



Comprehensive Approach of Testing and Evaluation and Involvement of NDT in the Ammunition Life Cycle

Petko BONCHEV, Delyan NEDELICHEV

Defence Institute, Sofia, Bulgaria,
e-mail: d.nedelchev@di.mod.bg

Abstract

In this article, we propose NDTs involvement as a part of comprehensive approach to support reliable evaluation of tools during ammunition life cycle. The comprehensive approach is based on the mix between traditional standardized (chemical stability, live-fire, etc.) and the non-destructive methods. This approach support adequate quality assurance, but most important ensures precisely evaluate safety and reliability during service life, to compensate existence of mixed results obtained from different parts of lots. In result of long storage, elements of ammunition are subjected to degradation by impact of environmental factors. Changes of temperature can accelerate these processes. During transport and service manipulations, mechanical damage can happen leading to formation of places susceptible to damage. Pyrotechnical materials undergo physicochemical changes (e.g. chemical reactions like decomposition, oxidation, and phase transitions). In whole, this triggers different hazards. The main problem for implementing NDT is the lack of standardization in this area, but in case the non-destructive methods applications is to provide additional information in order to “transfer” precisely the results obtained from destructive standardized methods over the whole lot, but non-destructive methods can be use widely as support tool adding valuable test data. Compensating the lack of standardization, this study conceptualize non-destructive methods and tools as a part of comprehensive approach.

Keywords: ammunition life cycle, ammunition service life, solid propellant rocket motor, non-destructive testing

1. Introduction

Nowadays, the emphasis in military understanding is on the provision of military capability, to which the weapon systems and ammunitions probably are the most significant and directly referred add of the materiel [14]. From logistics prospective, for ammunitions this means establishment of large stockpiles in order to ensure current and future operational or training activities and needs [8]. From manufacturing perspective the adequate structure for ensure quality of products and control of manufacturing processes. Being one-shot devices, the most important task during their life cycle is to ensure their safety during service life¹ and of course their performance. Starting in very early phase (in design and development stages) and continues during service, safety and performance lie on the munitions system reliability. To ensure it, the periodical tests, predominantly destructive ones, plays significant role.

The service life period seems more complex [8]. Service life assessment begins in the development phase and monitoring programs must be developed and implemented during the life span of the system and two interacting iteratively paths to produce current service life estimates are used [9]. One path is analytical which assesses the rate of material aging, the effect of material aging on the system (i.e., stability, performance, integrity, etc.) and the statistical probability of system failure during service life. The typical approach is to specify conservative service life period, determinated under harsh environment conditions and severe service loadings. Generally, the base for service life period for the whole system is this of the non-

¹ The service life is defined as the time that ammunition is able to operate reliably, safely, accomplish the setted requirements under the real life loads [8]

replaceable part with energetic material with the shortest service life period, nevertheless that the designed ammunition/missile or their elements can be used safely longer (Table 1) [8].

Table 1. Expected service life for different tactical missiles components

Components	Expected service life, years	Possible degradation
Pyrotechnics	20	- Destruction of pressed or glued joints [8];
Composite propellants (sealed)	20÷35	- Depletion of chemical precursors [5]; - Diffusion [5];
Propellants (sealed)	20÷35	- Micro and macrocracks generation [8]; - Moisture [5].
Electronic components	25-30	- “Electronic” aging; - Damages after service loads [8].
Optical components	>50	- Damages after service loads; - Moisture.
Power units	10-20 [9]	
Contact surfaces		- Damages of seals; - Contact corrosion.
Rubber and plastics components	10-20	- Damages after service loads; - Thermal degradation.
Metal components	>50	- Damages after service loads; - Thermal degradation [2].

Why the service life assessment is more important. During storage and deployment of ammunition and missiles, uncontrolled thermal environments and random vibratory loads due to transportation induce random stresses and strains in the propellant, which provoke mechanical damage [9]. In addition, structural capability degrades due to environmental conditions and induced stresses and strains as well as material capability parameters have inherent uncertainties [7]. In this proposed probabilistic service life prediction, uncertainties along with degradation mechanisms are taken into consideration [6]. Vibration loads are accounted by utilizing acceleration spectral density values, which are induced during various deployment scenarios of ground, air, and sea transportation [8, 9].

