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STORAGE OF AMMUNITION - QUANTITATIVE RISK ASSESSMENT - EVALUATION AND FURTHER APPROACH

Paper for presentation at the twenty-seventh Department of Defence Explosives Safety Seminar -August 1996, revised edition of the paper presented at the 2nd Australian Explosive Ordnance Symposium -October 1995.

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HISTORY

In Norway, we use ammunition storage regulations very similar to the NATO recommendations. As a compliment to the regulations we use risk assessment for some of our approvals for ammunition storage. However, by the late seventies one third of licences for explosive storehouses could only be issued with a concession. Many of these waivers arose from minor infringements of the quantity distance rules, and the Explosive safety Board considered that most of these were acceptably safe.
In 1989 action was started to reduce the number of waivers.
This was done by :

- seeking approval to licence storehouses on the basis of risk assessment
- building new storages
- accepting reduced availability.

There are now very few waivers remaining in force. The remaining waivers are the result of temporary situations such as operational training and unforseen demands. These waivers can be permitted by the officer commanding a particular storage area under the terms of their delegated authority

ORGANISATION

The Parliament have stated the "Act of explosive goods", from which the Defence are excepted, provided the Government keep their own rules for the management of military ammunition. The authority of approvals for our regulations are further delegated to the Minister of Defence. Our organisation is (of course) under revision. Until recently the Department of Defence had an Explosive Safety Board for their advice in ammunition safety matters. The Board have representatives from the Materiel commands, the Defence Construction Service, the Defence Research Establishment and Chief of Defence logistic branch. There are six members, with six active vice members. The number of civil servants is about equal to the number of officers. The activity could be estimated to about two men per year. The Board is currently continuing their action under the Army material command which is given the responsibility for the ammunition safety matters by the Chief of Defence Materiel Council.
On the basis of the NATO recommendations, with national adaption, the Explosive Safety Board have the responsibility of maintaining the Department of Defence Service Regulations.
The material commands have the operational responsibility of the regulations in the respective services, and could give supplementary regulations. The Army Materiel Commands Ammunition Control Centre carries out the risk assessment procedure for all services. (Procedure for granting approvals in annex A)

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **26 JUL 1996**	2. REPORT TYPE	3. DATES COVERED **00-00-1996 to 00-00-1996**

4. TITLE AND SUBTITLE **Storage of Ammunition - Quantitative Risk Assessment - Evaluation and Further Approach**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Norwegian Army Materiel Command,Ammunition Control Centre (HFK-AMK),Box 34,2831 Raufoss, Norway ,**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM000767. Proceedings of the Twenty-Seventh DoD Explosives Safety Seminar Held in Las Vegas, NV on 22-26 August 1996.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report "SAR"**	**11**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

LIMITING THE EXTENT OF THE ASSESSMENT

One objective of the Norwegian Ministry of Defence's Service Regulations for safe storage of military explosives is to protect members of the general public who are exposed to risk from ammunition storage, but are not involved in military operations. (Later referred to as *the third person*)

An other objective is to provide adequate protection to the employees and duty service personnel in our organisation (referred to as *the second person*), including those directly involved with the handling of explosive stores (referred to as *the first person*)

A lesser, but still important objective, is provide adequate protection to the environment and from material damage to buildings and military equipment.

Attempts to make numerical quantification to all these hazards would be a task consuming resources we do not have, so it is found necessary to focus on the narrowest possible event when it comes to the analysis. It might be many possible outcomes and consequences to an accident in an explosive area.(Annex B)The various outcome of an initial event could bring danger to different categories of people.

It is credible that an accident involving single items or a few items will have quite local effect, and mainly be hazardous to the people in the proximity to the event. The people exposed to significant risk will be *the first part*y.

An event involving a stack of ammunition, or a load of ammunition will have an effect hazardous to the people in the magazine area, and thereby involving both the first part and *the second part*y.

An event which involve a full magazine contents might in addition have consequences to the vicinity of the storage area *and the third part*y.

Our risk assessment procedure currently concentrates on the risk to members of the general public (third person) from a full detonation of the entire contents of a particular explosive storehouse.

Occasionally risk analysis have been used to evaluate the risk to people working in an explosive workshop near a potential explosion site (PES) to compare this additional risk with the risks from their own activity.

ESTABLISHMENT OF ACCEPTANCE CRITERIA

To quote the national "Service regulations for the defence":

- With regard to ammunition, it must be recognised that absolute safety cannot be achieved, and the responsible authorities must identify a residual risk which will be considered acceptable.

