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# Quantitative Safety Risk Requirements for Small Arms and Ammunition

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**Abstract:**

*Implicit in a discussion of the acceptability of a safety level for arms and ammunition is an understanding of risk. The method of requirements definition of arms and ammunition safety risks introduced in the paper enables to unambiguously identify the area of unacceptable risk that could result in arms or ammunition failure with serious consequences.*

**Keywords:**

*quality of arms and ammunition, safety of arms and ammunition, safety risk requirements*

## 1. Introduction

Quality of small arms and ammunition (further only arms and ammunition) represents the ability of inherent characteristics of all parts of arms and ammunition to fulfil expectations, needs and requirements of the user. Arms and ammunition belong to dangerous products that contain explosives. The figure on the right-hand side shows damaged shotgun barrel which has caused shooter's injury. That is why we consider the safety of arms and ammunition to be one of their most important characteristics [5], [8], [9]. We require the arms and ammunition to resist a wide range of effects of ambient/external environment without getting dangerous or useless. The safety must be kept during common manipulation, transportation, storing and also during operation

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when arms and ammunition must fulfil all required functions. Arms and ammunition are affected not only by climatic environment but also by individual phenomena and events arising in the course of their life cycle, especially while shooting.

Arms and ammunition construction contains a wide range of materials (e.g. metals, explosives, plastics, varnishes, etc.) that interact. It is important to avoid such chemical and physical reactions among materials used in arms and ammunition that could lead to an unacceptable decrease in safety of arms and ammunition in the course of their usage.

Arms and ammunition safety may also be restricted by unacceptable degradation degree of its individual elements after multiple or long-term exposure to normal, but first of all extreme climatic conditions and to loading during all processes of use.

Apart from the above mentioned facts, practically all elements of arms and ammunition must stay safe not only in the period of use, but also in the period of retirement when they are either irreversibly adjusted or physically liquidated.

## 2. Combat Quality, Reliability and Safety of Arms and Ammunition

Combat quality of arms and ammunition is a set of their characteristics related to their ability to fulfil requirements of armed forces at manipulation, storing, transportation and especially at combat actions [4], [6], [8], [9]. From the point of view of the armed forces, combat quality of arms and ammunition represents fulfilling their needs and requirements.

Arms and ammunition reliability is a part of combat quality related to their behaviour during the whole period of use, i.e. primarily during storing and shooting. Arms and ammunition is considered to be reliable if only a minimum failure occur during the period of use. In safe arms and ammunition no hazard arises in relation to a person (a shooter), to the arm or to the ambient environment (other persons or objects in the terrain, environment). In other words, in safe arms and ammunition there is no failure which could endanger health or even life of the user, or which could damage asset or environment. Thus, arms and ammunition safety is their general quality that enables them to be during fulfilling their functions in such conditions when health and life hazard, as well as endangering assets or environment are restricted to an acceptable level. Arms and ammunition safety can be quantified as the probability that it will cause no threat hazard during all periods of its life cycle (development, production, use and retirement) and the risk level of damaging human health, assets and/ or environment is very low (negligible) [1], [2], [5], [8], [9].

The above mentioned concepts – arms and ammunition combat quality, reliability and safety are integrated (interconnected) and they form a common whole. They create a common pyramid with combat quality as a base and a frame and with safety on the peak (see Fig. 1).

Determining requirements for arms and ammunition are safety requirements. Even top qualities of arms and ammunition have no value without ensuring their highest safety. If arms and ammunition reliability is to be assessed, its safety has to be proved first.

In safety, we analyze the effects of the failures (phenomena, events) arising during arms and ammunition life cycle on the possibility of damaging or destruction of arms and ammunition and on the possibility of damaging human health, assets or environment. What we mean by that is, for instance, incorrect (not required) operation of arms and ammunition, macro-plastic deformations, cracks, fractures of important functional parts and functional surfaces, defects of connections and seals, damaging of internal arrangement, prohibitive changes in chemical composition of the material from which arms and ammunition have been made, etc.


*Fig. 1 Arms and ammunition combat quality, reliability and safety*

## 3. Classification of Arms and Ammunition Hazards

A starting point for risk analysis for arms and ammunition (see Chapter 4) is classification of hazards [9]. Arms and ammunition hazards are characterized according to the severity of the worst repercussion to personnel, material assets and the environment that are results of their failures which may arise while using or liquidating arms and ammunition.

