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Report / Subtask

Mine-Clearing Vehicle MINEWOLF

Biomechanical Assessment of Mine-Clearing Tests with Live Mines in March 2004

Author: TROI Oliver Nies

WTD-Nr.: 91-**400 – 058** / **04**

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The report refers to trials that have been inserted by Germany in the ITEP Work Plan under Project 3.2.10 (Test and Evaluation of mechanically assisted clearance equipment).

German Federal Armed Forces
Technical Center for Weapons and Ammunition ***WTD 91***
Schießplatz, 49716 Meppen

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Fax
BwFw.: 90 2422- 88 (oder App.)

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Abtract

In March 2004, tests were conducted with the mine-clearing vehicle MineWolf, during which live antitank mines were cleared both with the flail and with the tiller. During four tests an instrumented ATD was placed on the driver's seat. The measured values had to be evaluated with a view to possible risks to the operator during mine-clearing.

The evaluation showed that the detonation of a mine in the area of the mine-clearing device does not cause an intolerable risk of injury. In case of a detonation underneath the vehicle, however, a risk for the operator cannot be ruled out. To avoid auditory defects, both the operator and persons outside the immediate danger area should wear ear protection.

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TROI Oliver Nies

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Distribution: No. of pages 29

WTD 91 – 310	**3 EA**
DirWTD 91	**1 EA**
BWB - FlSt	**1 EA**
WTD 91 – 450	**2 EA**

Table of Contents

1 Task Description

In March 2004 tests were conducted at WTD 91 with the mine-clearing vehicle MineWolf, during which live antitank mine (ATM) types DM 21 and TM 57 were cleared. Four tests were first conducted in calendar week 10/04 with the vehicle remotely controlled. During these tests an ATD (Anthropomorphic Test Device = instrumented test dummy) was placed on the driver's seat, on which various sensors were attached to measure human-relevant loads during mine-clearing. The evaluation of the measured data showed whether the MineWolf operator would be subject to an intolerable risk of injury during the clearing operation; this would have led to the consequence that no tests with human operators in the driver's cab would have been conducted at WTD 91.

An initial evaluation showed that – provided certain precautionary measures were taken - there was no intolerable risk for the operator. These results were briefly presented to the safety board. The present report contains a detailed evaluation of the test results.

2 Summary of Results

During normal clearing operation there is no intolerable risk of injury for the MineWolf operator sitting in the driver's cab. Temporary minor disturbances like headache or muscular pain are possible, especially if loads occur repeatedly at short intervals. Due to the blast pressure load caused by the mine detonations, however, it is necessary that the operator wears ear protection both when mounted and when dismounted, because otherwise he might suffer auditory defects.

Should a mine detonate underneath a track or underneath the vehicle itself, which – due to the design of the MineWolf is not very likely but still possible – completely different effects have to be considered.

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Should a mine detonate underneath a track or underneath the vehicle itself, which – due to the design of the MineWolf is not very likely but still possible – completely different effects have to be considered.

Based on the tests conducted so far, no statements can be made on the consequences for the operator in this case. Intolerable loads, i.e. when the applicable limits for mine protection tests are exceeded or the mine protection criteria are not fullfilled, cannot be excluded according to the present state of knowledge.

To ensure the greatest possible degree of safety for the operator, it is recommended – analogously to the tests with mine-protected vehicles – to perform static contact detonations with charges placed underneath the track and underneath the vehicle, which have to be evaluated using the valid biomechanical assessment methods and criteria. Only then will it be possible to make a final statement on the risk of injury for the operator in the event of a mine detonation outside the mine-clearing device.

3 Short Description of the Test Item

The tests were conducted with a fully operational MineWolf as well as both types of mine-clearing devices, i.e. flail and tiller. The vehicle could be operated both in remote control mode and by an operator sitting inside the driver's cab.

4 Schedule and Required Effort

Test site: WTD 91, Meppen
Test period: calendar week 10/2004

5. Detailed Description of Tests

5.1 General

The tests were conducted on the premises of WTD 91 with original antitank mines DM 21 (5.6 kg TNT) and TM 57 (6.5 kg TNT) that had been buried. This report covers only those tests which served to gather human-relevant data. To this end, one test each with the flail and the tiller was performed for each mine type. Thus, a total of four tests has to be evaluated. Table 1 shows an overview of the marginal conditions. More detailed data are contained in the report prepared by WTD 91 – 310.

	Test 1	**Test 2**	**Test 3**	**Test 4**
Date	01 Mar 2004	02 Mar 2004	02 Mar 2004	03 Mar 2004
Mine	DM 21	TM 57	DM 21	TM 57
Clearing device	flail	flail	tiller	tiller

Table 1: Marginal Conditions of Tests 1 – 4

5.2 Test Methods

The vehicle operator was replaced by an anthropomorphic hybrid III-ATD of the 50th male percentile. It was fitted with triaxial acceleration sensors in its head. On its lower leg, which was a THOR-Lx type, the forces and accelerations were measured triaxially. Furthermore, a uniaxial force sensor was installed in the right upper leg to measure the shear force. To determine the loads on the dorsal and the lumbar spine, the accelerations induced across the driver's seat surface were measured. To this end, the ATD was placed on a cushion into which a triaxial acceleration sensor was integrated. In addition, the axial spine force was measured.

In addition to the measurements performed on the ATD, acceleration measuring points were installed on the driver's cab floor and at the seat. These measurements also served the purpose of making the tests comparable with previous tests on mine-clearing vehicles, since similar measurements had been performed there.

The human-related assessment of the loads for the operator was based on the assessment methods and criteria specified for mine-protected vehicles, which are also applicable in this case. Limit values and tolerance limits are defined for the different body regions. The criteria are shortly described in the following. For further details see the relevant technical literature.

The human-related assessment is subject to a master criterion which stipulates that a probability of injury (AIS ~ 2) of 5 % must not be exceeded.

5.2.1 Head

The criterion for the head is the "No Impact Criterion" (NICon) [1]. This means that the head of the ATD shall not hit the vehicle roof or other vehicle components. In this case the design of the driver's cab and the operator position were such that an impact of the head was highly unlikely. Thus, no specific individual demonstration was necessary. The criterion is considered fulfilled for all tests.

5.2.2 Dorsal and Lumbar Spine

The method used to assess the probabilities of injury of the dorsal and lumbar spine is the "Dynamic Response Index" (DRI) [2,3]. The DRI describes the behavior of the spine by means of a cushioned spring-mass system. The acceleration/time histories in X, Y and Z direction are used as input parameters. On this basis the deformation of the spine and thus the respective probability of injury in X, Y and Z direction is determined.

The probabilities of injury shall not exceed 5%.

