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# The European Regulation 2003/10/EC and the Impact of its Application to the Military Noise Exposure

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## ABSTRACT

The European Regulation 2003/10/EC, voted by the European Parliament in 2003, is implemented in most of the countries of the European Community since 2006. This regulation defines different actions to be taken by the employer when the employees are submitted to continuous or impulse noise which exceeds the lower or upper exposure action value. It also defines maximum exposure levels to which employees can be exposed. For continuous noise, these levels are given as daily noise exposure levels ($L_{EX,8h}$), for impulse noise only the peak pressure level is relevant. The actions to be taken are: - at the lower action level ($L_{EX,8h}$ ≥ 80 dB(A) or $L_{peak}$ ≥ 135 dB(C)) hearing protectors have to be made available to the worker and - at the upper action value ($L_{EX,8h}$ ≥ 85 dB(A) or 137 dB(C)) the hearing protectors have to be used. The exposure limit values (including the hearing protection) are $L_{EX,8h}$ = 137 dB(A) for continuous and $L_{peak}$ = 140 dB(C) for impulse noise. As the noise environment to which the soldiers are exposed are often exceeding these values, it is important to analyze the impact of this regulation on the efficiency in training and/or combat. The principal types of noise to which the soldiers are exposed will be presented. The exposure criteria which are used for weapon noise in different countries will be discussed and compared to the European regulation.

## INTRODUCTION

Since March 2006 the European directive 2003/10/EC [1] had to be implemented by the member states of the EU. Until this time, the Damage Risk Criteria (DRC) for continuous noise used in the European military community were close to those used for civilian; A-weighted exposure level ($L_{EX,8h}$).

For weapon noise, however, no civilian legislation was applicable. Therefore different DRC, especially developed for weapon noise, where used in different countries. These criteria, like the MIL-STD-1474(D) [2], the Pfander- and Smoorenburg-Criteria were used by different countries in order to protect soldiers and other personnel exposed to high level impulse noise. They are based on the peak pressure level and on related durations (A-duration, B-duration …). Other DRC based on A-weighted energy (Dancer [3], Asherly and Martin [4]), or on the full pressure time history (Price and Kalb [5]).

All these criteria used for continuous or for impulse noise take the spectral distribution and the total energy into account when evaluating the hazard of the noise exposure. This may be done directly through the A-weighted energy or indirectly through the peak pressure level and duration.

As the DRC used for the evaluation of the continuous noise is very close for military and civilian noise, the paper will give only a short overview on the impact on continuous noise exposures. It will mainly concentrate on the introduced DRC for weapon noise and the impact of the European directive, if implemented in the military community, on the training and the use of weapon.

## THE EUROPEAN DIRECTIVE 2003/10

"*This Directive, … , lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to noise and in particular the risk to hearing*". The expressed scope of this directive is mainly intended for industrial noise and defines different measures to be taken when defined noise exposure levels are reached. Three distinct levels are defined for continuous and impulse noise:

1. The lower exposure action values:
   continuous noise: $L_{EX,8h}$ = 80 dB(A)
   impulse noise: $p_{peak}$ = 112 Pa ($L_{peak}$ = 135 dB(C))
   The employer has to make available individual hearing protectors to the employees.

2. The upper exposure action values:
   continuous noise: $L_{EX,8h}$ = 85 dB(A)
   impulse noise: $p_{peak}$ = 140 Pa ($L_{peak}$ = 137 dB(C))
   The individual hearing protectors have to be used

3. The exposure limit values:
   continuous noise: $L_{EX,8h}$ = 87 dB(A)
   impulse noise: $p_{peak}$ = 200 Pa ($L_{peak}$ = 140 dB(C))
   This exposure level shall not be exceeded. For the determination of the effective exposure, the attenuation provided by the protection devices is taken into account.

