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Work Safety and the Duration of Munition Testing

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Abstract. This paper presents the aspects of work safety and the standardization of time (duration) that relate to the diagnostic testing of munitions. This paper identifies the sources of hazards during munition disassembly, caused by the physical and chemical processes occurring during the years of service, and the hazards of non-conformities with the standard processing procedures used during the manufacture of the munitions. Munitions, given their intended use, are not usually designed for disassembly. With the manufacturing processes of munitions being monitored at every stage, and the application of proper grades or quality of the materials and components, munitions may retain their combat performance for a very long time following the expiry of their original warranty period. The extended shelf life of munitions (past the original warranty period/shelf life) can be determined with certain tests. The tests, however, require tampering with the internal structure of a munition by disassembling the munition into its component parts in order to allow assessment of the current technical condition and to project the technical fitness for extended service.

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Disassembly activities are hazardous and require the prior preparation of safe processes, workstations, procedures, and a comprehensive health and safety assurance system. Health and safety assurance in munition testing requires high capital expenditure to acquire sufficient engineering facilities and proper monitoring of all the disassembly activities attempted on munitions. Operator safety has the highest priority in munition disassembly; it is then pointless to regulate the time required for completing the individual disassembly operations.
Keywords: munitions, work safety, service safety, time regulation

1. INTRODUCTION

The safe servicing of munitions requires continuous monitoring of their technical condition (sometimes known as health). Over their long life, munitions suffer from certain physical and chemical processes that affect their performance. Most munitions contain explosive materials that, upon accidental initiation, may result in hazards to human life and property within the explosion radius. The consumption of munitions during times of peace is immeasurably low in comparison to their stock levels. The manufactured munition lots are stockpiled for a period which greatly exceeds the shelf life (OPT) specified by the manufacturer.

The entirety of munition quality control and safety is regulated in Poland by "Manual for Munition Quality Control and Safety in the National Defence Service" [5]. The Manual states that when the original warranty period of a munition, or the OPT granted to a munition by a cognizant R&D unit, expires, it is mandatory to determine the actual technical condition of the munition and project its future maintenance time. Upon expiry of either the original warranty period or OPT, the munitions concerned are subject to diagnostic testing to assess the actual parameter values of all the munition components and parts, which include high-energy materials, that affect the service safety and reliability of performance. Accessing the individual parts of a munition requires disassembly down to the level of detail required for diagnostic testing. Munitions, given their intended use, are not usually designed for disassembly. Hence, disassembly of munitions requires very specific conditions to permit tampering with their structure. The process of disassembling munitions is extremely dangerous, since those munitions referred for diagnostic testing are those whose OPT expired many years ago, and a preliminary radiographic analysis of the munition is required to evaluate advanced structural changes of the inner surfaces caused by ageing or, in some cases, manufacturing defects. Manufacturing defects are a frequent hazard in disassembly operations, more so than ageing, since they cannot be reasonably foreseen. Each manufacturing defect requires an individual approach, which interrupts the established testing schedules of the diagnostic testing organisation.

Modification of downstream standard operating procedures are required with the application of dedicated, highly-specialized testing equipment, the preparation of workstations to permit safe disassembly, and the engagement of extra personnel. This is necessitated for work safety assurance and greatly extends the diagnostic testing time.

The time required to complete the diagnostic testing of a manufacturing defect is difficult to estimate beforehand, and it is not recommended to expedite any operation anywhere in the process.

When attempting to undertake diagnostic tests on a munition which has already been repeatedly tested, it is difficult at first to estimate the total time to complete the entire diagnostic testing process. Practical experience dictates that the duration of diagnostic testing of this type of munition can be several times longer or shorter than any standard benchmark. The analysis summarized above indicates the causes and the rationale for differences in the duration of diagnostic testing. Hence, any standard or regulation for testing time in relation to munitions causes controversy, especially in munition testing customers. The munition testing contractor must assure work safety irrespective of the costs involved to achieve this objective. The obligations of the munition testing contractor as an employer are established in the applicable regulations, [1] through [4].