5.2.3 Upper Leg

At present, only a static method – the Femur Shear Force Criterion (FSFC) – is available for the assessment of the upper leg load. The shear force in the upper leg is used as a parameter. This force shall not exceed 2860 N [1].

5.2.4 Lower Leg

To assess the probability of injury of the lower leg the "Lower Leg Threshold" (LL_{TH}) is used, where the acceleration-time histories serve as input parameters [4]. The mean resulting acceleration is calculated from these by integration. The time of exposure to be considered is the onset duration of the velocity history. For short times of exposure, a tolerable mean acceleration is assigned to a certain time of exposure. A quasi-static limit of 20 g applies to times of exposure of more than 20 ms, which must not be exceeded.

5.2.5 Fragments

The criterion for fragmentation is the "No Fragment Criterion" (NFC) [1]. This means that no fragments may occur in the driver's cab, neither those caused by ruptures or penetrations from outside (primary fragments) nor any caused by secondary fragmentation.

5.2.6 Lumbar Spine Force

The lumbar spine force is not a criterion for mine protection tests since the area of the spine is covered by the DRI. Therefore, this force is normally not measured. In the present case it was recorded as a supplementary information. A limit is not defined, however.

6. Determination of Results and Assessment

6.1 Test 1

6.1.1 Head

Fig. 1 shows the acceleration history in the head of the ATD. The measured values in X and Y direction are very low. The sensor for the Z axis had failed. As can be seen, the measured accelerations have a relatively high frequency and are so low that they are already within the range of measurement inaccuracies. Injuries in the head area are not to be expected. Since there was no head impact, the NICon is also fulfilled.

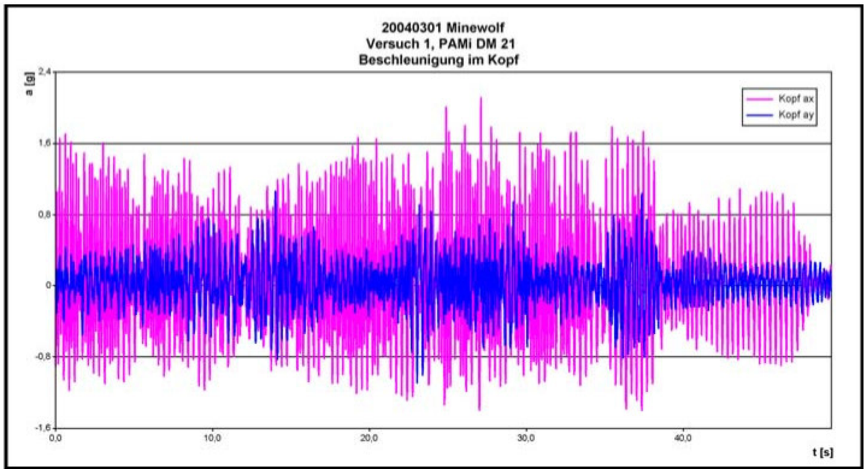

Fig. 1: Head Acceleration Test (Test 1)

6.1.2 Dorsal and Lumbar Spine

Fig. 2 shows the DRI histories in X, Y and Z direction. The probability of injury in all three directions is less than 5 %. The criterion is thus fulfilled.

6.1.3 Upper Leg

Fig. 3 shows the shear force history in the right upper leg. The measured values are again within the range of the intrinsic noise of the measuring system, as can be seen from the diagram. The values are far below the limit of 2860 N. The FSFC is thus fulfilled.

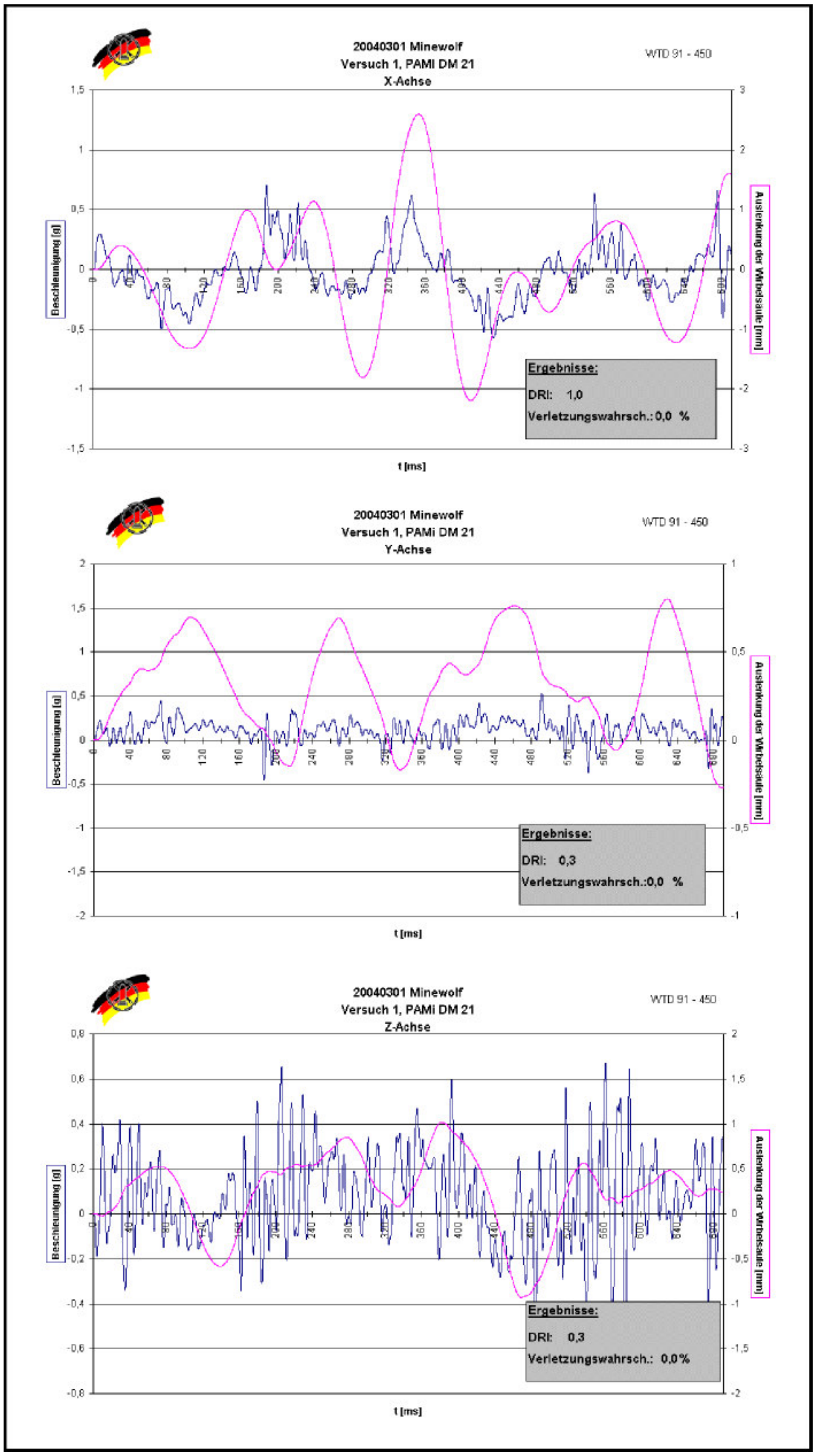

Fig. 2: DRI Histories in X, Y and Z Direction (Test 1)

