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FINAL REPORT OF NIAG SG.173 ON LOW COST GUIDED MUNITIONS CONCEPTS

Note by the NIAG Secretary

1. Enclosed is the Study Report on Low Cost Guided Munitions Concepts, conducted by NIAG **SG.173**, which is now published and distributed to the Sponsor Group.

(signed) Nathalie Van Donghen

1 Enclosure

Original: English

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FINAL REPORT

NATO INDUSTRIAL ADVISORY GROUP, SUB GROUP 173
(NIAG/SG-173)

LOW COST GUIDED MUNITIONS CONCEPTS STUDY

May 2014

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LOW COST GUIDED MUNITIONS CONCEPTS STUDY

1 INTRODUCTION

This document and the accompanying CD-ROM comprise the Final Report of the NIAG Sub-Group 173 (NIAG/SG-173) of analysed, low cost concepts for guided munitions for indirect fire suitable for member and partner nations of NATO.

This Study was sponsored by NATO Artillery Armaments Group (NAAG), Integrated Combat Group Indirect Fire (ICG IF). The Point of Contact POC/1, Mr. Joakim Lewin, from Försvarets Materiel Verk (FMV), Sweden and ICG IF Vize-Chairman, Mr. Bob Dombrowsky from the Army Research Development and Engineering Center (ARDEC), US, who participated as appropriate, in NIAG/SG-173 meetings to provide technical and business direction.

1.1 Purpose

This Final Report provides an overview of the work performed, the conclusions and recommendations reached by NIAG/SG-173.

1.2 Background

Over the last decade the ICG IF and several nations have identified the need for increased precision when using indirect fire. Some munitions have been developed and some are in development. Examples are:

- GMLRS rocket
- 155 mm EXCALIBUR and VULCANO
- Course correcting fuzes (CCF) for
  - 105 mm ECF
  - 155 mm SPACIDO, PGK, ECF
  - 81 mm and 120 mm mortar systems

Most of these systems rely on GPS access for navigation. SPACIDO is based on radar tracking and uplink command. For pin point accuracy of guided munitions SAL or FarIR Sensors can also be integrated.

The most important reasons for developing munitions with better precision have been:

- Better efficiency, i.e. same or better lethality with less rounds fired
- First round effect on target
- Reduced logistic burden
- Reduced risk for collateral damage

The total cost for the existing precision munitions are high. The total cost can be defined as:

- Development cost
- Qualification cost
- Production cost
- Procurement cost
- Training cost
- Storage cost
- Cost at the higher system level (personnel, launcher, tracking radar etc.)
- Cost for government program management
- Demilitarization cost
- ➪ Summarized as life cycle cost (s. Annex D)

1.3 Scope and Objectives

The goal of this study is to identify low cost concepts for guided munitions for indirect fire suitable for Member and Partner nations of NATO.

Based on ICG IF, the current intention for the study is to address two sections, which have influence over the lifecycle costs associated with guided munitions. One section is the technical solution; the other is associated to the cost, with perhaps a greater potential of cost savings, of current and innovative ways to do business.

The study shall primarily address:

- Cost elements building up to the total life cycle cost in a multinational co-operative program.
- Innovative ways to develop, procure and maintain a capability for indirect fire guided munitions; within a context where NATO Member and Partner nations cooperate.

2 GENERAL ISSUES

2.1 Joint Programs – multinational; harmonization

The primary approach for governments to procure guided missiles and munitions until now has been for each country to produce a requirement, oversee a competitive development program, conduct a qualification effort and subsequently procure, store and use or demilitarize the munition.

However, over the past 20 years several cooperation models have evolved to develop, produce and manufacture precision munitions. These models have ranged from nations agreeing to cooperate on a program, commercial Joint Ventures between companies, and government funded concept/ product development programmes. Table 1 summarizes some known cooperation models:

Table 1 Cooperation Model Examples for Precision Munitions

Program	Partners	Description
Excalibur Block 1	United States/ Kingdom of Sweden	KOS joined US during the development to merge the Trajectory Corrected Munition (TCM) program with Excalibur. Commercial agreements were made between the US Prime (Raytheon Missile Systems) and Bofors for work share.
Vulcano	OTO Melara/Italian MoD and Diehl/German MoD	Commercial agreement between OTO Melara and Diehl to develop precision munition. OTO Melara has lead with funding primarily from the Italian MoD funding
BONUS	KOS and France	Joint French and KOS requirements with work share agreement for subsystems and production.

European Correction Fuze (ECF)	BAE Systems (Munitions and Weapons) and Junghans	Joint funding from MoDs and industry to develop a 105mm ECF, with a growth strategy for 155mm.

It can be said that no PGM or CCM programme, conducted in the last decade has been organised as a real multination cooperation programme from the outset. However we can note some projects which are now operating as multinational cooperation programmes, such as Excalibur (US + SE) or more recently Vulcano (IT + GE).

Observations of said programmes highlight two main constructs for multinational programmes. The first, which has been observed for guided munitions programs, is driven by a leader, which has been joined later on by other companies and their respective MoDs. The second, not yet observed for guided munitions, would consist of an agreement of a common programme and requirement from the beginning, between the different companies and their respective MoDs.

Problems arise not only where capability requirements differ between nations, but where there exist usage (both operationally and in training). Where there is a significant difference in volumes between nations, an agreement must exist to divide funding and requirements trading fairly. This presents a challenge to defence ministries to work together and agree a commercial and mutually beneficial partnership.

The Excalibur and Vulcano programs demonstrate the first option with US (Raytheon) and Italian (OTO Melara) as leader, joined later by Sweden (BAE Systems Bofors) and Germany (Diehl) respectively. In the case of the Excalibur program, Raytheon competitively won a US competition to develop the munition. Later in the program the US and Kingdom of Sweden agreed to merge the Excalibur and TCM programs and develop a common munition under the existing Excalibur program. The countries may be tentatively committed to buying a certain number of rounds to achieve a certain unit production price. In these two cases, the requirements have been negotiated at the beginning of the program between the leading business and his MoD, and then fully accepted by the joining parties.

The closest programme to this second construct is the BONUS smart munition. From the outset the requirements were agreed between Swedish and French ministries. Responsibilities for subsystems, and their subsequent production, were agreed and defined also. This programme appears successful as both nations have fulfilled the programme and undertaken serial production.

2.2 Requirements Harmonisation

Typically each nation will specify its requirements that define product characteristics and performance. These requirements of course, complement its own system (army's regime and equipment). As a result, in multinational programmes it is easy to understand how each nation will require a tailored version of the product. This variance between nations is likely to be the largest contributor to additional cost, both in programme management, development and serial production. Where the programme is developed to suit both nations, there is a risk that added or improved subsystems (required by either nation) will result in a product that is not optimised for either and is too expensive to justify a collaboration programme.

The viability of collaboration programmes is likely to be influenced heavily by the number of system interfaces. Therefore collaboration on subsystems is more likely to be successful than product or weapon system level programmes; unless nations share platforms, supporting/ancillary equipment and doctrine.

Alternatively, a baseline product standard could be established, either between nations or industries that allows for cost effective tailoring to nations requirements; by deciding subsystem boundaries. The principle of open architectures and modular designs offer the technical approach to such programmes. In this case, the common requirements need to be conveyed and agreed from the outset for all participating nations.

2.3 Transparency of Requirements, Monopoles and Political Issues

Continuing the principles of requirements harmonisation, baseline products, open architectures and modular designs, there is a clear need for common requirements to be communicated between nations and / or industry for future capability requirements.

An attempt at least would highlight the feasibility of common multination programmes for CCM and PGMs.

2.4 Key Points

- Over the last 20 years there has been an emphasis on developing the guidance technologies required to survive the harsh environments of artillery and mortar launch while providing the guidance and control needed to achieve the desired accuracies. The progress made during these years has enabled focus for future programs to be placed on miniaturization and integrations as opposed to technology development.
- Generally COTS development has improved the performance and driven down cost of microprocessors, but has exposed the products to commercial obsolescence.

- Military specific GPS boards remain the largest single cost drivers for precision munitions. The lack of a commercial market for these items and the complexities with meeting defense requirements continues to be a cost driver.
- Advanced telemetry and data recording techniques have improved data collection for testing and resulting in the reduction in the number of development testing required.
- Standardization of testing and requirements across NATO countries can have the largest near term cost savings effect for the development and qualification of precision munitions. Acceptance of testing results and the data that supports such results can avoid un-needed duplication of testing. If a test result is approved by one NATO country, it should also be approved by the other NATO countries.
- Sharing of unfunded requirements for precision munitions across NATO countries can provide the basis for discussion of the development of joint programs. If member nations are sharing capability gaps, this could lead to common requirements in an early state. Possible main contractors should exchange requirements with possible sub-contractors or component suppliers.

3 TECHNICAL ISSUES

3.1 Open Architecture and Modularity – Subsystem and System Level

This term of technique has the objective to search for cost saving potentials.

In the short term specifications are not cost effective to change; only the use of higher quantity or competitive procurement at component level can reduce costs.

