Criteria for the safe use of commercial vehicles to transport personnel in the underground environment (GEN 702)

January 2002

Final document

Project study report
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EXECUTIVE SUMMARY

This report details the research done into the use of commercial vehicles (bakkies) in the underground mining environment. The research was prompted by concern from the DME about the use of non-flameproof vehicles in fiery mines. Although flameproofing is of primary concern in this document, general safety requirements for bakkies used underground are also addressed.

Statistics from the SAMRASS database indicates that vehicle related accidents account for a significant number of accidents, injuries and fatalities in mines. The current situation in the mines was determined through visits to the mines. A questionnaire was filled out by the mines regarding the use of bakkies underground. Some of the industry role players were also visited to determine the level of support and competency in industry.

Two SABS standards pertaining to flameproofing and braking respectively were evaluated and DME documentation relating to the use of bakkies underground is also discussed. General vehicle safety, from a vehicle engineering point of view, is also addressed.

The research indicated that although the SAMRASS database is very comprehensive, there is not distinguished between bakkies and other personnel transporting vehicles, which makes the accident statistics difficult to interpret. The accident statistics may therefore be misleading, as far as non-flameproof bakkies are concerned.

It was also concluded that all the mines visited during this project follow a different approach when selecting, implementing and maintaining non-flameproof (as well as flameproof) bakkies. It appears as if some of the mines do not go through the same development and research effort, as did the pioneers of non-flameproof bakkies. Since all vehicles are not necessarily equally suited for deration, or engine modifications, each vehicle will have to be analysed and tested in detail. It is however evident from visits to mines that use non-flameproof vehicles, that these vehicles are much more reliable, less expensive to maintain, better suited, safer (crashworthiness) and cheaper than flameproof transporters.

All the mines have a good driver training program in place and monitor the use of bakkies carefully. It is also very noticeable that at most mines, although the non-flameproof vehicles are still new, few accidents and almost no fatalities or injuries were recorded since the introduction of non-flameproof bakkies. From the response of the mines to the questionnaire it can be concluded that the mines will go a long way to retain exemption to use these vehicles.

Some of the industry role players are very sceptical about the non-flameproof vehicles and most of them feel that proper guidelines and specifications should be provided for these vehicles.

The SABS 868 flameproofing standard has been revised several times and it was found that some of the issue levels contains conflicting information. This standard also makes no provision for non-flameproof vehicle requirements. The SABS 1589 braking standard used for underground trackless mining vehicles was found to be less strict than that used for commercial vehicles, such as bakkies, in terms of stopping distance and mean fully developed acceleration. Non-flameproof vehicles found at the mines are generally in very good condition and conform to strict safety standards, although health and safety can be improved in various areas.
The DME documentation regarding non-flameproof vehicles was revised several times the in past few years and although none of the documents provided sufficient guidelines, it was found that the documentation became less prescriptive with regards to braking, temperatures and emissions. Although the DME aimed to provide guidelines for implementing non-flameproof vehicles with these documents, it still remains the responsibility of the mine management to provide a safe working environment for the workers. According to the Mine Health and Safety Act (MHSA) (Act 29 of 1996), the manager must draw up codes of practice (paragraph 9), supply training (paragraph 10) and assess and respond to risks (paragraph 11). This will entail performing a Hazard Identification and Risk Assessment (HIRA) for each new vehicle model introduced in the mine. This report supplies some examples of significant risks and suggests possible ways to address it, but since each mine is unique a thorough HIRA has to be performed for all non-flameproof vehicles (see paragraph 4.4).

As part of this study a quick reference guide was compiled (included as Appendix F), which summarises the decision making process when implementing bakkies in mines. This guide highlights the steps in the process and stresses the importance of an effective HIRA and the associated tasks that follow that.

From what was experienced at the mines and judging from the number of mines that has been granted exemption for using non-flameproof vehicles, it can be seen that these vehicles can be operated in a safe manner.

Proposed future work in the field of non-flameproof vehicles includes the following:

- Establishment of phasing out policies for non-flameproof vehicles
- Systems for preventing access to hazardous areas
- More refined fail safe braking systems
- Updated SABS 868 standard for non-flameproof vehicles
- Updated SABS 1589 to included LDV sized vehicles
- Compilation of Guidelines for compiling COP’s with regards to non-flameproof vehicles
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NOMENCLATURE

Bakkie Commercially available Light Delivery Vehicle with a carrying capacity of approximately 1ton.

CAE Centre for Automotive Engineering

Commercial vehicle Commercially available vehicles which are designed, built and approved for use on public roads.

COP Code of Practice

DME Department of Minerals and Energy

EEC European Economic Community

Flameproof vehicles Vehicles conforming to SABS 868:1997 can be classified as flameproof vehicles.

