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Statistical Analysis of the Results of Test Artillery Tracers

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Abstract. A statistical analysis of multiyear laboratory test results of artillery tracers number 8 is presented in this article. This analysis was aimed at testing the impact of a natural ageing process on quality indicators during the long-time storage of these tracers. The influence of storage time on taking a diagnostic decision, relating to quality of lots after the conducted laboratory tests and on different classes of inconsistencies that occurred during these tests, was analysed. A detailed analysis of the impact of the storage time on diagnostic shooting decisions taken was also presented. The conducted statistical analysis suggests an assumption, that it is possible to change an evaluation module in the previous test's methodology. Modification of this evaluation module will not negatively impact on the quality of further diagnostic tests. It will not negatively impact on correct evaluation of the prediction process of the tested elements of ammunition such as artillery tracers.

The statistical analysis, carried out in the article, may have a significant impact on the modification of test methodology of the artillery tracers.
Keywords: ammunition, tracer, exploitation, inconsistencies, test cycle, properties

1. INTRODUCTION

An artillery tracer [1] is a separate element mounted directly at the bottom of the artillery projectile and it is scratched or screwed there. It can also be placed in a special screw, which is screwed into the bottom of the projectile.

The basic task of tracers is to create a light streak on the flight path of projectiles intended to destroy the discovered solid targets and, above all - the moving targets. The light trail behind the projectile allows the shooter to observe the flight path and to quickly apply corrections when the projectiles diverge from the required direction (target).

This article attempts to perform a statistical analysis of the obtained results of laboratory tests and an analysis of the evaluation module of the tested tracers from artillery projectiles. Of course, the tested tracers are after long–time storage in warehouses of the Polish Army.

The aim of the article is statistical evaluation of the taken post-diagnostic decisions, paying particular attention to the taken decisions "shooting tests" after laboratory tests and the proposal to modify the evaluation module of the tested tracers. Generally, it can be said that field testing is performed in order to determine the degree of loss of combat property and to determine the impact of inconsistencies, detected during laboratory tests, on the safety and reliability of cartridges or their elements.

Due to editorial limitations, only tracers No. 8 will be considered, which are used in 57 mm fragment - tracer projectiles for S-60 and S-68 anti-aircraft guns. However, the conclusions determined after the analysis also apply to all other types of artillery tracers used in artillery cartridges. The received results of tests and checks were thoroughly analyzed in the article, showing different types of inconsistencies that were diagnosed during laboratory tests.

2. PROPERTIES OF ARTILLERY TRACERS

The essential requirement that should be an answer of the tracer is good visibility of the flame during the day and at night. Especially, visibility of the trail during the day is a very demanding challenge. The tracer lights up in the barrel while shooting from the flame of the charge of the cartridge. The exceptions are tracers of anti-tank guided missiles, in which the ignition of the tracer occurs from the electric primer via the on-board of cannon or launcher.

Trailing materials used in tracers are mixtures of flammable and flame-staining substance, oxidant, and binding material.

The tracer composition usually contains about 45% strontium nitrate, 28% magnesium powder, 9% aluminum powder, 8% graphite, and 10% resinous of calcium [1].

The main features according to [2] (from the point of view of users) what should be characterized by tracers is, first of all, safety and reliability of their work, that is physical and chemical durability of the trail mass.

Diagnostic tests were performed to check a number of physic – chemical properties of the tracer composition, which determine the correct technical condition of the tracers. The following properties (features) of tracers were tested: resistance to corrosion of metal parts, moisture of the tracer composition, swelling of the tracer composition, smears of salt in the tracer composition, burning time of the tracer composition, the density of the tracer cubes, non-smoking or extinction of the tracer, cracking of the tracer cubes, metal activity, fragility of tracer cubes.

The tested properties (features) of the tracers have been divided into three importance classes: A, B, and C. The B and C classes characterize the safety and reliability of the tracer work, whereas the class A characterizes the degree of advancement of the natural aging process. As a result of diagnostic tests of tracers, in accordance with [2], the following post-diagnostic decisions could be taken:

B5 – "positive laboratory test result", the lot is ready for use and storage, the next laboratory test should be carried after 5 years of storage,

BS – the results of laboratory tests are insufficient to make the final decision, the lot should be "shooting tested",

Z – a lot suitable for use but unsuitable for long storage. The lot should be "used in the first place",

W – lot unsuitable for use and storage – "withdraw from exploitation".

3. THE METHOD OF DETERMINING THE QUALITY OF TRACERS

The results of laboratory tests of samples from the storage lots of tracers No. 8 were subjected to statistical analysis. These tracers were stored in three storage subsets: separately (the subset "L"), in artillery cartridges in the warehouses of Land Forces (the subset "K"), and in naval warehouses in a marine climate (the subset "M"). The sets of test results of this type of tracers are the most numerous, which is why they were subjected to this analysis.

An additional aim of this analysis is to learn about the processes of natural aging of the analyzed tracers and about the impact of these processes on their quality indicators, that is on post-diagnostic decisions.

As a measure of statistical analysis, the result of the test of one sample from a lot of tracers of size equal to twenty pieces was accepted.

The tested properties are attributed to entire lots of tracers and not only to the tracers included in these samples. It should be remembered that poor technical condition of a given tracer does not directly affect the quality of the cartridge in which it is located. It is the only tested element of the cartridge, which does not reduce the quality category of the stored ammunition, after the diagnostic tests, of course in the case of receiving a negative diagnostic assessment.

