Acceptable risk from ammunition storage

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Abstract

The Norwegian risk acceptance criteria for ammunition storage are based on a study at the Norwegian Defence Research Establishment (FFI) in 1983. In the study, the acceptable societal risk from ammunition storage was found from the general rate of fatal accidents. The relative costs of storing military ammunition in Norway compared to the gross domestic product were then taken into account. Criteria for the group risk from a single storage were also established. The acceptable individual risk was found from the risk caused by natural hazards. Later, criteria for persons involved in the storing of ammunition were determined. The accident statistics employed in the study were from 1979. Now similar considerations have been made with recent accident statistics. The result is larger acceptable individual risk for unrelated persons than in the current criteria. For fully involved persons the acceptable individual risk is smaller. The acceptable group risk is reduced for third parties. For fully or indirectly involved persons the acceptable group risk is found by a new approach with a separate criterion for each of these groups.

Introduction

In Norway, acceptance criteria are used to assess the risk associated with storage of ammunition and explosives. The current criteria were established based on a memorandum written by Svein Rollvik at FFI in 1983 [1]. Rollvik proposed values for acceptable societal risk and personal or individual risk. The values were derived from accident statistics.

The societal risk considered here is the average risk to a person from storing military ammunition in Norway. However, when assessing the risk to the public from a storage facility or storage area, societal risk is not very applicable. Therefore, group risk, which is the risk that a single storage site poses to its surroundings, is used instead. The acceptable group risk can easily be compared with the results of a risk analysis.

The Norwegian risk acceptance criteria differentiate between first, second and third parties. A first party is directly involved in handling or inspecting ammunition. A second party works in the defence sector but not with ammunition. Third parties have no connection to ammunition-related activities [2].

The acceptance criteria for individual risk and group risk were approved and adopted by the Norwegian Ministry of Defence in 1983 [3]. They applied to third parties, and further assessments were later made to determine acceptable risk for first and second parties. These criteria were first developed for the Norwegian Directorate for Fire and Explosion Prevention and then in 2001 approved by the Norwegian Ministry of Defence [3, 4]. The acceptance criteria have since been applied both in military and civilian sectors.

Accident statistics have changed since 1983, and we have investigated how this affects the acceptance criteria. This means that Rollvik's analysis is repeated with updated statistics. We have also repeated previous assessments to establish criteria for first and second parties.

The results are presented in this paper along with a description of the analysis. The paper is a translated and adapted version of an upcoming Norwegian report [5].

The group risk depends on the probability of an accident in an ammunition magazine. Based on statistics in Norway from 1945 to 1983, Rollvik estimated the probability to $5 \cdot 10^{-5}$. From 1983 to 2023 there have been no accidents, so the estimated probability of event is now reduced to $3 \cdot 10^{-5}$ [5].

The values of risk and probability presented in this paper are all for a period of one year.

Acceptable risk

Rollvik compared the risk level of ammunition storage with the risks associated with other types of activities. He pointed out that the majority of those exposed to risk from ammunition storage are third parties. They are unlikely to accept a significant increase in accident risk due to ammunition storage.

Rollvik did not consider first and second parties. For them, a higher risk level is acceptable since they benefit from the activity that exposes them to danger and are, to some extent, voluntarily exposed. They are also aware of and can influence the risk.

The degree of influence is larger for a first party than for a second party. The actual risk for a first party will also normally be greater than for a second party, as the latter is typically exposed for shorter periods of time. Therefore, the acceptable risk can be higher for a first party than for a second party.

The accident risk is the number of fatal accidents per person during a year. The updated figures in this paper are based on Norway's average population in the period 2019–2023, which was 5.4 million inhabitants [6].

Individual risk

Criterion for third parties

For the individual risk to third parties, Rollvik based his assessment on the probability of dying from natural hazards such as lightning, avalanches, and floods. He referred to a value of approximately $2 \cdot 10^{-6}$ [7]. He then set the requirement that the individual risk should be less than one-tenth of that value, i.e., $2 \cdot 10^{-7}$. This ensures that an ammunition magazine only gives a small increase in the overall risk these individuals are already exposed to.

During the period 2019–2023, an average of 32 people died annually in nature-related accidents in Norway [8]. This gives a probability per person of $6.0 \cdot 10^{-6}$, which is three times higher than the value from 1983. If the acceptable contribution from ammunition storage is one-tenth of this, the acceptable individual risk becomes $6 \cdot 10^{-7}$.