The Directive states that *"If the risks arising from exposure to noise cannot be prevented by other means, appropriate, properly fitting individual hearing protectors shall be made available to workers and used by them in…"*. This means that the noise reduction at the source has to be considered before hearing protectors shall be made available and used. In the military environment the life cycle of equipment is usually very long and therefore does not allow modifications at the noise source. New developed equipment which could permit lower noise levels at the source, however, often has higher performance and therefore produces usually equal or higher noise levels as the older one.

## CONTINUOUSE NOISE EXPOSURE

Typical noise exposure in terrestrial military vehicles are in the range between 80 dB(A) for light vehicle and 110 dB(A) for a Tank(c.f. Table 1). The third octave spectra of these noise exposures are shown in Figure 1 (linear) and Figure 2 (A-weighted). For all vehicles, the maximum energy of the unweighted noise exposures is found in the low frequency range; therefore the A-weighted levels are substantially lower for 3 of the 4 vehicle types (14 dB to 19 dB). Only for the wheeled tank, which shows important third octave band lev-

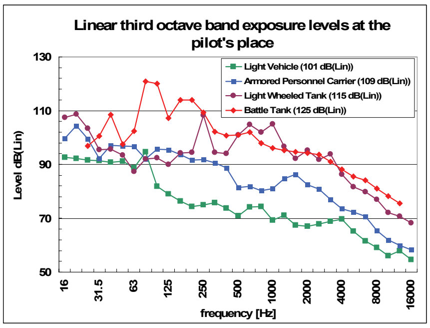


**Figure 1**: Linear third octave band noise exposure levels for different terrestrial military vehicles

els in the frequency range between 250 Hz and 2 kHz, this reduction is lower (5 dB). The levels to which the pilots of the vehicles are exposed (Table 1) are, at a speed of 60 km/h, all higher than the lower exposure action value. Only the light vehicle may be safe to be used without hearing protec-

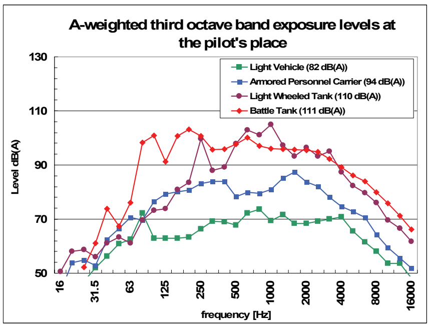


**Figure 2**: A-weighted third octave band noise exposure levels for different terrestrial military vehicles

tion when driving for an eight hour period, but even in this case hearing protectors have to be provided. The exposure level at the pilot's position of all armored vehicles, exceed the upper exposure limit value and therefore cannot be operated without hearing protectors. However, the allowable daily exposure time is very much dependant on the type of hearing protector. When using protector "Type 1" (Table 1), which corresponds to an initially deployed helmet with hearing protector, none of the armored vehicles can be driven for more than 1.3 hours. The pilot in the tanks reaches the daily allowable noise dose of 87 dB(A) already after about 2 minutes. In order to comply with the exposure criteria, the soldiers had to be equipped with hearing protectors with better

**Table 1**: A-weighted exposure levels for different terrestrial military vehicles at the pilots place

| | | | Exposure time for $L_{EX,8h}$=87dB(A) | | | |
|---|---|---|---|---|---|---|
| | Speed Km/h | Exposure Level A-weighted | unprotected | Protection Type 1 | Protection Type 2 passive | Protection Type 2 active |
| Light Vehicle | 60 | 82 dB(A) | >8 h | N/A | N/A | N/A |
| Armored personal carrier | 60 | 95 dB(A) | 1.3 h | 1.3 h (95 dB(A)) | >8 h (81 dB(A)) | >8 h (72 dB(A)) |
| Light wheeled Tank | 60 | 110 dB(A) | 2.4' | 7.6' (105 dB(A)) | 3.2 h (91 dB(A)) | >8 h (86 dB(A)) |
| Main Battle Tank | 60 | 111 dB(A) | 1.9' | N/A | 19' (101 dB(A)) | 8 h (87 dB(A)) |

performance. For the "Main Battle Tank" an adequate protection could only been reached with a helmet equipped with ANR (Active Noise Reduction).

