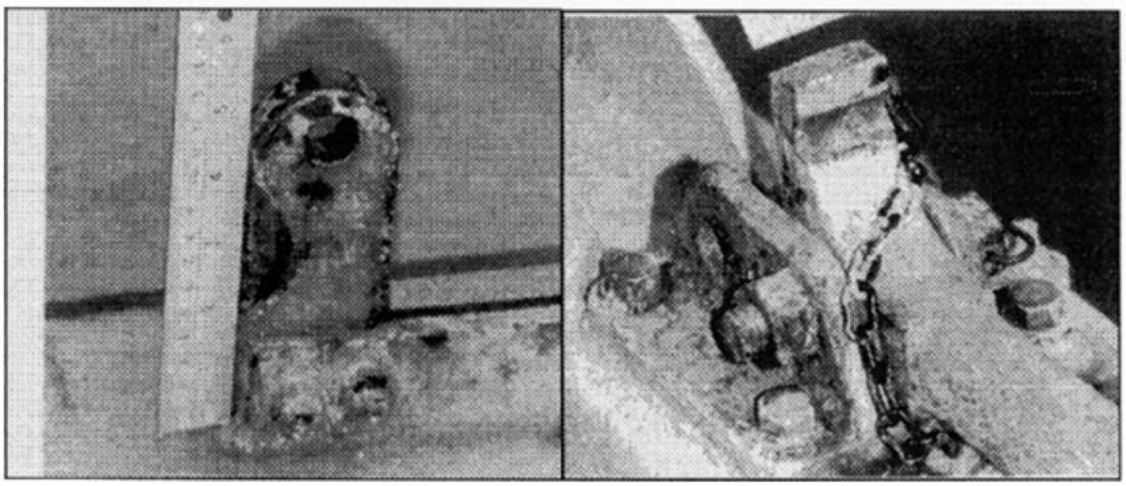

Figure 8 - Typical Deck Fittings

In summary the trials have been useful in helping the weapon safety authorities decide whether stores are suitable for service. The empirical relationship which showed the way in which the response increased with drop height provided confidence that so long as a weapon survived a test drop it would survive all lesser threats.

Unfortunately some recent trials have shown some unexpected and worrying exceptions to this rule. A development warhead was tested at drop heights of 10 meters and 1.75 meters. In the former case the warhead ignited and burned whilst in the latter a high order explosion occurred. The high order event from a height equivalent to the back of a truck has eroded the confidence of the safety authorities. For the warhead in question it has prevented its introduction to service.

Other results have also shown that the highest drop heights do not necessarily bring about the worst response. The results from a GRP cased underwater weapon are shown in Figure 9.

Figure 9 - Spigot Results Showing Slight

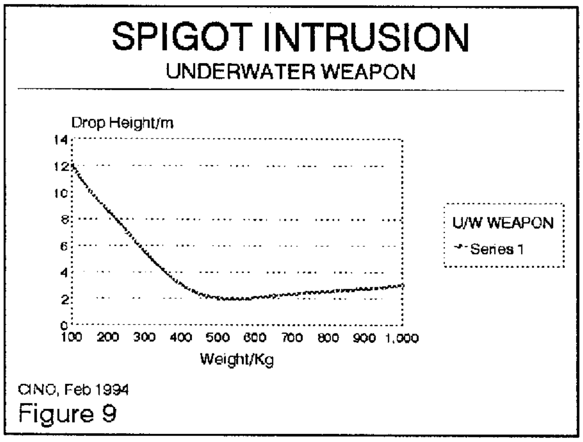

Figure 9 - Spigot Results Showing Slight Decrease in Responsiveness with Increasing Height

This recent experience has underlined that our understanding of the mechanisms at play is inadequate. This is because real in-service stores have been used in trials and only in-service case/filling combinations have been available to test. It has therefore not been possible to look at the effect of case material or other parameters in isolation. Furthermore because these were large scale field trials the quality of trials data and extent of the instrumentation was not adequate to support a mechanistic model. For this reason CINO has instigated some experimental studies in order to acquire a better understanding of the relationship between the stimulus and the response.

Experimental / Theoretical Studies

DRA Fort Halstead

There are several elements to these studies. The first involves the work using a fully instrumented experimental facility at DRA Fort Halstead. The experimental spigot rig shown at figure 10. has been used to characterize the response of various fillings to spigot attack.