It could be argued that the basis for acceptable individual risk should include all accidents affecting third parties, not just those caused by nature. However, it is difficult to find a general accident rate just for third parties.

The individual risk can be expressed by the formula,

$$R_\mathrm{i} = P_E \rho \lambda \qquad (1)$$

Where,
R_i = individual risk
P_E = probability of event
ρ = presence factor = the portion of the day a resident spends at home, or a regular traveller spends on an exposed route
λ = lethality

Hence, an acceptable individual risk corresponds to an acceptable lethality. Rollvik assumed a presence factor of 2/3 for residents and 1/24 for regular travelers. The values of P_E and R_i from 1983 and 2023 then gives the maximum fatality rates shown in Table 1.

Table 1. Lethality criteria for an ammunition depot.

Year	1983	2023
Acceptable individual risk, R_i	$2 \cdot 10^{-7}$	$6 \cdot 10^{-7}$
Acceptable lethality, Residence	0.6%	3%
Acceptable lethality, Travel route	10%	50%

Higher acceptable risk and lower probability of explosion lead to acceptable lethality values that are five times higher in 2023 than in 1983.

Criteria for involved persons

The current acceptance criteria for first and second parties are based on the probability of dying in a work-related accident. This is described in a memo from 1993 [9]. Employees in the Armed Forces should not be exposed to greater risk in their work than is normally accepted in other parts of the workforce. In 1990 and 1991 the accident frequency across all industries was $4.3 \cdot 10^{-5}$ per worker per

year. Based on this, the acceptable risk for first party was set to $4 \cdot 10^{-5}$. The criterion for second party was set between the values for first and third party to $3 \cdot 10^{-6}$.

Looking at new statistics, the accident frequency in the period 2019-2023 was $1.3 \cdot 10^{-5}$ [10, 11]. Based on this figure, we propose an acceptable risk for first party of 10^{-5}. For second party the proposal is to keep the current criterion value of $3 \cdot 10^{-6}$. This is close to the geometric mean of the values for first and third party, as it is for the current criteria.

The new values for acceptable individual risk are shown in Table 2 along with the current criteria.

Table 2. Current and updated acceptance criteria for individual risk from ammunition storage.

	Current	Updated
1. party	$4 \cdot 10^{-5}$	$1 \cdot 10^{-5}$
2. party	$3 \cdot 10^{-6}$	$3 \cdot 10^{-6}$
3. party	$2 \cdot 10^{-7}$	$6 \cdot 10^{-7}$

Societal risk

To determine an acceptable societal risk, Rollvik started from the general accident rate or societal risk. This risk is the result of all activities in Norway. The acceptable societal risk from ammunition storage was found by multiplying the general accident rate with the ratio of the costs of ammunition storage and the gross domestic product (GDP):

$$R_\mathrm{s} = \text{General societal risk} \cdot \frac{\text{Costs of ammunition storage}}{\text{GDP}} \qquad (2)$$

Where,
R_s = societal risk from ammunition storage

Using data from 1979, Rollvik found the values shown in Table 3. The table also shows the results with new data.

Table 3. Acceptable societal risk from ammunition storage and the figures it is based on

Year	1983	2023
Number of fatal accidents per year	1,893	2,006 [8]
General societal risk	$4.6 \cdot 10^{-4}$	$3.7 \cdot 10^{-4}$
GDP / billion Norwegian kroner	240	5,100 [12]
Ammunition storage costs / billion Norwegian kroner	0.4	3.1 [13]
Acceptable risk from ammunition storage	$7.7 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$

The acceptable risk from ammunition storage was then further reduced by a factor of 10 because the general societal risk includes all parties, whereas the risk from a major storage accident primarily applies to third parties. The acceptable risk level was thus set to $8 \cdot 10^{-8}$.

The corresponding figure for 2023 is $2 \cdot 10^{-8}$. The main reason it is lower is that the proportion of GDP spent on ammunition storage in 2022 is one-third of the proportion in 1979.

Group risk

As shown by Rollvik, an average group risk can be found from the societal risk by the relation:

$$R_g = R_S \frac{N}{n_m} \quad (3)$$

Where,
N = number of inhabitants
n_m = number of magazines

The group risk can also be calculated as the probability of an accident multiplied by the consequence of the accident, which is the expected number of fatalities:

$$R_g = P_E \, C_E \quad (4)$$

Where,
R_g = group risk
C_E = consequence of the event

The group risk that is compared with the acceptance criteria is the perceived group risk, R_{gp} [14]. This takes society's aversion to accidents with multiple fatalities into account by the aversion factor, ϕ:

$$R_{gp} = P_E \, \phi \cdot C_E \quad (5)$$

ϕ is found from C_E as shown in Figure 1.

