An International Review of the Use of Environmental Data Loggers in Peace-Time and Operations

Emmanuel Schultz
Wade Babcock
North Atlantic Treaty Organization
Munitions Safety Information Analysis Center
S-040 Batiment Z
B-1110 Brussels

e.schultz@msiac.nato.int

ABSTRACT

This paper provides a brief introduction to an MSIAC report which provides an overview of the use of environmental data loggers and of the data that is registered. This was achieved via a survey sent to representatives in MSIAC member nations and thanks to documents from the AVT groups dealing with this topic as well as other literature found in the MSIAC databases. These systems provide access to the real environment the munitions are exposed to. The report describes the type of sensors and how they are used, the effects of the environment on ammunition, and how the data is used. Through examples, methods to optimize the use of these data are also suggested in order to make them useful in the following situations: optimization of the surveillance program, life-extension decision, detection of "out-of-specification" environment, combination with aging models to determine the condition of the product, accident analysis.

1. INTRODUCTION

This paper is a limited summary and introduction to the use of environmental data loggers throughout a number of nations. The material presented here is a subset of a much more detailed analysis in MSIAC limited report L-193, Munition Health Monitoring – Feedback from the Use of Dataloggers. These data loggers are being used to monitor munitions environmental exposure during their life cycle.

It presents the types of sensors, their characteristics and where and on which munitions they have been deployed. Some real environmental data are provided and analyzed to understand the effect the environment had on the munitions. In addition to the current policy on in-service surveillance, examples of best practice to use the data are provided.

2. ACRONYMS

AVT: Applied Vehicle Technology

CSO: NATO Collaboration Support Office

EDL: Environmental Data Logger

EO: Explosive Ordnance

HMOM: Health Monitoring of Munitions

HUMS: Health and Usage Monitoring System

IMHM: Integrated Munitions Health Management

ISS: In-Service Surveillance

MHM: Munitions Health Management

MSIAC: Munitions Safety Information Analysis Center

NATO: North Atlantic Treaty Organisation

STO: NATO Science & Technology Organisation

3. BACKGROUND

STO/AVT has been really active in the area of health monitoring and health management of munitions. A lot of information on the use of data loggers as well as on research and demonstrator programs has been collected during the following STO/AVT activities:

- AVT-119: Health Monitoring of Munitions (2003 – 2007)
- AVT-160: Health Management of Munitions (2007-2009)
- AVT-176: Advances in Service Life Determination and Health Monitoring of Munitions (2010)
- AVT-208: Technical advances and Changes in Tactical Missile Propulsion for Air, Sea and Land Application (2012)
- ET-112: Exploratory Team to prepare AVT-212 (2011)
- AVT-228: Lecture series on Munitions Health Management (2013)
- AVT-212: Application of Integrated Munition Health Management – Developing Methodologies for Implementation (2011 – 2015)

The reports from these activities can be downloaded from the STO/CSO website.

In addition, the report from the cooperative demonstration of technologies from AVT-212 is accessible on the MSIAC secure website under the reference L-192.

A questionnaire was sent to the MSIAC member nations to get an overview of their involvement in this area. The following nations have provided an answer to the questionnaire: Australia, Belgium, Canada, Finland, Germany, Norway, Sweden and the UK. The Netherlands have published several papers in this area and have asked MSIAC to use these papers as a basis for their answer.

4. DRIVERS / POLICY

4.1 NATO POLICY

The use of data loggers for health monitoring or health management of munitions is linked with in-service surveillance activities and life assessment. NATO has recently drafted STANAG 4675 dealing with in-service surveillance of ammunition. It covers three AOPs with the following structure:

This STANAG covers:

• Methods of test and assessment

• Selection of surveillance assets

• Methods for determining life

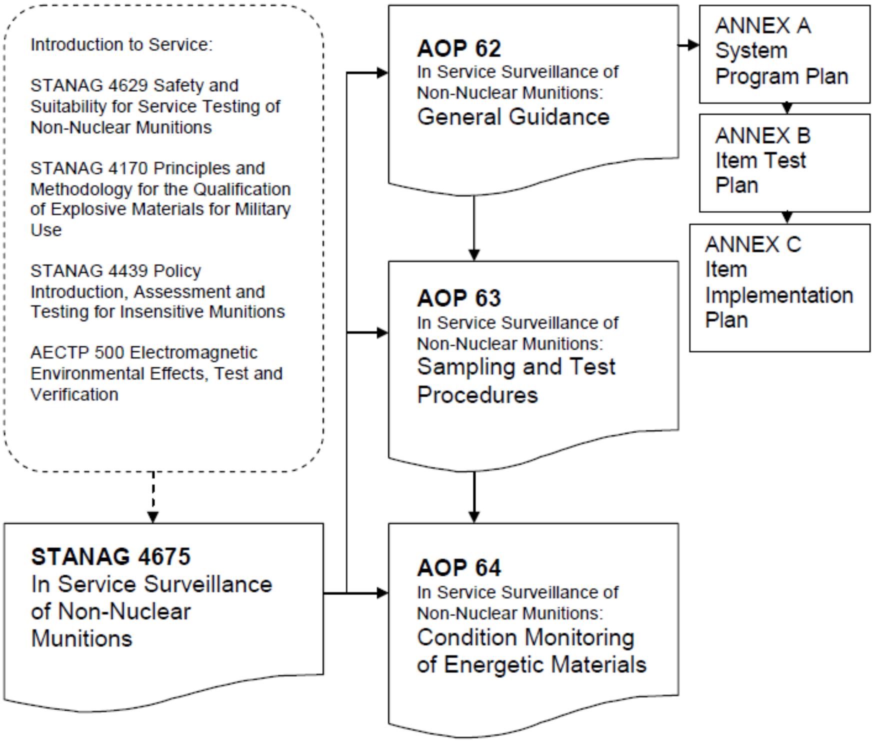

Figure 1: STANAG 4675 document structure

It assumes that safety is the primary criterion for limiting a munitions' life. Ratifying nations agree to follow the guidance given in the three AOPs and provide on demand the relevant safety and reliability data when transferring munitions to other NATO nations. In these AOPs, environmental monitoring is mentioned as part of the process.

The first aim is to know what munitions have experienced. AOP-62 described the ISS framework (Fig. 2), which includes environmental monitoring:

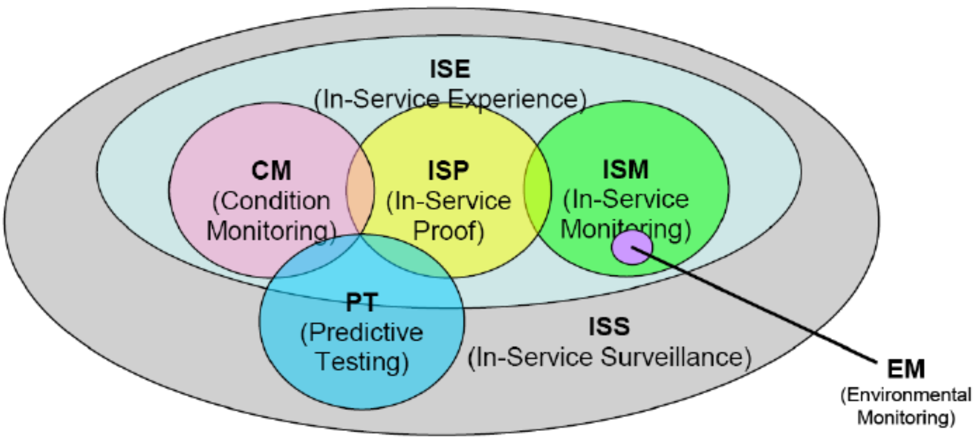

Figure 2: ISS framework (extract from AOP-62)

Part of the terminology and the objectives of environmental monitoring are defined in AOP-62: an extract of this document dealing with this is provided hereafter:

a. Environmental Monitoring

Environmental monitoring (EM) can be considered as a subset of ISM whereby 'real-world' data is gathered throughout the storage and/or deployment of a munitions system. In its simplest form this can be temperature and humidity data manually recorded in depot, or meteorological data recorded in theatre, through to analysis of data recorded during trundling/field trials or by Environmental Data Loggers (EDL).