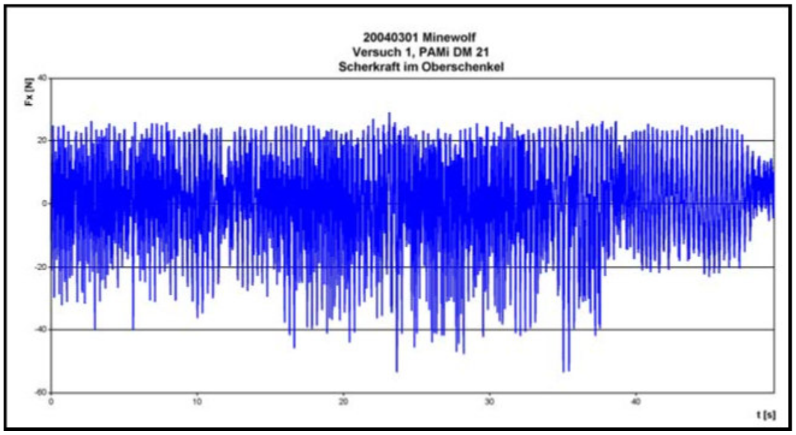

Fig. 3: Upper Leg Shear Force (Test 1)

6.1.4 Lower Leg

Fig. 4 shows the acceleration history in the right lower leg. The quasi-static limit value of 20 g is not exceeded, thus no further evaluation in accordance with the LL_{TH} is required. The criterion is fulfilled.

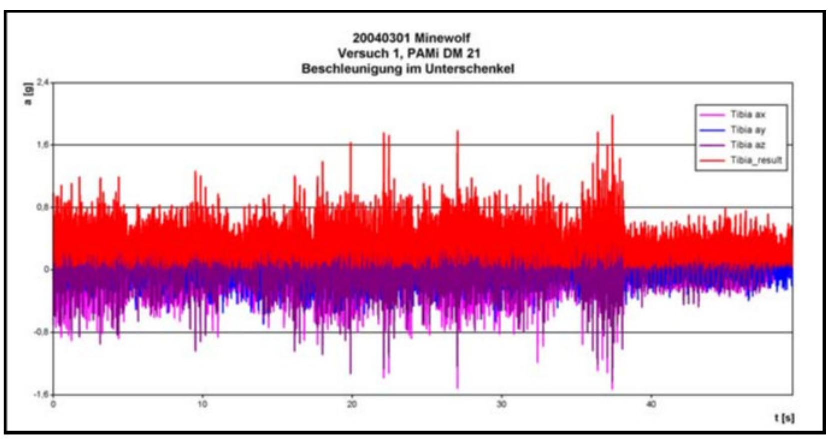

Fig. 4: Acceleration History in the Lower Leg (Test 1)

6.1.5 Fragments

No primary or secondary fragments occurred in the driver's cab. The NFC is thus fulfilled.

6.2 Test 2

6.2.1 Head

Fig. 5 shows the acceleration history in the head of the ATD. Again, the measured values are very low and comparable to those of test 1. Injuries in the head area are not to be expected. Since no head impact occurs, the NICon is fulfilled.

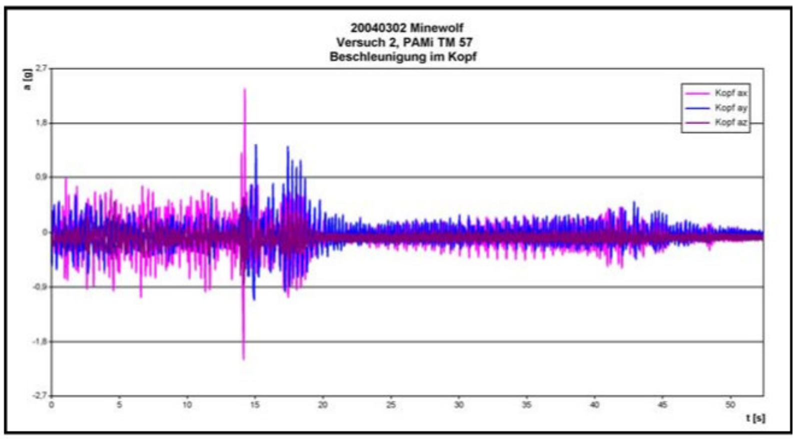

Fig. 5: Head Acceleration (Test 2)

6.2.2 Dorsal and Lumbar Spine

Fig. 6 shows the DRI histories in X, Y and Z direction. The probability of injury in all three directions is less than 5 %. The criterion is thus fulfilled. Fig. 6 shows the DRI histories in X, Y and Z direction. The probability of injury in all three directions is less than 5 %. The criterion is thus fulfilled.