The Minister of Defence has decided that it is necessary to state acceptable levels of risk and also the worst consequences of an accident which might be tolerated if the accident does unfortunately happen.

It is found most important to have acceptance criteria both for the individual risk and consequence.

The individual risk is the probability of fatality for a person at the exposed site. The individual should be a defined person living/existing in one of the exposed objects.

The consequence in this context could easiest be described as the product of the number of fatalities provided an accident, and the likelihood of the accident to occur. Three numbers of describing consequence is used in order to explain the relationship between them:

- expected (average) number of fatalities
- group risk
- societal risk

The initial investigation methods used to establish a quantitative value are:

1) Comparison with risk related to other activities in the society.
2) Risk level accepted in the present QD-tables.

Definitions:
The values associated with risk-calculation are defined as follows:

P_E - Probability of detonation involving the contents of one storage yr^{-1}.

Effect ..blast,debris,... ,as a function f(quantity-distance)

Lethality λ - ,as a function g(blast,debris,....)

Presence factor ρ- which is an average frequency of presence for persons in an exposed object.

Individual risk:

$r_i = P_E * \rho * \lambda$

Societal risk:

$$r_s = \frac{\text{storages} * R}{\text{NO Population}} = \frac{\text{storages} * P_E * M}{\text{NO Population}}$$

R - Group risk
P_E - Probability of explosive event
M - Expected number of fatalities

Finding the quantitative acceptance criteria:
Societal risk:
We have not yet been able to calculate a defensible value for the societal risk accepted following our present regulations, it is thought to be a heavy task.

From the explosives accident statistics it have been found that the average probability of an accident occurring is approximately:

$P_E = 5 * 10^{-5} yr^{-1}$

Ammunition storage have the value of about 1/1000 of gross national economy.

Total number of lethal accidents (in -79)	1893
Number of accidents involving 3. person	approx. 300
NO population	4073000

General accident rate for 3. person 300/4073000 $8*10^{-5} yr^{-1}$

If we accept a proportional contribution from ammunition storage

$r_s = 8*10^{-5} / 1000 = 8*10^{-8} yr^{-1}$ (average risk to a Norwegian caused by one ammunition storage)

Group risk

In the above value of societal risk we have the average risk contribution from each ammunition storage facilities to the average Norwegian. For the analysis of one storage the acceptable group risk (∑ risk to those exposed to risk from one magazine) would be a more applicable number, since finding the exact number of people exposed to hazard from one potential event might be difficult. By using the definition for societal risk and applying the average probability of an explosion it could be found that the group risk criteria should be:

$R = \quad = 1 * 10^{-4}\ yr^{-1}$

Individual risk

Accepted pressure at IBD:		P_s =	5 kPa
Lethality	λ = f(P_s = 5 kPa) =		0.002
Probability of an explosion:		P_E =	$5 * 10^{-5}$
Presence factor		ρ =	0.8

Individual risk because of airblast:

$r_I = P_E \quad = 5 * 10^{-5} * 0.8 * 0.0002 =$ $8 * 10^{-9}\ yr^{-1}$

All effects included: r_I = $2 * 10^{-8}\ yr^{-1}$

Individual risk values have been identified for

- earthquake,
- flood and
- stroke by lightning to be $2 * 10^{-6}\ yr^{-1}$
- third party risk from chemical industry $10^{-6} - 10^{-7}\ yr^{-1}$

These values are all considered acceptable because there is little or no public anxiety about the general level of deaths from these causes. On the other hand risk to children from traffic accidens is also a good example of third person situations. In 1979, 54 died from a population of 912000 and this was certainly not acceptable.

This risk equals: $6 * 10^{-5}\ yr^{-1}$

Evaluations of this kind of values have given us the quantified acceptance criteria:

r_I = $2 * 10^{-7}\ yr^{-1}$

The Ministry of Defence have stated 8*10-8 as a tolerable value of societal risk, and $2*10^{-7}$ as a tolerable value for the individual risk. Our accepted numeric values of risk have been unchanged since 1985, and we plan to investigate if this level could still be justified according the way society have changed in ten years.

The Directorate for Fire and Explosion Prevention (DBE), which is the competent authority in civilian sector are currently making an attempt to state similar fixed values for the civilian storage of explosives.

Economical risk and environmental risk have never been addressed concerning ammunition storage. It might however be useful to do this as an exercise, to improve the communication to the decision system as the system is perceived to be increasingly dominated by economical principles.