For safety reasons the predicted environment used in basic failure/degradation models is usually (but not always) pessimistic. EM provides service data to replace the predicted service environment used in these models with an actual service environment. EM is also very closely linked to CM and is essential to making accurate predictions of the remaining life for munitions. In very basic terms, degradation models involve comparing the stresses experienced and survived by test items during predictive testing with the actual stresses experienced during service use. Provided in-service stresses remain below those experienced during testing, the in-service items can be expected to survive as comfortably as the test items. Therefore in many cases EM can lead to an increase in service life through more accurate modelling of the environment and associated degradation.

It is also possible to control the environment, an example of which is to use thermally controlled ISO containers for the transport and storage of munitions. This can slow down the degradation of munitions. The use of a controlled environment does not allow a munitions manager to ignore the effects that the surrounding environment could cause. In field conditions air-conditioning can fail quite frequently and carrying out repairs quickly is not always possible. Even in controlled environments monitoring should still be considered.

b. Environmental Data Loggers

Environmental Data Loggers (EDL) is the title given to any device that will provide data about the environment the munitions experience. The term EDL is mostly associated with independent electronic devices that record and store temperature and humidity data. EDL is a generic term covering all devices that improve knowledge of the environments experienced by an item. This can range from simple chemical devices that change colour at certain temperatures, to health usage monitoring systems (HUMS) that can record temperature, humidity, shock, vibration, and pressure over many years.

EDL can also range in position from a loose association with munitions, such as using platform based data or placing EDL outside munitions containers, to being fully embedded within the munitions. If the EDL is not fully embedded then initial assessment and analysis regarding the placement of the EDL should also include the derivation of a transfer function that can translate the data recorded by the EDL to the position on the monitored item where degradation is most likely.

As EDL technology advances, this technology should be incorporated into the ISS Plan. The more that is known about the environment actually experienced by items in service the more that testing can be focused on areas of concern. A fully monitored fleet of missiles or munitions would allow 'fleet leaders' to be easily identified and tested and where environments are less extreme than predicted could even allow for less frequent removal of test items for inspection.

Table 1 extracted from AOP 63 mentions the way to monitor the environment munitions are exposed to.

Table 1: Extract from AOP-63 – Test Selection Guide

Category of Testing	Testing Technology/Methods	Remarks
Non Destructive Examination (Probabilistic, Basic Testing)	a. Physical Examination	Used to determine a snapshot of the in-service condition of munitions and select "fleet leader" samples.
	b. Radiography- X-ray, gamma and neutron particles	
	c. Imaging – Computerised axial tomography	
	d. Ultrasonics – Laser and piezoelectric	
	e. Interferometry – Holograph	
	f. Boroscope	
	g. Electronic test sets performance of the electronics	
Non-Destructive Examination (Monitoring)	a. Environmental Data Logger (EDL) Temperature, humidity, vibration, pressure and shock	Used for through life monitoring to help populate life estimation models and select "fleet leader" samples.
	b. Health Monitoring Systems platform data for temperature, vibration and shock	
	c. Embedded sensors	
	d. Weapon Record Books Time on platform, launcher etc…	
Destructive Testing (Basic and Predictive Testing)	a. Hazard safety testing (charge scale & small (powder) scale)	Used to meet basic objectives of ISS to help make basic judgements regarding the condition of the Item.
	b. Mechanical Testing - (eg Dynamic mechanical analysis)	
	c. Thermal testing - Microcalorimetry	
	d. Chemical composition - (Chromatography etc…)	
	e. Performance testing - burning rate, closed vessel, static motor firings.	
	f. Energetic material characterisation - prediction of degradation processes and vulnerability.	
	g. Proof and Service firings, arena trials	
Systems Tests & Life Modelling (Predictive Testing)	a. System/item level accelerated aging – diurnal cycling	Used to meet extended objectives of ISS to help populate ageing models for Item and System. Note that a., b. and c. can be sequential .
	b. System/item level accelerated aging - transport and tactical vibration and shocks	
	c. System/item level accelerated aging – destructive testing at extremes of temperature	
	d. Monitored/controlled natural ageing of material samples (storage life modelling)	
	e. Monitored/controlled accelerated aging of material samples (material life monitoring)	