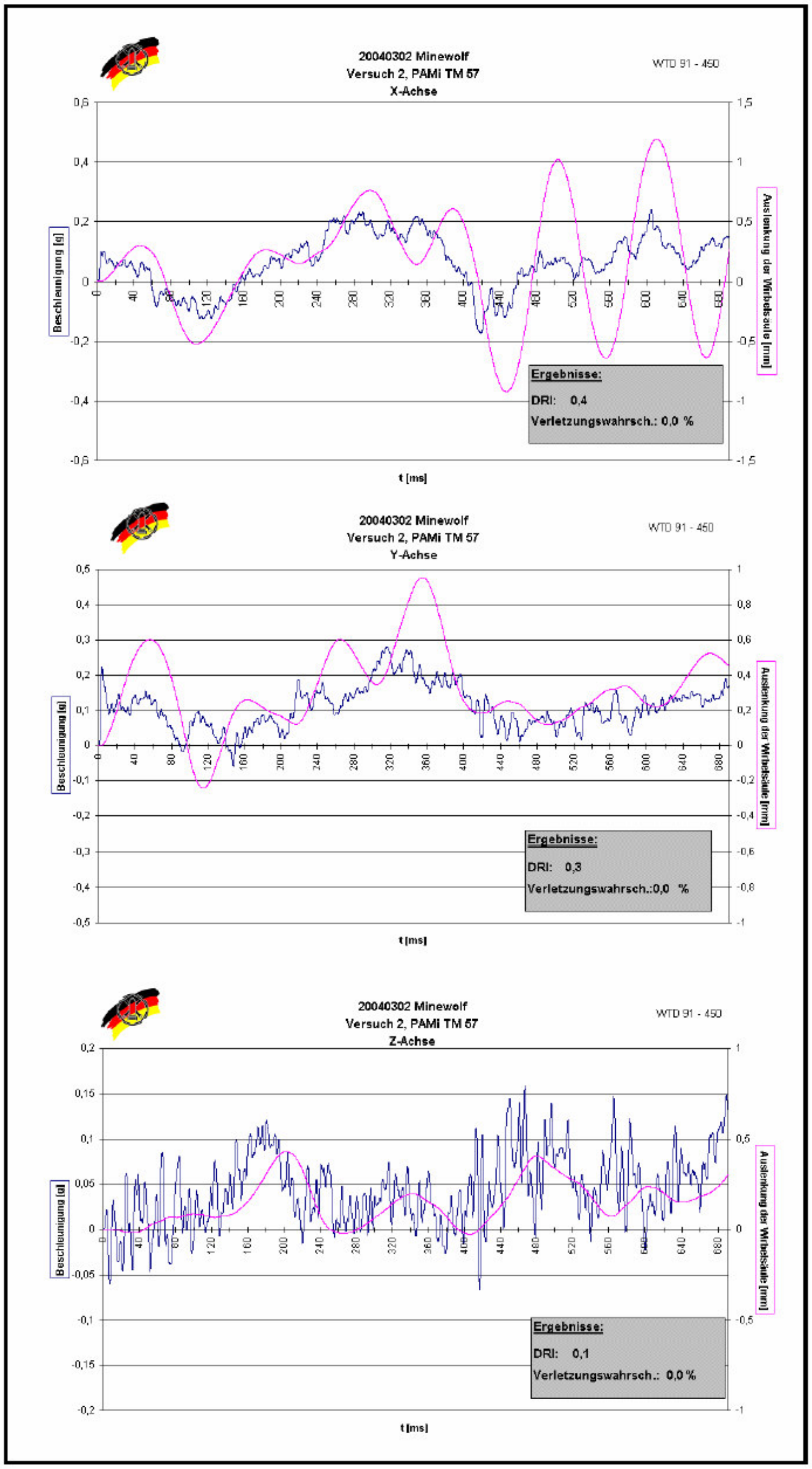

Fig. 6: DRI Histories in X, Y, Z Direction

6.2.3 Upper Leg

Fig. 7 shows the shear force history in the right upper leg. As can be seen, the measuring sensors failed (presumably a broken cable). Therefore, an assessment on the basis of the measured data is not possible for test 2. In view of the other results for test 2 and the upper leg data of the other tests, the probability is very high that the limit of 2860 N was not exceeded.

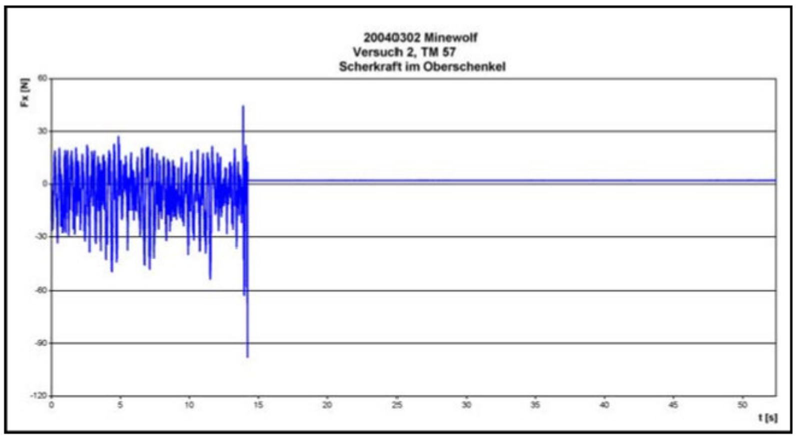

Fig. 7: Upper Leg Shear Force (Test 2)

6.2.4 Lower Leg

Fig. 8 shows the acceleration history in the right lower leg. The values are slightly higher than in test 1 but are generally very low. The quasi-static limit value of 20 g is not exceeded, thus no further evaluation in accordance with the LL_{TH} is required. The criterion is thus fulfilled.

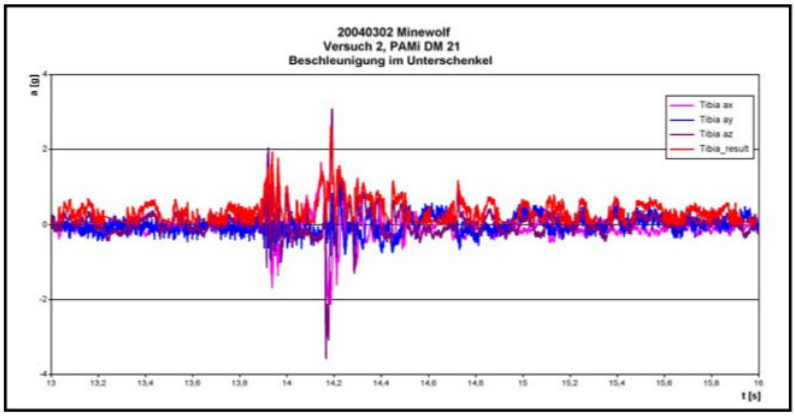

Fig. 8: Acceleration History in the Lower Leg (Test 2)

6.2.5 Fragments

No primary or secondary fragments occurred in the driver's cab. The NFC is thus fulfilled.

6.3 Test 3

6.3.1 Head

Fig. 5 shows the acceleration history in the head of the ATD. Due to the results from tests 1 and 2 the measuring range was adjusted to provide for a better representation. Again, the measured values are very low and comparable to those of tests 1 and 2. Injuries in the head area are not to be expected. Since no head impact occurs, the NICon is fulfilled.

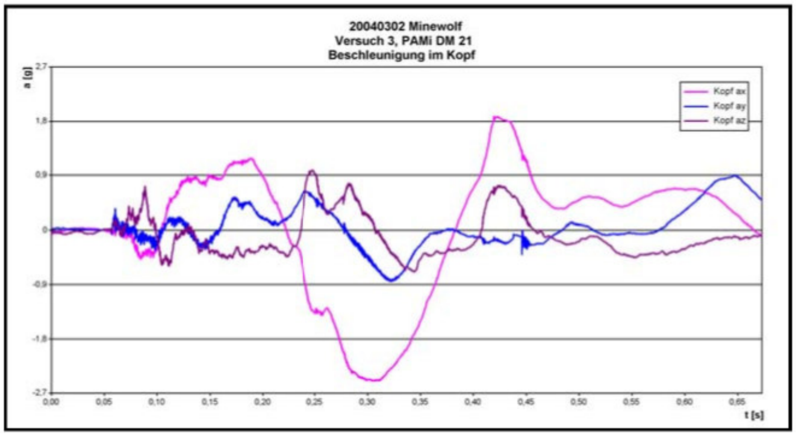

Fig. 9: Head Acceleration (Test 3)

6.3.2 Dorsal and Lumbar Spine

Fig. 10 shows the DRI histories in X, Y and Z direction. The probability of injury in all three directions is less than 5 %. The criterion is thus fulfilled.