Furthermore, thermal loads are represented with a mathematical model being a harmonic function of time [8]. Throughout the finite element analyses, a linear viscoelastic material model is to be used for the propellant. Change in the structural capability of the propellant with time could be calculated using Laheru’s cumulative damage model [8]. Moreover, to include aging effect of the propellant, Layton model could be used [8]. To determine the effects of induced stress and strains under variations and uncertainties in the random loads and material constants, mathematical surrogate models are constructed using response surface method. These suggestions are valid for the majority of them use solid rocket motors and most of the propellants [8].

During its life cycle, ammunitions, and missiles elements experiences thermal loads under the variation of environmental storage temperature, but also vibrational and impact loads because of transportation and service handling. All of these affect on the rocket motor in distinct way depending from [8]:

- Design, materials and used technologies;

- Overall climatic profile of service life;
- Reaction of energetics to real environmental and service handling loads;
- Current service life period.

Negative combination from these factors could lead to irreversible changes in chemical composition and mechanical properties, cracking and other damages, which compromise normal engine performance. As a result, unstable combustion may occur, and worse – destruction or even explosion of the rocket engine and poor ballistic performance of propellants. [8].

Current munitions and their elements are designed to function within narrow performance boundaries. In order to guarantee safety and performance we must be able to predict their behaviour, as well as determine their residual life span after the system has been subject to handling and storage under varying conditions, which are not always being completely recorded.

The second path is system surveillance, which includes system observation and system trend analysis. As a result, the service life estimate may predict a minimum service life (safe interval) that will likely be extended on testing at a later period. All aspects of service life issues for solid rocket motor will be addressed including chemical and physical aging mechanisms, methodology and techniques for determining service life, application of the service life methodology and techniques to systems and non-destructive test methods. For these paths, except non-destructive methods, existing system of standards and best practices [8]. Most of them is based on the destructive methods – live firings, chemical analyses, aging, mechanical tests, etc. [8]. In turn, the non-destructive methods (NDT) methods are powerful tool for many industry areas, but due to their inherent limitations and complementary nature of different types, many of them need to be applied depending on their suitability as a service life estimation tool [8].

Unfortunately, they are not so popular tool (except the visual methods) in service life of ammunitions (except the production phase) (see Fig. 1) [8], following to the main problems for implementing NDT for qualification of the ammunition – the scope and lack of standardization. For inspection at various stages of its production and service life for instance [8]:

- NDT methods such as radiography, ultrasonic testing and dye-penetrant testing are being employed for the inspection of hardware [1, 3, 4, 5, 6, 7, 8, 12];
- Magnetic methods for shells and mortar bodies [10, 13],
- Ultrasonic testing is applied for checking the bond-line integrity of case, ammunition elements and insulation layer [5, 10] and
- X-ray radiography is employed for evaluating both the integrity of propellant mass and the bond-line integrity of propellant and insulation [3, 8].

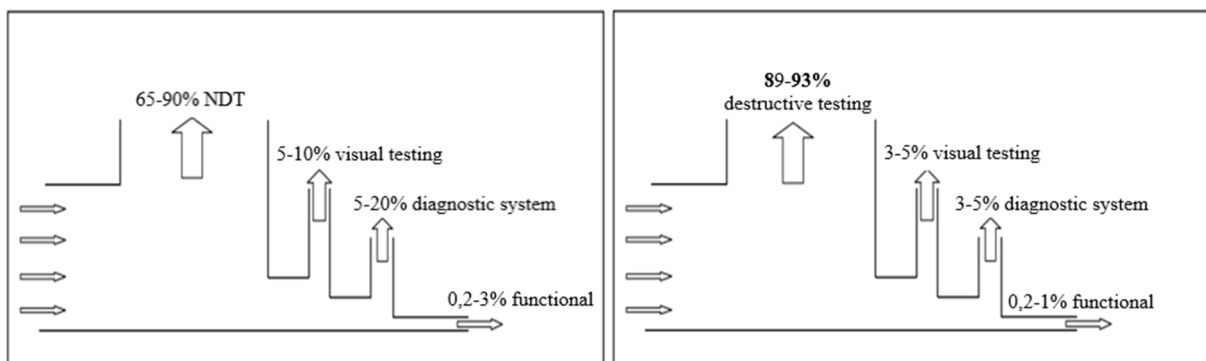


Fig. 1. Coverage of different methods in the industry (left) and in ammunition life cycle (right)
(Adapted by [8])

This was compensated in previous studies [5, 6, 7, 9] and in thesis [8], where some non-destructive methods were verified and this is stimuli for proposal in this study a methodology incorporated standardized destructive and non-destructive methods.