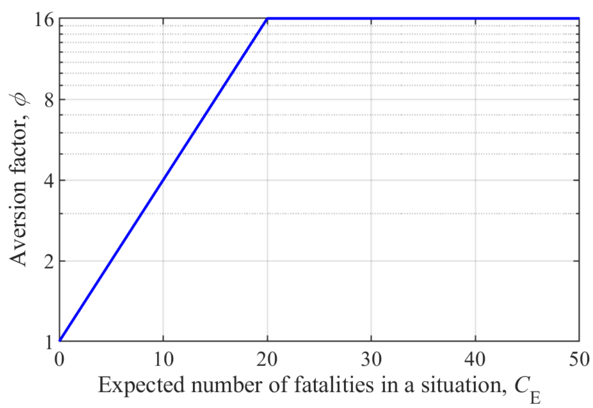

Figure 1. Aversion factor ϕ as a function of consequence C_E

Since the number of people present at exposed objects can vary over time, C_E and ϕ may have different values in different time periods or situations. Then $\phi \cdot C_E$ in (5) is the time-averaged value.

The risk from a depot can also be represented by FN-curves [15]. These curves show the cumulative frequency or probability of a number of fatalities as a function of the number. Acceptance criteria then specify the upper limit for these curves and can address the same concerns about large consequences with low probability as an aversion factor would. However, using an aversion factor helps to mitigate some weaknesses of FN-curves [16].

Criterion for third parties

From Equation 3, Rollvik found that if the societal risk is to be less than $8 \cdot 10^{-8}$, then the acceptable group risk for third parties must be less than 10^{-4}. Figures from 2023 give an acceptable group risk of $7 \cdot 10^{-5}$.

Criteria for involved persons

To find the acceptable group risk for involved persons, a criterion used in the explosives manufacturing industry was employed. The criterion sets a limit of maximum five fatalities in an accident [17]. With $P_E = 5 \cdot 10^{-5}$, Equation 4 then gives a group risk of $2.5 \cdot 10^{-4}$. Rounded up to $3 \cdot 10^{-4}$, this value was set as a criterion for all parties. A criterion for both second and third parties was set between the values for all parties and third party to $2 \cdot 10^{-4}$.

Hence, separate criteria for first and second party were not established as they were for individual risk. Given how the reports from the AMRISK application [18] are structured, it was considered more robust to assess the group risk for second and third party together against the acceptance criterion. The risk to a first party is normally not assessed in the analyses, as the risk for depot personnel is tied to all the work they perform in the depot, not to how much time they spend in each magazine. In any case, the criterion for third parties is the most important when assessing the risk from an ammunition depot.

The probability of an accident during the production of explosives is much higher than the accident probability in an ammunition depot. Accident statistics from Norway is not available, but from incidents in explosive maintenance and processing in the U.S. military, the probability of an unintended explosion is estimated to $1.7 \cdot 10^{-3}$ per facility per year [19]. This includes military operations, so the probability for civilian production can be estimated to 10^{-3}.

It is therefore not reasonable to accept the same number of fatalities from accidents at ammunition depots and production plants. Instead, we set the acceptable group risk for a depot equal to the acceptable group risk for a plant.

When the acceptable number of fatalities in an ammunition depot was set to five, aversion was not considered. However, it should be included as the acceptance criterion applies to the perceived risk.

Five fatalities give an aversion factor of 2. When $P_E = 10^{-3}$, the perceived group risk becomes 0.01 (Equation 5).

Multiple criteria for acceptable risk for second and third party may be confusing. Moreover, the risk for third party contributes very little to the total group risk from a depot. We therefore propose to use 0.01 as the acceptable group risk only for first party.

A criterion for second party is found by using the same ratio between the acceptable group risks for second and first party as between the acceptable individual risks for the same groups. This results in an acceptable group risk for second party of $3 \cdot 10^{-3}$.

Table 4 shows the updated criteria for group risk as well as the current criteria:

Table 4. Current and updated accept criteria for group risk from ammunition storage.