In the medium to long term there will be opportunities for cost reduction by using common components. For the way ahead specifications have to be mutually agreed. The Table 2 identifies those components, which the respective potentials.

3.2 Example of common used and qualified subsystems

Note: the following information, descriptions, and equipment specific materials are from open sources, to avoid ITAR or classification issues.

Common Fuze Technologies

Component standardization (common technologies) when possible, is a cost effective approach. Therefore, fuze manufacturers should attempt to implement, in their catalogue of fuzes, proven technologies, components or COTS; for example: batteries, S&A, height of burst sensors, processing units, algorithms, etc.

An example of sharing common technologies: the MK432 ET is the navalized[1] version of M762A1 also the MK437 MOFN, the navalized version of M782 MOFA.

Common Component Technologies

Also Guidance, Navigation and Control (GNC) components can be used as common technologies. This means, the sensors - flight path sensor as well as target detection sensors – can be used in different calibres and different types of ammunition. The same is valid for the flight computer and the control actuation systems. Therefore the following Table 2 identifies the respective ammunition components.

[1] John Hendershot, NAVSEA. Navy Fuze S&T and Acquisition Strategy. 56th Annual Fuze Conference. 2012.

Table 2 Common and Unique Components

Common Component	**CCF**	**PGM**
GPS (CA) Antenna	 x x	 x x
GPS P(Y) Antenna	 (x) optional (x) optional	 x x
IMU	x	x
Magnetometers		x
CPU / Flight computer	(x) optional	x
Terminal Homing Sensor excluding housing		x
Power Supply		x
Agreed ICD's	x	x
TM (development tool)	x	x
Simulation environment	x	x

Unique Component	**CCF**	**PGM**
CAS		x
SAD	x	x
Communication uplink	x	x
Navigation & Control algorithms	x	x
Control surfaces	x	x

Components and technologies which can be commonly used not only in CCF or PGM but also in conventional munitions and fuzes see Annex B.

3.3 Future technologies which enable different approaches

The following section provides an overview of technologies that can potentially be used to improve the performance and/or to reduce the costs.

With the objective to miniaturize and to harden up to high g-level of the components the application field will be widened and the flexibility will be increased. It is important to investigate future technologies for the following components.

- Navigation sensors:
  - GNSS (Global Navigation Satellite System)
    - GPS (USA)
    - Galileo (Europe)
    - GLONASS (Russia)
    - BeiDou-2 (former: Compass) (China)
    - IRNSS (India)
    - QZSS (Japan)
  - MEMS technology for IMU Sensors
- Power sources:

  With the point of view regarding miniaturization and g-hardening the materials and designs have to be analysed and developed. This means with these requirements the energy density has to be increased. Another important topic is the maintainability of power sources. The objective is to have maintenance free components.

  - Activatable batteries
    - Thermal batteries
    - Reserve batteries
  - Accumulators
- Data uplink

  With respect to costs an analysis of data uplink vs. flight path sensors is necessary. It can also be helpful to have the possibility to use information from forward observer with data uplink in addition to autonomous flight path sensors. This could be necessary, if the requirement of a mission abort capability becomes mandatory due to suddenly changes in the target area.

- Target detection sensors

  Regarding future technologies the actual possible miniaturization of electronics and optical sensors allows a wide spectrum of application of such devices. Depending on the detection mode semi-autonomous and autonomous sensors can be used.

  - Semi Active Laser Sensors (SAL-S)
  - Far Infrared detectors (FarIR)

- Warheads

  With the application of guided ammunition a warhead could be optimized and be smaller compared to conventional munitions. This will save costs.

3.4 Standards for Qualification

The qualification process adopted by all participating nations is based broadly on system engineering principals. The approach is illustrated in the Figure 1 below which is based on information from the UK Ministry of Defence Acquisition Operating Framework (MODAF; similarly DODAF is used in the US).

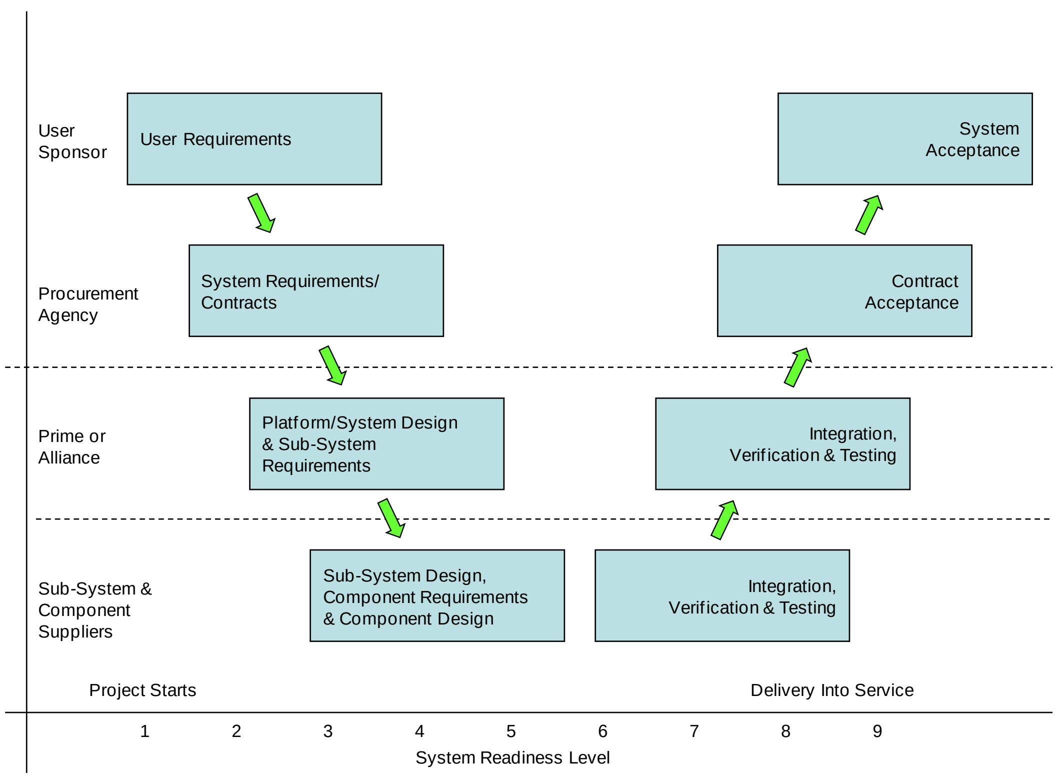

Figure 1 – Example of System Engineering applied to Defence Procurement

User requirements define the 'gap' between the existing military capability and the required capability. It should focus on the outcomes and effects that the user needs to fulfil their military objective; it should not specify the solution.

A System Requirements Document (SRD) is the structured definition of the system requirements and includes constraints and verification activities. It should be structured to show the link between the user requirements and the system design solution.

Test and evaluation are the means by which the evidence is gathered to verify and validate the equipment against the system and user requirements. The complete test programme is often set out in the Integrated Test, Evaluation and Acceptance Plan (ITEAP). The ITEAP describes all of the tests and evaluation activities that must be conducted before the equipment can be accepted into service.

It is common for nations to define test and evaluation requirements that are based on national or international standards. In the UK the procedures and requirements for design and qualification of munitions for use by the British Armed Forces is described in Defence Standard (DefStan) 07-85 "Design Requirements for Weapons and Associated Systems". The DefStan is a substantial document made up of four volumes. Each volume makes reference to many other standards (STANAGs) and procedures (AOPs) when specifying the evidence that must be produced to demonstrate compliance with requirements. However, the requirements and associated evidence that are applicable to gun launched munitions can be divided into five broad categories:

- Safety
- Performance
- Environmental
- Reliability/maintainability
- Life assessment

Development and qualification of conventional munitions has traditionally been conducted as a two distinct activities, e.g. qualification doesn't start until the design is fully mature and evidence doesn't flow across the boundary. Furthermore the evidence for qualification is derived from firing a very significant number of projectiles.

3.4.1 Qualification of Conventional Munitions

For a new munition that is to be fired from an existing ordnance and charge system the following safety trials would typically be required:

- Qualification of Explosives to STANAG 4170

- Fuze Safety Trial to STANAG 4157
- Safety & Suitability for Service Trials to STANAGs 4224 and 4439

In addition to the above trials would also need to be conducted to demonstrate performance and to obtain range and accuracy data for the weapon fire control system.

3.4.1.1 Fuze Safety

STANAG 4157 (Fuzing Systems: Test Requirements for the Assessment of Safety and Suitability for Service) requires all new fuzing systems to be tested in accordance with the standard and Allied Ordnance Publication 20 (Manual of Tests for the Safety Qualification of Fuzing Systems). The actual test programme is to be based on a safety hazard assessment conducted in accordance with STANAG 4187 (Fuzing Systems: Safety Design Requirements). The complete assessment involves performing a series of shock, vibration, climatic, safety, arming functioning and electrical tests on the fuzes or fuze systems.

Participating nations agree to document and maintain records of the testing of fuzes and fuzing systems in accordance with the STANAG and associated test procedures. They also agree to provide this information to other nations and therefore there is scope to read across the test results where appropriate.