It can be summarized, that in the case of continuous noise the implementation of the exposure limits, imposed by the European Regulation, seems to be possible for ground vehicles. However, the crews of armored vehicles have to be equipped with adequate hearing protection. In the case of battle tanks, only ANR equipped protectors or double protection (ear-muff combined with earplug) will provide enough attenuation to allow reasonable exposure time. The same is true for most of the helicopters and propeller aircraft. For ground crews working close to jet aircraft (e.g. on aircraft carriers) even these protection devices will not be sufficient. In this case, sound attenuation helmets with face shields have been developed.

## WEAPON NOISE EXPOSURE

For small calibre weapons, like handguns or assault rifles, a typical signature is shown in Figure 3 (upper graph). The peak pressure level for these weapons is typically in the order of 160 dB. The A-duration is quite short, typically 300 to 600µs. For large calibre weapons, like howitzers or mortars, Figure 3 (lower graph) the peak pressure at the servant's ear is up to 190 dB and A-durations exceed 2 ms.

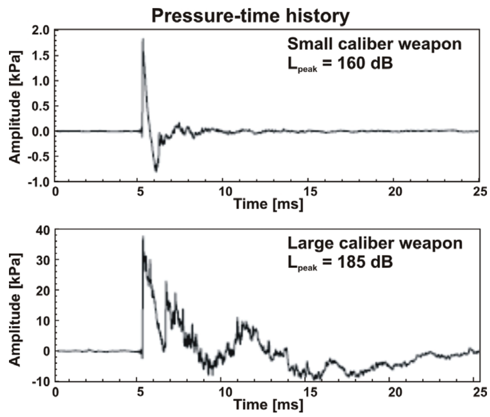


**Figure 3**: Typical pressure-time history of a small (upper graph) and a large (lower graph) caliber weapon

The differences in peak pressure level and A-duration have an impact on the spectral composition of these signals. The modification of the third octave band spectra due to different peak pressure levels and to variations of the A-duration is shown in Figure 4. If sole the peak pressure is modified and the A-duration of the signal is kept constant (upper drawings), only the amplitudes of the spectral components are shifted proportionally to the change in peak pressure. The shape of the spectra is not affected. In the case that the peak pressure of a shockwave is kept constant (lower drawings), a longer duration induces more energy in the low frequency bands; whereas the high frequency content of the spectrum stays the same. As the damage risk to the auditory organ depends on the frequency, this should be taken into account, for exposure criteria.

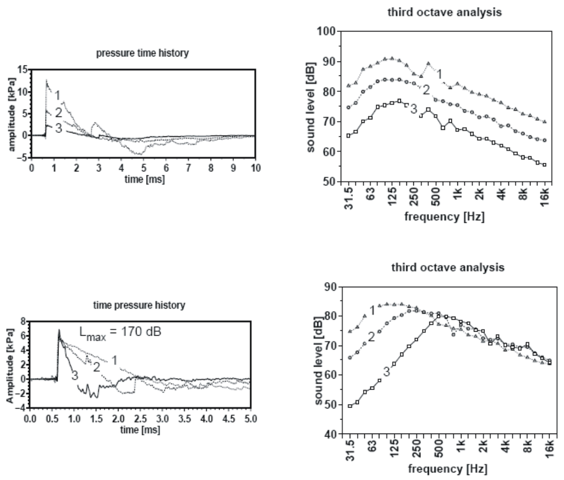


**Figure 4**: Spectral composition (Third Octave Analysis)
Upper figures - for weapon noise with constant A-duration and different peak pressure levels.
Lower figures – for weapon noise with constant peak pressure and different durations.