2. SOURCES OF WORK HAZARDS IN THE TESTING OF MUNITIONS

Munitions, given their intended use, are disposable products. The technical specifications and design of munitions are developed to achieve safe service and reliable performance. Depending on the specific type of a munition, it may or may not require certain overhaul procedures. Munition designers usually do not assume that their products will be disassembled into its components. This is what makes any human intervention into the structure of a munition so hazardous. Diagnostic testing of munitions requires access to the individual parts of the munition product; this means disassembly into mechanical components that can be tested and the explosive material itself.

The ageing processes of the materials used to produce munitions may affect the technical parameters of individual munition components in a way impossible to foresee. Hence, all munitions manufactured anywhere from a dozen years to several decades ago require extreme scrutiny during testing.

The intensity and rate of the ageing processes largely depend on the climatic conditions of storage. A comparative analysis of the test results for part of a munition lot stored in the Polish climate zone and for another part from the same lot stored in a subtropical climate (Iraq and Afghanistan) showed significant differences in technical condition. High temperatures accelerate the thermal decomposition of high-energy materials.

The dusting or leaching of various hazardous substances concomitant to thermal decomposition may leave deposits on the thread forms of munition components, resulting in a risk of explosion initiation during disassembly.

Elevated airborne dust concentrations and/or relative humidity levels accelerates the corrosion of the mechanical parts of munitions.

Defects in the process of munition manufacturing also pose a great safety hazard. This is so significant because manufacturing defects are largely unforeseeable. A part made in deviation from the engineering specifications/ drawings, a small but vital safety missing, and similar defects may initiate the defective munition at the least expected moment during disassembly or service.

One example here is the defective manufacturing of a production lot for the M12 fuze, which initiated detonation of a mortar projectile in the barrel of a 120 mm mortar, rupturing the latter (see Figure 1). All figures in this paper were made at the Military Institute of Armament Technology (Zielonka, Poland).

Fig. 1. The effect of a mortar projectile detonation inside a mortar barrel

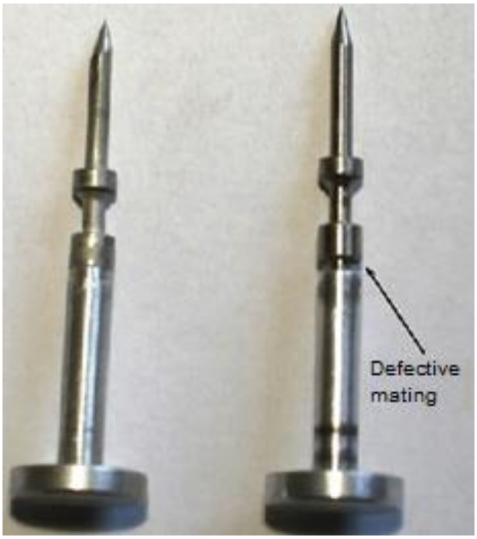


Fig. 2. Firing pin of the M12 fuze: correct assembly (left); defective assembly (right)

The root cause of this accident was defective mating of the M12 fuze firing pin parts. The force inputs applied during use of the mortar projectile caused the firing pin parts to fail and arm the M12 fuze while the mortar round was being dropped into the barrel (see Figure 2).

The same defective mating of the M12 fuze firing pin components triggered another M12-fuze detonation while testing its resilience to input forces during shipping and handling. A tragedy was averted only by use of the proper safeguards at the test rig and the experience of the test operators.

Choosing sub-par or defective materials to manufacture munitions may result in accelerated corrosion and compromise the safety of service. An example here is the installation of a plastic pad with open pores in the rocket motor of an M21 missile. The plastic pad began to wick up humidity from ambient air (see Figure 3). Above-zero temperatures caused the condensate to evaporate from the plastic pad and condense again on other parts of the rocket motor, causing rapid corrosion of the metal components (the grate, the aluminium baffle of the 9Ch227 igniter, and the inner lining of the rocket motor combustion). The corrosion of the thin-walled baffle of the 9Ch227 igniter was extremely hazardous. Under extreme conditions, the baffle became perforated and released black powder grains into the rocket motor combustor. The ingress of black powder grains between any surfaces rubbing against each other during shipping or handling (e.g. the metallic parts of the grate) may result in the uncontrolled ignition of the black powder charge, followed by ignition of the rocket propellant grain. Removal of the grate with the 9Ch227 igniter compromised as above for testing is also hazardous due to the risk of frictional ignition of the black powder grains between the grate parts. The rack removal operation will require great caution and focus from the testing team.