Table 2. Review of applications in ammunition life cycles on non-destructive testing methods with their advantages and disadvantages [7]

NDT Methods	Testing Area	Applications	Advantage	Disadvantages
Acoustic emission (AE)	Cracking, debonding and delamination	Composite, fiber materials	Easy detection of cracks, fractures, debonding, microcracks in matrix and delamination	Time consumed in data processing, required skills and experience, existence of external loads.
Ultrasonic (UT)	Material surface and internal defects	Elements, nonmetals, forging material and glued joints	Easy to detect, precession to find defects and adaptable defect area	Testing process on complex objects is complicated and more process time.
X-ray	Internal material defects	Material casting, non-metal parts and composites	Material defects i.e., porosity, slags, material abnormal penetration	Crack detecting is not possible in perpendicular axis; not possible to measure depth; costs are high.
Eddy current	Material surface and small defects	Electrically conductive material	The operational equipment is advanced; less time to complete the test	Delicate in signals owing edge effect, suddenly alter, easy to allow the wrong display.
IRT	Calculate thickness, interlayers, and surface	Metallic and Nonmetallic materials	Noncontact of testing object, working area is large	To detect the material defect depth, complex algorithm/mathematical calculations are required.
Magnetic Particle	Material surface and small defects	Ferromagnetic materials	It is low cost, portable and subsurface defects also detected	Restricted to ferromagnetic materials.

2. Concept for comprehensive approach for assessment of ammunition and missiles

2.1. Justification of combined use of classical and non-destructive methods

The current approach is periodically to test in field environment and initiating elements and electronics is subjected to laboratory testing [8]. Due to the fact most of these methods have got destructive outcome, quantities subjected to testing are low. The negative combination from this inefficient approach for surveillance and testing, lack of environmental records and the age of ammunitions and missiles often “produces” mixed results (see fig.2) when classical approach is used, based only on sampling of some numbers from one lot.

It is well a fact that the input elements, units, and aggregates change their characteristics [4, 5], and for munitions, producers tie the aggravable deadlines of the individual with the prescribed lifetime. The term aging is marked by the generalized change in mechanical and chemical factors as compared to properties immediately after production.

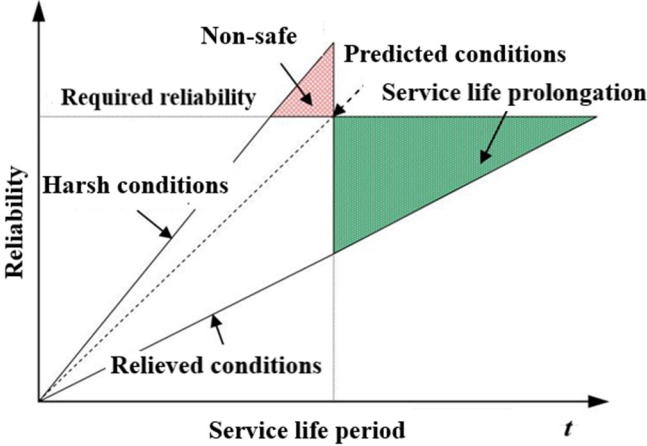


Fig.2. Different service life expectations for different specimens from one lot

Usually, the associated problems during the service life are related to explosives in rocket motors (solid propellant and pyrotechnics). During the service life they change their properties [10], the integrity of solid propellant is disturbed, the bond-lines are disintegrated, and defects like cracks, voids and depletion appear (fig. 3). Also, during the service life, the continuing changes in chemical composition are appeared. In detail, the aging processes in different energetic materials and their displays is described in [20].

The pyrotechnics are even more vulnerable, mainly because the trend to absorb the moisture.