6.3.3 Upper Leg

During test 3 the measuring sensor failed again, so that no valid data of the upper leg load are available. Thus, no assessment according to the FSFC is possible.

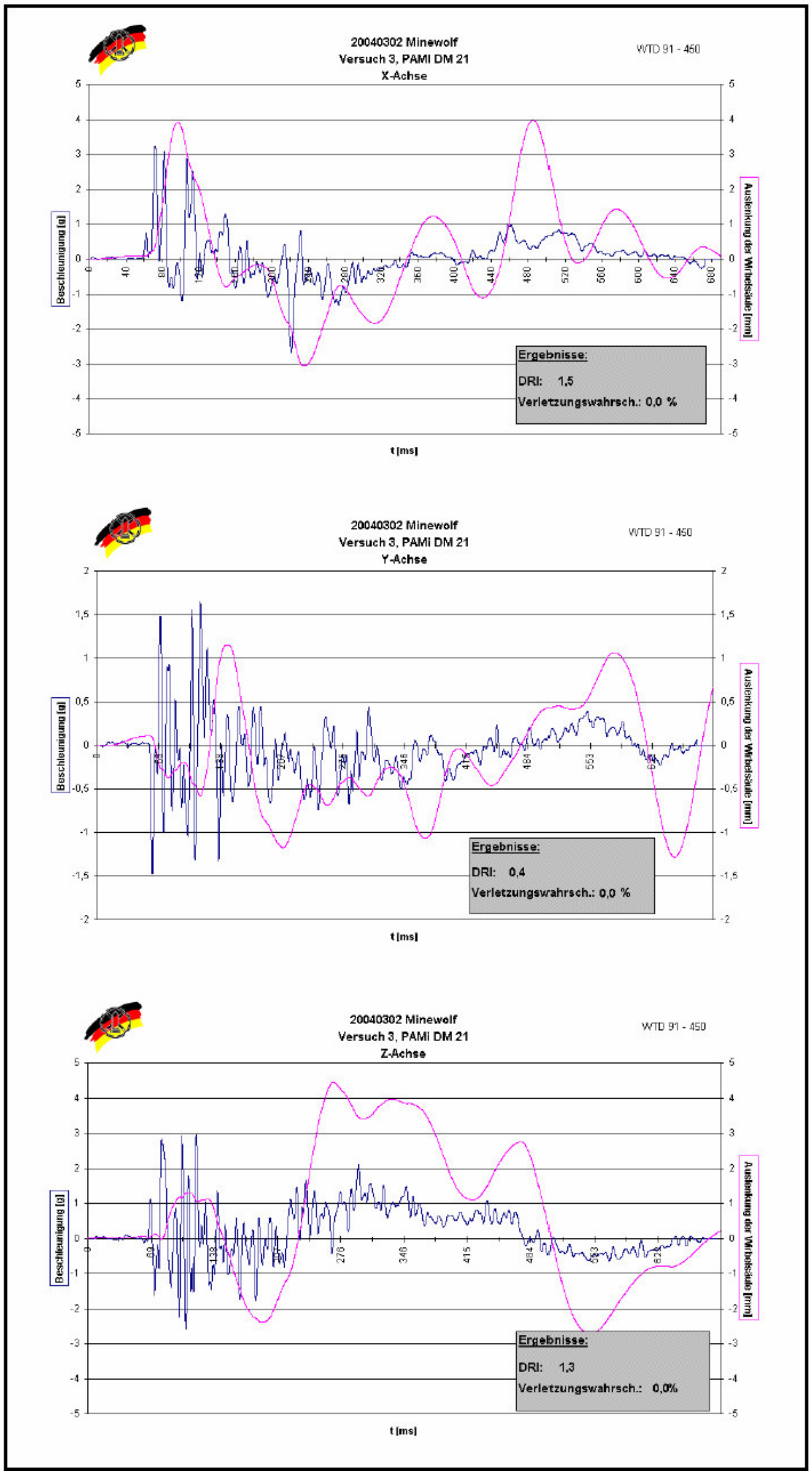

Fig.10: DRI Histories in X, Y, Z Direction (Test 3)

6.3.4 Lower Leg

Fig. 11 shows the acceleration history in the right lower leg. As can be seen, the quasi-static limit value of 20 g is not exceeded. Thus, thus no further evaluation in accordance with the LL_{TH} is required. The criterion is fulfilled.

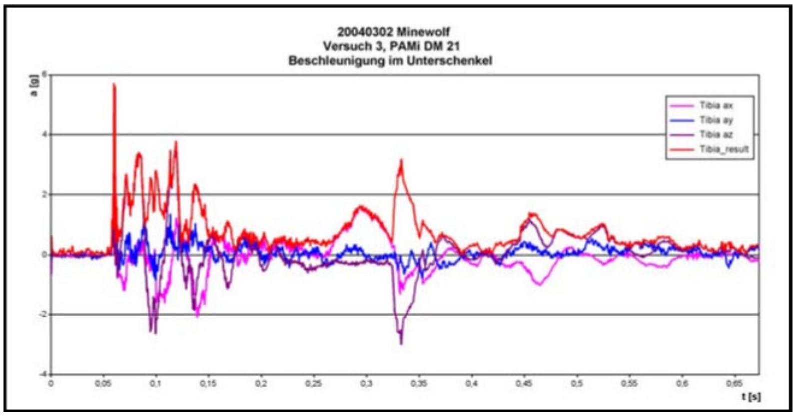

Fig. 11: Acceleration History in the Lower Leg (Test 3)

6.3.5 Fragments

No primary or secondary fragments occurred in the driver's cab. The NFC is thus fulfilled.

6.4 Test 4

6.4.1 Head

Fig. 12 shows the acceleration history in the head of the ATD. Again, the measured values are very low and comparable to those of the previous tests. Injuries in the head area are not to be expected. Since no head impact occurs, the NICon is fulfilled.