QUANTITATIVE CALCULATION TOOL

The procedure usually applied to estimate risk uses the Swiss Ammorisk program to support the necessary calculations. Risk is calculated from the probability of an event occurring, its effect, presence of exposed persons and the expected effect on them. Approval or rejection of the proposal is based upon the comparison of the estimated risk with the established acceptance criteria.

AVERSION FACTOR

The current level of deaths from road accidents in Norway is about 300 per year, and this figure is only marginally acceptable. The public demand for action to improve road safety is more likely be brought as a response to a single horrific accident than to multiple less serious accidents even though the result may be the same.

In the explosives storage area we have to take careful account of this aversion when considering risks on transport routes. Although the probability of exposure of for example passengers of public transport to an accident is very low, the expected number of fatalities could be considerable. In general **-**any short term situation where a high number of persons are exposed **-** should be given special attention.

A related problem arises in Norway's underground storage facilities. Although these can be shown to be extremely safe, there is a residual probability of the contents detonating. With this low probability, using the acceptance criteria for consequence strait forward would mean acceptance of a very rear accident with horrific results.

As a remedy to this obvious weak point in the grouprisk criteria the Ammorisk software used by Norway offers an opportunity to make allowance for an aversion factor. The function used is:

$\varphi = 2^{(Fn/5)}$

φ - factor used to scale up consequences in each situation of constant exposure to the perceived level of an accident in the situation.

Fn - Expected number of fatalities in each situation

Using aversion factors is a defendable alternative to contentious risk threshold criteria, and highlights situations with short durations and high potential consequences. This function are given a form which will increase the significance of situation with the expected number of five fatalities, by a factor of 2.

PLANS FOR THE FUTURE

Data collection/ data handling

Data input in the -87 version of the program ammorisk requires too much resources. Improved data interface is being developed.

Restructuring ammunition stock accounting is currently an ongoing project, which soon will make it possible to have online updated detailed information on the items stored in every magazine in Norway. The types of magazines are limited to a few types and is supplied in a separate database, and exact location of ES and PES could be found from digital maps which in most cases is available.

We are planning to tie the information in different databases together into the risk assessment tool. The analysis could then be performed on the exact quantity of ammunition in storage, data update is simplified and capacity increased.

Improved effect/response calculation

We use to support the NATO recommendations on effect and response. AC/258 have some time had the production of a risk manual (AASTP -4) at the agenda. Current status is draft chapters on explosion effects. When finished, this thought to be some sort of bible for risk analysis. Our goal is to put the recommended models/methods into our calculation tool as soon as they can bee agreed upon, and made available in the AC/258.

Probability of accident

Safety distances does to very little extent take into account the variations in probability of an accident related to the different items and types of storage.

This is done in our risk assessments, but in a very crude manner, with only a few factors to influence the result.

Some thoughts have been spent how to do this better by taking more parameters into account. A preliminary effort is shown in the
annex C

Riskassessments for other purposes

A group has been formed within the Defence and DBE to consider other areas for riskassessments.

In the storage of ammunition, QRA are used with the main purpose of documenting acceptable safety.

The storage of ammunition compared to the use, handling, loading/unloading and transportation are very different activities. The probability of an accident is much more dependent of the actions of the personnel. The complexity of rules and regulations are increasing, but unfortunately the personnells ability to follow them are decreasing.

People of today are brought up to think for themselves and to understand, rather than blind obedience to rules. However it is very difficult to judge from own personal experience wether a situation which might occur one time in ten thousand years is worth considering at all.

We think, by applying the same philosophy, and slightly different methodology, the risk assessment might be a useful tool to point out week links in our handling/management procedures (in order to improve them) and to increase the understanding of the necessity to follow strict rules to achieve safe explosive management.

CONCLUSION

In our experience risk assessment have solved a lot of problems related to our ammunition storage. At the same time it has brought a lot of new questions and possibilities to our attention.

A critical question could of course be if all those numbers could be justified, and which degree of uncertainty exists within the models/tools that we use. Sensitivity study of the storage riskassessment method have not unexpectedly concluded that the main uncertainty at present is within the factors :

- probability of an accident
- mass of explosives actually detonating

It seems difficult to come up with defensible estimates to these two factors, but it might be a good way of spending some resources getting closer.

In response to the often stated criticism that risk assessments contain too many assumptions to be useful, I offer a quote from

Arnfinn Jenssen from the Norwegian Defence Construction Service.