In statistics, studying the impact of one factor on another comes down to studying the relationship between these factors. This article presents only the most important relationships that show the mutual relations of the analyzed quantities.

Therefore, for this statistical analysis, the methods of regression analysis and linear correlation were used to assess and determine the nature of the relationship between the analyzed variables. Specialized statistical software [4] was used, which the Institute owns. Only the resulting graphs, which are the most important and in the subjective opinion of the author of the article, were analyzed and discussed in the most significant article. The analysis was also based on annual reports [3] on the testing of ammunition and on cards from tests of tracers [5], which are in the archives of the Institute.

4. STORAGE TIME AND LABORATORY DIAGNOSTIC DECISIONS

The general indicator of the quality of exploited lots of tracers is the decision on this lot taken after testing the sample from it. In the first stage of this analysis, two subsets of the diagnostic decisions will be considered. A subset of positive decisions that include the decisions: B5 and Z, and therefore decisions on the compliance of the tested lots of tracers with the requirements, i.e., their suitability for use, i.e., storage and use. To the second subset, of so-called the subset of negative decisions, including the accepted BS decisions and W decisions. The criteria of the conducted analysis were tightened by the adoption of the BS decision as a negative decision. This decision tells us that the tested lot of tracers has an unfinished test cycle. To complete this test cycle, it is necessary to carry out dynamic tests, i.e., shooting tests. After these tests, a given test cycle should be completed and a final decision should be taken. The final decision may be positive, i.e., the lot may be intended for the first use or it may be negative, i.e., it may be withdrawn from further use.

The quality of the entire set of lots of a given type of tracers, at a given moment of the test, may depend on the period of storage of individual lots of this set and from the decision about the quality of these lots undertaken as a result of diagnostic tests.

The effect of the impact of this storage time is the occurrence of aging changes of tracers, which may cause inconsistencies due to their individual properties.

Testing the character of this dependence, it was assumed that the dependent variable is the fraction (percentage) of positive decisions taken. Therefore, the fraction is the ratio of the number of the undertaken positive decisions to the total number of the tested lots in a given storage age of the analyzed tracers. As an independent variable, the time of storage until the given test was adopted. This time is calculated in years, as the difference between the year of a given test and the year of production of the tested lot of the tracer.

Figure 1 shows the fraction of positive decisions as a function of storage time. On the basis of the broken curve, representing the results of this analysis, it can be concluded that along with the change in storage time there is a tendency to change the fraction of positive decisions, i.e., as the storage time expires, this fraction increases. The linear correlation coefficient is r = 0.4897 which means the increase in fraction of positive decisions along with the expiration of the storage time.

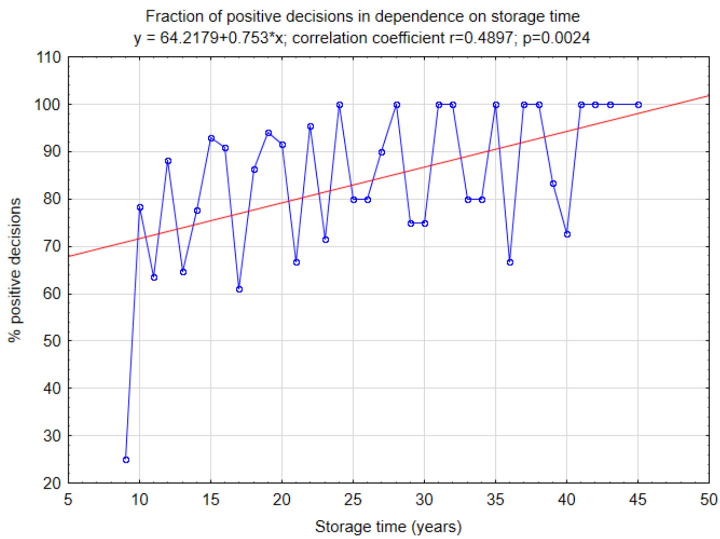

Fig. 1. Graph of dependence between the storage time and a fraction of positive decisions and a regression line describing this dependence

The next graphs are the dependencies of fractions of positive decisions in individual test cycles on the time of storage. Figure 2 shows this relation for cycle 1, Figure 3 for cycle 2, and Figure 4 for cycle 3. The other three test cycles have too few inconsistencies to plot regression curves.

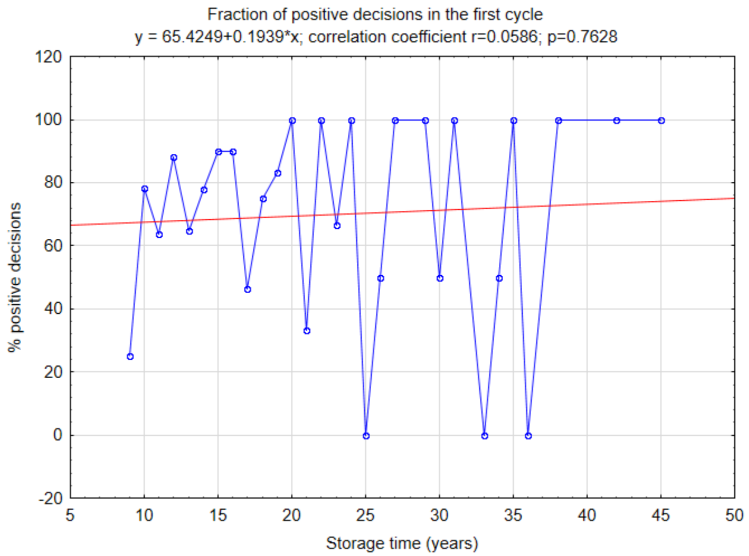

Fig. 2. Graph of dependence between the storage time and a fraction of positive decisions in the first cycle and a regression line describing this dependence

Figure 2 shows the dependence of a fraction of positive decisions in the first test cycle on the storage time. It appears from this figure that with the expiration of the storage time, the fraction of positive decisions in this test cycle very slightly increases, i.e., more inconsistencies were found during testing the younger tracers than when testing the older tracers. The linear correlation coefficient is r = 0.0586.