## DAMMAGE RISC CRITERIA (DRC) FOR WEAPON NOISE

Risk assessment for the exposure to continuous noise is done in the civil and military community with criteria based on the noise dose. For impulse noise, only the military have developed DRCs. These existing, or proposed DRCs can be divided in three categories:

- Criteria based on the peak pressure level and an action time.
- Criteria based on the noise dose delivered by the impulse noise
- Criteria based on the pressure time history of the noise impulse

### Peak Pressure Level – Action Time based Criteria

The three major DRCs, presently used by armed forces are “Peak Pressure Level – Action Time” based criteria:

- The criterion defined in the MIL-STD 1474D [2] is mainly used in the USA and in the UK. It makes a difference between impulse noise in the free sound field or in a reverberant area. When used for noise in the free sound field, the A-duration is used. In a reverberant environment, or in the case of rapid (automatic) firing, the B-duration is used. The method for the determination of these durations is shown in Figure 5.
- The Pfander criterion, mainly applied by the German armed forces, uses a different way to determine the action time called C-duration (c.f. Figure 5). It does not make a difference between reverberant or free field exposures.
- The Smoorenburg criterion (The Netherlands) uses the D-duration for the determination of the exposure duration (see Figure 5) and doesn’t make a difference between free field and reverberant conditions.

The drawing on yellow background in Figure 5 presents the exposure limits for all three criteria. In order to determine whether a shot is within the acceptable limits, first the peak

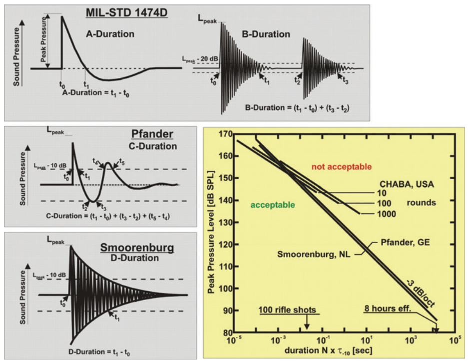


**Figure 5**: Calculation methods for the different exposure durations for impulse noise (grey background). Chart for the graphical determination of the auditory damage risk (yellow background). All three criteria are represented on this graph.

pressure level and the duration is determined. If the point corresponding to these values is located below the exposure limit line the shot is believed not to be an auditory hazard. If the soldier is submitted to multiple shots during one day, the durations are added. If hearing protectors are worn, the exposure limit lines are translated by a factor corresponding to the provided insertion loss of the used hearing protector. We can see that the Pfander and the Smoorenburg criterion are almost identical (~ 1 dB difference). Both of them correspond to the iso-energy principle. This means that for each doubling of the duration, the peak pressure level of the impulse must be reduced by 3 dB (factor = $\sqrt{2}$ ). These strictly iso-energy oriented criteria do not take into account the modification of the spectral shape if the duration of the noise increases (Figure 4). The CHABA criterion is not iso-energy orientated. Instead of decreasing by 3 dB per doubling of the exposure duration it decreases by 2 dB. This allows taking into account partly the changes in the spectrum when the duration of the impulse increases.

These three criteria have been developed and verified using small arms. The differences in the spectral distribution of the energy are not taken into account when these criteria are applied to large calibre weapon. Therefore they tend to overrate the danger of large calibre weapons. It has been shown [6][7] that the overestimation can reach 20 dB for large calibre weapons. Another problem of these criteria is that they cannot predict risk from exposure to impulse noise combined with continuous noise. This is a major problem in the military community where the soldier is exposed to high level continuous noise (e.g. Armoured Personnel Carrier) and weapon noise.

### Noise Dose (Lex) based Criteria

Atherley and Martin [4] as well as Dancer [3] have proposed to evaluate weapon noise in the same way as continuous noise (comparable to ISO 1999 [8]). They propose to determine an A-weighted equivalent noise level for 8h ($L_{EX,8h}$) for every round. The maximum daily exposure is reached for a $L_{EX,8h}$ of 85 dB(A). The advantage of this proposal is that it fits perfectly into the noise protection standards for continuous noise (ISO 1999, NIOSH, European Directive…) and therefore allows assessing the combined risk of continuous and impulse noise.