"It is better to be approximately right than exactly wrong!"

References:

(1) Wissenshaftlich-technische grundlagen fuer die berechnung von schadenwirkungen durch explosionen - Gruppe für Rüstungsdienste Forshung/Technische Abteilung 6

(2) Grundlagen für die Sicherheits beurteilung von Munitionsanlagen - Schweizische Armee Eidgenössishes Militärdepartement Studienkommission füer Munitionslagerung

(3) Program "AMMORISK" - Ernst Basler & Partner

(4) 40522/83/B/FFIVM/TK/LH/Oppdr 6/83:738 By S Rollvik NDRE

(5) Annual Norwegian statistics 1993

(6) Technical report - Notat - tekn arb gr 30/4 -93 HFK-AMK

(7) TfF 738 - National ammunition safety regulations

(8) Technical report - Teknisk notat 29/11-93 - HFK-AMK

(9) Compendium used in NAMC risk - course - 94

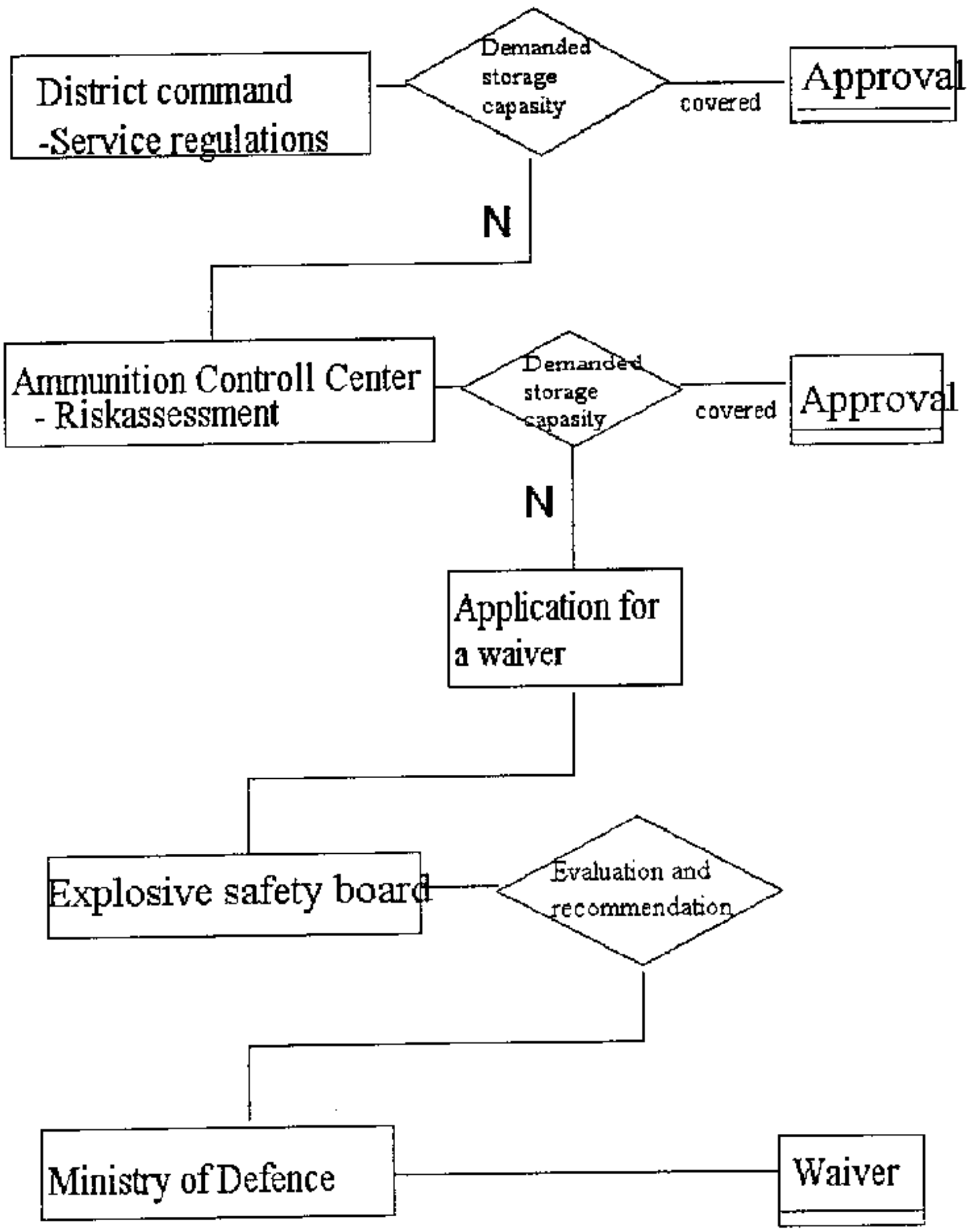
(10) Sensitivity study - FFI/NOTAT-90/4021 by KO Ingebrigtsen NDRE