Fig. 3. Defective plastic pad and the effects of its installation in the rocket motor of an M21 missile

Non-conformity with the manufacturing process established for a specific munition is another potential cause of munition non-conformity. Although rare, this defect type forces testers to remain extremely vigilant during the disassembly and testing of such munitions. Any disregard of this defect could be disastrous.

Aside from the objective hazards which may occur during diagnostic testing of munitions due to the structure and service, subjective, human-dependent hazard factors must also be considered. Repetitive disassembly of many rounds of the same munition product causes the test operator to relax in the face of existing hazards. Repetitive activities reduce the level of human focus essential to assure sufficient work safety.

A major impact on work safety results from the short lead times for commissioned testing. It is not unusual for customers to demand very short deadlines for tests. This can greatly intensify the work load of a diagnostic testing organisation, especially at the end of the calendar year.

3. WORK SAFETY ASSURANCE IN TESTING OF MUNITIONS

Comprehensive testing of the technical status of munitions requires experienced and professional engineering and testing personnel, sufficient know-how, and sufficient technical and scientific facilities. Assurance of a correct level of testing safety is an interdisciplinary problem. Engineering and testing personnel comprise professionally experienced employees from different disciplines: high-energy materials, military armament, munition design engineers, and mathematicians specializing in the theory of reliability and statistical quality control, the effects of whose work is the theoretical foundation and methodology of the technical status testing and assessment applied to in-service munitions. The testing methodology is the cornerstone of developing the required testing processes, workplace regulations, and technical status assessment of specific munitions.

The testing of any type of munition first requires a series of preparatory actions. The engineering documentation, other available references, and the proprietary experience of the diagnostic testing organization are all inputs in the development of the testing process for the munition. Development of the testing process is preceded by a thorough analysis of the munition's design and potential hazards during disassembly. The analysis serves to select the characteristics of the munition with the most significant impact on its service safety and performance reliability. The selected characteristics of the munition will be tested and evaluated.

The next stage is to develop a munition disassembly process that ensures the safe decomposition of the munition into its component parts, which then allows the evaluation of each selected characteristic of the munition. The munition disassembly process includes the engineering equipment essential for the safe completion of all operations on the munition to be tested. Regarding the above, the scope of work safety is very broad. It includes the buildings, rooms and workstations, which must meet specific technical requirements for safety, as well as fire protection, health and safety, and a properly trained workforce.

The test operators who directly carry out tests on munitions that require disassembly must have the specific in-depth knowledge and professional skills required, as well as a suitable set of physical and mental traits. Aside from the technical know-how, the test operators must have the very specific predispositions required for work with munitions and be certified by psychological screening. If a professional lacks these psychological predispositions, they will, after a time, resign from munition testing.

The test workstations and their equipment must meet specific standards, which are intended to provide protection against the various environmental hazards that may occur during the testing of munitions. The occupational health and safety workplace regulations are an essential package of safety management procedures for these work places. These regulations are developed according to the applicable laws and reasonably foreseeable hazardous events. The regulations detail the scope and sequence of operations, lists of hazardous materials that are allowed at any time at specific workstation, the list of personnel authorized to operate specific workstations, the emergency response procedures, and much more. A critical condition for authorizing an employee for unsupervised work is hands-on training at their workstation. Extremely hazardous operations require two-man staffing, where the second person supervises all the actions done by the first (the operator).

Before disassembly, the munitions qualified for testing must pass a sequence of inspections, checks, and a visual assessment of the external condition. These are followed by a non-invasive (non-destructive) review of the internal structure of every specimen of the test samples. This allows the identification of those munition products not in conformity with the engineering documentation, assess the non-conformities (defects) and make informed decisions about subsequent test activities. All munitions proven to be extremely hazardous to disassemble are removed from downstream testing and their user is immediately notified of all hazards that further service of the same munition lot may cause.

