INSENSITIVE MUNITIONS
UNDERSTANDING THE RISKS, REAPING THE BENEFITS

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ABSTRACT

Risk is defined as the combination of the frequency, or probability, and the consequence of an accident. Insensitive Munitions (IM) are defined as those which minimise the probability of inadvertent initiation and severity of subsequent collateral damage. Thus, put simply, IM are munitions which minimise risk. But how well does the safety assessment community address IM in terms of risk? The paper explores the current approach taken by the UK munitions community and argues that whilst munition IM signatures are now well characterised, the probability of inadvertent initiation is not assessed nor does IM testing attempt to collect detailed data on collateral damage. The paper explores how both these deficiencies could be overcome and proposes improvements which would enable a more objective assessment of the reduced risk presented by IM.

With a better understanding of how IM reduce risk, it would then be possible to identify and articulate the resulting benefits in a way which could influence the decision makers, particularly when making difficult choices over investment in IM. Based on studies carried out for the UK MOD, the paper outlines a range of operational, safety and logistic benefits which accrue from IM and discusses ways of quantifying them. Whilst a number of sophisticated cost benefit tools are now available, in many cases it may be possible to quantify the benefits more simply, and the paper proposes a protocol to guide the thought processes of those doing such analyses.

The paper concludes that whilst the munitions community has made enormous strides in developing and delivering IM, little progress has been made in quantifying the reduction in risk and understanding how this impacts the logistic and operational scenarios. If we are to reap the full benefits of the safer inventory which IM will provide, we must start to address these issues now.

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Introduction

Insensitive Munitions (IM) are defined as those which minimise the probability of inadvertent initiation and severity of subsequent collateral damage when subjected to unplanned stimuli, whilst delivering the required performance[1]. Since risk is defined as the combination of the frequency, or probability, and the consequence of an accident[2], IM can be defined more simply as munitions which minimise risk. However, the IM assessment process rarely, if ever, considers a munition's IM characteristics in a way which enables informed evaluation of how the munition minimises risk. The IM assessment process evaluates IM in terms of level of response to selected credible threats. The 7 IM tests in STANAG 4439 encompass the principal accident and hostile threat scenarios, address key response mechanisms such as SDT and DDT, and provide a well-established baseline for assessment. The NATO response level classification system, although by no means a perfect scale and open to subjective interpretation, provides a universally accepted threshold against which achievement of IM requirements can be demonstrated and measured and a means of measuring and comparing improvements in IM characteristics. AOP-39 makes clear that IM assessment should not rely solely on the results of a few full-scale tests but should make use of the full body of evidence including relevant information from energetic materials characterisation, small scale and component level tests, modelling and read across. Using this approach, as is done in the UK by MOD's IM Assessment Panel, IM assessment can be considered to be as comprehensive and rigorous as possible and there should be good confidence in the resulting munition IM signatures which are assessed.

However, IM assessment does not normally extend beyond this point. The assessment process characterises how a munition will react when it sees a specified threat. But it does not assess, measure or quantify the associated risks or how a particular IM minimises risk. It must be emphasised that at this stage the assessment process is addressing munition-specific characteristics in terms of behaviour when exposed to a particular threat, not the probability of seeing that threat, which is addressed later in this paper. Nor does the assessment process assess, or even attempt to assess, how IM minimise the probability of inadvertent initiation, despite this being the first half of the definition of IM. But should it be? Implicit in a munition's IM signature is the expectation that it will react (inadvertently initiate) at the assessed response level whenever it sees a particular threat. So whilst an IM will react with a lower order event than a non-IM, it is not true to say that an IM minimises the probability of that event. This is perhaps the Holy Grail which, in the longer term, IM technology should be seeking: munitions which are unlikely to react at all when exposed to IM threat stimuli. Then the probability of initiation will indeed have relevance.

IM assessment today concentrates on the second half of the definition of IM, minimising the subsequent collateral damage. But even here, the assessment

[1] STANAG 4439
[2] Def Stan 00-56

process is weak. We assess by reaction type, not by severity of collateral damage. Whilst, for a specific munition, the higher the order of response, the greater will be the blast, fragmentation and heat, these outputs are munition specific. A Type IV deflagration of a 1000 lb bomb will result in significantly greater collateral damage than the Type I detonation of a box of grenades and yet we would say that the bomb is far closer to IM compliance. A Type V IM-compliant response from the very large boost motor of a ship-launched missile may still have devastating consequences in some circumstances. At present, IM assessment does not measure output in a way that can usefully be related to collateral damage. Collateral damage will also be highly relevant to Hazard Classification, particularly for munitions classified as HD 1.2.3 (Unit Risk). In summary, although the IM assessment process to assign an IM signature is robust and comprehensive, it neither attempts to measure the probability of inadvertent initiation nor does it measure collateral damage.