Figure 3 shows the dependence of a fraction of positive decisions in the second test cycle on the storage time. It can be seen from the plotted curve that the fraction of positive decisions in this cycle slightly decreases with the expiration of the storage time. The linear correlation coefficient is r = -0.1176.

Figure 4 shows the dependence of fractions of positive decisions in the third test cycle on the storage time. It can be seen from the presented curve, that as the storage time expires, a fraction of positive decisions increases in this test cycle. The linear correlation coefficient is r = 0.1276. The next three test cycles were not considered because of the insufficient number of test results.

Figure 5 shows the next stage of the analysis. Here, relations of percentage of the received shooting decisions is shown with respect to the time of storage. Negative decisions "W", that are the decisions about the absolute withdrawal of a given lot of tracers from exploitation, were not taken into consideration here. The character of the changes in this curve tells us that as the time of exploitation expires, decreases the percentage of shooting decisions. The linear correlation coefficient is r = -0.4529.

Based on this curve, it can be concluded that the older the artillery tracers were tested, less decisions were made on dynamic tests, i.e., there were fewer inconsistencies during the test that would indicate such a decision undertaking.

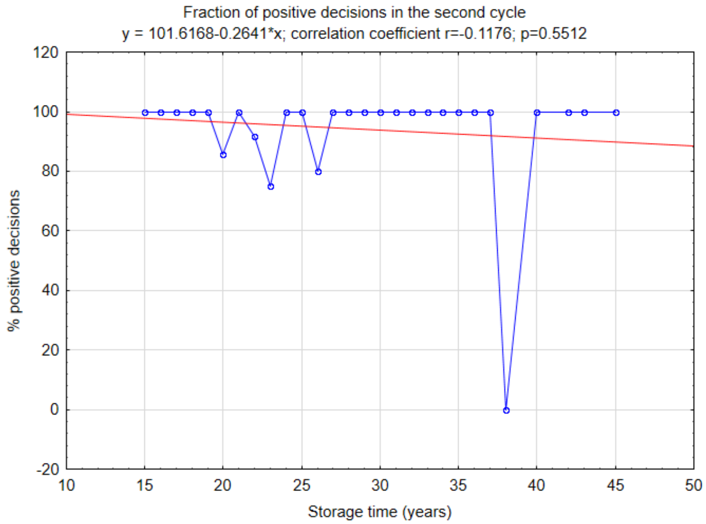

Fig.3. Graph of dependence between the storage time and a fraction of positive decisions in the second cycle and a regression line describing this dependence

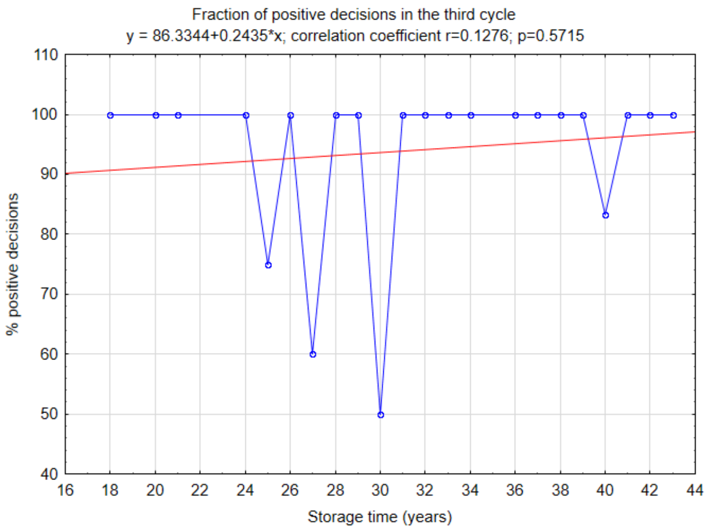

Fig.4. Graph of dependence between the storage time and a fraction of positive decisions in the third cycle and a regression line describing this dependence

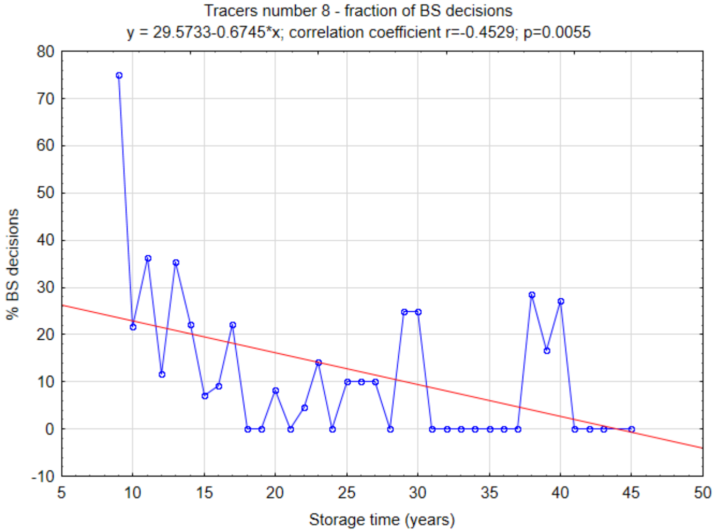

Fig.5. Graph of dependence between the storage time and a fraction of shooting decisions and a regression line describing this dependence