The programme requires a significant number of fuzes or fuzing systems to be tested. There is some overlap with tests that must be completed on the munition and therefore they may be combined to avoid duplication.

3.4.1.2 Safety and Suitability

STANAG 4224 (Large Calibre Artillery and Naval Gun Ammunition Greater than 40mm, Safety and Suitability for Service Evaluation) provides the template for the assessment of safety and suitability for service of large calibre gun ammunition. The assessment requires a significant number of munitions to be fired in a series of tests which are described in the annexes of the STANAG. It requires that the tests are performed on the final design of the munition manufactured to the production standard. This would seem to preclude the use of evidence that is obtained during developmental testing.

Participating nations agree to conduct the tests in accordance with the requirements of the STANAG and to maintain evidence, plus make it available to other nations on request. The document also contains a statement that participating nations: "*agree that safety and suitability performed in accordance with this agreement shall be acceptable to the ratifying nations*". Hence read across of qualification evidence should be acceptable where appropriate. However, detailed differences between gun systems may limit the applicability of the evidence.

STANAG 4439 (Policy for Introduction and Assessment of Insensitive Munitions) defines the policy to be used for the introduction into service of insensitive munitions. The document calls up a number of additional STANAGs which define tests which determine the response of the munition to specific threat stimuli. The actual tests to be conducted are based on an evaluation of the threats to which the munition is exposed to during it manufacture to target or disposal sequence. The STANAGs require a comparatively small number of munitions to be subjected to a number of destructive tests.

3.4.1.3 Range and Accuracy

Data from ballistic range and accuracy trials is likely to be required for the fire control system of a guided projectile. This may be needed if the guidance system is based on correcting the basic ballistic trajectory or to determine the ballistic impact point in the event of a failure of the guidance system.

Range and accuracy trials require the projectile to be fired on a number of occasions, with several guns and using each charge zone at a number of elevations. This test matrix results in a requirement to fire a significant number of projectiles. However, if charge zones and elevations are restricted for guided munitions then the number of rounds required to generate the data may be significantly reduced.

If the use of surrogate rounds can be justified, the costs associated with such trials can be further reduced.

3.4.1.4 Performance

Performance trials are not generally covered by standards, but are specifically designed to gather evidence that demonstrates the projectile and other elements of the gun system are compliant with the SRD. It is possible that with careful planning of the overall programme, the data collection objectives of development, safety and suitability for service and performance trials could be combined to satisfy all three goals.

3.4.1.5 Rounds required for Qualification of conventional munitions

This analysis provides an illustration of the number of rounds that would be required to qualify (or re qualify in a different gun system) a new guided munition if the current approach to conventional munitions were used. It should not be taken as describing an actual qualification programme, as this would require details of the specific munition, its operating environment and the wider artillery system.

The numbers of rounds required by the STANAGs have been taken “at face value”. No rationalisation of the testing has been undertaken, other than the removal of duplicate sequential environmental testing. The results are shown in the table below.

Table 3 Number of Rounds regarding STANAG 4224

STANAG 4224

Standard Mandatory (all 1-6) (Naval 7-12)		Live	Inert	Proof
Tests based on environment and hazard assessment in accordance with AOP-15				
1 - Safety Drop iaw STANAG 4375	Three drops, packaged and unpackaged	6		
2 - Propellant Safety iaw Annex A	Part 1 - Two lots, three temperatures, 10 rounds			60
	Part 2 - Two occasions, two barrels, two lots, 7 rounds			56
3 - Projectile SOD in accordance with Annex B	Two temperatures		21	
4 - Projectile Safety in accordance with Annex C	Short environmental sequence, two temperatures	120		
5 - Worn Barrel iaw Annex D	Two temperatures, 4/4 barrel	60	10	
6 - Sequential Environment in accordance with Annex E	Full environmental sequence, two temperatures	120		
7 - Liquid Fuel Fire in accordance with STANAG 4240	Static test	1		
8 - Sympathetic Reaction in accordance with STANAG 4396	Two static tests (confined and unconfined), assumed 15/pallet	8	22	
9 - Slow Heating in accordance with STANAG 4382	Static test	1		
10 - Bullet Attack in accordance with STANAG 4241	Packaged/unpackaged and most sensitive/centre of mass	4		
Supplementary As directed by assessment in accordance with AOP-15				
1 - Fall back	Bespoke trials procedure, covers hand ram		50	
2 - Low charge (stickers), ITOP 8-2-804	Bespoke trials procedure		25	
3 - Flick ramming	Bespoke trials procedure		50	
5 - Muzzle blast overpressures	Bespoke trials procedure		180	
7 - Cook-off in gun	Bespoke trials procedure	1		
8 - Air delivery drop	Covered under 6			
9 - 3m drop iaw STANAG 4375	Covered under 6			
10 - Transport vibration iaw STANAG 4370, AECTP 400, method 401	Covered under 6			
11 - Mechanical shock iaw STANAG 4370, AECTP 400, method 403	Covered under 6			
12 - High temperature iaw STANAG 4370, AECTP 300, method 302	Covered under 6			
13 - Low temperature iaw STANAG 4370, AECTP 300, method 302	Covered under 6			
31 - Shaped charge	Packaged/unpackaged and most sensitive/centre of mass	4		
32 - Fragment impact	Packaged/unpackaged and most sensitive/centre of mass	4		
	Totals	329	358	116
Note above is for separate fuzed ammunition Annex H is for pre-fuzed ammunition and requires above testing of projectile and STANAG 4157 for the fuze plus the tests below Tests listed are where fuze and projectile have not previously undergone S3 individually				
STANAG 4157, plus Annex H, table H-1		124		
	Totals	124	0	0
	Grand Totals	453	358	116

Notes where the standard does not specify numbers to be tested typical values have been used
1 - STANAGs do not make distinction between live, inert and proof rounds, these have been added to identify opportunities for substituting lower cost test items
2 - Where the standard does not specify numbers to be tested typical values have been used

3.4.2 Qualification of Guided Munitions

In October 2011 STANAG 4667 (Gun Launched Guided Munitions [GLGM], Safety and Suitability for Service Evaluation) was first issued and covers safety and environmental testing of artillery and Naval gun launched guided munitions. It addresses a number of firing and static tests which for conventional munitions would be covered by a number of individual STANAGs (e.g. 4224, 4157 and 4439), but also includes a guidance safety test. It does not include the requirement for range and accuracy trials. If the fuze functionality is integrated in the GNC functionality, be aware that the GNC has to be qualified in accordance with STANAG 4157.

One significant difference with this STANAG is the statement: ”*The safety and suitability for service of GLGM shall be a judgement that the safety authority of the developing nation makes considering all of the results of available analysis and testing. In making the assessment, the results of developmental testing, testing of subassemblies and tests performed for reasons other than safety, such as* *performance and reliability tests, shall be considered*." This statement would suggest that evidence from earlier development work is admissible in qualification and may reduce the overall number of rounds that must be fired.

It is important to note that STANAG 4667 specifically excludes the course correction devices: "*The mere application of a Course Correction Fuze that cannot perform controlled munition guidance, onto a conventional projectile does not render the shell a GLGM*".

As with other STANAGs participating nations agree to conduct the tests in accordance with the requirements and to maintain evidence, plus make it available to other nations on request. The document also contains a statement that participating nations: "agree that safety and suitability performed in accordance with this agreement shall be acceptable to the ratifying nations". Hence read across of qualification evidence should be acceptable where appropriate. It should be noted that both the UK and US have not ratified this STANAG.

3.4.2.1 Rounds required for Qualification of guided munitions

A second analysis was undertaken of the number of rounds that would be required to qualify/re qualify a guided weapon using the new STANAG 4667. The results are shown in the table below.

Table 4 Number of Rounds regarding STANAG 4667

STANAG 4667

Tests based on environment and hazard assessment iaw AOP-15		Live	Inert	Proof
7.b Explosive safety, iaw STANAG 4170	Small scale explosive characterisation test			
7.c Software	Safety audit of software systems			
7.d UN classification iaw 4123 & AASTP-3	Small scale tests, plus packaged and unpackaged rounds			
7.e Fuze and arming iaw STANAGs 4187 & 4157	Static test, environmental test and firing trials	20	30	
7.f Environmental and Safety, Propellant safety, Annex A	Part 1 - Two occasions, two barrels, two lots, 7 rounds			56
	Part 2 - Short environmental sequence, two temperatures (charge)			32
7.f Environmental and Safety, Projectile safety, Annex B	Part 1 - Environmental sequence, two temperatures (live HE, inert/dummy fuze)	60		
	Part 2 - Two temperatures, 4/4 barrel (live HE, inert/dummy fuze)	60		
7.f Environmental and Safety, Fuze safety, Annex C (Integrated fuze, otherwise STANAG 4157)	Part 1 - Environmental sequence, two temperatures (inert HE, live fuze)	30		
	Part 2 - Environmental sequence, two temperatures (inert HE, live fuze) - National procedure (AOP-20?) assumed 21 rounds each temp	42		
7.f Environmental and Safety, Guidance safety, Annex D	Part 1 - Environmental sequence, two temperatures (inert HE and fuze, recommends telemetry) - National procedure to determine number, assumed 21 rounds each temp		42	
	Part 2 - Environmental sequence, two temperatures (inert HE and fuze, although demonstrates SD) - National procedure to determine number, assumed 21 rounds each temp		42	
7.f Environmental and Safety, Liquid Fuel Fire iaw STANAG 4240	Static test	1		
7.f Environmental and Safety, Sympathetic reaction iaw STANAG 4396	Two static tests (confined and unconfined)	8	22	
7.f Environmental and Safety, Slow heating iaw STANAG 4382	Static test	1		
7.f Environmental and Safety, Bullet attack iaw STANAG 4241	Packaged/unpackaged and most sensitive/centre of mass	4		
7.f Environmental and Safety, Safety drop iaw STANAG4375	Three drops, packaged and unpackaged	6		
7.f Environmental and Safety, HERO iaw STANAGs 4324 & 4370, AECTP-500	Static EMC test	1		
7.f Environmental and supplementary, example in Annex E				
	Totals	233	136	88