IM Assessment and Risk

The challenge is to create a closer link between IM assessment and risk, so that the information from IM assessment can provide a key input to the subsequent risk-based munition safety assessment. This is also essential if IM assessment is to be a fully integrated element of munitions safety assessment rather than a stand-alone, stovepiped activity.

The first question is whether greater effort should be made to attempt to quantify the probability of initiation of different energetic materials. Such information would provide an intrinsic component of risk which should be of help to munition designers in selecting energetic materials for IM solutions. However, even if it was possible to obtain meaningful probabilities, would this information be of use? It is only one factor in what should be a systems approach to achieve IM. Munition design, packaging and mitigation measures will all affect both the probability of initiation and the subsequent level of response. From a munitions safety standpoint, it makes more sense to assume that if a munition sees a threat, it will react, with a probability of one. The IM signature for a munition represents an assessed worse case scenario; the munition will not produce a higher order response for a particular threat than that shown in the signature; there are no probabilities involved. Thus the assessment of a munition’s IM signature should be deterministic, not probabilistic; probabilities have no place in the assessment of an IM signature.

Where probabilities do have an important role to play is in terms of being exposed to each of the individual IM threats. For some threats, such as a fire in storage depot, a helicopter crash on deck and a vehicle accident or fire, there is a considerable body of historical data which can be used to derive representative probabilities. For other threats, such as exposure to combat threats, the data may be very limited or not exist at all and judgement will have to be used. Probabilistic risk assessment is a standard aspect of current safety assurance practice and it is essential that those responsible for IM assessment engage with those responsible for risk-based safety assessment to ensure that the relevant IM information is appropriately fed into their calculations; it is at this stage that the probability of exposure to the threat and the subsequent level of response should be considered throughout the munition life cycle to ensure that risks are tolerable and ALARP. However, in order to fully evaluate the risks posed by the reaction of a munition, some measure of the output and collateral damage will be needed.

Collateral Damage

Although IM are defined to minimise the severity of collateral damage, IM tests do not measure collateral damage. The data collected are used principally to determine the type of response, ranging from detonation to burning. Whilst some of these data may also provide some indication of likely collateral damage, such as the size and distance that debris might be thrown, they are seldom used in any quantifiable way, nor do they provide a complete picture. This was recognised in the 1997 NIMIC Workshops on IM Testing when the proposal was made to measure blast, heat flux and fragment throw at set distances from the test item to quantify output against a standard scale. It was recognised that there would be a continuing need to categorise the Type of response using the NATO Type I to V response descriptors and the test procedures would remain unchanged. However, it was proposed that tests should include additional instrumentation to gather extra data specifically to inform an assessment of collateral damage. This proposal received strong support in the final plenary session of the workshop but eight years later, they have yet to be taken forward. Until this issue is addressed, expensive IM tests will continue to gather only a fraction of the data needed and it will not be possible to quantify collateral damage. For a comparatively small investment in the extra instrumentation required, so much more useful information could be obtained.

Measurement of collateral damage would offer significant benefits in informing risk-based safety assessment. Armed with knowledge of the probability of experiencing the appropriate threats across the munition life cycle, the assessed level of response from the munition's IM signature and the associated output in terms relevant to assessment of collateral damage, the safety assessment community would then be in a position to make a more informed and objective assessment of risk and be better placed to identify appropriate measures to mitigate those risks to an acceptable level.

Articulating the Benefits of IM

With a better understanding of how IM reduce risk, it should then be possible to identify and articulate the resulting benefits in a way which will help to inform and influence the decision makers, particularly when making difficult choices over investment in IM, both in terms of developing the enabling technology, for example for gun propellants, and for specific munitions. In particular, with shrinking defence budgets, spend to save measures such as IM upgrade programmes frequently become casualties of the financial review process. If the benefits which IM can offer, both operational and logistic, can be explained and quantified, the decision makers may be in a better position to support IM improvement and upgrade programmes. IM upgrades will continue to be a key aspect of the UK's IM Implementation Strategy for some years to come given the size of the legacy munition inventory and the lack of IM compliance of many of these legacy munitions. If progress is to be maintained and, as new technology becomes available, the risks associated with these legacy munitions maintained as ALARP, it is essential that upgrades are approved and implemented when opportunities arise. The same will be equally true for other nations seeking to improve the IM characteristics of their legacy munitions inventories.