In summary, the analysis of dependence of a fraction of positive decisions, in relation to the storage time in individual test cycles, has shown that in the first and the third test cycle it has increasing nature, i.e., as the storage time increases, the incidence of this type of inconsistencies increases, too. In the second cycle of tests, this is a declining trend, which indicates a decrease in this type of inconsistencies. In total, the fraction of positive decisions in all test cycles has a growing tendency, i.e., as the storage period expires, the percentage of these decisions increases.

It was also found that the fraction of the shooting decisions, depending on the time of storage, has a decreasing tendency, which means that the older the tracer lots were tested, less the shooting decisions were taken, i.e., there were fewer inconsistencies in the tested lots that would undertake the shooting decision.

5. STORAGE TIME AND DISPERSION OF INCONSISTENCIES IN LABORATORY TESTS

Another element of the analysis will be the presentation of the dependence of the dispersion of inconsistencies belonging to individual classes of inconsistencies from the storage of the tested lots of tracers.

As an independent variable, the time of storage until the moment of testing was assumed, while the number of inconsistencies in individual classes was assumed as a dependent variable. Figures 6 ÷ 8 show the dispersion of the class A, B, and C inconsistencies for the analyzed tracers No. 8.

The graph in Figure 6 shows the dependence of occurrence of the class A inconsistencies on the storage time. It is clearly visible that as the storage period continues, fraction of inconsistencies of the class A drops, practically, for the tracers aged over 26 years of storage, this percentage is zero. The linear correlation coefficient is r = -0.2524.

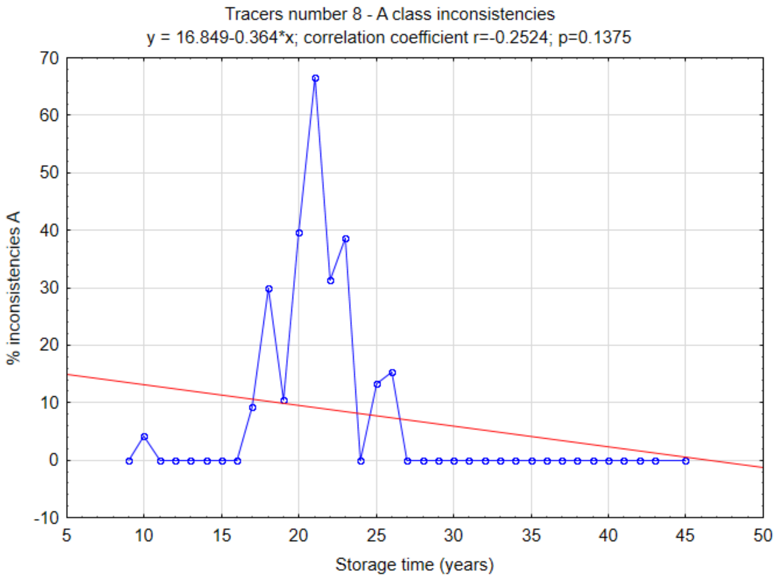

Fig.6. Inconsistencies of the class A in dependence on the storage time and a regression line describing this dependence

Figure 7 shows a graph of a dependence between the class B inconsistencies as a function of storage time for the analyzed tracers No. 8. In this case, we also see a declining trend, i.e., with the increase in exploitation time, the analyzed inconsistencies' class decreases. The value of the Pearson's linear correlation coefficient is r = -0.3337.

The class C inconsistencies are presented in Figure 8. It follows from this graph that with the expiration of the storage time, a fraction of the class C inconsistencies also decreases. The linear correlation coefficient is r = -0.5005.

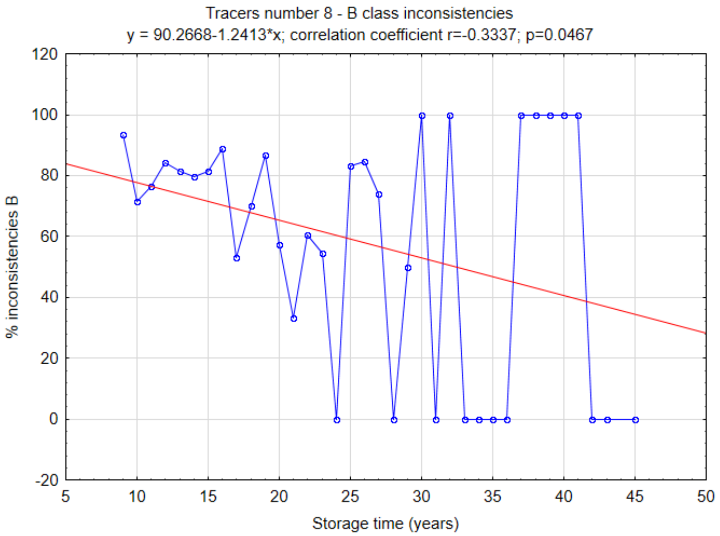

Fig.7. Inconsistencies of the class B in dependence on the storage time and a regression line describing this dependence