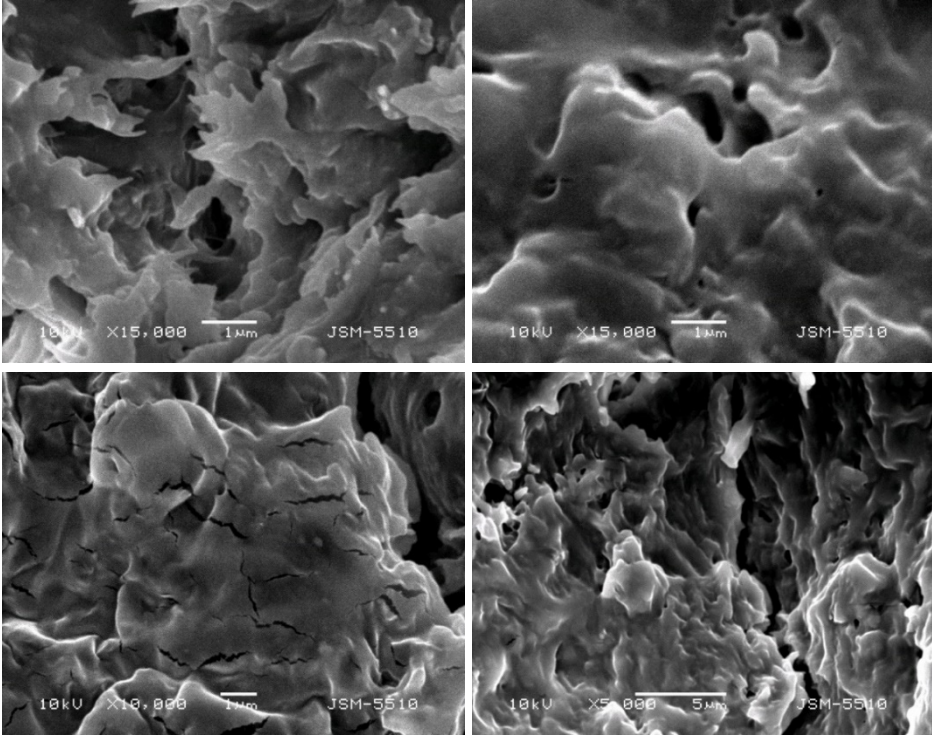


Fig. 3. “Sharpening” (first row, left), “rounding” (first row, right), micro (second row, left) and macro cracks (second row, right)

Complexity of these can affect negatively on performance and safety during service life and field and laboratory testing cannot provide reliable results [8].

To monitor these changes during service life in this study we propose comprehensive methodology for evaluation of ammunitions and tactical missiles.

2.2. Comprehensive approach for service life assessment of solid rocket motors

Schematic view of methodology for evaluation of ammunitions and missiles is showed in Figure 4. For expensive and complex systems, the number of sampled units for destructive full-system tests, which are considered the gold-standard measurements of the performance of the system, may necessarily be small and it's hard task to make conclusions for whole lot performance based on the full-system test result of several test samples [8]. Fortunately, there are other sources of information on the system or component level and in this methodology, we incorporate many other types as an alternate sources of information – from functional tests on component level to non-destructive testing, that practically could be performed on the whole lot [8]. Logically, the relative proportion of data available from these alternate sources may reduce the need for full-system and in our case – subsystem tests, and can enhance precision of evaluation [8].

The key aspects of this approach will be explained in some detail in this paper are: (1) how non-destructive methods can be added to “classical” destructive methods to produce single informative platform and (2) a unified methodology for precisely evaluating solid propellant rocket motors system level that combines with prediction up from the component level data, but for clarity of presentation we will not go into details for incorporation of data because this process we described well before – in [8] the author demonstrate Bayesian approach to incorporate data from different sources and here we present only the results on sub-system level. Also, due to same reasons, the sub-system decomposition process is not presented in details here.

The proposed methodology is divided into two branches – “destructive” and “non-destructive”. “Destructive branch” includes performance tests, all applicable standardized and validated methods, described in standardized documents (mainly STANAGs and allied publications) and specialized documentation – manuals, guidances etc.

The “non-destructive branch” combines different techniques. Two of them (Ultrasound technique implementation for aging characterization and X-Ray technique for defects characterization) are validated by the author in [8] and here only cursory notes are added. The rest non-destructive tests are well-known [8].