A relevant arms and ammunition hazard can be defined as a hazard that could realistically end in a failure with serious consequences, such as killing people, severe damaging assets, or severe damaging environment.

A possible hazard classification in relation to the severity of arms and ammunition failures is given in Table 1 [9].

*Tab. 1 Matrix of severity of arms and ammunition failures*

| *Failure category* | *Failure magnitude for* | | |
|---|---|---|---|
| | *Persons/ humans/ people* | *assets* | *environment* |
| *Category I* | *death* | *loss (total damage)* | *severe damage* |
| *Category II* | *severe injury or illness* | *severe damage* | *major damage* |
| *Category III* | *minor injury or illness* | *minor damage* | *minor damage* |
| *Category IV* | *no effect* | *no effect* | *no effect* |

According to the severity, we divide arms and ammunition failures into the four categories. The most serious is category I. This category covers such arms and ammunition failures that result in human death, complete destruction of asset or severe damage to the environment.

Failure category II includes arms and ammunition failures that cause severe injury or illness, severe damage of asset or major damage to environment. Severe injury or illness disables the person for more than one day. Severe damage to asset causes that the asset is out of order and unserviceable for fulfilling tasks for more than one day.

Category III represents such kinds of failures which cause minor injury or illness, minor damage to asset and only minor damage to environment. Minor injury or illness disables a person for maximum one day. Minor damage to asset causes that the asset is out of order or unavailable for maximum one day.

Failure category IV includes such failures that do not cause any consequences on people, asset or environment [9].

## 4. Risk Level

Risk analysis evaluates all data about the given risk that can be caused by the given arms and ammunition type. It also transforms these data into information to be used in decision-making about arms and ammunition safety. This information has to contain a loss dimension potential which is imminent if the given risk occurs. This risk is expressed by so-called risk level.

Risk level is a number that consists of combination of the given failure occurrence probability and severity of consequence of arms and ammunition failure, if this failure arises.

The value of risk level $RL$ is calculated by multiplying failure occurrence probability $Q$ and severity of consequences $C$:

$$RL = QC\ . \tag{1}$$

Risk level $RL$ describes phenomena and processes related to arms and ammunition safety. Values of risk level enable to evaluate the level of arms and ammunition safety.

Risk analysis usually evaluates failure occurrence probability qualitatively. For instance, in [9] the following degrees of failure occurrence probability are defined: frequent, probable, occasional, remote and improbable. Determining probability only in qualitative way does not enable clear definition of the area (areas) of unacceptable risk for arms and ammunition user. In practice, it is not possible to unambiguously measure and evaluate the failures in relation to safety according to qualitative categorizations only.

The following parts of the article will present a method of defining requirements for safety risks of arms and ammunition by quantitative indicators. The indicators are firstly quantified for ammunition and consequently for small arms.

## 5. Ammunition Safety Indicators

Ammunition fulfils its task only at firing and that is why it belongs to the group of one-shot weapon systems [4]. Firing duration, i. e. ammunition operation itself, is very short – in the order of milliseconds. In practice the duration is neither measured nor recorded for reliability analysis.

All projects of a new kind ammunition development must contain the procedure of safety evaluation of the given ammunition in so-called safety programme [9]. The content of safety programme is ammunition analyses and tests aimed at its safety, i.e. verification that the explosive components of the ammunition and ammunition as a whole will fulfil the required functions by prescribed way and with acceptable (negligible) risk degree of the whole life cycle.

To be able to effectively control individual risks in safety programme, i.e. to accept meaningful measures for decreasing unacceptable risk level, it is necessary to determine requirements for acceptable degree of failure occurrence probability of ammunition.

Let us indicate gradually failure occurrence probabilities:

$Q_I(t)$ failure occurrence probability of category I,
$Q_{II}(t)$ failure occurrence probability of category II,
$Q_{III}(t)$ failure occurrence probability of category III,
$Q_{IV}(t)$ failure occurrence probability of category IV.

The quantification of indicators of failure occurrence probability $Q_I(t)$ - $Q_{IV}(t)$ includes only those failures that belong to the given failure category.

Failure numbers of individual categories and their possible ratio are graphically illustrated in Fig. 2.