Notes
1 - Guided munitions only, doesn't cover course correction devices
2 - STANAGs do not make distinction between live, inert and proof rounds, these have been added to identify opportunities for substituting lower cost test items
3 - Where the standard does not specify numbers to be tested typical values have been used
4 - UN classification tests may be combined with insensitive munitions testing

3.4.3 Opportunities for reducing cost

Actual standards of Qualification consider only non-guided ballistic Projectiles and will be performed regarding the safety of the ammunition. Guided / corrected ammunition will add functionalities to the projectile, which can be compared with functionalities of missiles. But nevertheless the guidance functionality in ammunition has to withstand the high g-load.

Therefore it will recommend separating the safety (munition part) and functionality (guidance) in the qualification process. This recommendation will require new and specific standards (STANAGs) for qualification, but has also to consider guidance safety (s. STANAG 4667).

Since ammunition qualification tests require a huge number of rounds, this is the main cost driver in lifecycle costs of ammunition. Therefore procedures have to be created to reduce the cost of the test items.

The qualification tests can be reduced by simulation modelling and simulation procedures. These kinds of reduction are more a medium term due to creation of data basis and require the acceptability of modelling as well as simulation procedures like HWIL simulation to supplement data obtained from firings.

The qualification tests can also be reduced with:

- Modern Techniques - Data Rich Trials
- Type Qualification - use of a baseline qualification programme
- Reuse of qualified Components
  - Explosives
  - Safe and Arm Devices (SAD)
    depending on environmental conditions
  - GPS receivers and antennas
  - Inertial Measurement Unit
  - Launch activated batteries
  - Proximity antennas

3.4.3.1 Lessons from Guided Weapon community

Lessons learned from the restructuring of the TRIGAT Program:

- Prior approach was to conduct many firings both as development and as proof
  - Large numbers were carried out at temperature both high and low
- Around 430 full missile firings were included in the original programme
- All proof firings at missile level were eliminated
  - Proof activities were undertaken at warhead and motor level only
- The full up development firings were reduced to around 30 by the use of simulation
  - Only 4 were at environmental extremes
- Resulted in the removal of around 380 firings with the associated costs
- Some additional environmental and safety tests were added particularly in the area of IM
- Final programme was an amalgamation of all 3 nations needs that was acceptable to all

3.4.3.2 Read Across

As indicated by the earlier sections the read across of qualification data obtained by a programme conducted by another nation is permitted under the STANAG test regime. However, there are few examples of this happening with conventional munitions. Additionally, despite agreements like the Joint Ballistic Memorandum of Understanding defining compatibility requirements for 155mm gun systems, there can be significant differences between the details of individual technical solutions that could prevent direct read across. This is illustrated by the range of different 39 and 52 calibre 155mm guns and charge systems in service within NATO countries.

However, this situation may change in the future due to financial pressures on national defence budgets, consolidation of defence industry leading to fewer solutions and initiatives such as EDA “pooling and sharing”.

3.4.3.3 Evidence from development

With careful planning one test can sometimes serve several purposes, saving on time and cost. In particular, major benefits can accrue from using engineering development and manufacture test evidence to support verification. This approach appears to be advocated in STANAG 4667. By planning the ITEAP earlier in the project lifecycle it may be possible to conduct development tests in a way that satisfies the requirements of qualification and hence provide a means of reducing the number of tests that must be undertaken to bring the equipment into service.

3.4.3.4 Modular design and re-use

Open system architecture. An example for modular system design are the Vulcano 155mm and 127mm rounds which have only different outer shell, but internally inside the two sub-calibre projectiles the same components. Additionally, the development of common ICDs for subsystems such as GPS circuit cards, gun hardened IMU and power supplies will enable the use of multiple vendors for such components. The acceptance of subsystem testing in a relevant environment can also reduce costs.

3.4.3.5 Modelling and simulation

In the late 2000s the UK MOD had a need for a Ballistic Sensor Fuzed munition compliant with insensitive munition requirements. In order to assist UK MOD in reducing the cost of qualification testing QinetiQ proposed using validated computer modelling to support the assessment of explosive safety in gun. The modelling allowed analysis of the failure modes of the explosive in terms of its response to linear and angular acceleration and jerk. The output provided confidence that the firing programme could be completed successfully. It also allowed the gun firing scenarios to be tailored to the most appropriate tests of the explosive response. It was proposed that the Projectile Safety in Gun tests be reduced to 28 rounds rather than the 120/60 required in STANAG 4224 Annex C. Unfortunately the programme was terminated before the test programme was completed.

The use of HWIL simulation will reduce the number of rounds fired due to the facts, that the guided projectile can demonstrate the guidance and navigation loop of the flight path under reproducible conditions in the laboratory, which are not available in the real flight due to changes in weather and environment conditions. The HWIL simulation can be used in the system development as well as in the system acceptance tests before firing. Real firings are still necessary, but with a substantial reduction in the numbers.

Typically, extensive HWIL testing with a few flight verification tests to verify the results has been well accepted for missile development programs. However, the gun community has been less willing to accept modelling and simulation results in lieu of actual gun firings. This may be due to the relative newness of guided projectiles as compared to guided missiles. As confidence in HWIL and Modelling and Simulation builds with guided projectiles, we would expect that the need for actual gun firings to verify results would be dramatically reduced.

New testing facilities and tools such as the SCat (Soft Catch) gun, a full scale 155mm artillery cannon which uses a combination of pressurized air and water to recover fired projectiles allow the testing of munitions in the actual ballistic environment. After the firing the munition can be fully recovered allowing the inspection of mechanical and electronic subsystems. This data is being used to correlate models and help better predict structural survival of designs.

NABK (NATO Armament Ballistic Kernel) can be mentioned as a good example of the benefits of having a common simulation engine, in NABK case, to standardize the way firing tables and ballistic calculations are made. Its main idea can be applicable to generate a common 6DOF simulation environment that NATO accepts as evidence that can avoid some testing. For corrected and guided munitions the respective trajectories have to be implemented.

Modelling of internal ballistics or finite elements as a standard will be helpful development and qualification tools.

3.5 Design Principles for Subsystems

- Open architecture (s.3.1) will allow to increase quantities
- Common Components / Key Products between different programs

4 BUSINESS ISSUES

4.1 Short Term Potentials – Cost Savings / Low Cost Guided Munition

The study group investigated several business models to reduce the cost of precision munitions. Several potential scenarios are outlined below. Examples are already mentioned in the technical chapter.

- NATO to start a Working Group for definition of capability for guided ammunition/Course Correction Fuzes.
  - When member nations have differing performance capability requirements industry cannot leverage an approach for a more common solution, thus member nations procure smaller quantities, losing their economies of scale, and industry loses their advantage of focused and potentially shared investments aimed at a common standard. Based on varied requirements there are currently various approaches that will deliver differing performance results that drive differing unit and lifecycle costs. By having a common problem to solve, industry can partner and leverage their resources towards a specified requirement. This approach will increase competition, which will usually lower costs, and focus industry investments with their limited resources.
- Sharing of technology roadmaps.
  - The sharing of road-maps will provide the opportunity to influence the design and development of appropriate performance/cost optimized products. This is an ideal state, but efforts to encourage industry to communicate through public or sponsored forums and through secure internet sites should be encouraged.
- Sharing of qualification reports including mutual acceptance
  - Member nations should be more forthcoming with product qualification testing in order to minimize, or eliminate redundant testing. If member nations could agree through appropriate STANAGs what an appropriate and affordable standard is, then duplication of testing might be avoided and costs minimized. An example might be whether testing should be focused on performance extremes in terms of temperatures, QE's, and charges, or should it be more focused on a more likely specified Operational Mission Profile. Testing in most likely engagement scenarios will save money towards qualification, but member nations need to reach agreement to avoid duplication of costs.
  - As part of the award of any R&D development programme there should be a business case generated where the entire lifecycle is addressed (to include the cost for qualification and procurement).