The proposed ultrasound technique, based on different propagation velocities for different aged samples. The technique is well described in [8] and here we will not go into details. This technique may give significant advantage, because other known techniques is based on chemical composition changes and related with destruction of the solid propellant. Otherwise using this ultrasound technique could be automated easily, it's fully non-destructive and hence all the lot could be subject on testing. The ultrasound technique is proposed as an additional tool in existing system of standards for service life qualification of solid rocket propellants. The method is partially proof for propellants include nitrate esters on micro level by electronic scanning microscopy.

Some notes regarding X-Ray technique proposed. It is verified by medium power industrial system with film with passable quality for relatively small rocket motors with thin metal case [8]. The results obtained showed possibility for detection of flaws with diameter less than 0,7-0,8 mm, that is not perfect but fully acceptable result for the designed purposes. Understandable, the limitations of x-rays (and γ -rays) in the control of materials with a small atomic number in the presence of materials with a large atomic number (a classic example is metal-lined explosives) still exist and we cannot expect to detect relatively small defects.

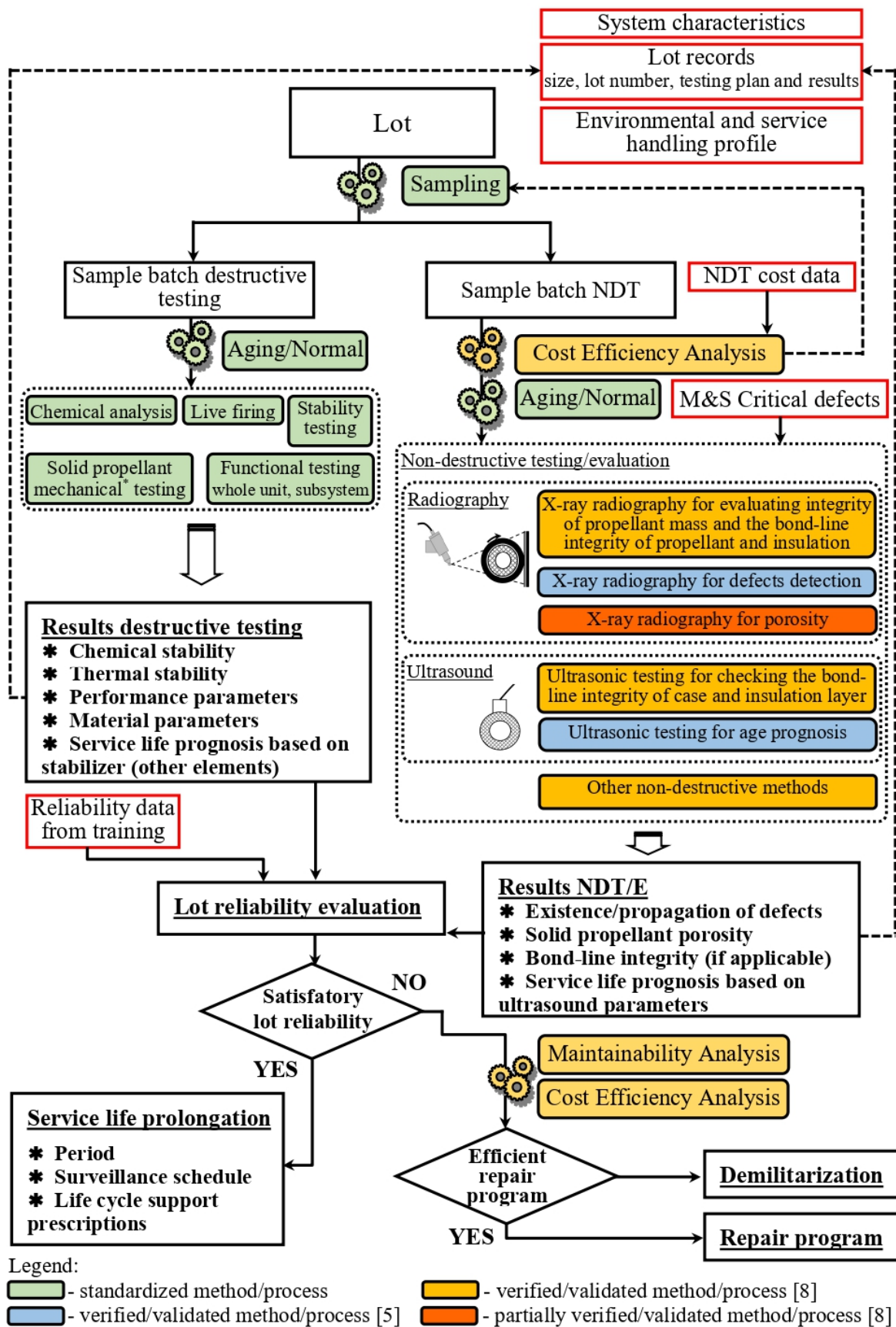


Fig. 4. Comprehensive approach for service life assessment of solid-propellant rocket motors [8]