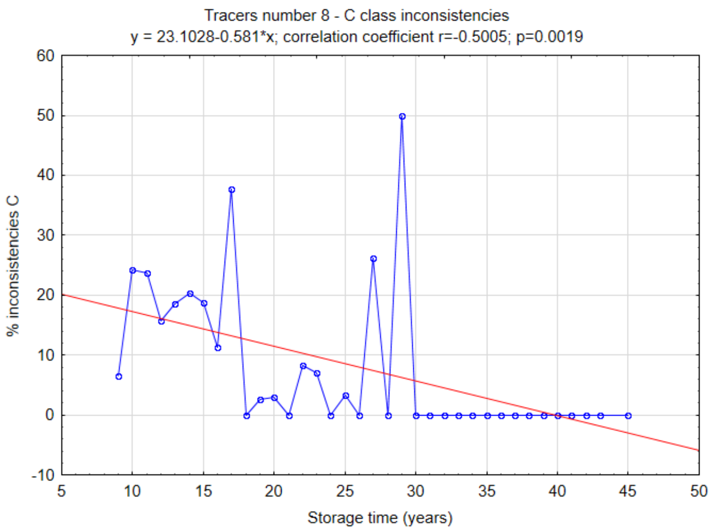

Fig.8. Inconsistencies of the class C in dependence on storage time and a regression line describing this dependence

The next two figures show the dependencies of fractions of inconsistencies of the B and C classes on the time of storage, but only for the taken shooting decisions. These decisions were undertaken only in four test cycles. Inconsistencies of the class A were not considered because of lack of such a type of inconsistencies.

Figure 9 therefore shows fractions of the class B inconsistencies depending on the storage time. As storage time increases, the percentage of the class B inconsistencies increases, which obviously indicates a significantly progressive aging process of the tested tracers. The linear correlation coefficient is r = 0.3396.

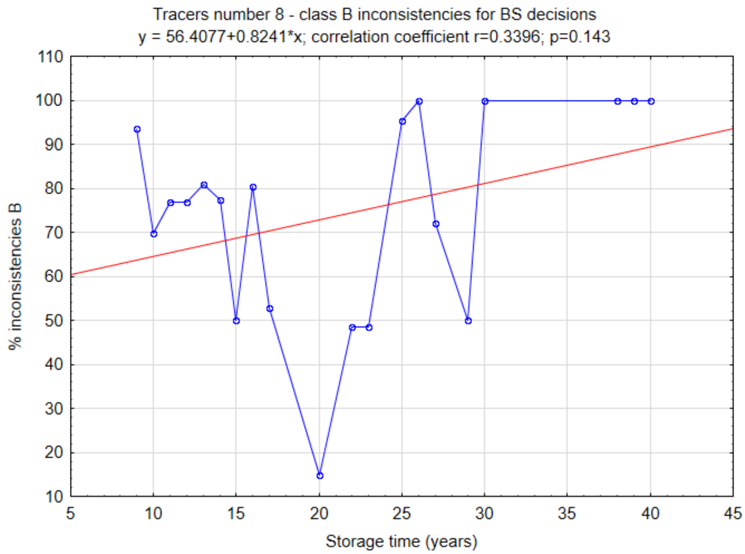

Fig.9. Inconsistencies of the class B in dependence on storage time for a shooting test and a regression line describing this dependence

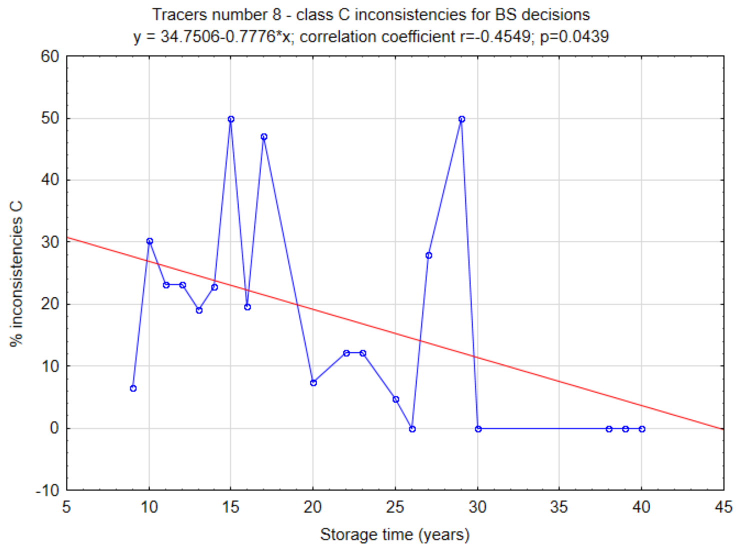

Fig.10. Inconsistencies of the class C in dependence on the storage time for shooting test and a regression line describing this dependence

Figure 10 shows the dependence of fractions of the class C inconsistencies on the time of storage. The graph shows that we are dealing with a downward trend, that is, as storage time goes on, the percentage of the class C inconsistencies decreases. The linear correlation coefficient is r = -0.4549. So, you can feel that as the storage years go by, the quality of the tested tracers increases, which of course, can be misleading. The reason for such a situation may be too small amount of the tested lots of tracers, which have received a shooting decision after laboratory tests.