4. EXAMPLES OF HAZARDS FOUND DURING MUNITION TESTING

The testing process established in the respective testing methodology for each type of munition ensures that the subsequent processing stages will identify the technical status of the munitions and the earliest possible detection of all and any non-conformities which may be hazardous for downstream operations. Each test sample provided for testing is formally examined for compliance between the labelling of the test sample munitions and their containers. If any of the required labelling information is missing, it may indicate that the specific munition lot might have suffered from certain deviations during production or service.

Any munition lot which contains unlabelled elements (e.g. the production lot number is missing) is assessed as hazardous for further service. The following lists some examples of non-conformities found during diagnostic testing of munitions and which meant the munitions were considered as hazardous in service.

During the visual inspection of the external condition of a production lot of the OG-9 projectile a leak of brownish, oily liquid was found on the external surface of one of the rounds. The liquid was sampled for testing with all due precautions. The chemical determination revealed a high content of trinitrotoluene, which identified the liquid as TNT oil. TNT oil contains 2,4,6-trinitrotoluene (TNT for short) and its mono and dinitro derivatives which, when stored at elevated temperatures, may recrystallize uncontrollably and increase the risk of accidental explosion. Had this mixture of TNT and its mono and dinitro derivatives penetrated and recrystallized within the threaded joint of the fuze and the projectile shell, any attempt to fire the round or remove its fuze would have resulted in the mechanical effects initiating the detonation of the crystals. TNT oil can leak out of a projectile and recrystallize on its outer surface, where it resembles a coat of grease (see Figure 4) [2].

Fig. 4. TNT oil on the outer surface of an OG-9 projectile in a hermetically sealed plastic bag

Fig. 5. TNT oil on the thread form of an OG-9 projectile

However, TNT oil is not always visible on the outer surface of a projectile. A test operator with sufficient knowledge and great experience in munition testing is well aware of which products may pose this hazard. If this hazard is present, the operation of removing a fuze must be done on a hazardous processing workstation. Figure 5 shows an example of TNT oil traces on the thread form of the projectile with the fuze removed.

Before attempting to disassemble the munitions, they are subject to a radiographic examination (Figure 6), provided they are small enough to fit in the radiographic examination workstation. The radiographic examination workstation provides a thorough and non-invasive overview of the internal structure of the munition and a means of detecting different manufacturing or service defects; if these are present, the radiographic image is used to assess the impact on the safety of downstream testing. The munitions assessed as extremely hazardous are eliminated from downstream processing. The remaining munitions can be released for further regular disassembly or, depending on the radiographic examination findings, diverted for disassembly on the hazardous processing workstation.

Fig. 6. Munition radiographic examination workstation

Any non-conformities (defects) found are analysed to make informed decisions about how to proceed with the testing of the munition concerned (Figure 7).

In the example shown here, only the rules present in the testing process for handling munitions qualified for diagnostic testing prevented the PG-76 projectile from inadvertently dropping out of the RPG-76 grenade launcher. This meant the work safety hazard was very low for downstream operations and it was decided to proceed with the tests.

A munition disassembly process provides a number of operations which are qualified a priori as hazardous and must only be attempted on hazardous processing workstations.

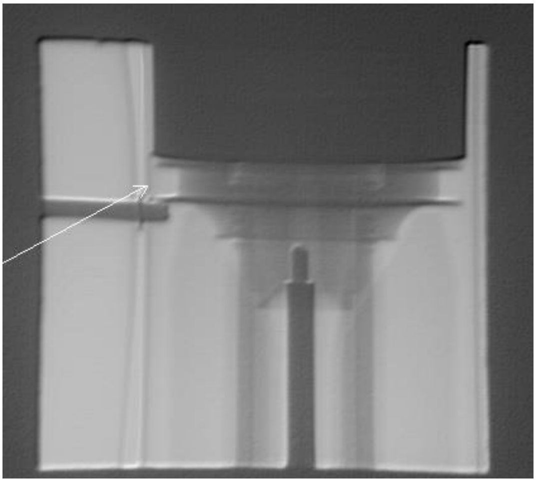
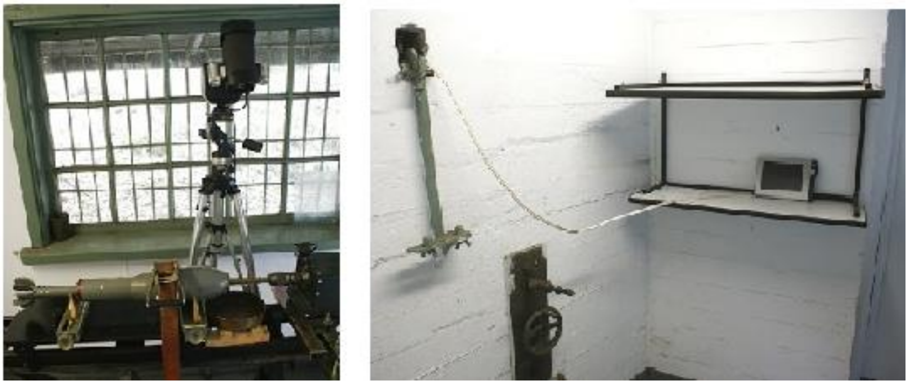