- Avoid single Nation development across NATO countries
  - Competition is good to lower procurement costs, but that can be achieved without duplications of development costs. If a design could be brought to production readiness, the Technical Data Package could be procured from the developer for future competition in production. Focused development investments with a path to competition amongst the NATO member industrial partners should be considered. Efforts should be made to not replicate development investments that have already been made and instead be focused on the securing of TDPs for competition.
- Avoid start – stop – start in development and production programs / accelerated programs
  - A continued multi-year effort to bring a program to production readiness is necessary to maintain the engineering talent pool to complete projects. Without a commitment from member nations, industry will move their best talent to other funded initiatives and the ability to reconstitute that talent when funding is restored may prove to be challenging, as well as inefficient.
  - Also, multiyear contracting in production would reduce the product UPP by allowing industry to gain component technology buying efficiencies. As an example, a key cost driver for many precision munitions is a gun hardened GPS. A gun hardened GPS is very price sensitive to quantities. A prime contractor who can buy key cost drivers in economically significant quantities based on multiple year procurements will achieve price advantages for member nations.
  - In an environment where the customer wants to save funding for future upgrades or when the required quantities are uncertain, industry needs to develop a strategy for managing start/stop production. In parallel the customer needs to pay the industry to be prepared.
- Potential to decrease qualification numbers through analogy
  - This is a cost advantage that should be considered and handled on a case-by-case basis, but an example would be qualifying a lower cost component item within a product that has already been qualified in a similar product. For instance a GPS receiver qualified in an artillery system should be able to be inserted into another artillery munition or mortar munition with greater ease and subsequently less cost. Compatibility could be achieved without an extensive requalification of the munition.

  - Also, if a product is qualified in one member nation howitzer, a duplication of qualification should not be necessary in a similar howitzer. This is where a common qualification understanding between nations would be helpful. Compatibility testing in lieu of qualification testing would provide member nations substantial cost savings.

- Allow an increased use of modeling and simulation, replacing the need for testing

  - The missile communities qualify their products in much less quantity than the projectile communities. This is because firing missiles in quantities similar to conventional munitions is simply unaffordable for any member nation. Consequently, great use has been made to characterize missile performance and reliability through minimal live fires that validate models and then greatly expand modeling and simulation results for qualification. With the advent of guided projectiles and kits, it is necessary for member nations to accept that precision projectile live fire quantities cannot follow the path of conventional projectile qualification, and instead need to more closely follow the missile community model. Member nation qualification and test communities for Precision Projectiles and Course Correction Kits need to embrace a different paradigm for qualification to leverage modeling and simulation capabilities and avoid costly live fire test quantities that are more appropriate for less expensive conventional projectiles often thought of as a commodity product. Precision projectiles and Course Correction Fuzes are too expensive to be thought of as a commodity product. An increased use of modeling and simulation for expensive precision munitions creates significant cost saving opportunities in qualification testing.

- Pooling of production requirements as well as existing stock across NATO Members

  - Creating redundant inventories of capability across all member nations could be considered inefficient if not done for individual country readiness reasons. If member nations could create reliable access to a common precision munition inventory that could be accessed for both training and operational use, member nations could spend procurement funds based on available budgets for usage and then would replenish the inventory as required. A guaranteed minimum annual investment would be needed to ensure industry availability to maintain production, but otherwise member nations would not need to stockpile large quantities of inventory that may, or may not be used.

- Also, by having a continuous draw from this inventory from several cooperating nations the possibility of shelf life concerns could be somewhat minimized.

4.2 Long Term Potentials – Cost Savings / Low Cost Guided Munition

- Establish a NATO IPT of users and industry.
  - This body has the potential to inform each other of capabilities and costs to allow member nations to firm up resources requirements and better inform member nations of the performance/cost trades that are available. This would also better inform member nations of emerging concepts, while industry would get feedback on capability member nation needs.
- Industry recommends the harmonizing of requirements
  - Industry recommends the harmonizing of requirements for both future concepts and interoperability requirements to enhance production quantities necessary for achieving cost savings through economy of scale benefits. It is noted that enforcement of common standards have been lacking and sometime even after agreements, member nations fail to maintain a common standard with new developments. To have any effectiveness member nations should consider a more strenuous application of standards to harmonize requirements that industry could then rely on.
  - One of the more economical scenarios is to develop a common specification and leverage investment from countries for development and procurement of guided munitions. This approach would capitalize on the economies of scale of producing larger quantities of munitions over a longer period of time.
- Open / Common architecture, modularity inherent in design to facilitate capability for upgrades
  - A common / modular architecture is strongly linked to affordable qualification of upgrades.
  - Industry should be incentivized to create modular designs that separate the traditional fuze function (safe and arm) from the guidance piece of precision. Through these modular designs to guidance and the systems architecture this would enable technology advances to be inserted without the need to fully qualify the fuzing portion of the weapon, which of course is most critical. Performance testing of guidance could therefore be in quantities suitable for maturation and validation of modeling and simulation and then literally thousands of fir-

ings could be accomplished and evaluated with nearly an unlimited set of conditions in a very affordable manner. A modular approach allows a Precision Projectile, or a Course Correction Fuze, the opportunity to avoid the very necessary qualification costs of the fuze safe and arming time after time with each upgrade to the guidance part of the solution. This creates the opportunity for much less expensive qualification over time.

- Interchangeability of components
  - A STANAG that created a common form factor applicable to critical and common components would create an opportunity for non-unique component items. This would provide industry with guidelines and prime manufacturers with less expensive components. Component providers, with this information to guide them, could then leverage their investments in a more focused way achieving cost savings for industry that would be shared with member nations, and also by increasing competition at the supplier level.
- Increase where appropriate use of COTS
  - This is an opportunity that should be examined on a case-by-case basis, but increasingly defense unique items are being procured in smaller and smaller quantities thus driving UPPs significantly higher to maintain industry interest in the market. The use of COTS components, makes Defense industry less vulnerable to the vagaries of component suppliers who may ultimately decide to leave the industry because the lack of a market to sustain them. Having qualified COTS component items that Defense industries can make use of when needed has the advantages of providing a reliable source, and also potentially the economies of scale necessary to achieve cost savings.
  - In considering the use of COTS equipment there is a need to be aware of:
    - The dynamic nature of the commercial market and that components may become obsolete rapidly, no guarantee of supply over 10,15,20 years
    - The supply of COTS components will be in accordance with the details of a datasheet with little opportunity for bespoke development or qualification
    - Due to the cost challenge and the need to be competitive no margin for through-life-support is incorporated into COTS product pricing
    - COTS supplier through ethical reasons may not wish to supply to military markets

- Military programme quantity requirements may be be orders of magnitude less than commercial customers securing the cost advantage of volume supply

❖ Having qualified COTS component items that Defense industries can make use of when needed has the advantages of providing a reliable source, and also potentially the economies of scale necessary to achieve cost savings.

➢ Reuse existing/available equipment-subsystems

❖ Commonality/Modularity/Reuse covered already?

❖ Once a subsystem is qualified by its own on an existing munition, for example Excalibur or Vulcano. The subsystems (Control Actuation System, warhead) or components (GPS receiver, gun hardened IMU, battery) can be reused on new designs with very little additional development and qualification, if there are similar or less stressful environmental conditions.

4.3 Partnerships and Ways of Doing Business

➢ Stacking of burdens and fees in hierarchical program structures

➢ Co-Contractor ship (as opposed to Prime – Sub relations)

➢ Joint Venture of Industries based on multi Nation Programs

➢ Multiple levels of program and engineering supervision in hierarchical program structures

➢ Bi-lateral or trilateral working arrangements are to be preferred

➢ Reduction on “Profit on Profit” etc..

➢ Crowd Source Funding Models

➢ How can we work together on low level technology

❖ EDA tries to bring together R&D efforts

❖ Crowd Source Development (ref. DARPA initiative)

5 MAIN CONCLUSION

Short term perspective:

- Pooling and sharing, joint procurement as well as efficient business models and program structures can significantly reduce the unit production price.
- Read across, qualification by analogy or joint qualification by multiple customers can reduce the cost of introducing a new product (share of Qualification Programs & Costs).

Long term perspective (beyond 5 years):

- Open architecture and commonality at subsystem and component level will lead to reduced component prices.
- Harmonized requirements will facilitate the creation of joint programs leading to sharing of development cost and economy of scale in production.
- Separating qualification of safety from qualification of performance will allow for a reduction of total qualification cost. Qualification of performance will rely on new “data rich” test methods to increase knowledge and reduce future firing costs. Increased use of simulation technologies will reduce the test effort and reduces development time.