Current		Updated	
1., 2. and 3. party	$3 \cdot 10^{-4}$	1. party	$1 \cdot 10^{-2}$
2. and 3. party	$2 \cdot 10^{-4}$	2. party	$3 \cdot 10^{-3}$
3. party	$1 \cdot 10^{-4}$	3. party	$7 \cdot 10^{-5}$

The aversion factor is introduced primarily to account for short periods with high consequences for third parties. Persons involved in ammunition storage are usually present for longer periods, such as during working hours. The aversion factor for these groups should therefore perhaps be different from the factor for the public.

Usually, first party is not included in risk analyses since their exposure in the depot is inevitable. Therefore, it may be inconsistent to include first party in the number used to calculate the aversion factor. An alternative is to use aversion factors that are based on the expected number of fatalities in the group the factor applies to, rather than the total number.

Comparison with other risk criteria

An assessment of the proposed new acceptance criteria can be made by comparing them with other similar criteria.

Table 5 shows values of acceptable individual risk used by different nations.

Table 5. Proposed Norwegian accept criteria for individual risk compared with criteria from other nations [20].

	1. party	2. party	3. party
Canada	10^{-4}		10^{-6}
Netherlands			10^{-5}*
Norway	10^{-5}	$3 \cdot 10^{-6}$	$6 \cdot 10^{-7}$
Switzerland	$3 \cdot 10^{-5}$	$1,5 \cdot 10^{-5}$	$3 \cdot 10^{-6}$
Sweden			10^{-6}
UK	10^{-3}†		10^{-4}†
Germany	10^{-4}‡		
USA	10^{-4}		10^{-6}

*Continuous presence of one unprotected person
†Acceptable risk 10^{-6}
‡Depends on the situation, 10^{-4} used as an example

The updated Norwegian criterion for third party is more in line with other countries than the current criterion. Switzerland is the only other nation with different criteria for first and second party, and their criterion for first party is close to the Norwegian criterion. Other countries have higher acceptable individual risk for involved persons than Norway.

The Norwegian criterion for individual risk applies to the person most present at an exposed object. In other countries, the individual risk is calculated from the average presence of all individuals. Hence, a direct comparison of the values is not straightforward.

In the British acceptance criterion, an individual risk of 10^{-6} is considered broadly acceptable for all persons. Risk values between 10^{-6} and the values in the table are acceptable but should be reduced to a level that is reasonably practicable. This form of acceptance criterion is called ALARP (As Low As Reasonably Practicable).

The Norwegian Directorate for Civil Protection (DSB) has proposed acceptance criteria for individual risk from hazardous substances [21]. These are also based on the ALARP principle. The maximum risk is 10^{-7}- 10^{-6} for third party and 10^{-5} for first and second party, while the acceptable risk is 10^{-7}. The updated criteria are in good agreement with these values.

The proposal refers to the fact that the risk of dying in various types of accidents in Norway is between the criterion values of 10^{-7} and 10^{-5}. Moreover, the MEM rule (Minimum Endogenous Mortality) is used to assess the acceptance criteria. This means they are compared with the general mortality rate in the age groups with the lowest mortality. Using updated figures [22], the mortality rate in the period 2019–2023 was lowest among boys between 5 and 9 years old, with a value of $6.0 \cdot 10^{-5}$. DSB's argument that "the involuntary risk from risk-related activities contributes little to the general risk in society" therefore also applies to ammunition storage.

Acceptance criteria for group risk are less common than criteria for individual risk. Table 6 shows a comparison of existing group risk criteria.

Table 6. Proposed Norwegian accept criteria for group risk compared with criteria from other nations [20].

	1. party	2. party	3. party
Canada	10^{-3}		10^{-5}
Norway	10^{-2}	$3 \cdot 10^{-3}$	$7 \cdot 10^{-5}$
Sweden			10^{-4}
USA	10^{-3}		10^{-5}

The table does not include the Swiss criterion for marginal cost per saved life. In the Netherlands and the United Kingdom, the acceptable group risk is given in the form of FN-curves [20]. Canada uses ALARP for group risk, but without an upper limit.

The proposal for acceptable group risk in Norway is somewhat above the criteria used in Canada and USA. For Norway the criterion applies to perceived risk, while the values for USA and Canada refer to actual risk.

Conclusions

New acceptance criteria for the risk from ammunition storage in Norway are proposed. They are based on updated accident statistics.

Acceptable individual risk and group risk for third parties are derived in a similar manner as the current criteria. The method for finding acceptable group risk for persons involved in ammunition storage is somewhat modified from the previous approach.

The update of the criteria results in higher recommended values for acceptable individual risk for third parties and lower values for first parties. The new values for acceptable group risk for first and second parties cannot be directly compared with the current values. The acceptable group risk for third parties has been slightly reduced.