Figure 10 - DRA Fort Halstead Spigot Intrusion Facility

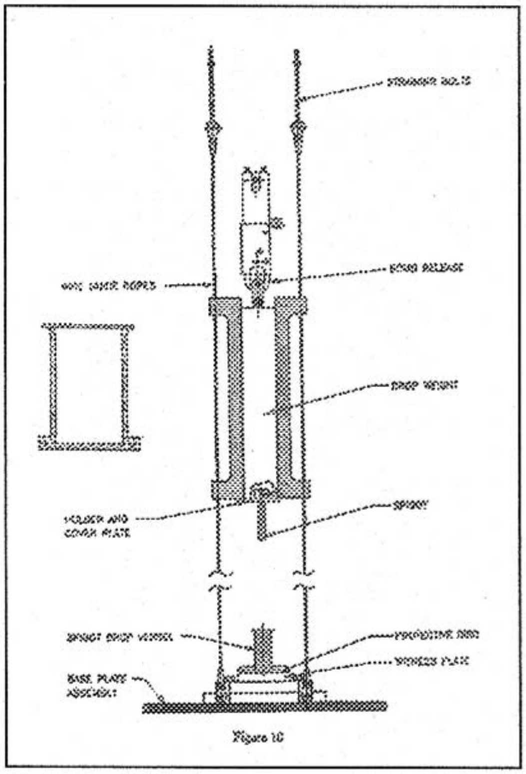

Figure 10 - DRA Fort Halstead Spigot Intrusion Facility

A programme of work has commenced to look in more detail at each of the factors which influence the results of the tests. Some preliminary results at table 1 show the response of a number of different fillings to a fixed weight spigot falling from a variety of heights. In each case the test sample construction is identical with a steel cylindrical case and steel end plate. A further range of explosive fillings is currently being examined. It is also intended to look at the way in which different case materials effect the results.

Table 1

Materials	Approx Composition	Median Ignition Height
Propellants:		
EDB unfilled	NC/NG	1.2m
CDB unfilled	NC/NG	1.3m
EDB filled	NC/NG/Nitramine	1.1m
CDB filled	NC/NG/Nitramine	0.6m
EMCDB unfilled	NC/NG/Elastomer	0.7m
EMCDB	NC/NG/Elastomer/RDX	0.7m
Composite unfilled	AP / Al / HTPB	0.8m
High Explosives:		
Torpex	RDX/TNT/Wax	>6.8m
PBX	HMX / Nylon	1.0m
EDC	HMX / RDX / TNT / Wax	2.7m

Table 1

RMCS Shrivenham

Work at RMCS is concentrating on the interaction between the case material and the impacting spigot. Preliminary work here has shown that for steel cased stores the metal disk displaced reaches temperatures above 900 degrees Celsius. This hot disk is thought to contribute to the thermal initiation of the store. The more ductile aluminum cased stores do not show the same adiabatic shear heating shown by steel. Much of this work was carried out using inert fillers so that such that evidence from the impact with the weapon is retained.

More recently a drop weight facility illustrated in figure 11 has been used to examine the way in which various metallic and non metallic case materials behave under impact conditions. Water jet cutting is also being used to examine sections taken through explosively filled stores which have not ignited to see what evidence can be found of melting or incipient ignition.

Figure 11 - RMCS Drop Weight Testing

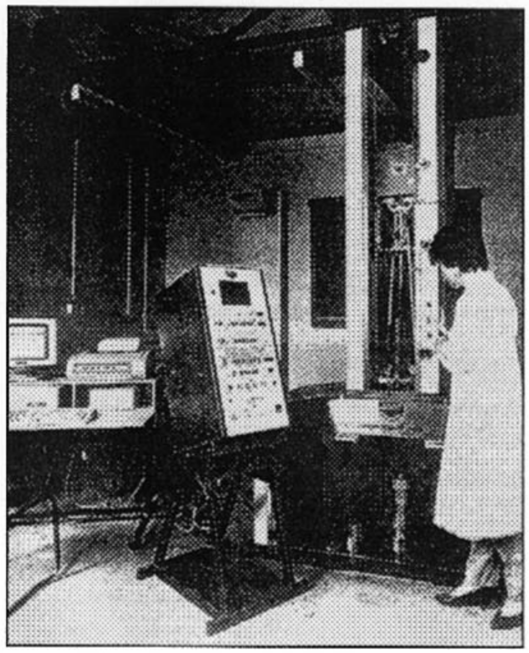

Figure 11 - RMCS Drop Weight Testing

Imperial College London

Finite element modeling at Imperial College London has been used to calculate the pressure time history at selected points near to the point of impact of a HE filled shell. Some typical results are shown at figure 12 for pressure and figure 13 for temperature. To date modeling has not included intrusions into the store but it is planned to extend the scope of the model.