Fig. 7. Manufacturing process non-conformity: the lock pin securing the PG-76 projectile position in the RPG-76 grenade launcher is not engaged

The hazardous processing benches are installed at a safe distance from public buildings. The equipment installed on each hazardous processing workstation allows remote control of the manipulators and operations (Figure 8(a) and (b)). The design and operating principle of each hazardous processing workstation protect the test operators from the effects of any explosion.



a b

Fig. 8. Hazardous processing workstation:
(a) Hazardous processing workstation for high explosive material sampling for laboratory testing
(b) Remote control desk of hazardous processing manipulators

Most munition parts are not designed for disassembly. If a testing process allows the testing of inaccessible munition parts (e.g. high explosive material in closed shells), disassembly is done by cutting the munition apart on a remote-controlled hazardous processing workstation (see Figure 9).

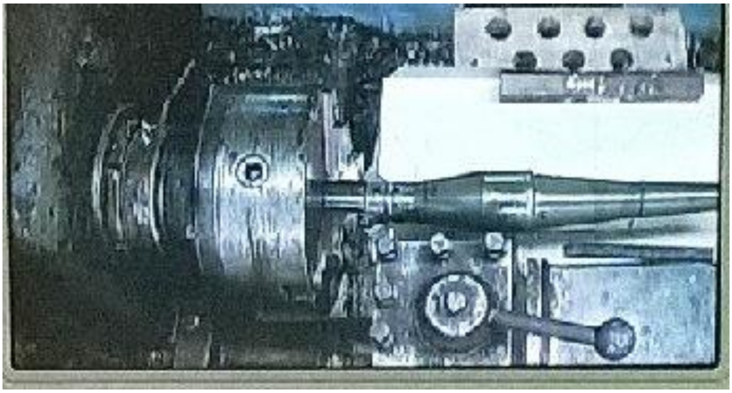


Fig. 9. Disassembly of a PG-76 projectile warhead by cutting (viewed on a video monitor)

Example: accessing the explosive material in a PG-9 projectile warhead requires cutting the projectile open along a strictly defined path: This operation requires very good knowledge of the structure of the munition involved and a high resistance to stress.

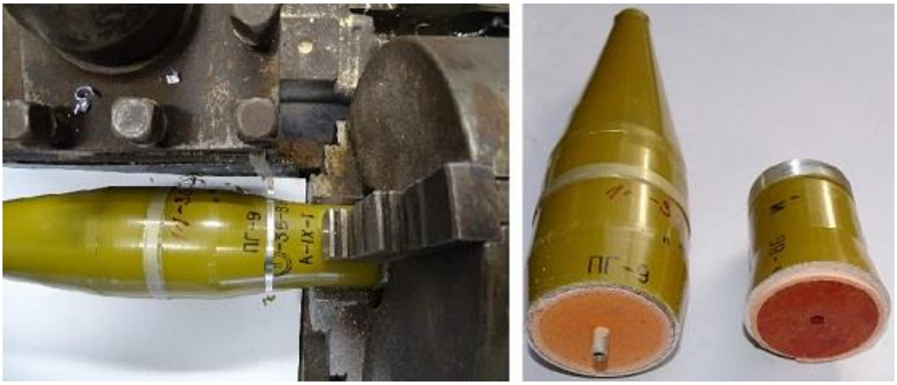


Fig. 10. Disassembly of a PG-9 projectile warhead by cutting; the same projectile warhead is shown cut open

The need to disassemble munitions on hazardous processing workstations has been proven by rare (fortunately!) instances of initiation. Figure 11 shows a rocket motor of a GROM SAM (surface-to-air missile) ruptured by deflagration of the explosive material, which was initiated during cutting across the warhead metallic wall.