References

1. Rollvik, S., "Akseptabelt risikonivå i forbindelse med lagring av ammunisjon/eksplosiver i Forsvarets lagre, vedlegg til godkjenning," 11275/83/B/FD IV/EBjH/MS/738, Forsvarets forskningsinstitutt, 1983.
2. "Reglement for Ammunisjonstjenesten - Fellesregler," Forsvarsmateriell, 2017.
3. Brokhaug, B., and Hermansen, T., "Akseptkriterier og definisjoner i forbindelse med ammunisjonstjeneste," 1997/00663-037/FBT/T/843, Forsvarets bygningstjeneste, 2001.
4. Sørli, A., and Bjørseth, P., "Akseptkriterier og definisjoner ifm ammunisjonstjeneste," 2001/0174-2/FD IV 4/ANS/925, Det kongelige forsvarsdepartement, 2001.
5. Holm, K. B., and Øiom, H., "Akseptabelt risikonivå ved lagring av ammunisjon - oppdatering av kriterier fra 1983, revidert utgave," Report to be published, Forsvarets forskningsinstitutt, 2025.
6. "Table 07459: Population by sex and one-year age groups (M) 1986 - 2025," Statbank Norway, Statistisk sentralbyrå, https://www.ssb.no/en/statbank, 2025.
7. Schneider, T., and Merz, H., "Short course on risk analysis and risk management in ammunition storage," Ernst Basler & Partners, 1982.
8. "Dødsfall med underliggende dødsårsak ulykke. Antall døde per år, 2019-2024," https://statistikk.fhi.no/daar, 2024.
9. Øiom, H., "Akseptkriterier for risiko overfor tilsatte i Forsvaret," HFK-AMK, 1993.
10. "Table 10913: Fatal accidents at work, by regulatory authority and industry (SIC2007) 2000 - 2023," Statbank Norway, Statistisk sentralbyrå, https://www.ssb.no/en/statbank, 2024.
11. "Table 13470: Employed persons, by industry division (5 digit level, SIC2007). 4th quarter (M) 2008 - 2024, Employed persons by place of work," Statbank Norway, Statistisk sentralbyrå, https://www.ssb.no/en/statbank, 2024.
12. "Table 09189: Final expenditure and gross domestic product 1970 - 2024, Gross domestic product, market values, current prices, 2024," Statbank Norway, Statistisk sentralbyrå, https://www.ssb.no/en/statbank, 2024.
13. Based on restricted information.
14. "Annex F. Methods for ESMRM in use - Norway," in AASTP-04, Volume I: Explosives safety risk analysis - Guidelines for risk-based decisions, Edition B, Version 1, Allied Ammunition Storage and Transport Publication, NATO Standardization Office, 2024.
15. "AASTP-04, Volume II, Explosives safety risk analysis - Technical background", Edition B, Version 1, (Allied Ammunition and Transport Publication), NATO Standardization Office, 2024.
16. Evans, A. W., and Verlander, N. Q., "What is wrong with criterion FN-lines for judging the tolerability of risk?," Risk Analysis, vol. 17, no. 2, pp. 157–168, 1997.
17. "Sikkerhetshåndbok (Handbook of security)", Dyno Industrier, 1990.
18. "Annex H. National Background for ESMRM - Norway," in AASTP-04, Volume II, Explosives safety risk analysis - Technical Background, Edition B, Version 1, Allied Ammunition Storage and Transport Publication (AASTP), NATO Standardization Office, 2024.
19. Hardwick, M. J., Hall, J., Tatom, J. W., Baker, R. G., Ross, T. et al., "Approved methods and algorithms for DoD risk-based explosives siting," Technical Paper TP 14, Revision 4a, Department of Defense Explosives Safety Board, Alexandria, Virginia, 17 March 2017.
20. "AASTP-04, Volume I: Explosives safety risk analysis - Guidelines for risk-based decisions", Edition B, Version 1, (Allied Ammunition and Transport Publication), NATO Standardization Office, 2024.
21. "Sikkerheten rundt anlegg som håndterer brannfarlige, reaksjonsfarlige, trykksatte og eksplosjonsfarlige stoffer," Temarapport 13, Direktoratet for samfunnssikkerhet og beredskap (DSB), 2012.
22. "Table 05848: Deaths, by sex and age (per 100 000 mean population) 1866-1870 - 2020-2024," Statbank Norway, Statistisk sentralbyrå, https://www.ssb.no/en/statbank, 2024.

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