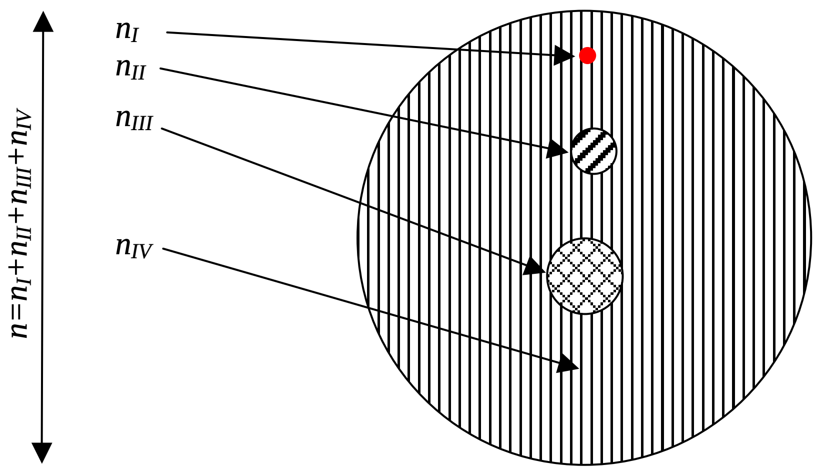



*Fig.2 Schematic illustration of an example of the ratio/ proportion of the number of failures of individual categories*

Statistical estimation of the probability of category I failure is given by the relation:

$$\hat{Q}_I(t) = \frac{n_I(t)}{N}, \tag{2}$$

where $n_I(t)$ is the number of category I failures,
$N$ is the total number of pieces of ammunition,
$t$ is the period of use.

Statistical estimations of the probability of category II, III and IV failure are defined for ammunition according to the following relations:

$$\hat{Q}_{II}(t) = \frac{n_I(t) + n_{II}(t)}{N}, \tag{3}$$

$$\hat{Q}_{III}(t) = \frac{n_I(t) + n_{II}(t) + n_{III}(t)}{N}, \tag{4}$$

$$\hat{Q}_{IV}(t) = \frac{n_I(t) + n_{II}(t) + n_{III}(t) + n_{IV}(t)}{N} = \frac{n(t)}{N}, \tag{5}$$

where $n_{II}(t)$ is the number of category II failures,
$n_{III}(t)$ is the number of category III failures,
$n_{IV}(t)$ is the number of category IV failures,
$n(t)$ is the number of all category failures,
$N$ is the total number of pieces of ammunition.

The relation (5) implies that the total number of failures $n(t)$ is the sum of failures of all categories:

$$n(t) = n_I(t) + n_{II}(t) + n_{III}(t) + n_{IV}(t). \tag{6}$$

## 6. Requirements for Ammunition Safety Risks

Requirements for new kinds of ammunition illustrate the need or expectation of users (armed forces, police) that should be addressed by the given kind of ammunition. The better the requirements for a new kind of ammunition are met, the more favourable the response of the users (soldiers, policemen) will be to it. To correspond fully to the ammunition safety definition, it is necessary to determine an acceptable level of probability of failures of all categories for safety indicators.

The requirements for small-arms ammunition safety can be defined by values of probability of failure occurrence in the following way:

Failures of category I having the most serious consequences for persons, assets and environment must be extremely improbable. The probability of failure occurrence $Q_I$ must be in all defined regimes (storing, transportation, manipulation, shooting) and in the defined liquidation method lower than $10^{-11}$.

Failures of category II must also be extremely improbable, but the probability of failure occurrence is in one order lower than in the category I. That is why $Q_{II}$ must be lower than $10^{-10}$ during the whole period of ammunition using or in the period of its retirement (disposal).

Failures of category III must also be extremely improbable, but with the probability in two orders lower than in the category I, i.e. $Q_{III}$ must be lower than $10^{-9}$ during the whole period of ammunition using or in the period of its retirement (disposal).

Failures of category IV are without an impact on the safety, and so they can be probable on the level that is acceptable for the user. From the point of view of safety, the probability of failure/ malfunction occurrence $Q_{IV}$ can be higher than $10^{-9}$ during the whole period of ammunition using and the period of its retirement (disposal).

Fig. 3 shows graphically the requirements for ammunition safety risk.