When considering the benefits of IM, there are 2 separate issues: the direct benefits of improved safety; and the consequent benefits associated with greater flexibility in storage, transportation and use. Without doubt, the most significant benefit is the increased safety and the reduced probability of a catastrophic event resulting from an accident or hostile action. Cost Benefit Analysis tools are available, such as the MSIAC-developed CBAM which takes a probabilistic approach to evaluate, cost and compare the benefits associated with safer munitions based on the reduced damage and loss of life in accident situations involving IM. CBAM is a well-designed, comprehensive tool, ideal for investigating trade-offs and benefits between options in major new munitions programmes. However, the complexity of conducting a comprehensive cost benefit analysis makes it less suitable for evaluating benefits in legacy upgrade programmes where the issue is more usually not about choosing between competing IM options but simply whether to choose the IM upgrade option or to continue to procure the existing non-IM design.

It can be difficult to present a convincing case to the decision makers to invest in IM when major accidents due to lack of IM characteristics have been extremely few in number and there is little data on which to base any estimate of likely probability. Those few major accidents that have occurred, such as Forrestal and Camp Doha, have been well documented, as have near misses. The last major munitions accident in the UK was the loss of the Naval Armament Vessel 'Bedenham' in Gibraltar in 1951, over half a century ago. What is not in dispute is that any major accident involving non-IM munitions is likely to have catastrophic consequences. It does not require probabilities to work this out and indeed, had a probabilistic risk assessment been carried out, would either the Forrestal or the Camp Doha accidents have been identified as risks which needed to be managed?

The consequent benefits associated with greater flexibility in storage, transportation and use of IM may not be as dramatic as those associated directly with safety but may provide a more convincing case in that the benefits are tangible. Much of the work has already been done. In the UK, between 1998 and 2001, the MOD commissioned a series of studies into the operational and logistic benefits of IM. These were the subject of papers presented at the 1999 and 2001 NDIA IMEMTS[3][4] and at the NIMIC Workshop on Cost Benefit of IM held in Sweden in 2001, the proceedings of which provide an authoritative compendium of information. At that time, the HD 1.2.3 Hazard Division for munitions which satisfy the STANAG 4439 IM criteria was

[3] Insensitive Munitions and their Impact on Logistic Costs, A S MacKichan, Charlcombe Associates Ltd.
[4] The Logistic and Operational Benefits of IM, A S MacKichan, Charlcombe Associates Ltd.

only a proposal; today it has become reality. Within the UK, Storm Shadow is the first weapons system to be assigned to HD 1.2.3, effectively a 'Unit Risk' classification. Thus the potential benefits from the reduced quantity distances and more flexible transportation regulations associated with improved Hazard Classification are no longer an aspiration, they exist today.

The operational and logistic benefits associated with improved Hazard Classification are very situation specific and may be significant or may be trivial. For example, for depot storage in the UK where there is ample HD 1.1 storage available, reduction in HD is likely to yield few benefits other than, perhaps, improved flexibility in choice of storage location. In contrast, the reduced HD of non mass-detonating weapons may have a highly significant benefit for the storage, handling and carriage of munitions at crowded coalition airfields. There are potential benefits for loading and offloading munitions onto naval platforms, and an easing of the problems associated with berthing ammunitioned warships in UK naval ports. There is also potential for easing constraints imposed on the handling of certain munitions to protect against the possibility of sympathetic reaction. It is essential that these benefits are expressed in terms that will have the greatest meaning to the decision makers, in particular demonstrating any improvements in operational flexibility and increased operational tempo. Many of the operational and logistic benefits can be quantified quite simply without the use of a complex model; all that is needed is a protocol to guide the thought processes of those doing the analysis. An example of a simple draft protocol developed for the UK MOD is attached.

Conclusion

The munitions community has made enormous strides in recent years in developing and delivering IM. However, rather less progress had been made in quantifying the reduction in risk and understanding how this impacts the logistic and operational scenarios. If we are to reap the full benefits of the safer inventory which IM will provide, we must start to address these issues now. In particular, the collateral damage associated with the response of a munition should be assessed as a standard element of IM full-scale testing and this information should then be fed into both the subsequent munition safety assessment and an evaluation of the consequent operational and logistic benefits. IM assessment is not a stand-alone activity but an integral part of munition safety assessment. It is time that we made it so.