The analysis of the evaluation module contained in the test methodology [2] shows that the shooting decision is undertaken in the case of a significant amount of "B" class inconsistencies and the occurrence of even a small amount of "C" class inconsistencies. The inconsistencies found during the tests tell us about the current technical condition of the tested tracer. They do not directly affect the security of storage of a given cartridge, which is completed in a given tracer, however, they can decide on the reliability of this tracer while shooting. If it does not fulfill its task during this shooting, which is after all indicating the direction of flight of the data of projectiles, it means that the tested tracer is not working properly and practically this ammunition (tracer) does not meet its requirements. According to [2], in the case when a given lot of tracers received a shooting decision, then the next tracer should be replaced at the next repair, provided that such a repair can be carried out without the need to dismantle the cartridge, which in most situations is not possible.

In summary, in the case of the analysis of the disparity of inconsistencies of different classes, depending on the time of storage, which were detected during laboratory tests, we see a decreasing tendency of changes of these inconsistencies in all classes of inconsistencies (A, B, and C). The nature of these changes is different, from the smallest for inconsistencies of the class A to the highest for inconsistencies of the class C. A large impact on this situation may be too few of the tested lots which were stored for over 30 years. For this reason, the graphs of the curves obtained have such a course.

On the other hand, the analysis of the dependence of the fractions of inconsistencies of individual classes on the storage time, only for shooting tests, showed an upward trend for the class B inconsistencies and a decreasing tendency for the class C inconsistencies. The class A inconsistencies were not considered because of their small amount.

6. TEST CYCLE AND LABORATORY DIAGNOSTIC DECISIONS AND DISPERSION OF INCONSISTENCIES

The article also analyzes the received diagnostic decisions depending on the next test cycle. Figure 11 presents dependencies of dispersion of the obtained positive decisions on test cycles. The graph shows that the fraction of positive decisions increases in the next test cycles.

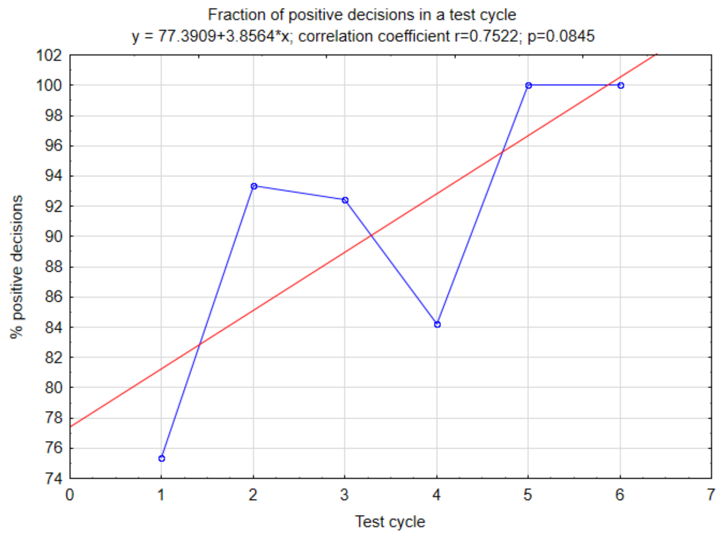

Fig.11. Graph of dependence of fractions of positive decisions on individual test cycles and a regression line describing this dependence

The linear correlation coefficient is r = 0.7522. Some people looking at the graph may think that in the fifth and sixth test cycle we have 100 percent positive decisions. This is of course the case, but one should take into account the fact that only a few lots of tracers were tested in these test cycles. However, in general, it can be concluded that the fraction of positive decisions in individual test cycles obtained during the research of the No.8 tracers is high.

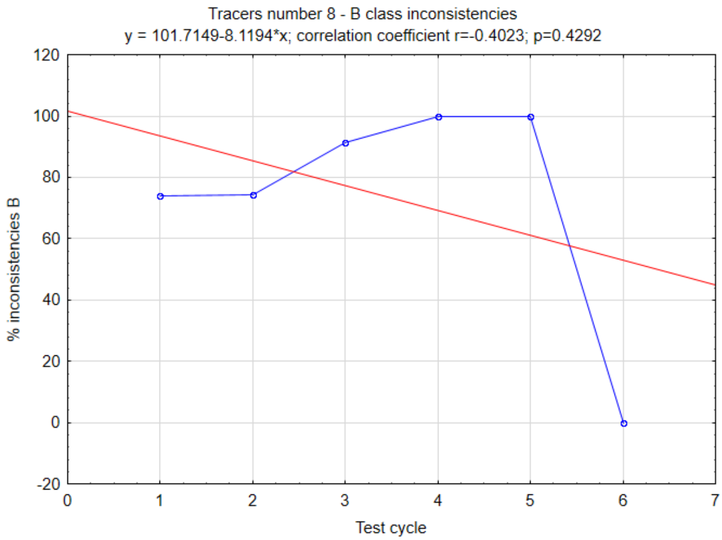

Fig.12. Graph of dependence of fractions of the class B inconsistencies in the individual test cycles and a regression line describing this dependence

The next figures show the dependencies of the fraction of inconsistencies of individual classes, broken down into next test cycles. Not all classes of inconsistencies were analyzed because of insufficient amount of inconsistencies that occurred during shooting tests. An example of this are the class A inconsistencies, which occurred only in three years of the test.

For the class B inconsistencies, the graph of which is shown in Figure 12, we can see that the inconsistencies of this class have a downward trend, which means that with the expiration of storage time, inconsistencies in this class are decreasing. The value of the linear correlation coefficient is r = -0.4023. Interpreting this curve, it can be said that in the next test cycles, the aging processes of this class of inconsistencies are decreasing.