A very hazardous non-conformity which may result in uncontrolled initiation of a munition is the ‘dusting’ of the explosive charge inside the munition or its fuze. Explosive material dusting is caused by defective pressing or bonding of the explosive charge inside its enclosure.

Fig. 11. A part of the GROM SAM warhead remaining in a lathe chuck

This defect causes the particles of the explosive material inside a finished projectile to detach from the explosive charge by the force inputs applied during service (i.e. transport or handling), which then move around inside the projectile shell or inside the fuze and become deposited on various internal surfaces. If dusting happens inside a projectile shell, the particles may be deposited inside the threaded connection of the fuze and the shell; if dusting happens inside a–fuze, explosive particles can move around the entire internal volume. Any mechanical input to the dust, such as that caused by friction between the thread forms during removal of a fuze or the striking of a hard part of the fuze, may initiate the detonation of the particles and the initiation of the explosive charge inside the projectile. Figure 12 shows an example of explosive material dusting traces on the internal components of an artillery round fuze [6].

Fig. 12. High explosive dust inside the fire hole of fuze head (a) and around the fire fire hole (b) in the body of an RGM fuze

Dynamic testing of munitions can be very stressful for test operators. An example here is thrust testing of rocket motors installed in the ŁWD mine-clearing line charge. When running, a rocket motor emits a very loud noise.

Sometimes a rocket motor explodes during testing, which is very distressing for the test operators and causes heavy damage to the test stand. Figure 13 shows the effects of improper operation of a rocket motor. Figure 14 shows the failed chamber of the rocket motor being tested.

a b c

Fig. 13. ŁWD rocket engine thrust test stand:
(a) the rocket motor installed and ready for testing;
(b) the test stand following the explosion of the rocket motor during the test;
(c) the destroyed fixture and measurement systems.

Fig. 14. Burst rocket motor of an ŁWD mine-clearing line charge

5. STANDARDIZATION OR REGULATION OF MUNITION TEST DURATION

A very controversial issue is the regulation or standardization of the work time in the diagnostic testing of munitions. Budget-wise, standardization of test duration has a major cost effect on munition testing. In a transaction between a test customer and a testing organization, the cost of testing is a key criterion of munition testing and the need to determine the costs is undisputed.

Given the work safety issues discussed here, it is very difficult to apply any method with sufficient accuracy to achieve test duration standardization.

Many operations and activities, especially at the stage of munition disassembly, cannot be done at a specific continuous or periodic work rate. Any deviation from a normal disassembly procedure established for a munition must stop the work for an analysis on how to make an informed decision on how to proceed. An operation estimated to be completed in a given unit of time can take up to a dozen times longer if any deviation from a standard condition of the tested munition product is found, since defects, deviations or irregularities require departures from the established procedure in favour of special workstations and equipment, to do hazardous processing activity. Professional munition testing personnel with years of experience cannot estimate with any reliable certainty how long it will take to remove a fuze type they are familiar with and which they have removed from munitions many times in the past. The only viable, reasonable and honest answer here would be "As much time as needed". This happens very often in the munition testing laboratory. The problem stems from the variations in the technical status of the same types of munitions to be disassembled and the material changes introduced to the applicable engineering documentation. More often than not, munition ageing necessitates more time-consuming methods than originally anticipated in each case. The service life of most munitions referred for testing exceeds 10 years.

The years of practical experience and data from past tests allows an estimation of munition test duration standards with the aid of aggregate methods, which are used to estimate a standard work time without the division of the actual work into its components. The records of actual times for testing specific munition groups are used in the statistical development of test time (duration) standards that reflect the mean actual times of the same work operations completed in the last ten or so years.