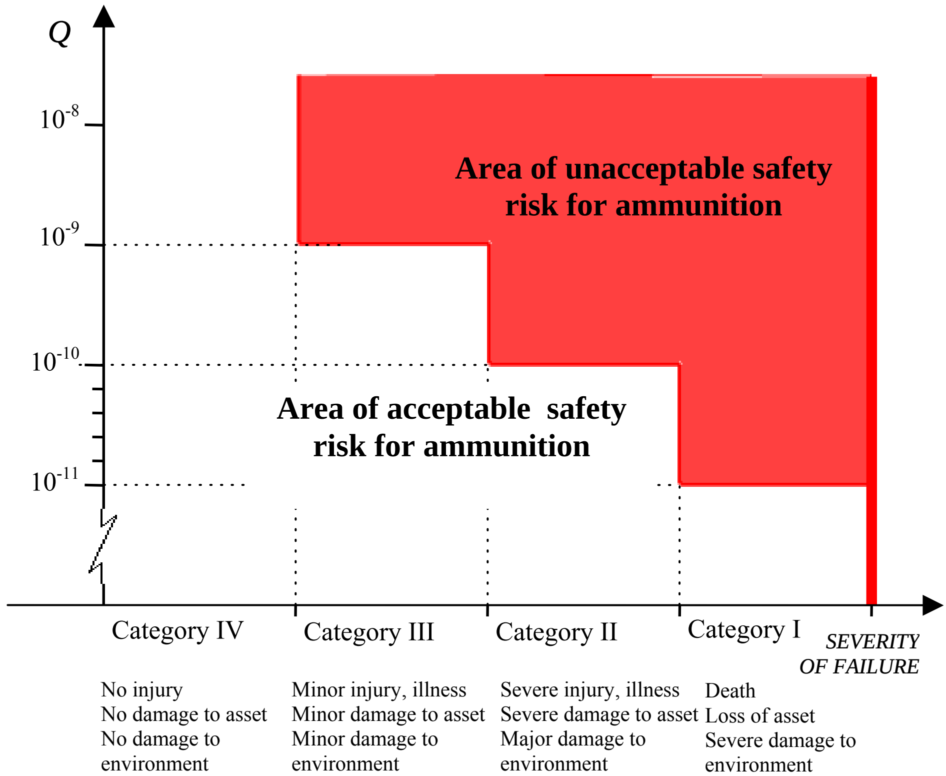



*Fig. 3 Requirements for ammunition safety risk*

Fig. 4 shows a model of ammunition safety and reliability. The model illustrates schematically the required level of ammunition reliability and safety.

The level of reliability could by defined by the indicator value of failure probability $Q$. Nowadays, it is around $Q(t = 5 \text{ years}) = 10^{-6}$ for small-arms ammunition during the period of use of five years. It includes only category IV failures that cause neither injuries nor damage to assets or environment (e.g. misfire shot).

Fig. 4 shows that the level of safety risk of small-arms ammunition is determined with a satisfactory provision above the level of its level of reliability. The lower limit of safety risk is minimally three orders higher than the level of reliability.

The difference of the level of reliability and the lower limit of ammunition safety is so-called safety range. The safety range represents safety provision of small-arms ammunition safety for unexpected dangerous behaviour of the users. Moreover, it is also a provision for worsening technical conditions of the ammunition outside prescribed parameters of technical requirements.

Safety range is also a provision for possible ammunition damage, breaking safety rules while using the ammunition by the user (most frequently while manipulation), as well as other unexpected situations that have not been identified as dangerous up to now.