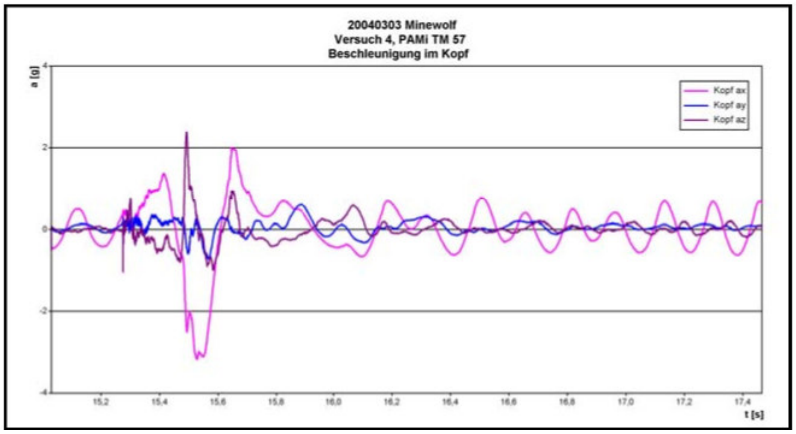

Fig. 12: Head Acceleration (Test 4)

6.4.2 Dorsal and Lumbar Spine

Fig. 13 shows the DRI histories in X, Y and Z direction. The probability of injury in all three directions is less than 5 %. The criterion is thus fulfilled..

6.4.3 Upper Leg

Fig. 14 shows the measured shear force history in the right upper leg. The unusual curve suggests the existence of a measuring error. Therefore, no final assessment according to the FSFC is made.

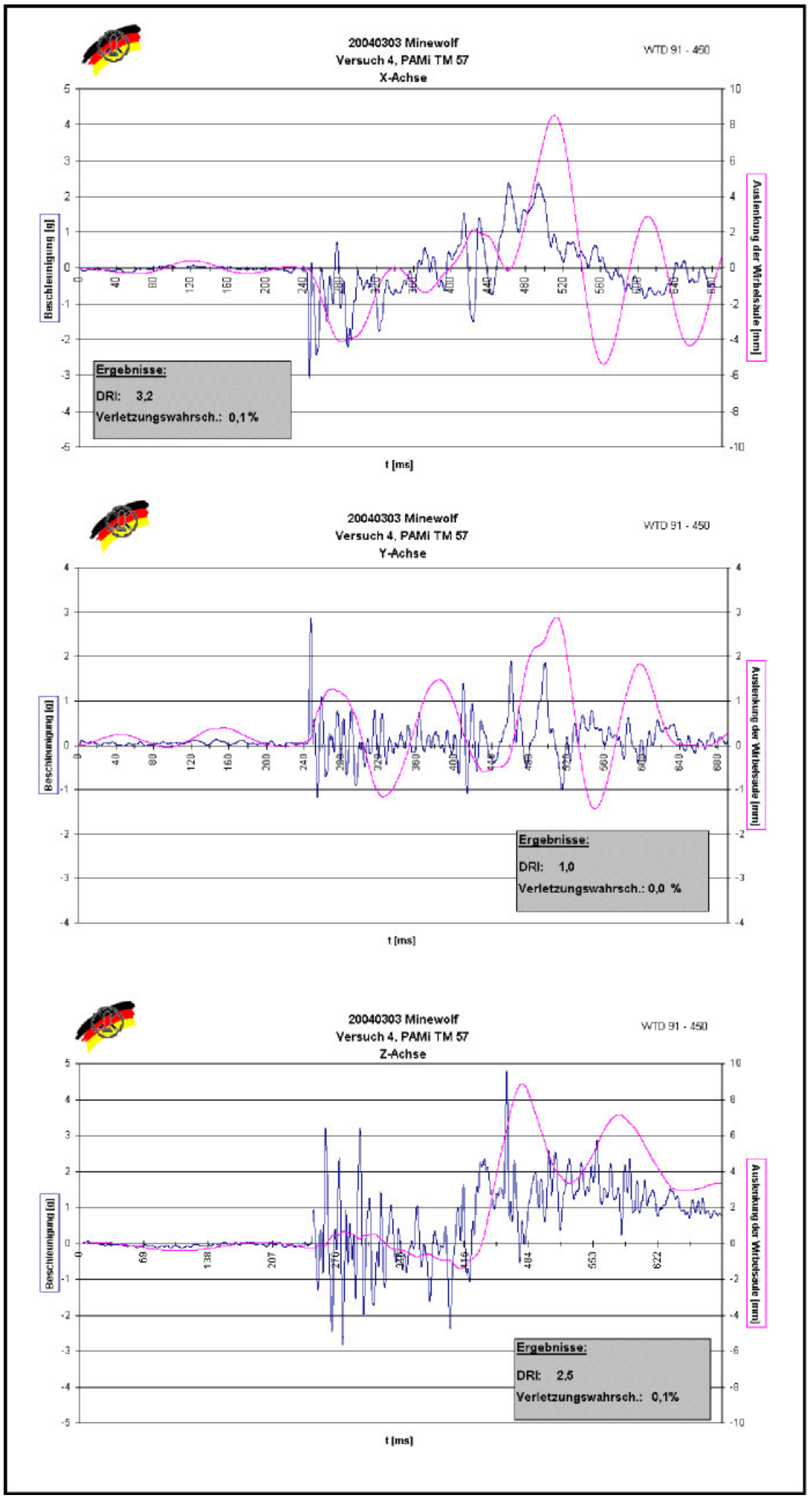

Fig.13: DRI Histories in X, Y, Z Direction (Test 4)

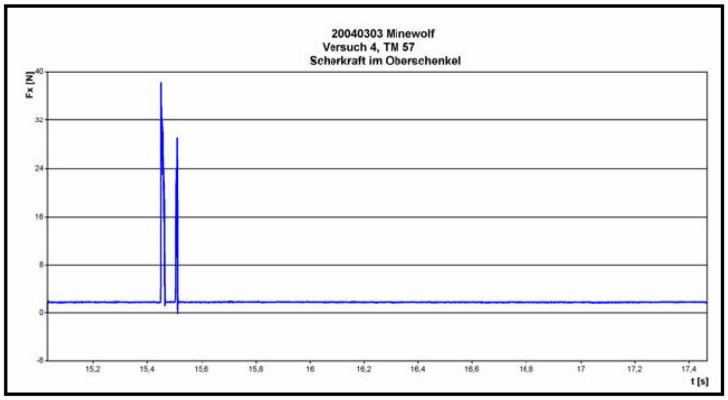

Fig. 14: Upper Leg Shear Force (Test 4)

6.4.4 Lower Leg

Fig. 15 shows the acceleration history in the right lower leg. As can be seen, the measured values are higher than in the previous tests but the quasi-static limit value of 20 g is again not exceeded. Thus, thus no further evaluation in accordance with the LLTH is required in this case either. The criterion is fulfilled.