3. Selected results – X-Ray

The results from X-Ray is shown on Figure 5.

Performed cost-efficiency analysis (subject on other article) showed that the (expected) whole cost of the performed test X-ray and ultrasound test is between 0,01 and 0,1 times of price of one unit in dependence of the type of the rocket. Nevertheless, one of the directions for future development, as well as improving sensitivity, precision, and productivity of the NDT methods) remains the cost reduction.

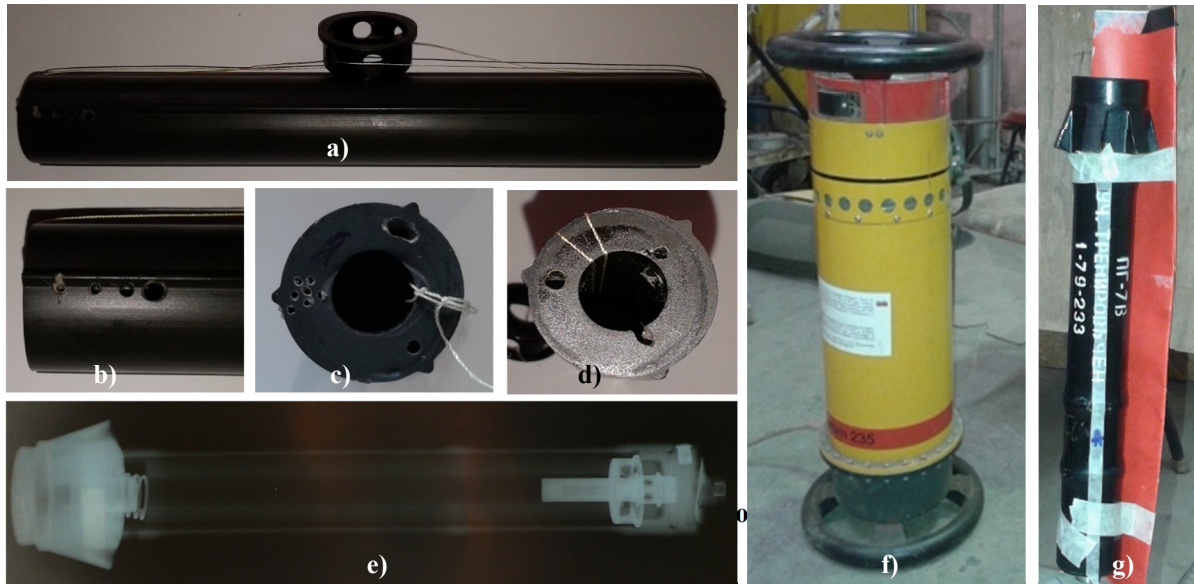


Fig. 5. X-Ray testing bet and result: a) solid propellant; b), c) and d) artificial flows; e) X-Ray film from rocket motor unit; f) X-ray system; g) sample with X-ray film.

Copied from [8]

Summary

In this study we propose comprehensive approach for service life assessment of ammunitions based on the mix between traditional standardized (chemical stability, live-fire, etc.) and the non-destructive methods. Because of the lack of standardization of non-destructive methods in this neurological area, their usage is only as an additional tool, improving awareness.

The initial results are encouraging and implementation of these methods definitely improved accuracy of evaluation and practically could nullify existence of mixed results obtained from different parts of lots in performance tests. In the near future the comprehensive approach for every type munition will be developed.

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