6 RECOMMENDATIONS

6.1 Technical Recommendations:

- Increase funding of applied research for innovative technology applicable for PGM/CCF.
- Increase funding of research of manufacturing technologies.
- To develop a methodology for validation and verification of PGM/CCF to include simulation modelling and use of instrumented rounds, HWIL etc. which may lead to revision of STANAG's
- Lot Acceptance Test (LAT) based on Lab Tests, no firings like LAT with Missiles
- The philosophy of STANAG 4667 should also be applied to CCF
- Plan the ITEAP early in the project lifecycle

6.2 Business Recommendations:

- Forums such as NAAG offer the opportunity to convey multinational mission statements and product aspirations. Therefore it should be investigated if said forums such as NIAG, EDA, JBMoU could be utilised to collect requirements from all nations, to filter and identify those common requirements for future products. Disseminating this information to industry could aid the identification of partnerships, and the industry strategy with regards to subsystem suppliers; to cater for the delta requirements of each nation.
- Member nations should be encouraged to establish bilateral or trilateral cooperation to harmonize requirements to create joint programs and increase pooling and sharing allowing for higher quantities for economy of scale

Annex A: STUDY ORGANISATION AND PROGRAM

A.1 National/Industrial participation

NIAG Sub Group 173 comprised representatives of the different nations shown in Table 5.

Table 5 National Participation

SUB GROUP COMPOSITION	
NATION	**PARTICIPANTS**
BE	2
CN	1
FR	3
GE	4
IT	1
NO	1
PL	2
PT	1
SP	2
SE	2
TU	7
UK	8
US	2
TOTAL	**36**

The 36 National Representatives participating in this study represented 13 nations and 28 companies (or divisions within a company). The study participants are listed in Annex B.

A.2 Study Organisation

The Sub-Group comprised 36 National Representatives from 13 NATO nations (BE, CN, FR, GE, IT, NO, PL, PT, SP, SE, TU, UK, US).

The Subgroup has given by themselves the following Board:

Chairman:	**Juergen Bohl**	Diehl BGT Defence	Germany
Deputy Chairman – 1:	**Jan-Olov Blix**	BAE Systems Bofors	Sweden
Deputy Chairman – 2:	**Dave Dorman**	ATK	US
Rapporteur:	**Rhys Owen**	BAE Systems	UK

National Focal Points (in total 36 participants from 28 companies):

1.	Belgium	Daniel Gilis	CMI Defence
2.	Canada	Stephan Dietrich	GD-OTS Canada
3.	France	Frederic Naccache	MBDA Missile Systems
4.	Germany	Gerhard Hubricht	Rheinmetall Defence
5.	Italy	Gianni Duccini	Oto Melara
6.	Norway	Oyvind Lien	Nammo Raufoss
7.	Poland	Wieslav Jedrzejevski	MEKSO (former: Bumar)
8.	Portugal	Andre Oliveira	Tekever
9.	Spain	Ruben Garcia Garcia	Expace
10.	Sweden	Jan-Olov Blix	BAE Systems
11.	Turkey	Ali Karakov	Tubitak-Sage
12.	UK	Rhys Owen	BAE Systems
13.	US	Dave Dorman	ATK

A.3 Study Meetings

The study was conducted by means of an inaugural meeting to brief participants and establishes initial tasks on March 22nd, 2013 at NATO HQ, Brussels.

The overall schedule of plenary meetings was:

Kick-Off	May, 14th - 15th, 2013	Roethenbach, GE,	Diehl
1st WGM	July, 23rd - 24th, 2013	Glascoed, UK,	BAE
2nd WGM	September, 24th - 25th, 2013	Bourges, France,	NEXTER
3rd WGM	February, 4th - 5th, 2014	La Spezia, Italy,	OTO Melara
4th WGM	April, 8th - 09th, 2014	Karlskoga, Sweden,	BAE
Core Team	June, 2nd – 5th, 2014, Final Report	Washington, USA,	ATK

A.4 Study Reporting

The study results were reported as follows:

Interim Report	to Sponsor Group, briefing	October, 08th-10th 2013 / Rome
Interim Report	to NIAG (6-8 pages, no briefing)	November 2013
Final Report	to NATO	June 26th, 2014 / Brussels
Final Report	to Sponsor Group	October 2014

A.5 List of Participants

Name	Country	Representing	Role
Bazela, Dr. Rafal	Poland	Military Institute of Armament Technology	
Bektas, Yildiz	Turkey	Turkish Aerospace Industries Inc.	
Blix, Jan-Olov	Sweden	BAE Systems Bofors AB	Co-Chair 1
Blomgren, Stefan	Sweden	BAE Systems Bofors AB	
Bohl, Dr. Jürgen	Germany	Diehl BGT Defence GmbH & Co. KG	Chair
Buzzett, Joseph	USA	GD-OTS	
Carlens, Olivier	Belgium	CMI Defense	
Casement, Alf	United Kingdom	Thales UK	
Daly, John	United Kingdom	Selex ES	
Dietrich, Stephan	Canada	GD-OTS-Canada	
Dorman, Dave	USA	ATK Defense Group	Co-Chair 2
Duccini, Gianni	Italy	OTO Melara S.p.a.	
Flintoff, Kevan	United Kingdom	UTC Aerospace Systems	
Garcia Garcia, Rubén	Spain	EXPACE	
Gilis, Daniel	Belgium	CMI Defense	
Guischard, Frank	Germany	Rheinmetall Waffe Munition	
Gündogdu, Murat	Turkey	Turkish Aerospace Industries Inc.	
Hubricht, Dr. Gerhard	Germany	Rheinmetall Waffe Munition	
Hurty, Michel	France	NEXTER Munitions	
Jedrzejevski, Dr. Wieslav	Poland	Bumar Ammunition S.A.	
Karakas, Mehmet	Turkey	ASELSAN Inc.	
Karakoc, Ali	Turkey	TUBITAK Sage	
Kautzsch, Karl	Germany	Diehl BGT Defence GmbH & Co. KG	

Lien, Oyvind	Norway	Nammo Raufoss AS	
Mills, Robert	United Kingdom	QINETIQ	
Oliveira, André	Portugal	TEKEVER	
Owen, Rhys	United Kingdom	BAE Systems	Rapporteur
Özdöl, Atilla	Turkey	ALTAY Kollektif STL.	
Özen, Murat Yasar	Turkey	TUBITAK Sage	
Perrin, Max	France	JUNGHANS Microtec GmbH	
Rey, Felix	Spain	EXPAL	
Saklambanakis, Alex	United Kingdom	Raytheon Missile System	
Sallot, Alice	France	NEXTER Munitions	
Shaw, John	United Kingdom	UTC Aerospace Systems	
Slade, Nigel	United Kingdom	MBDA	
Tazesavas, Onur	Turkey	MKEK	

Annex B: Technology Matrix

PGA Technology List (g-hardened components/subsystems)		Conventional	CCM (1D)	CCM (2D)	PGM	X = is used (X) = could be used ? = Requires Advise
A.	***Mechanics and Pyrotechnics***					
A.1	Fin/Canard opening mechanism			X		
A.2	Expulsion/Despin technology		X	X		
A.3	fin-stabilized flight dynamics				X	
A.4	spin-stabilized flight dynamics		X	X		
A.5	Fuzing / SAU	X	X	(X)	(X)	
A.6	Warhead	(X)	(X)	(X)	X	
A.7	Shell/Base/Obturator	X	X	X	(X)	
A.7.1	-- slipping obturator			(X)	(X)	
A.7.2	-- Carbon Shell	?	?	?	?	
A.8	Base Bleed	(X)	(X)	(X)?	(X)	
A.9	Rocket Assistance	(X)	(X)	(X)	X	
A.10	Parachute (opening/descend/controlled)	(X)	(X)			
A.11	Charge systems / propulsion	X	X	X	(X)	
B.	***Navigation***					
B.1	Navigation data receiver					
B.1.1	GPS (military)		(X)	X	X	
B.1.2	GPS (civil, C/A)		X	X	(X)?	
B.1.3	Galileo		(X)	(X)		
B.1.4	COMPASS (China)		(X)	(X)	(X)	
B.1.5	Beacon		(X)	(X)?	(X)?	
B.1.6	Navigation data link / radar track		X			
B.2	Navigation Sensors					
B.2.1	Accelerometers		(X)	X	X	
B.2.2	Gyro		(X)	X	X	
B.2.3	Magnetometer		(X)?	(X)?	(X)?	
B.2.4	North finder		(X)?	(X)?	(X)?	
B.2.5	Altitude (radar)	(X)	(X)	(X)	(X)	
B.2.6	IMU Integration		(X)	X	X	
B.3	Autopilot Software					
B.4	G&C Electronics					
B.5	Trajectory Management	(X)	X	X	?	
C.	***Target Detection***					
C.1	Laser Sensor					
C.1.1	quadrant detector		(X)	(X)	X	
C.1.2	lens system (optics)		(X)	(X)	X	
C.1.3	signal electronics		(X)	(X)	X	
C.1.4	targeting software		(X)	(X)	X	
C.2	IR Sensor					
C.2.1	Focal plane array /detectors	(X)	(X)	(X)	(X)	
C.2.2	signal electronics	(X)	(X)	(X)	(X)	
C.2.3	targeting software	(X)	(X)	(X)	(X)	
C.3	MMW Sensor					
C.3.1	FMCW 94 GHz active sensor	(X)?	(X)?	(X)?	(X)?	
C.3.2	35 GHz active sensor	(X)?	(X)?	(X)?	(X)?	
C.3.3	Radiometer	X	X	X	X	
C.3.4	signal electronics	X	X	X	X	
C.3.5	targeting software	X	X	X	X	
C.4	Image Sensor					
C.4.1	CCD detectors		X	(X)	(X)	
C.4.2	lens system (optics)		X	(X)	(X)	
C.4.3	signal electronics		X	(X)	(X)	
C.4.4	targeting software		X	(X)	(X)	
C.5	Alternate Sensors					
C.5.1	Acoustic		(X)	(X)	(X)	
C.6	Gimbal systems		(X)	(X)	(X)	