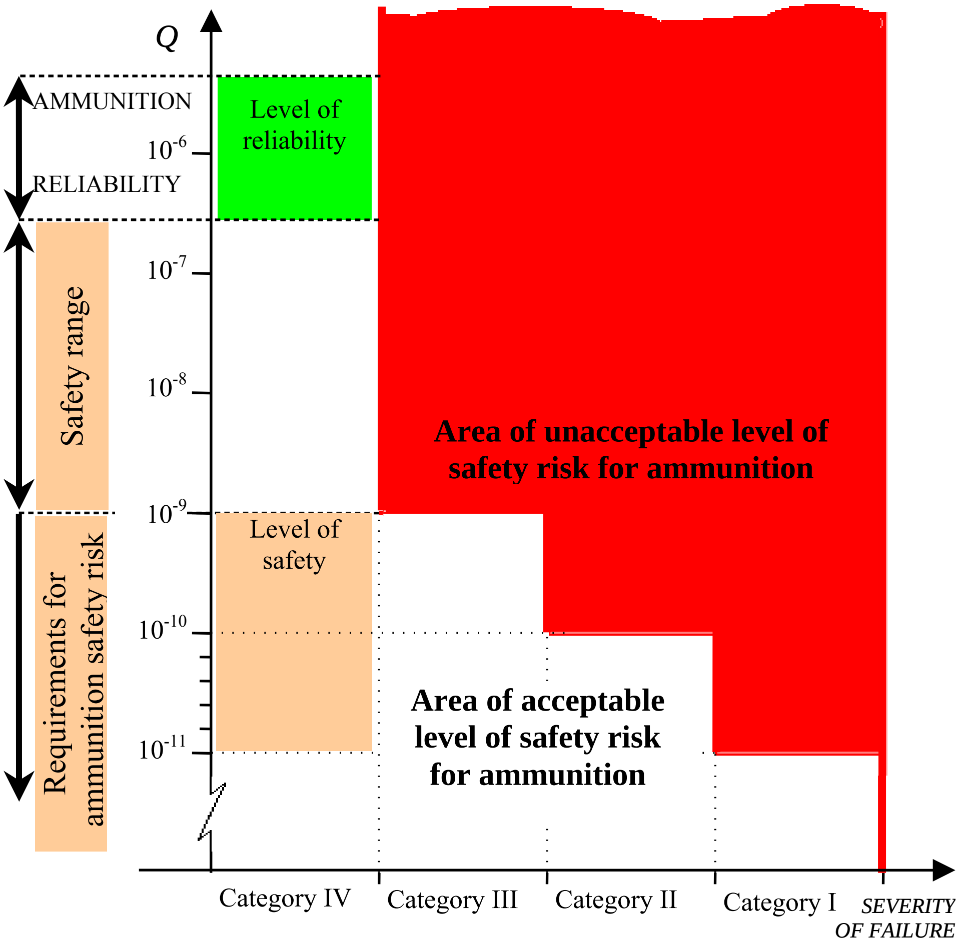



*Fig.4 Model of ammunition safety and reliability*

## 7. Arms Safety Indicators

When defining requirements for arms safety, it is necessary to determine an acceptable level of probability which admits the occurrence of failures of individual categories. To indicate the arms safety, we use failure rate $\lambda(t)$.

Failure rate represents the probability of arms failure in the interval of operation period unit. In other words, failure rate is the probability of arms failure related to one shot. Its dimension is [$shot^{-1}$].

Failure rate as an indicator of arms safety will be identified as follows:

$\lambda_I(t)$ Failure rate for failures of category I,
$\lambda_{II}(t)$ Failure rate for failures of category II,
$\lambda_{III}(t)$ Failure rate for failures of category III,
$\lambda_{IV}(t)$ Failure rate for failures of category IV.

Statistical estimation of the failure rate for individual failure categories can be calculated as follows:

$$\hat{l}_I(t) = \frac{n_I(\Delta t)}{\Delta t.N(t)}, \tag{7}$$

$$\hat{l}_{II}(t) = \frac{n_I(\Delta t) + n_{II}(\Delta t)}{\Delta t.N(t)}, \tag{8}$$

$$\hat{l}_{III}(t) = \frac{n_I(\Delta t) + n_{II}(\Delta t) + n_{III}(\Delta t)}{\Delta t.N(t)}, \tag{9}$$

$$\hat{l}_{IV}(t) = \frac{n_I(\Delta t) + n_{II}(\Delta t) + n_{III}(\Delta t) + n_{IV}(\Delta t)}{\Delta t.N(t)} = \frac{n(\Delta t)}{\Delta t.N(t)}, \tag{10}$$

where $n_I(\Delta t)$ is the number of arms failures of category I in the interval of $(t, t + \Delta t)$,
$n_{II}(\Delta t)$ is the number of arms failures of category II in the interval of $(t, t + \Delta t)$,
$n_{III}(\Delta t)$ is the number of arms failures of category III in the interval of $(t, t + \Delta t)$,
$n_{IV}(\Delta t)$ is the number of arms failures of category IV in the interval of $(t, t + \Delta t)$,
$n(\Delta t)$ is the number of arms failures (of all categories) in the interval of $(t, t + \Delta t)$,
$N(t)$ is the number of arms in working mode at the moment $t$ – i.e. at the beginning of the interval $(t, t + \Delta t)$,
$\Delta t$ is the length of the time interval of arms operation (number of shots).