(11) Report from the AC/258 ST Ahtwp meeting in april 95

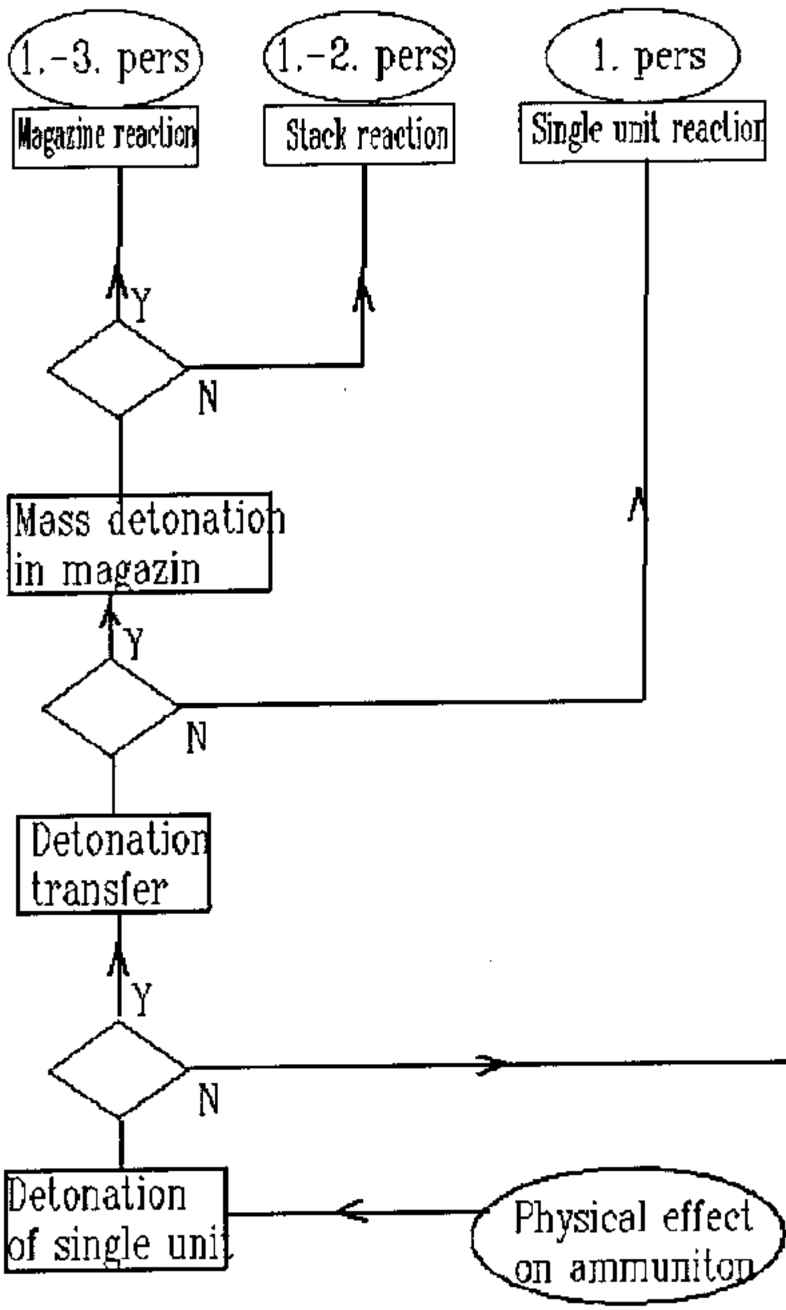
(12) Foreløpig rapport for vurdering av risikoanalyse som metode der ammunisjon er tilstede. (Preliminary report from the group considering riskassessment to assist safety in management of ammunition).