Figure 12 - Pressure vs time plot **Figure 13 Temperature vs time**

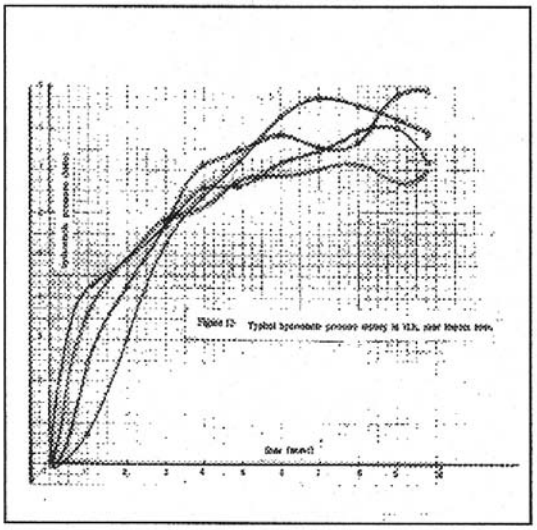

Figure 12 - Pressure vs time plot

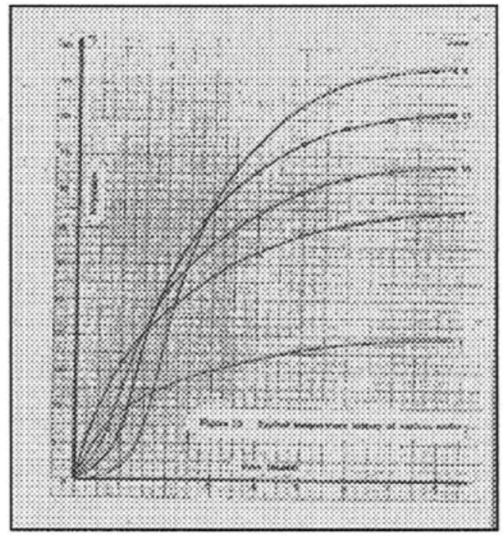

Figure 13 - Temperature vs time

Cavendish Laboratory

A research programme which looks at the interaction between the spigot and the explosive is commencing at Cambridge in the next few weeks. It is anticipated that this will utilize high speed photography and thermal imaging to identity the mode and sites of ignition. Some recent work on impacts on gun propellant have shown the formation of hot spots around the voids in the propellant grain (Figure 14).

Figure 14 - Cavendish Labs Propellant Impact Rig

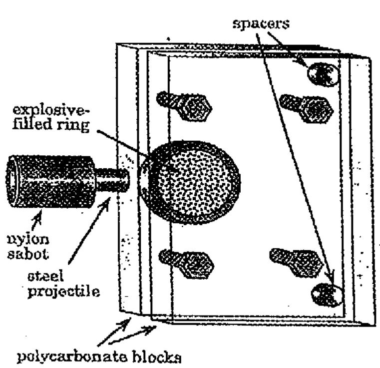

FIGURE 2. SCHEMATIC DIAGRAM OF THE TARGET ARRANGEMENT.

Figure 14 - Cavendish Labs Propellant Impact Rig

Conclusions

There has been some speculation over the mode of initiation but there is a growing consensus that thermal initiation is the likely cause. This is consistent with the trials and experimental evidence so far obtained. The comparatively long induction time between impact and ignition and the contribution from the hot disk are consistent with this view. The subsequent violence of the event will depend on factors such as confinement and filling damage.

However is not the purpose of this paper to draw conclusions about the mechanisms but to illustrate that in accident scenarios there is a mode of ignition of ordnance stores which is credible, unpredictable and not well understood. Some of the proposed work described should throw some light on this problem and it is hoped that the results can be reported at the next seminar.

Acknowledgment

This paper reports the work of numerous colleagues over more than ten years. In particular the contributions of Ron Marshall at CINO for his trials work, Dave Mullenger at DRA(FH) and Alan Bailey at RMCS for their experimental work have been invaluable.