### Pressure Time History based Criteria

Price and Kalb [5] have developed the AHAAH (Auditory Hazard Assessment Algorithm for the Human) which takes into account the whole signal transmission from the free sound field to the cochlear structures. Based on the calculated time-history of the displacement of the basilar membrane (mechanical stress, elongation, number of cycles …) AHUs (Auditory Hazard Units) are calculated for each event. For a single event the maximum of 500 AHUs is allowed and if this limit is exceeded permanent hearing loss may occur. The AHUs are cumulative if the subject is exposed to repeated events.

This method, like the "peak pressure – action time" based criteria is not compatible with the criteria used for continuous noise exposure and therefore cannot be used for combined exposures. Moreover, there is still controversy inside the scientific community about some of the validation testing.

## THE DIRECTIVE 2003/10/EC APPLIED TO IMPULSE NOISE

The EU directive (2003/10/EC) introduces exposure action and limit values for continuous and impulse noise. As for impulse noise two exposure action values and one limit value are defined:

- The Lower Exposure Action Value (LEAV) is $p_{peak}$ = 112 Pa or $L_{peak}$ = 135 dB(C)
  When an impulse noise exceeds this value the employer has to provide appropriate hearing protectors to the employee.
- The Upper Exposure Action Value (UEAV) is $p_{peak}$ = 140 Pa or $L_{peak}$ = 137 dB(C).
  When an impulse noise exceeds this value the employee has to wear appropriate hearing protectors.
- The Exposure Limit Value (ELV) is $p_{peak}$ = 200 Pa or $L_{peak}$ = 140 dB(C).
  This peak pressure level is not to be exceeded at any time.

The LEAV and the UEAV are determined without taking hearing protectors into account. However, for the ELV the directive states*:" When applying the exposure limit values, the determination of the worker's effective exposure shall take account of the attenuation provided by the individual hearing protectors worn by the worker".*

For continuous noise, as the limits are expressed in A-weighted equivalent noise levels, the effectiveness of a hearing protector can be taken into account without any problem. As the ELV for impulse noise has to be determined using the C-weighted pressure time history of the impulse, no precise calculation method is available today. Therefore, it would be necessary for the determination of the ELV to measure the acoustic signal underneath the hearing protector. At this moment, there are no standards available for this type of measurements. These measurements are feasible for ear muffs ([9]). However, for ear plugs they are extremely difficult, and possibly misleading.

As a fact, the EU demands the application of a directive without giving methods for the determination of the basic parameters. Presently, the acoustic signal under an earplug undergoing high level impulse noise can only be, for ethical reasons, determined with an artificial head equipped with an ear simulator. As these measurements usually overestimate the insertion loss, the values have to be corrected by some "magic" number. As the intra- and inter-individual differences of human subjects cannot be measured either, a second correction has to be applied.

However, even if the problems in the application of the directive would be resolved, the main problem of this directive will persist. As the directive, when applied to impulse noise, takes into account only the peak pressure, neither the spectral composition (C-weighting does not reflect the sensibility of the auditory organ), nor the energy of the impulse are taken into account for the determination of the hazard. When neglecting these two parameters, the scientific validity, concerning the impulse noise part of the directive, is questionable.

## CONSEQUENCES OF AN APPLICATION OF THE DIRECTIVE 2003/10/EC TO WEAPON NOISE

Tests using blast waves (Figure 6, upper graph) to simulate weapon noise were made at different peak pressure levels in order to demonstrate the consequences of an application of the EU directive in the military environment. The A-duration was kept constant at 1 ms. On the lower plot in Figure 6 the measured peak pressure level at the microphone of the ear simulator of the artificial head is drawn as a function of the peak pressure level in the free sound field. The measurements were done with three configurations of the hearing protection (ear plug, ear muff and double protection) and three peak pressure levels (150 dB, 170 dB and 190 dB). The broken lines represent the measured values, whereas the values corresponding to the solid lines have been corrected for inter-individual differences (5 dB) and for the overestimation of the noise reduction due to the use of the artificial head (5 dB).