OPERATIONAL, LOGISTIC AND COST BENEFITS OF INSENSTIVE MUNITIONS
EXAMPLE OF A SIMPLE PROTOCOL

Ser No	MTDS Activity	Potential Benefit	CBA Approach
2	Transport by road	Munitions are routinely transported by road at various stages of the life cycle. Quantity of munitions per vehicle is determined as a NEQ limit which is governed by Hazard Division, Compatibility Group, Type of Vehicle (Ordinary Goods Vehicle (OGV) or Special Goods Vehicle (SGV) and bulk out considerations. Most road transport is by OGV.	▫ On what occasions will the munition be transported by road? ▫ What is expected method of transport: OGV or SGV? ▫ Does lower Haz Class allow increased quantity per load? ▫ If so, how many journeys are saved per year and what is the cost saving?
3	Storage at Depot	Benefits in depot storage are situation-specific and will depend on factors such as storage volume and explosive licence limit, stacking and access restrictions. Frequently HD 1.1 stores bulk out before the licence limit is reached; in such cases a lower HD will not offer any increase in capacity. However, lower HD may provide opportunity for improved use and optimisation of existing storage. If new build is planned, lower HD should result in reduced construction costs.	▫ Is munition to be stored at existing depot facilities or is new build planned? ▫ Does lower munition HD allow improved use and optimisation of storage facilities? ▫ Does improved use/optimisation allow existing facilities to be taken out of use, improved handling on site, reductions in manpower? ▫ Is new build planned? If so, what are cost savings compared with construction of equivalent HD 1.1 facilities?
5	Transport by Rail	For carriage of munitions by rail, there are limits on the maximum NEQ in any group of adjacent containers or wagons, a minimum separation distance between groups of containers or wagons, and limits on the NEQ in individual wagons.	▫ Is the munition transported by rail? ▫ Does the lower HD offer any benefits? Eg: ▫ No requirement for separation distances and buffer wagons? ▫ Increased flexibility in parking of wagons at loading and unloading point?
6	Transport by Air	Whilst there are no limits for the NEQ that can be carried on an aircraft, the limiting factor is the Explosive Licence Limit (ELL) of the relevant aircraft parking area at the air base. These are often small and may require other facilities on base to be vacated whilst explosives are present at the parking area. The reduced Q-D requirements of HD 1.2 may allow greater quantities of munitions to be handled and loaded at any one time and may ease or remove the requirement to vacate nearby buildings. At crowded deployment airfields overseas, there is likely to be greater flexibility in the offloading of munitions in terms of quantity, location and constraints.	▫ Is the munition likely to be transported by air? ▫ If so, what are the potential benefits from lower HD? ▫ Can a greater quantity of munitions be loaded/offloaded and transported at any one time? ▫ If so, what is the typical cost saving for a deployment based on the reduced number of air transport sorties required? ▫ Is the choice of location for loading/offloading improved? ▫ Are current constraints, such as the need to vacate nearby on-base facilities, removed?

7	Transport by Sea	Munitions are routinely transported by sea both in RN ships and in commercial ships (eg ammunition re-supply to BATUS, Canada). Berth licence limits can be restrictive both at military facilities and at commercial ports. The lower HD of IM-compliant munitions may offer increased flexibility in the loading and offloading of munitions for sea transport.	▫ Is the munition likely to be transported by sea? ▫ If so, what are the potential benefits from lower HD? ▫ Can a greater quantity of munitions be loaded/offloaded at any one time?
8	Storage in Theatre – Field Storage	The lower Hazard Division of IM-compliant munitions offers increased flexibility in field storage of munitions. Quantity distance requirements for HD 1.2 are significantly less than those for HD 1.1	▫ Will the munition be stored in field storage? ▫ What benefits can be obtained from the reduced Q-D requirements and the smaller Q-D footprint? ▫ Do the reduced Q-D requirements allow mitigation features (eg Hesco Bastion traversing) associated with HD 1.1 storage to be eliminated? ▫ If so, what is the cost saving?
9	Storage in Theatre - Airfield	The lower Hazard Division of IM-compliant munitions offers increased flexibility in storage of munitions at overseas deployment airfields. Quantity distance requirements for HD 1.2 are significantly less than those for HD 1.1, with the potential to offer increased flexibility in siting storage areas, storage of larger quantities of munitions and removal of the need for blast protection and traverses	▫ Will the munition be stored at overseas deployment airfields? ▫ What benefits can be obtained from the reduced Q-D requirements and the smaller Q-D footprint? ▫ Will the reduced Q-D requirements allow improved siting of the storage area? ▫ Can a larger quantity of munitions be stored? ▫ Do the reduced Q-D requirements allow mitigation features (eg Hesco Bastion traversing) associated with HD 1.1 storage to be eliminated? ▫ If so, what is the cost saving?
10	Parking of Armed Aircraft	The lower Hazard Division of IM-compliant munitions, which eliminate the risk of mass propagation, offers increased flexibility in parking of armed aircraft at overseas deployment airfields, allowing reduced separation distances and removal of the need for blast protection and traverses.	▫ If the munition is air-launched, will it be deployed to overseas airfields? ▫ What benefits result from the reduced risk due to IM-compliance? ▫ Are there benefits to aircraft parking, loading/offloading and arming arrangements? ▫ Do these benefits improve the operational tempo? ▫ Do the reduced Q-D requirements allow mitigation/protection features (eg blast screens, Hesco Bastion traversing) to be eliminated? ▫ If so, what is the cost saving?
11	Naval Munitions – Storage on Board	By removing the mass propagation hazard associated with HD 1.1 munitions, IM may offer increased flexibility in the storage of munitions on board RN ships, and may allow munitions to be stored closer to the point of use. IM will also remove the need for blast mitigation between munitions to prevent propagation.	▫ Is the munition stored on board RN ships? ▫ If so, consult STG to determine whether there are benefits to be gained from the removal of the mass propagation hazard, eg greater storage flexibility, removal of need for barriers.