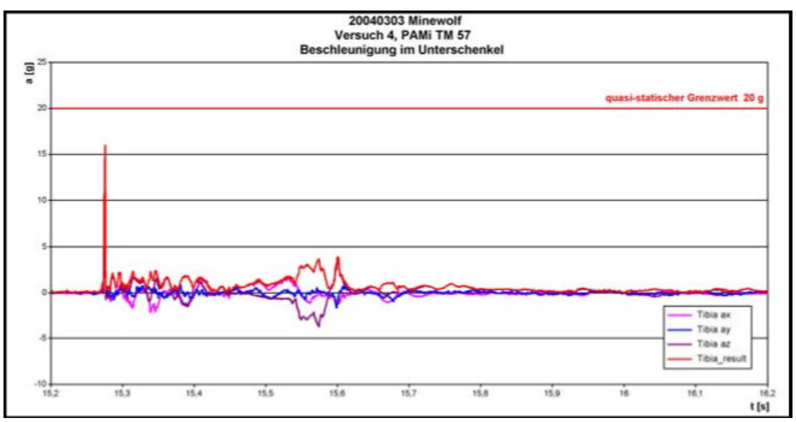

Fig. 15: Acceleration History in the Lower Leg (Test 4)

6.4.5 Fragments

No primary or secondary fragments occurred in the driver's cab. The NFC is thus fulfilled.

6.5 Lumbar Spine Force

In addition to the above-mentioned and assessed human relevant measurements, the axial force in the spine, the so called lumbar spine force, was also measured in tests 2 – 4. Fig. 16 shows the results. As can be seen, the maximum values are within the range of 1000 N. There is presently no criterion for mine protection investigations that takes the lumbar spine force into account, but this force is relatively small so that no spinal injuries are to be expected due to the compressive force. This assessment corresponds with the evaluation of accelerations according to the DRI, which in all tests also resulted in very low values and probabilities of injury for the dorsal and lumbar spine.

The measured forces can be compared to those measured in the contact detonation tests conducted by RUAG [5]. Thus, the above assessment of the results with respect to risks of injury confirms the conclusions of RUAG and is in line with the biomechanical assessment made by WTD 91 [6] on the basis of the RUAG report [5].

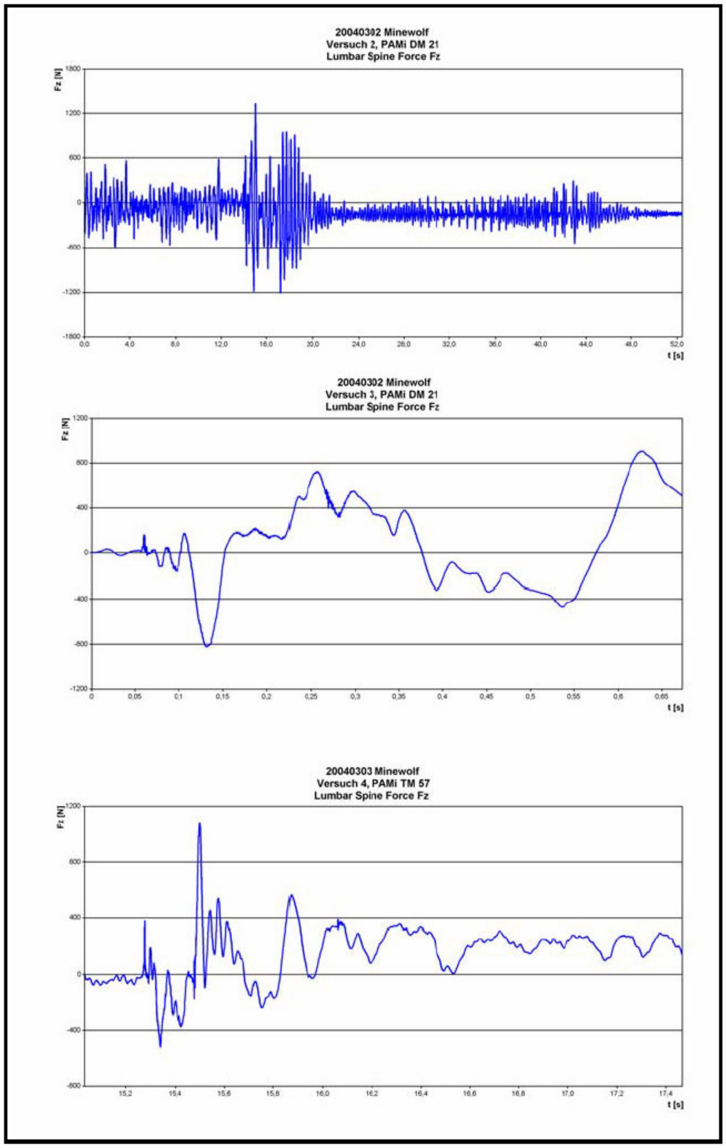

Fig. 16: Lumbar Spine Forces (Test 2 - 4)

6.6 Blast Pressure Load

Table 2 shows the measured maximum pressures, pressure levels and times of exposure. The results of the nine tests were averaged by WTD 91 – 630. This is normally not useful since the tests were conducted under different conditions (flail and tiller, various mines). However, in this case the differences between the individual tests are so small that averaging yields a relatively good and useful result.

lfd. Nr.:	Datum	Räumart	Minentyp	Mp 1 (Kopf des Fahrers)		
				$\hat{p}$ [kPa]	$\hat{L}$ [dB]	t_w [ms]
1	01.03.04	Schlegel	DM 21	0,54	148,6	90,80
2	02.03.04	Schlegel	TM 57	0,64	150,1	53,10
3	02.03.04	Fräse	DM 21	0,70	150,9	56,00
4	03.03.04	Fräse	TM 57	0,68	150,6	58,30
5	08.03.04	Schlegel	TM 57	0,75	151,5	70,70
6	08.03.04	Schlegel	TM 62 P3	0,82	152,3	49,50
7	09.03.04	Fräse	TM 57	0,82	152,3	88,23
8	09.03.04	Fräse	TM 62	0,84	152,5	62,15
9	09.03.04	Fräse	TM 57	0,87	152,8	84,90
Mittelwert				**0,74**	**151,4**	**68,19**
zulässige Minenanzahl **ohne Gehörschutz**				**0**		
zulässige Minenanzahl mit **Sprechsatz H - 280**				**23**		
zulässige Minenanzahl mit **MAX Lite**				**561**		

Table 2: Blast Pressure Values (source: WTD 91 – 630)

Fig. 17 shows the limiting level diagram according to Pfander [7]. The violet marking identifies the area where the pressure loads measured during the nine tests belong. As already mentioned, an exact differentiation is not necessarily required due to the relatively small differences, and is therefore not made. The exact values are contained in the measurement record of WTD 91 – 630 and/or table 2.