PGA Technology List (g-hardened components/subsystems)		Conventional	CCM (1D)	CCM (2D)	PGM	X = is used (X) = could be used ? = Requires Advise
D.	***Else***					
D.1	Power Supply					
D.1.1	thermal battery				X	
D.1.2	LiSo2/Cl2 Battery	X	X	X	(X)?	
D.1.3	Lithium-Thionyl	X	X	X		
D.1.4	Piezo Electric	(X)	(X)	?		
D.1.5	Fuel Cells	(X)	(X)	(X)	(X)	
D.1.6	permanent battery (not rechargeable)	X	X	X	X	
D.1.7	(Wind-)Generator	X	(X)	X		
D.2	Flight Control					
D.2.1	Fin/Canard Opening Mechanism		X	X	X	
D.2.2	Thrusters/Micro Reactors (Chem)		(X)	(X)	X	
D.2.3	Actuators (Electric)		(X)	X	X	
D.2.4	Actuators (Gas/Fluid)		X	(X)	(X)	
D.2.5	Power Electronics	(X)	(X)	X	X	
D.3	Data Link	(X)	(X)	(X)	X	
D.4	Pre-flight Programming					
D.4.1	WLAN/RF	X	X	(X)	(X)	
D.4.2	inductive	X	X	X	X	
D.4.3	wired	X	(X)	(X)	X	
E.	***System Support Technologies***					
E.1	Precision reconnaissance					
E.1.1	UAV	X	X	X	X	
E.1.2	Terrestrial observer	X	X	X	X	
E.1.3	Satellite	(X)	(X)	(X)	(X)	
E.2	Mapping (DTM)			(X)?	X	
E.3	Programming Units					
E.4	Laser Designation	(X)	(X)	(X)	X	
E.4.1	Terrestrial (Observer)					
E.4.2	UAV	(X)	(X)	(X)		
E.5	Navigation					
E.5.1	GPS Satellite System	X	X	X	X	
E.5.2	Galileo Satellite System	(X)	(X)	(X)	(X)	
E.5.3	Beacon (offset or mid-course)	(X)	(X)	(X)	(X)	
E.5.4	Radar Track (alternate solution)	(X)	(X)	(X)	(X)	
E.6	Metrological Data	X	X	(X)	(X)	
E.7	Data Link					
E.7.1	bi-directional	(X)?	(X)	(X)	X?	
E.7.2	uni-directional (ground to PGA)	(X)?	(X)?	(X)?	X?	
E.8	Command&Control (PGA Mission Planning)	X	X	X	X	
F.	***Test&Development Facilities***					
F.1	Wind Tunnel < 1 M	X	X	X	X	X = SIMILAR USE
F.2	Wind Tunnel > 1 M	X	X	X	X	(X) = POTENTIAL SHARED
F.3	Proving Ground + traj. tracking	X	X	X	X	
F.4	Soft Recovery Test facility	X	X	(X)?		
F.5	Component Shock Test	(X)	(X)	(X)		
F.6	Centrifuge	X	X	X	X	
F.7	GPS/Galileo Test facility		X	X	X	
F.8	HIL Simulation Test Facility					
F.8.1	-- Seeker target simulator	(X)	(X)	(X)	(X)	
F.8.2	-- Fin Loader System					
F.9	EMC	X	X	X	X	
F.10	Qualification Procedures	X	X	X	X - BUT DIFFERENT	
F.11	Interior Ballistics	X	X	X		
F.12	nDOF Simulation Software	X	X	X	X	

Annex C: Product Characteristics

Guided Munitions 155mm

Characteristics	**Fulfilled by Product**				
In service (year)					
g-load < 10.000g					
g-load < 15.000g					
g-load < 20.000g	SABER(18‘)	LWAM	MPM155	GAM155(18’)	V155GLR-SAL(18’)
g-load < 22.000g					
Magnetometer					V155GLR-SAL
INS only					
GPS & INS	SABER (PY)	LWAM	MPM155	GAM155(PY)	V155GLR-SAL(PY)
Video Sensorics		LWAM			
SAL Sensorics		LWAM	MPM155	GAM155	V155GLR-SAL
FarIR Sensorics					
Midcourse Guidance		LWAM		GAM155	V155GLR-SAL
Terminal Homing		LWAM		GAM155	V155GLR-SAL
1 axis CAS	SABER				
2 axis CAS		LWAM	MPM155		
3 axis CAS					
4 axis CAS				GAM155	V155GLR-SAL
Spin stabilized					
Aerodynamically stabilized				GAM155	V155GLR-SAL
CEP < 1m				GAM155	V155GLR-SAL
CEP 1m – 10 m	SABER		MPM155		
CEP 10m – 30m		LWAM			
CEP 30m – 50m					
CEP 50m – 100m					
SAD only				GAM155	V155GLR-SAL
Fuze standard geometry					
Fuze deep intrusion					
Fuze forward extention					
STANAG 4369	SABER				
STANAG 4593				GAM155	
Inductive setting	SABER (EPIAFS)			GAM155	
contact setting			MPM155	GAM155	V155GLR-SAL
Stationary Targets	SABER	LWAM		GAM155	V155GLR-SAL
Moving Targets		LWAM		GAM155	V155GLR-SAL
Compatibility with automatic loader	SABER		MPM155	GAM155	V155GLR-SAL
Incompatibility (Stand-ards/JBMOU)					

Guided Munitions 127mm

Characteristics	Fulfilled by Product
In service (year)	
g-load < 10.000g	
g-load < 15.000g	
g-load < 20.000g	
g-load < 26.000g	V127GLR-SAL(26')
Magnetometer	V127GLR-SAL
INS only	
GPS & INS	V127GLR-SAL(PY)
Video Sensorics	
SAL Sensorics	V127GLR-SAL
FarIR Sensorics	V127GLR-FarIR
Midcourse Guidance	V127GLR-SAL/FarIR
Terminal Homing	V127GLR-SAL/FarIR
1 axis CAS	
2 axis CAS	
3 axis CAS	
4 axis CAS	V127GLR-SAL/FarIR
Spin stabilized	
Aerodynamically stabilized	V127GLR-SAL/FarIR
CEP < 1m	V127GLR-SAL/FarIR
CEP 1m – 10 m	
CEP 10m – 30m	
CEP 30m – 50m	
CEP 50m – 100m	
SAD only	V127GLR-SAL/FarIR
Fuze standard geometry	
Fuze deep intrusion	
Fuze forward extention	
STANAG 4369	
STANAG 4593	
Inductive setting	
contact setting	V127GLR-SAL/FarIR
Stationary Targets	V127GLR-SAL/FarIR
Moving Targets	V127GLR-SAL/FarIR
Compatibility with automatic loader	V127GLR-SAL/FarIR
Incompatibility (Standards/JBMOU)	

Guided Munitions 120mm

Characteristics	**Fulfilled by Product**
In service (year)	
g-load < 10.000g	
g-load < 15.000g	GMM120(12')
g-load < 20.000g	
g-load < 22.000g	
Magnetometer	
INS only	
GPS & INS	GMM(SAASM)
Video Sensorics	
SAL Sensorics	GMM
FarIR Sensorics	
Midcourse Guidance	GMM
Terminal Homing	GMM
1 axis CAS	
2 axis CAS	GMM
3 axis CAS	
4 axis CAS	
Spin stabilized	
Aerodynamically stabilized	GMM
CEP < 1m	GMM
CEP 1m – 10 m	
CEP 10m – 30m	
CEP 30m – 50m	
CEP 50m – 100m	
SAD only	GMM
Fuze standard geometry	
Fuze deep intrusion	
Fuze forward extention	
STANAG 4369	
STANAG 4593	GMM
Inductive setting	GMM
contact setting	GMM
Stationary Targets	GMM
Moving Targets	GMM
Compatibility with automatic loader	
Incompatibility (Standards/JBMOU)	

Corrected Munitions 155mm

Characteristics	**Fulfilled by Product**		
In service (year)	PGK(2013)		
g-load < 10.000g			
g-load < 15.000g			
g-load < 20.000g	PGK(18')	SPACIDO	
g-load < 22.000g			ECF(22')
Muzzle Velocity Radar		SPACIDO	
GPS only	PGK		ECF
GPS & INS			
Airbrake		SPACIDO	ECF
Fixed Canard	PGK		
CEP < 1m			
CEP 1m – 10 m			
CEP 10m – 30m	PGK		
CEP 30m – 50m		SPACIDO	ECF
CEP 50m – 100m			
SAD only			
Fuze standard geometry		SPACIDO	ECF
Fuze deep intrusion	PGK		
Fuze forward extention			
STANAG 4369	PGK	SPACIDO	ECF
STANAG 4593			ECF
Inductive setting	PGK(EPIAFS)	SPACIDO	ECF
contact setting			
Stationary Targets			
Moving Targets			
Compatibility with automatic loader		SPACIDO	ECF
Incompatibility (Standards/JBMOU)	PGK(2916)		