12	EMF Munitions – Carriage on RN Ships	Many munitions in the EMF inventory have historically been IM non-compliant and HD 1.1. For carriage aboard RN ships, special barriers and mitigation may be required to reduce the risk of mass propagation. IM remove the blast propagation hazard and the need for mitigation. Sea Technology Group (STG) can provide specific guidance.	▫ Is the munition an EMF store carried aboard RN ships? ▫ If so, consult STG to determine whether there are benefits to be gained from the removal of the mass propagation hazard, eg removal of need for barriers.
13	Vertrep	Vertrep is only permitted if the munition gives a Type V response to Fast Heating (IM-compliant) and does not react in less than 6 minutes (not an IM requirement). Many non-IM compliant munitions are banned from Vertrep.	▫ Is Vertrep required? ▫ Does the munition satisfy Vertrep requirements? ▫ What are the operational benefits from being able to Vertrep this munition?
14	Ammunition-ing of RN Ships	Ammunitioning of RN ships is undertaken at specially designated berths, jetties and buoys which are subject to Q-D licensing. Whilst some limits are very generous, where licence limits are low, reduction in Haz Class to HD 1.2 may offer increased flexibility in the quantity of munitions able to be handled at the jetty or remove the need for the ship to be moved to a buoy and loaded from a lighter. In cases where special protective measures have to be provided, HD 1.2 will remove the need for such measures.	▫ At which licensed facilities will the munition be loaded aboard RN ships? ▫ Consult licensing authorities to establish whether reduction in Haz Class offers any benefits in ammunitioning.
15	Operational Constraints	Some current munitions have associated constraints because of non-compliant responses to IM stimuli.	▫ Are there any operational constraints associated with the munition which this munition replaces and do the IM characteristics allow the constraints to be removed? ▫ If so, what are the benefits? ▫ More munitions on the flight deck? ▫ Increased operational tempo?
16	Munition Life	PBX fillings in IM warheads have better mechanical properties than traditional TNT-based fillings and are expected to age better with reduced defects and in service surveillance requirements. Consult DOSG ST to establish whether the munition has the potential for a longer life than a non-IM equivalent.	▫ Will the energetic materials used in the munition design provide improved life compared to the non-IM equivalent? ▫ Can a mid life update to replace life-expired energetic materials be avoided? ▫ Will there be reduced requirement for in-service surveillance? ▫ What cost savings can be expected from improved life-related qualities?

17	Demil	What are the Demil implications of the IM filling and do these offer advantages or savings compared with the non-IM equivalent? Are there any green issues or requirements associated with Demil which the IM filling satisfies?	▫ What are the Demil requirements for this munition? ▫ Do the energetic materials used to achieve IM compliance offer any advantages over the non-IM equivalent? ▫ Can the energetic materials be recycled or re-used? ▫ What are the cost savings of any benefits or of recycling/re-use? ▫ Are there any green issues or requirements which the munition satisfies compared to the non-IM equivalent?
18	Other	The examples listed here are not exhaustive and there may well be additional areas, specific to each munition, in which IM and lower Haz Class offer benefits.	▫ Identify any additional areas specific to the munition under consideration in which IM and lower Hazard Classification have the potential to offer cost, logistic and operational benefits.