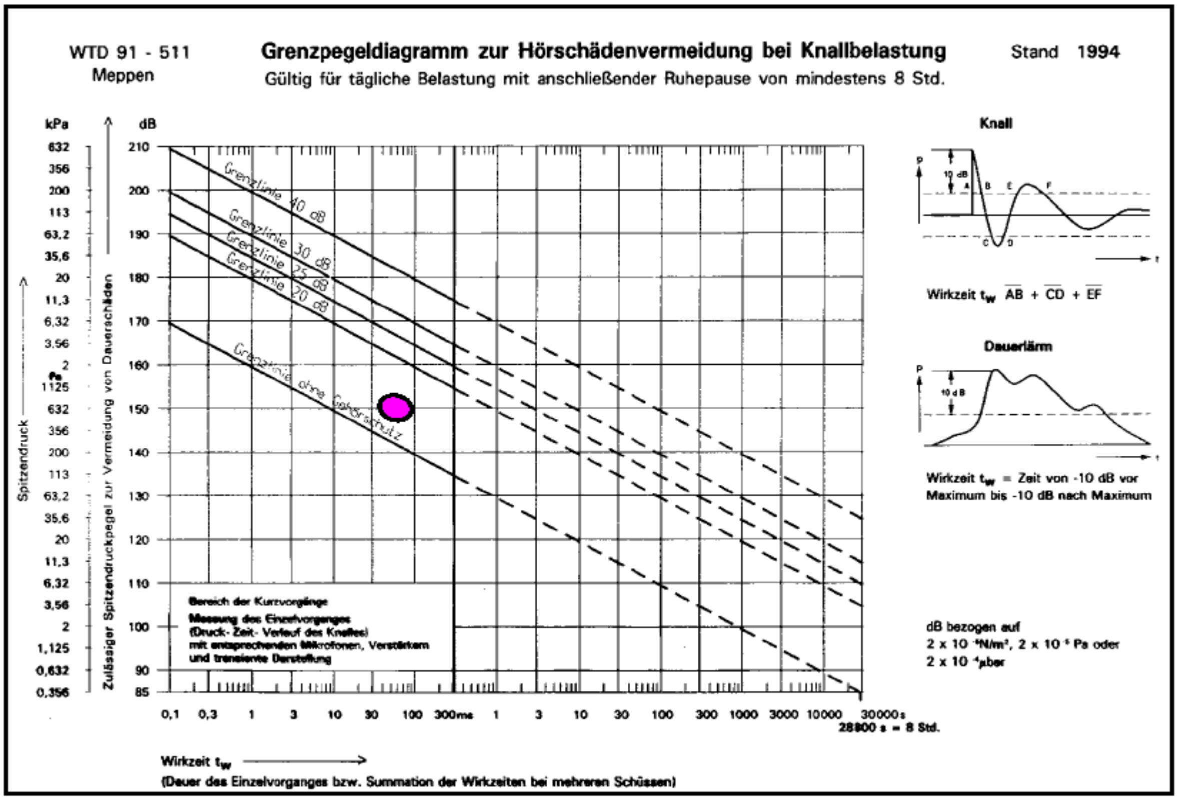

Fig. 17: Limiting Level Diagram

As can be seen, auditory defects of the unprotected ear have to be assumed in all cases. Therefore, it is absolutely necessary for the mounted operator to use adequate ear protection. This was already recommended prior to the tests by WTD 91 [6] and the RUAG [5]. In addition to the measured values, table 2 shows the theoretically admissible number of loads per day when wearing a H-280 headset and/or a headset in connection with "MAX Lite" earplugs.

The maximum pressures of 0.54 to 0.87 kPa measured in the driver's cab during the first tests at WTD 91 are approx. one tenth of those indicated by the RUAG [5] (50 mbar = 5 kPa). The reason therefore is not reproducible. At any rate, the maximum pressure values are so low that non-auditory defects, for example pulmonary damage, are not to be expected.

6.7 Summary and Conclusion

During the four tests all human-related criteria were fulfilled to the extent that they could be evaluated. For tests 2 – 4 the upper leg shear force could not be assessed due a failure of the measuring equipment. The results from test 1 and the measured values for the lower legs and the pelvis, however, highly suggest that the admissible limit was not exceeded in these cases either. Therefore, the missing final assessment has no negative influence on the overall result.

In all areas investigated the loads measured during tests 3 and 4 were higher than those in tests 1 and 2. This is explained by the fact that the tiller was used in tests 3 and 4, while the first two tests were conducted with the flail. Due to its design, the tiller transmits the loads released by the mine detonations better onto the vehicle structure than the flail; as a result, the driver's cab and the operator are subjected to higher loads. As already mentioned above, the overall loads are still very low.

In summary it can be stated that the operator sitting in the driver's cab of the MineWolf is not subjected to an intolerable risk of injury by the explosion of a DM 21 or TM 57 antitank mine if the mine detonates in the area of the mine-clearing device. The risk of injury is very

Low and far below the applicable limits for mine-protected vehicles of the Bundeswehr. The statements by the operator confirmed this analysis. Even in case of repeated successive loads no serious consequences have to be expected. Temporary light disturbances like headaches or muscular pain, however, cannot be excluded.

The assessment of the blast pressure load in the driver's cab showed that non-auditory effects are not to be expected. There is no risk of permanent auditory defects if adequate ear protection is worn. The use of ear protection was already recommended by the RUAG [5] and WTD 91 [6] prior to the tests. Even for observers outside the direct danger area or the dismounted operator during remote control operation of the MineWolf it is absolutely necessary to wear suitable ear protection.

Due to the principle of operation of the MineWolf, the detonation of a mine underneath the vehicle hull or a track during mine-clearing is not very likely, but cannot be ruled out. Based on the available measured data, the effects that an explosion underneath the hull or a track would have on the vehicle and the mounted operator cannot be assessed. It is definitely possible, however, that this would lead to critical loads. It is therefore recommended to investigate these cases – i.e. detonation underneath the vehicle hull or a track – by static contact detonation tests to be able to ensure the highest degree of safety for the MineWolf operator.

List of Figures

List of Tables

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List of Acronyms

ATD **A**nthropomorphic **T**est **D**evice

DRI **D**ynamic **R**esponse **I**ndex

FSFC **F**emur **S**hear **F**orce **C**riterion

NFC **N**o **F**ragment **C**riterion

NICon **N**o **I**mpact **C**riteri**on**

LL_{TH} **L**ower **L**eg **T**hres**h**old

APM **A**nti**p**ersonnel **M**ine

ATM **A**nti**t**ank **M**ine