Finally, AOP-64 deals with the condition monitoring of energetic materials. It provides ageing phenomena and their potential effects, segregated by energetic materials family, and how to test to monitor the ageing.

4.2 NATIONAL POLICY

Of respondents to MSIAC's request for information on the subject, Canada and Belgium provided details of national policy currently in place or in development.

Canada's Department of National Defense (DND) has a formal policy/standard on In-Service Surveillance

(D-09-002-017/SG-001, Standard In-Service Surveillance of Ammunition and Explosives). DND also has a policy (in development) for logging/recording of T and RH data regarding domestic ammunition storage (i.e. Volume 2 of the Ammunition and Explosives Safety Manual).

Belgium has a detailed instruction on "environmental data logging" DGMR-SPS-QAPOL-LABE-001 (which will be converted (renamed) in the near future to DGMR-GID-MNTMGT-LABX-003). They also have an integrated logistic support plan for ammunition (overarching policy). The policy on health monitoring of ammunition is in development.

4.3 DRIVERS AND CONDITION BASED MAINTENANCE

In addition to the policies, there are several drivers to perform environmental monitoring of munitions in service.

The first advantage of measuring data is to gain knowledge of the environmental conditions where munitions are stored and deployed. For the users it was particularly useful, especially during recent years with a lot of military operations, to register the real thermal environment and to realize that the number of hours of flight was much higher than expected (Afghanistan, Libya). This information could help to better define the technical requirement for future acquisition.

Measured data could also help to better investigate incidents or accidents, and even to prevent them. Actually, when an incident or an accident occurs, one of the first questions is related to the condition of the munitions. Most of the time, the only information available is the data from the last surveillance activity, which might have been performed several years before. Having data on the real exposure of the item involved in the incident could help in understanding the causes of an accident.

The idea of health management is to increase reliability and confidence in in-service surveillance decisions to better manage the stockpile, e.g.:

- to avoid disposing of munitions that are still reliable and safe,
- to avoid keeping in service munitions that are no longer reliable and/or safe,
- to adjust surveillance testing and inspection on munitions as a function of what they really experienced.

This could help save costs by reducing the amount of destructive tests during surveillance and by extending the life of weapon systems. A potential additional feature includes tracking of munitions, which could be useful in order to track the stockpile and to get access to the main principles of MHM [6]: condition, safe remaining life and location of assets.

Actually, Munitions Health Management contains several areas that AVT-212 summarized in this chart:

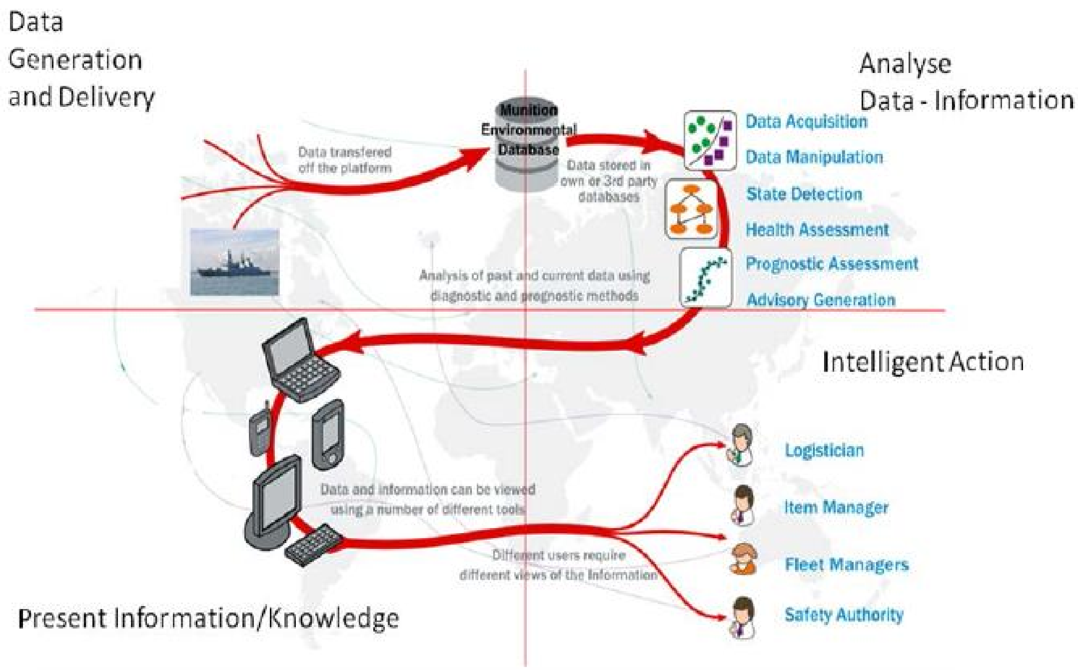

Figure 3: IMHM - from data generation to intelligent action

And on which phase the AVT activities were focused:

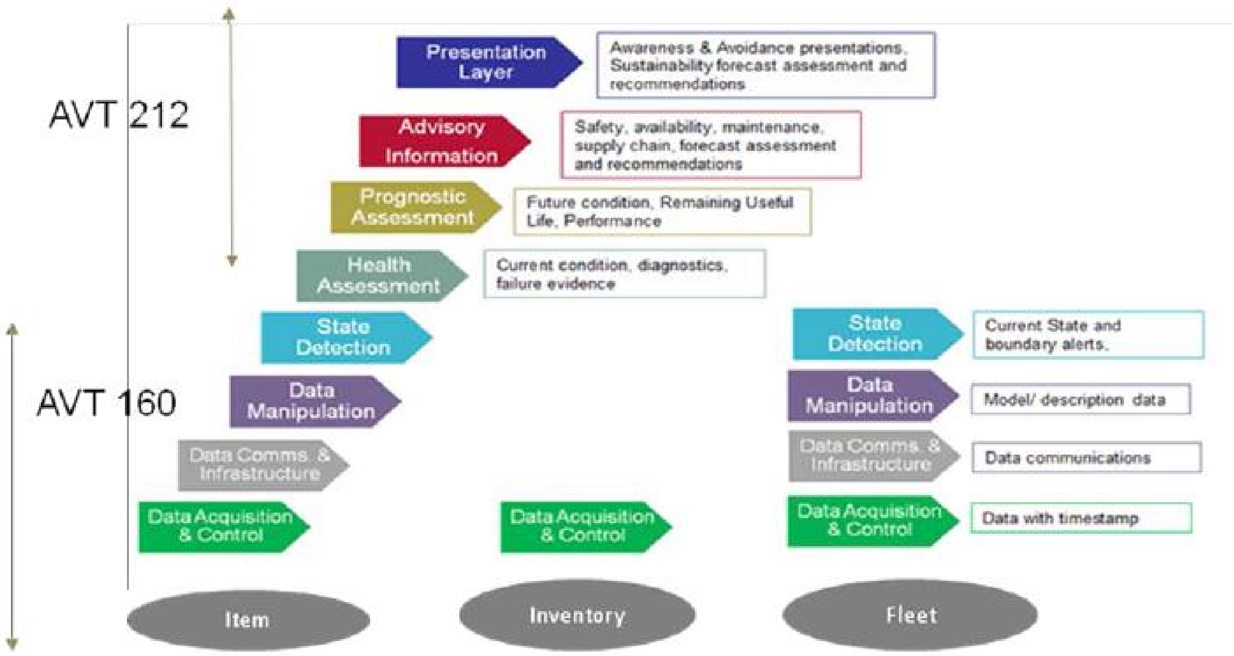

Figure 4: focus of AVT-160 & AVT-212

AVT-212 led to a cooperative demonstration of technology held at NATO HQ in October 2014. The content is summarized in AVT/MSIAC report L-192 [1].