## 8. Requirements for Arms Safety Risks

Requirements for arms safety risks can be defined using values of failure rate for individual failure categories in the following way:

Failure rate $\lambda_I(t)$ for failures of category I with the most serious impact on persons, assets and environment must be lower than $10^{-9}$ to one shot (see Fig. 5). This value of failure rate ensures that failures with fatal consequences are practically impossible. The given value of failure rate actually tolerates only the failure of category I in the average to 1 milliard of shots.

Failure rate $\lambda_{II}(t)$ for failures of category II must be lower than $10^{-8}$ to one shot. Also this value of failure rate ensures that failures with severe impact on health, assets or major impact to the environment are extremely improbable. The value of failure rate $10^{-8}$ tolerates the only failure of category II in the average to 100 million of shots.

Failure rate $\lambda_{III}(t)$ for failures of category III must be lower than $10^{-7}$ to one shot. The value of failure rate $\lambda_{III}(t) < 10^{-7}$ [$\text{shot}^{-1}$] guarantees that the failure with consequences of minor injury, minor damage to assets or environment is improbable (extremely rare), because it tolerates the only failure to 10 million shots.

Failure rate $\lambda_{IV}(t)$ for failures of category IV, i.e. such failures that do not cause damage to health, assets or environment can be generally higher than $10^{-7}$ to one shot.

Requirements for small arms safety risks create the area of unacceptable risks if an arms failure rate arises – see Fig. 5.