A similar situation is for the class C inconsistencies, which are presented in Figure 13. In this case, the tendency of this class of inconsistencies is of a strongly decreasing nature. The linear correlation coefficient is r = -0.8507. Concluding, from the course of the curve, it can be said that in the next test cycles fewer inconsistencies in the class C were found.

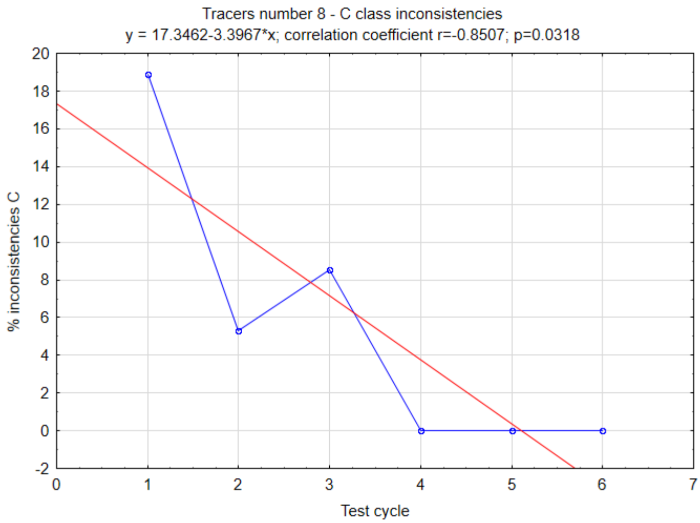

Fig.13. Graph of dependence of fractions of the class C inconsistencies on the individual test cycles and a regression line describing this dependence

The next two figures show the fractions of the class B and C inconsistencies in individual test cycles for the obtained shooting decisions. The class A inconsistencies were not analyzed because of insufficient number of them.

Figure 14 shows the dependence of the percentage of the class B inconsistencies in individual test cycles on the shooting decision. It should be remembered that the shooting decisions were taken only in four cycles of the tests.

From the course of the curve, it can be seen that in the next test cycles, the fraction of the class B inconsistencies is increasing, the linear correlation coefficient is r = 0.8581.

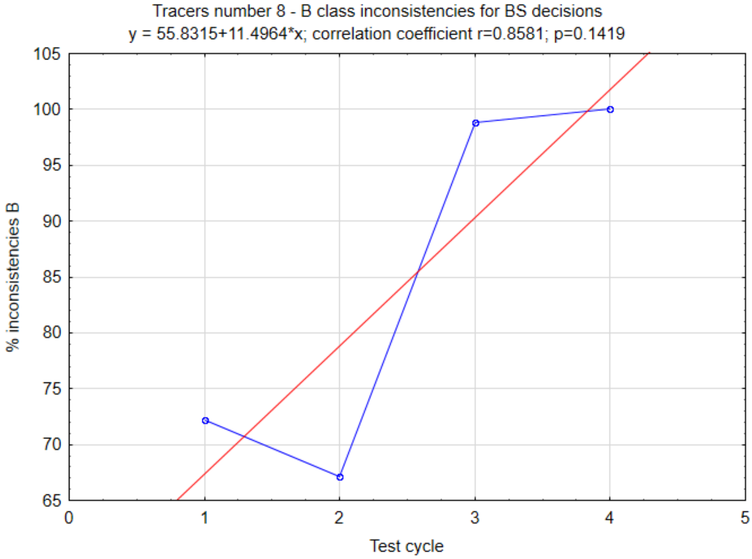

Fig.14. Graph of dependence of fractions of the class B inconsistencies on shooting decisions in the individual test cycles and a regression line describing this dependence

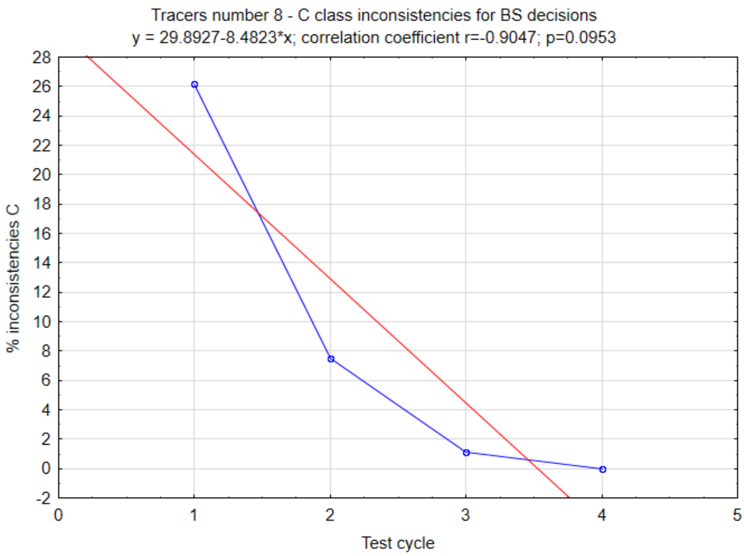

Fig. 15. Graph of dependence of fractions of the C class inconsistencies on shooting decisions in individual test cycles and a regression line describing this dependence

Figure 15 shows the dependence of the percentage of the class C inconsistencies, in individual test cycles, on the taken shooting decisions. This fraction has a decreasing tendency. The value of the linear correlation coefficient is r = -0.9047.