It can be observed, that the corrected values for single protection devices (muff or plug) exceed the ELV line (140 dB) at

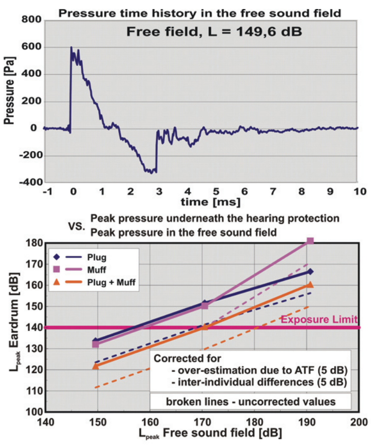


**Figure 6: Upper graph:** Pressure time history of a shockwave in the free sound field (A-duration = 1 ms). **Lower Graph:** Peak pressure level at the "ear drum" of the ear simulator (broken lines – measured values; solid lines: corrected values)

the 157 dB free field peak pressure level) whereas for double protection the ELV is reached at 170 dB free field peak pressure level. These values have been compared with an evaluation method proposed by the German "BG Metall" [7 in German language]. The results when using this calculation method were very close to the measured values.

The consequences of a strict application of the Directive 2003/10/EC for the use of weapon would be:

- No weapon can be fired without using a hearing protection device (for many countries this is already the case now)
- All weapons, even small calibre like assault rifles, have to be used with double hearing protection
- All weapons with a calibre of 12.7 mm and higher will be banned, even with double protection.
- Level dependent hearing protectors, like the “Combat Arms Earplug” (CAE) (US Forces) and the BNL (Bouchon Non Linéaire; French Army) cannot be used any more. These earplugs have been specially developed to allow a good perception of the acoustic environment and to provide sufficient hearing protection to the soldiers.
- Due to this overprotection the audio-communication will be difficult and lead eventually to accidents. Moreover, this situation will lead to a refusal of any hearing protection by the soldier.

## CONCLUSIONS

For industrial continuous noise the Directive 2003/10/EC will probably not create unsolvable problems. On the contrary, in cases where the daily equivalent exposure level cannot be reduced to the LEAL or the UEAL it is possible to expose the employees up to the ELV of $L_{EX,8h}$ = 87 dB(A). In Germany, the national implementation of the Directive defines the exposure limit to $L_{EX,8h}$ = 85 dB(A), as this limit was already imposed to the employers before. For the military community these exposure levels can be reached for most of the cases. However, many of the deployed personal hearing protection devices are inadequate and should be replaced by modern devices (e.g. Hearing Protection devices equipped with ANR (Active Noise Reduction)). This would allow longer daily training periods and to less fatigue due to excessive noise exposure, which will lead eventually to a better performance of the soldier.

Impulse noise in industry is not a real problem. There are little cases of workplaces where the employee will be exposed to peak pressure level of 150 dB(C) or more. Therefore single hearing protection (plug or muff) is sufficient in most cases. In the military community, however, the noise exposures to weapon noise start at peak pressure levels of about 160 dB(C) and reach up to 190 dB (C).

Until now, the military community used damage risk criteria which have proven to be rather overprotecting. The application of these DRCs still allows, with some restrictions, the use of most modern weapons. More recent DRCs, like the one proposed by Dancer [3], which is based on the A-weighted exposure level ($L_{EX,8h}$), takes into account more physical and physiological elements leading to noise induced hearing loss. They are still overprotecting, but allow the use of modern protection devices like the CAE (US) or BNL (France). The use of only one parameter (peak pressure) for the determination of an exposure limit, as does the Directive, is absolutely inadequate. It does not relate to any physiological and physical reality of hearing. Replacing the presently used or proposed DRCs by the Directive 2003/10/EC will lead to serious problems in the armed forces. An implementation of this directive in the military context may prevent normal use of weapons and lead eventually to accidents during training sessions due to a lack of perception of the acoustic environment. As no efficient training will be possible any more, it will also lead to less efficiency in combat and as a consequence to a refusal of wearing any personal hearing protection.

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