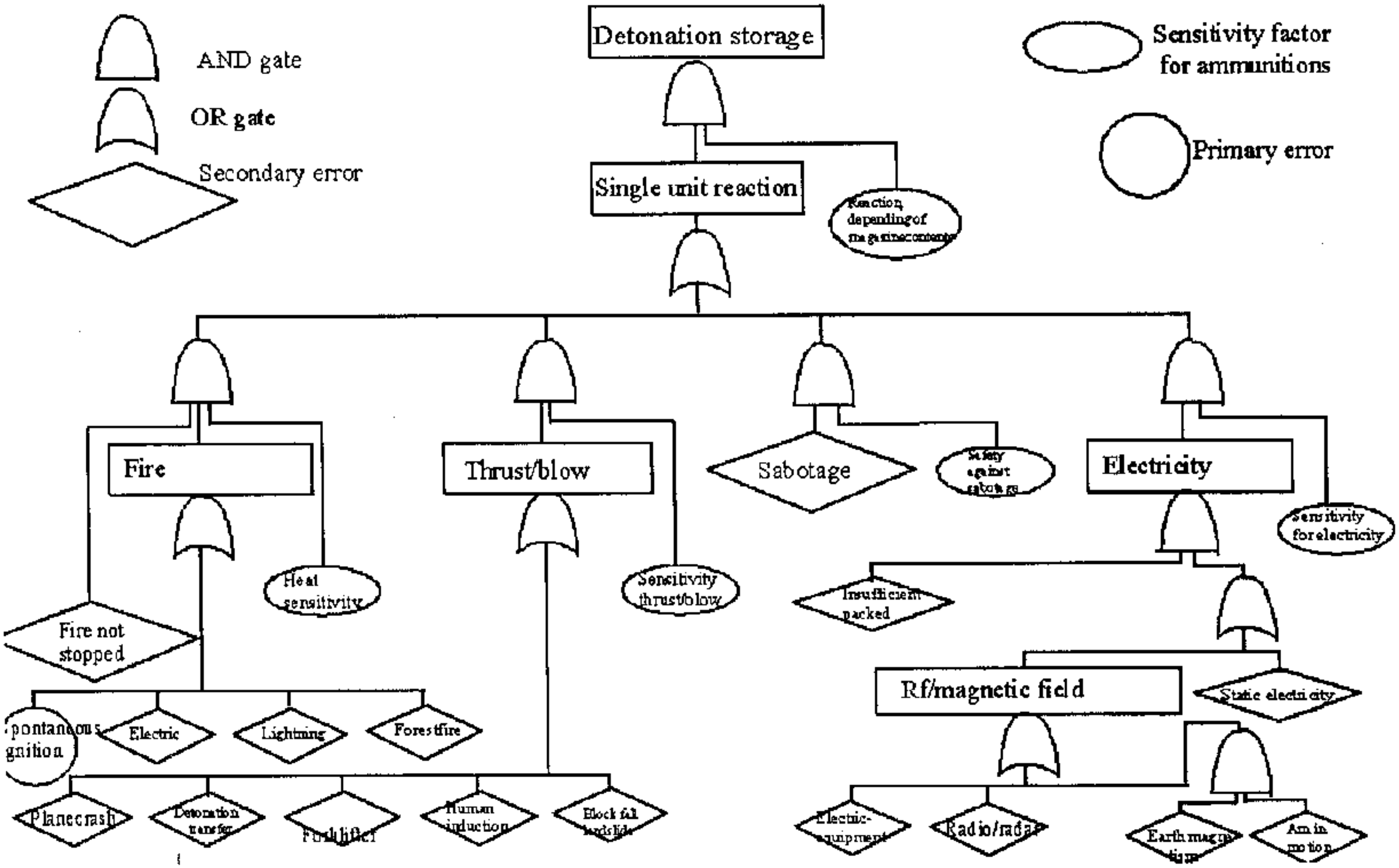
ANNEX A

Floatchart for ammunition storage approval



Event tree of munition accident in storages




AND gate
OR gate
Secondary error
Detonation storage
Sensitivity factor for ammunitions
Primary error
Single unit reaction
Reaction depending of magazinecontents
Fire
Thrust/blow
Sabotage
Safety against sabotage
Electricity
Sensitivity for electricity
Heat sensitivity
Sensitivity thrust/blow
Insufficient packed
Fire not stopped
Rf/magnetic field
Static electricity
Spontaneous ignition
Electric
Lightning
Forestfire
Planecrash
Detonation transfer
Forklifter
Human induction
Block fall landslide
Electric-equipment
Radio/radar
Earth magnetism
Am in motion