In summary, analyzing the dispersion of fractions of positive decisions in individual test cycles, we can see a clear upward trend, which means that as the time of storage increases, the percentage of positive decisions increases too.

On the other hand, the analysis of fractions of inconsistencies of particular classes, depending on the test cycles, was considered only in the classes B and C. The inconsistencies of these classes showed a decreasing tendency.

Additionally, the curves of fractions of the class B and C inconsistencies were plotted in individual test cycles for the shooting decision taken in laboratory tests. The class B inconsistencies showed a strong upward trend, while the class C inconsistencies showed a strong downward trend.

7. CONCLUSIONS

The article presents a statistical analysis of artillery tracers No. 8. The aim of this article was to show the tendency of aging the changes occurring in the analyzed tracers, based on the results of tests obtained in laboratory tests, and to propose a change in the assessment module of the tested tracers. The determinants of these changes were the resulting diagnostic decisions based on the number and types of inconsistencies found during diagnostic tests. Statistical analysis of the presented dependencies on the above graphs was an indispensable test element in order to show the possibility of modifying the evaluation module of the artillery tracers no. 8.

Analyzing the above-mentioned graphs on the nature of changes for individual relationships, it should be stated that most of the curves presented have a correct trend of changes, that is, a fraction of positive decisions increases as storage time passes and individual classes of inconsistencies decrease. This state of affairs may be caused by the fact that lots with poor technical conditions are withdrawn from the set of stored tracers and only lots suitable for use and storage remain. Only a fraction of the class B inconsistencies grows with the time of storage, and it is for all decisions taken and only for shooting decisions.

The post-diagnostic decisions, taken after the conducted shooting tests, confirm the supposition that the tested lots of the tracers No. 8 were mostly in good technical conditions. This is evidenced by the fact that positive diagnostic decisions have been taken after dynamic tests, i.e., the decisions Z - used in the first place. Even negative decisions taken after the shooting tests W - withdrawn from exploitation, were taken as a result of finding some inconsistencies during the tests, which do not directly affect safety of the stored ammunition.

In summary, it should be remembered that shooting tests are much more expensive than laboratory tests. Therefore, one should avoid conducting shooting tests, however, the current evaluation module in the test methodology [2] enforces the use of this type of test. After analyzing the test results of tracers No. 8 in this article, it can be proposed that the assessment module can be changed by introducing the "PS" decision - tested by the special program instead of the "BS" decision – shooting test. In this way, we avoid expensive dynamic tests and we proceed testing according to a special program, the scope of which will be determined in each case depending on inconsistencies obtained during the laboratory test.

This test will be relatively cheaper due to the fact that only those properties of tracers will be tested, which deviate from the norms established in the test methodology [2]. Introduction of such changes in the evaluation module, will reduce the future costs of conducting this type of tests. This will not, in any way, affect the storage security of the tested artillery tracers. It will not negatively affect the quality of diagnostic tests and will not affect the reliability of operation of these artillery tracers. The current test knowledge of the author of the article allows him to suppose that it is possible to modify the evaluation module of the tested tracers by changing the type of decision in the evaluation module of these artillery tracers.

Currently, on the shooting tests there are waiting a dozen of lots from the tracers No. 8 analyzed in this article. Therefore, to close the test cycle of the tested lots, it is advisable to modify the evaluation module according to the proposal presented in this article, i.e., all lots with an unfinished test cycle which received shooting decisions should be tested according to a special program with an extended scope test of these properties (features) whose inconsistencies were detected in laboratory tests. The proposed new evaluation module will certainly reduce the costs of diagnostic tests and will lead to a faster completion of test cycles of the tested lots of tracers No. 8. Of course, the proposal to modify the evaluation module also applies to other types of artillery tracers, which are subjected to diagnostic tests, because the evaluation table in the test methodology [2] is the same for all types of artillery tracers.

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Analiza statystyczna wyników badań smugaczy artyleryjskich

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Streszczenie. W artykule zostały przedstawione wyniki analizy statystycznej wieloletnich badań laboratoryjnych smugaczy artyleryjskich numer 8. Analiza ta miała na celu zbadanie wpływu procesu naturalnego starzenia się smugaczy na wybrane wskaźniki jakościowe podczas długoletniego składowania tych smugaczy artyleryjskich. Analizowano w niej wpływ czasu składowania smugaczy na podjęte decyzje diagnostyczne dotyczące jakości danej partii po przeprowadzonych badaniach laboratoryjnych oraz wpływ czasu składowania smugaczy na różne klasy niezgodności jakie wystąpiły podczas tych badań diagnostycznych. Przedstawiono także szczegółową analizę wpływu czasu składowania smugaczy artyleryjskich numer 8 na podjęte decyzje diagnostyczne typu badać strzelaniem. Przeprowadzona analiza statystyczna nasuwa przypuszczenie, że możliwa jest zmiana modułu ocenowego w dotychczas funkcjonującej metodyce badawczej. Modyfikacja tego modułu ocenowego nie wpłynie negatywnie na jakość prowadzonych dalszych badań diagnostycznych. Nie wpłynie ona także negatywnie na prawidłową ocenę procesu predykcji badanych elementów środków bojowych jakimi są smugacze artyleryjskie. Przeprowadzona w artykule analiza statystyczna może mieć istotne znaczenie dla przyszłej modyfikacji metodyki badań smugaczy artyleryjskich.

Słowa kluczowe: amunicja, smugacz, eksploatacja, niezgodności, cykl badania, właściwości