The demonstration highlighted the benefits of IMHM approaches, with one of the main goals being a shift to a condition based maintenance paradigm instead of the current in-service surveillance, also referred as calendar-based maintenance. The two approaches are compared hereafter, and further details are provided in the AVT-212 report [1]:

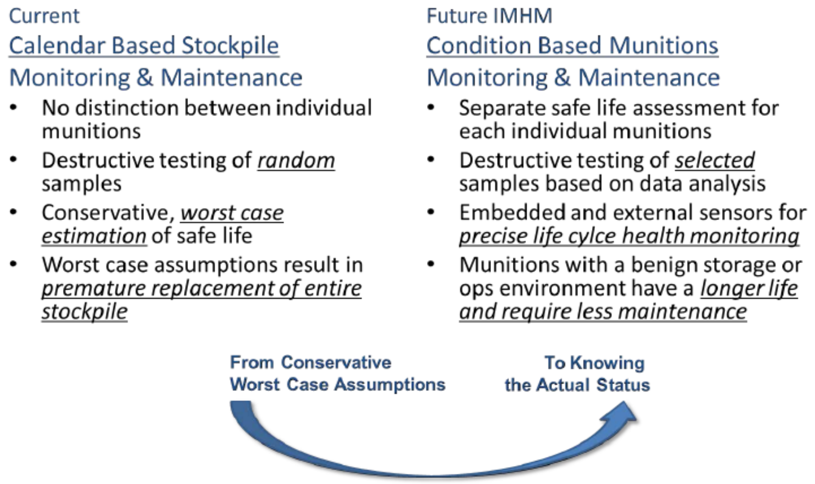

Figure 5: Calendar-based maintenance vs. Condition-based maintenance

5. CONCLUSIONS

This paper presents a limited overview of the contents which are provided in much more detail in MSIAC report L-193, Munition Health Monitoring – Feedback from the Use of Dataloggers. The accompanying presentation presents some of this data as well. In summary, there are a number of organizations using environmental data loggers, as well as performing or financing research in the area of Health Monitoring of Munitions:

- Governmental organizations: US Navy, US Air Force, EDA, UK MOD, NATO STO, …
- Forces: Australian Defence Forces, Norwegian Navy, Swedish Navy, Italian Navy, Danish and Dutch Army, Canadian Army, Royal Air Force…
- Industry: ATK, MBDA, Roxel, TNO, Thales,…
- Sensors have been deployed during recent operations in the following countries: Afghanistan, Iraq, Mediterranean Sea and the Gulf of Aden. They were used to monitor the conditions:
  - In national storage in peacetime (Australia)
  - In storage during expeditionary operations
  - Onboard platforms (aircraft, land vehicle, ships)

Most of the time, the monitoring was limited to temperature and relative humidity, and typically COTS environmental data loggers have been deployed in the field. Many munitions types have been examined, including medium caliber, tank ammunition, artillery propelling charge, pyrotechnic systems, shoulder launched rockets, as well as air-, surface-, and land-launched missiles. Extreme temperatures were encountered almost only when the munitions were taken outside their packaging and exposed to direct solar radiation. This emphasizes the importance of keeping munitions inside their packaging as much as possible and using sunshades wherever practical.

Thanks to all these activities, nations have gained a better knowledge of the conditions their munitions are exposed to, either in storage at home or during deployment in operations. Some nations realized cost savings due to life extension of several systems, instead of in-place disposal thanks to the measurement of the temperature only.

Additionally, a significant amount of experience has been gained in working with various EDL systems, handling their data, learning about their abilities and limitations, and acclimatizing personnel to their presence and use.