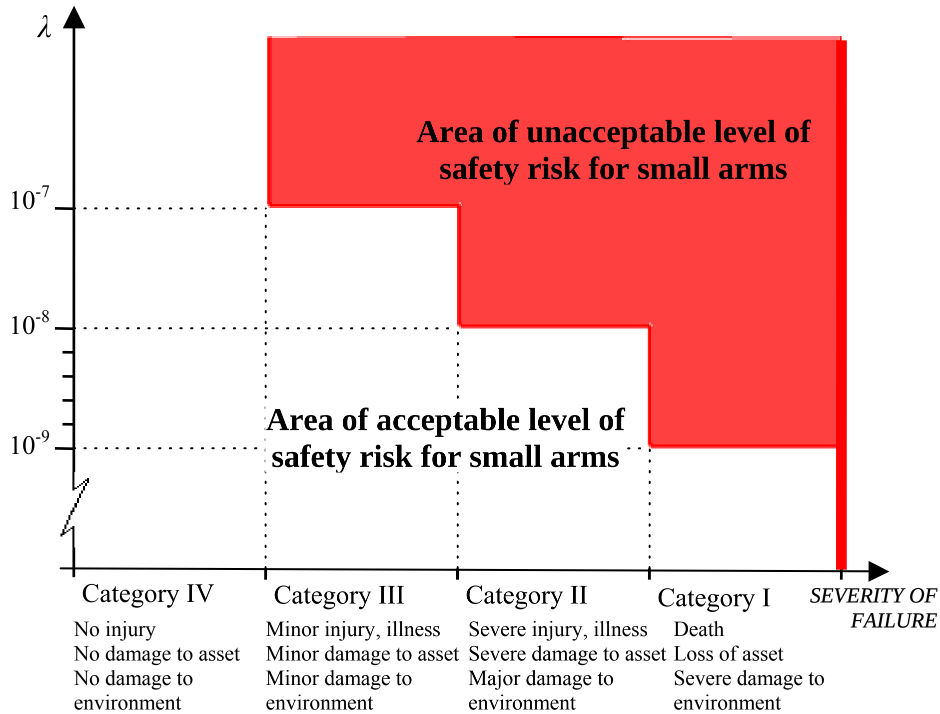


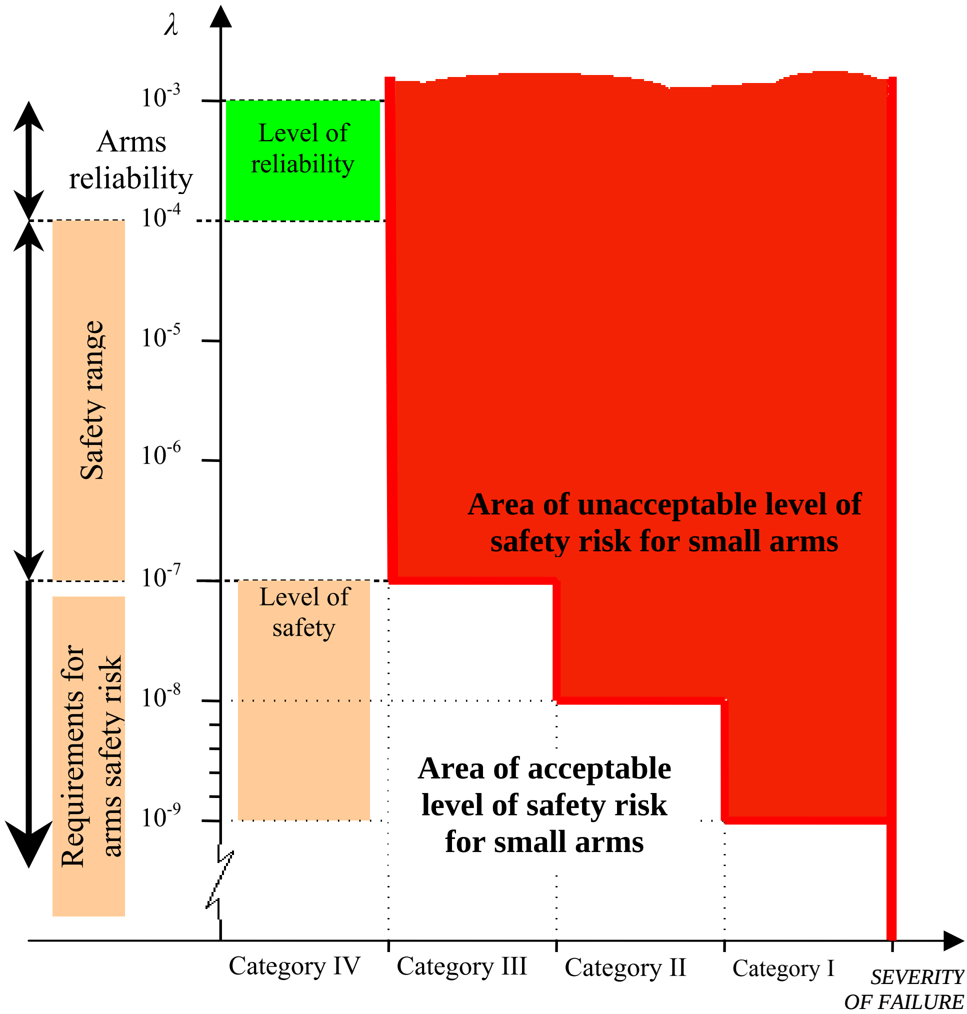

*Fig. 5 Requirements for small arms safety risk*

The method of defining requirements for small arms safety risks using the values of failure rate for failures of different categories identifies the area of unacceptable risks which could result in arms failure with serious consequences.

Fig. 6 shows a small arms safety and reliability model. This model illustrates the level of reliability and the required level of small arms safety risk.

The level of reliability is defined by the value of failure rate which nowadays ranges for small arms from $\lambda = 10^{-3}$ to $10^{-4}$ [$\text{shot}^{-1}$]. It includes only failures of category IV which do not cause injuries or damage to possessions or environment (e.g. the breech block stop at the rear position was not activated after firing the last round).

Arms safety model in Fig. 6 shows that the level of small arms safety risk is determined with a satisfactory provision above the level of reliability. The lower limit of safety risk is minimally three orders higher than the level of arms reliability.




*Fig, 6. Model of small arms safety and reliability*

The difference between the level of reliability and lower limit of safety risk level is the safety range. The dimension of safety range is three orders higher than the level of reliability of small arms.

## 9. Conclusion

The method of requirements definition of arms and ammunition safety risks introduced in the paper enables to identify unambiguously the area of unacceptable risk that could result in arms or ammunition failure with serious consequences. The method enables in practice to measure, monitor and evaluate risks of the given type of arms and ammunition. It also guarantees a clear and complete formulation of safety in tactical-technical specification for the development of a new kind of arms or ammunition.

Requirements for safety risks determine minimum acceptable level of reliability for the most important parts of the arms (elements that have decisive effect on arms and ammunition safety).

Requirements for acceptable level of arms and ammunition safety risk have to be adjusted in safety analyses of concrete arms and ammunition types. They should also be critically evaluated with regard to:

- Range and character of damage that might be caused by the given arms or ammunition,
- Expected period of using ammunition,
- Expected number of shots during the period of arms life cycle,
- Expected number of produced pieces of arms, ammunition, etc.

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