To enforce any standardized, limited duration of individual operations in munition diagnostic testing, and specifically munition disassembly, is borderline dangerous. There have been cases reported of disastrous consequences of attempts to enforce test duration limits. Every work operation done on products which contain explosive materials first requires a thorough analysis of the expected hazards and preparation of the workstations according to the applicable health and safety rules.

6. CONCLUSIONS

1. Every munition type requires a thorough analysis of the hazards present during disassembly, followed by the development of a full testing process documentation before actually testing the munition type.
2. Extremely hazardous activities must be carried out on dedicated, explosion-safe workstations.
3. Time constraints must not be applied as a lead time limit in munition testing.

4. Occupational hygiene and safety in munition testing require constant monitoring. All latest achievements in science and engineering should be applied whenever they can improve the protection of the health and life of the test operators working with munitions.

REFERENCES

[1] Ustawa z dnia 26 czerwca 1974 r. Kodeks pracy (Dz.U. z 1998 r., Nr 21, poz. 94 z późn. zmianami).

[2] Rozporządzenie Ministra Pracy i Polityki Socjalnej z dnia 26 września 1997 r. w sprawie ogólnych zasad bezpieczeństwa i higieny pracy (Dz.U. z 2003 r., Nr 169, poz. 1650).

[3] Rozporządzenie Ministra Gospodarki i Pracy z dnia 27 lipca 2004 r. w sprawie szkolenia w dziedzinie bezpieczeństwa i higieny pracy (Dz.U., Nr 180, poz. 1860).

[4] Ustawa z dnia 30 października 2002 r. o ubezpieczeniu społecznym z tytułu wypadków przy pracy i chorób zawodowych (Dz.U. z 2005 r., poz. 1242, 1442).

[5] Instrukcja o kontroli jakości i bezpieczeństwa środków bojowych w procesie eksploatacji w resorcie obrony narodowej sygn. Logis 3/2010.

[6] Krysiński Bogdan, Agata Kamieńska-Duda. 2014. „Szczególne przypadki wad materiałów wybuchowych”. *Problemy Techniki Uzbrojenia* 130 : 59-64.

[7] Maranda Andrzej. 2004. „Metody badania wrażliwości materiałów wybuchowy na bodźce zewnętrzne w aspekcie przepisów ADR oraz norm polskich i europejskich”. Górnictwo i Geoinżynieria 28(3).

Bezpieczeństwo pracy a czas badań środków bojowych

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Streszczenie. W artykule przedstawiono problematykę bezpieczeństwa pracy oraz normowania czasu w badaniach diagnostycznych środków bojowych. Wskazano źródła zagrożenia bezpieczeństwa podczas demontażu, których przyczyną są procesy fizykochemiczne zachodzące w czasie wieloletniej eksploatacji oraz zagrożenia wynikające z nieprzestrzegania procesów technologicznych podczas produkcji. Środki bojowe, z racji swojego przeznaczenia, najczęściej nie są podatne na demontaż. Kontrolowany, na każdym etapie produkcji, proces technologiczny wytwarzania środków bojowych oraz stosowanie odpowiedniej jakości materiałów sprawia, że środki bojowe po upływie okresu gwarancyjnego jeszcze przez długi czas mogą zachowywać swoje właściwości bojowe. Okres ich przydatności technicznej do dalszej eksploatacji można określić poprzez wykonanie odpowiednich badań. Badania te wymagają ingerencji w ich strukturę wewnętrzną poprzez demontaż na detale niezbędne do oceny aktualnego stanu technicznego i prognozy dalszej eksploatacji. Prace wykonywane przy demontażu zagrażają bezpieczeństwu i wymagają wcześniejszego przygotowania odpowiednich procesów, stanowisk, procedur oraz kompleksowego zapewnienia bhp. Zapewnienie bezpieczeństwa podczas badań środków bojowych wymaga dużych nakładów na stworzenie odpowiedniego zaplecza technicznego oraz odpowiedniego monitorowania wszystkich bieżących czynności podczas dekompletacji. Przy wykonywaniu tych prac na pierwszym miejscu stawiane jest bezpieczeństwo pracowników, a próba normowania czasu wykonywania poszczególnych operacji nie ma sensu.

Słowa kluczowe: środki bojowe, bezpieczeństwo pracy, bezpieczeństwo eksploatacji, normowanie czasu