Corrected Munitions 120mm

Characteristics	Fulfilled by Product
In service (year)	
g-load < 10.000g	
g-load < 15.000g	
g-load < 20.000g	
g-load < 22.000g	
Muzzle Velocity Radar	
GPS only	MGK(SAASM)
GPS & INS	
1 axis CAS	
2 axis CAS	
Airbrake	
Fixed Canard	MGK
CEP < 1m	
CEP 1m – 10 m	MGK
CEP 10m – 30m	
CEP 30m – 50m	
CEP 50m – 100m	
SAD only	
Fuze standard geometry	
Fuze deep intrusion	
Fuze forward extention	MGK
STANAG 4369	
STANAG 4593	
Inductive setting	MGK(EPIAFS)
contact setting	
Stationary Targets	MGK
Moving Targets	
Compatibility with automatic loader	MGK
Incompatibility (Standards/JBMOU)	MGK(2916)

Corrected Munitions 81mm

Characteristics	**Fulfilled by Product**
In service (year)	
g-load < 10.000g	RCGM
g-load < 15.000g	
g-load < 20.000g	
g-load < 22.000g	
Muzzle Velocity Radar	
GPS only	
GPS & INS	RCGM(SAASM)
1 axis CAS	
2 axis CAS	
Airbrake	
Fixed Canard	RCGM (roll contr.)
CEP < 1m	
CEP 1m – 10 m	RCGM
CEP 10m – 30m	
CEP 30m – 50m	
CEP 50m – 100m	
SAD only	
Fuze standard geometry	
Fuze deep intrusion	
Fuze forward extention	RCGM
STANAG 4369	RCGM
STANAG 4593	
Inductive setting	RCGM
contact setting	
Stationary Targets	
Moving Targets	
Compatibility with automatic loader	
Incompatibility (Standards/JBMOU)	

Annex D: Lifecycle Costs

- What does the life cycle costs look like for conventional, corrected and guided munitions?
  - Procurement cost
  - Storage cost
  - Training costs
  - Shelf life, upgrades and demilitarization
  - Government management
- How much to buy?
  - Units have high visibility and it is given how much to procure.
  - Ammunition is a commodity that is extremely specialized
  - Long lead time
  - Important for unit effectiveness and sustainability
  - Ammunition has almost no visibility to the public
- Long term storage
  - All ammunition must be stored safe and secure
  - Low humidity and slow temperature variations are preferred – nations have different methods based on their preconditions
  - Controlled classifications of weapons results in substantial costs, as man power, security and “red-tape” is increased.
- Training
  - Training Need Analysis
    - What is hard to do?
    - Stressful situations
      - The need to train Forward Observers drive the need to do live firings with Field Artillery
      - The need to train handler and weapon crews with live ammunition
  - Level
    - Personal skills
    - Team, small unit
    - System-of-system (battalions, brigades, functional chains etc.)
  - Purpose
    - Knowledge and skills

    - Build confidence

- ❖ Training equipment
    - Simulators (forward observers, decision makers, double-sided manoeuvre exercises)
    - Inert ammunition for handling
    - Presentations
    - Reduce expenditure of ammunition - if expensive
    - Repetitions, avoid wear
    - Targets
    - EOD models

- ❖ Train as you fight
    - But needs to be safe!
        - This must be an early design criteria!

- ❖ Cost
    - Depends on national cost model
        - Cost of ammunition itself – is this a cost if we bought it 5 years ago?
        - Cost of set up
        - Personnel costs

- ❖ Live firing – lessons learned
    - Needed to build confidence
    - Need to repeat requirements on the product before the training event
    - Need to allow expenditure also at unit level training
        - Special budget
    - Need to have some instrumentation to be able to explain
        - Example: track with counter battery radar

➢ Shelf life expectancy and Upgrades

- ❖ Stock pile surveillance
    - Support for this should be included in design
    - Forecasting still not good enough

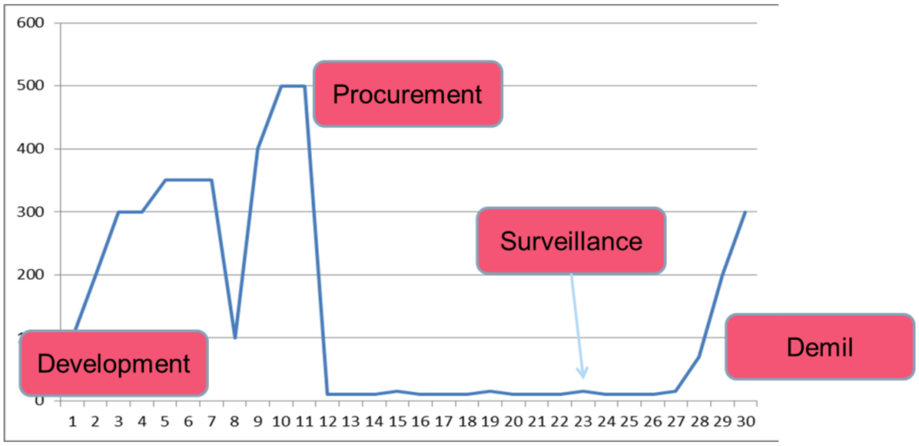

Figure 2 – Life cycle cost projectiles

- ❖ If a nation invests in development that cost is often greater than the procurement cost
- ❖ Upgrades
    - Software
    - Hardware
        - Propellants, rocket motors

- ➢ Demilitarization
    - ❖ The more complex the product is, the more expensive it is to demilitarize
    - ❖ Better to use in training
        - Important that there are no environmental problems with that

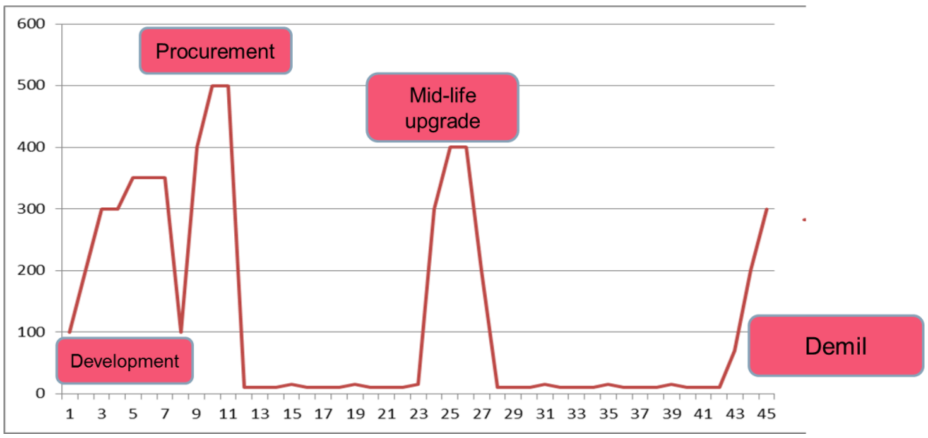

Figure 3 – Life cycle cost with upgrade

- ❖ Missiles typically allow for upgrades but may require more maintenance. The costs of such weapons do tend to be an order of magnitude above those of CCMs and PGMs, so the trade-off between midlife updates and serial production should be considered to understand any potential cost benefit.

- Government management
  - Technical experts are needed throughout the whole life cycle
  - Government or long term contractor support

Annex E: Abbreviations

AOP	Allied Ordnance Publication
BONUS	
CAS	Control Actuation System
CCF	Course Correction Fuze
COTS	Component of the Shelf
CPU	Central Processing Unit
ECF	European Correction Fuze
EOD	Explosive Ordnance Disposal
FarIR	Far Infrared
GAM	Guided Artillery Munition
GLGM	Gun Launched Guided Munition
GLONASS	Globalnaja Nawigazionnaja Sputnikowaja Sistema
GMM	Guided Mortar Munition
GNC	Guidance Navigation and Control
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HWIL	Hardware in the Loop
ICD	Interface Control Document
ICG IF	Integrated Combat Group Indirect Fire
IMU	Inertial Measurement Unit
IPT	Integrated Project Team
IRNSS	Indian Regional Navigation Satellite System
ITEAP	Integrated Test, Evaluation and Acceptance Plan
MOD	Ministry of Defence
MPM	Metric Precision Munition
NAAG	NATO artillery Armaments Group
NABK	NATO Armament Ballistic Kernel
NIAG	NATO Industrial Advisory Group
PGK	Precision Guidance Kit
PGM	Precision Guided Munition
QZSS	Quasi Zenit Satellite System

SAD	Safe and Arm Device
SAL	Semi Active Laser
SG	Sub-Group
SRD	System Requirement Document
STANAG	Standardization Agreement
TDP	Technical Data Package
TM	Telemetry
UPP	Unit Production Price
WGM	Working Group Meeting