FOPS Falling Object Protection System

HIRA Hazard Identification and Risk Assessment

LDV Light Delivery Vehicle

MHSA Mine Health and Safety Act (Act 29 of 1996)

Non-flameproof vehicles Vehicles not conforming to SABS 868:1997. Non-flameproof vehicles may include some form of flameproofing

ROPS Roll Over Protection System

SAMRASS South African Mines Reportable Accident Statistical System

Semi-flame proof vehicles Semi-flameproof is generally used to describe a commercial vehicle that is only fitted with a scrubber box and does not conform to SABS 868:1997 flameproofing specification.

SIMRAC Safety in Mines Research Advisory Committee
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1. Introduction

1.1 Project Background

The first applications for exemption to use a non-flameproof vehicle underground were received in 1998, after extensive studies were conducted by some of the mines. In these studies, it was found that the use of non-flameproof vehicles could drastically reduce the capital expenditure, as well as the maintenance costs of underground personnel transporters, as well as increase comfort and safety.

Project GEN702 is concerned with research into the safe use of commercial vehicles to transport personnel in the underground environment. The requirement to research the use of commercial vehicles underground originated at the head office of the DME, who had received numerous applications for exemption to use non-flameproof vehicles.

Initially, the focus of this project was on all underground commercial vehicles, but after the initial phase of the study, it was decided at a SIMRAC meeting that the current trend is towards using bakkies for transporting personnel underground. It was therefore decided to only focus on bakkies.

1.2 Problem statement

Statistics from the SAMRASS database indicate that many injuries and fatalities are caused by vehicle accidents underground. The database does however not discriminate between commercial vehicles and other underground machinery. In order to minimise the number of accidents it is important to know what the causes of the accidents are. The causes of accidents on commercial vehicles therefore had to be determined.

Since many mines have already obtained exemption for using commercial vehicles underground, the current standards, directives and guidelines were evaluated. These include, amongst others, the guidelines of the DME for compiling a COP with regards to non-flameproof vehicles, as well as two SABS standards concerning flame proofing and braking systems of underground vehicles.

1.3 Objectives

The objective of this study can be summarised as follows:

- Determine the current state in South African mines with regards to the use of commercial vehicles to transport personnel underground.

- Comment on the current standards, regulations and procedures from a safety and health point of view.

- Suggest ways in which underground vehicle safety can be improved.

- Draw up a guideline for the safe use of bakkies in an underground environment.
2. Methodology

The methodology used for the research conducted for this project will briefly be discussed in the following paragraphs.

After the statistical analysis of the accident records it became apparent that a qualitative analysis would be necessary. The qualitative research was based on visits to the mines, industry as well as to offices of the DME. The comments of the mines and companies were recorded and will be discussed in detail in paragraph 3.

Apart from the statistical accident analysis and the comments from the mines, issues such as flameproofing, braking, roll-over and visibility was investigated from a vehicle engineering point of view. Basic vehicle engineering principles were used to evaluate modifications made to vehicles, as well as the maintenance and safety procedures.
3. Research / Work Done

In this section accident statistics obtained from the SAMRASS database are analysed in order to determine the major causes of accidents and fatalities in mines. Mine and industry visits, as well as the standards and other documentation are also discussed.

3.1 Analysis of accident statistics

Accident statistics from the SAMRASS database were used to determine the major causes of accidents in mines. Initially this project was focussed on all commercial vehicles used to transport personnel underground, but this was later narrowed down to cover only bakkies. The main reason for this is that the current trend is towards using non-flameproof bakkies to transport personnel rather than busses, tractor-trailers and transporters.

Since no distinction is yet made between bakkies and other personnel transporting vehicles, the statistics presented in this section are for the current three categories, namely tractor-trailers, transporters and motor vehicles. Although these statistics might therefore not reflect the true accident rate of bakkies underground, it is still worthwhile noting what percentage of accidents are vehicle related.

The accident statistics obtained from SAMRASS spans the twelve years from 1988 to 1999 and includes all Gold, Coal, Platinum, Diamond and Chrome mines. In these twelve years 83 people were killed and 780 injured in 843 vehicle related accidents. Figures 1,2 and 3 graphically represent the accident statistics.

Figure 1 shows the total number of accidents, fatalities and injuries over a period of twelve years. It is clear that the Gold and Coal mines have the largest number of vehicle related accidents.

In Figure 2, the number of occurrences (accidents, fatalities and injuries) is normalised to the number of workers in each mining sector. This indicates that the Coal and Gold mines have the highest vehicle accident rate. According to 1999 statistics the number of workers in each mining sector were as follows:

Gold: 166 938
Coal: 25 287
Platinum: 65 656
Diamond: 4 714
Chrome: 3 641

Figure 3 indicates accidents, fatalities and injuries as a percentage of the total number of occurrences for all mining sectors. From this figure, it can be seen that accidents in Gold and Coal mines make up the largest part of the total number of accidents, while the Platinum, Diamond and Chrome mines are significantly lower.

From the statistics it is therefore evident that the coal mines have the highest number of accidents, fatalities and injuries per 1000 workers and that this study should focus primarily on Coal mines.
Figure 1: Number of accidents, fatalities and injuries over 12 years

Figure 2: Number of accidents, fatalities and injuries per 1000 workers over 12 years
Figure 3: Percentage of accidents, fatalities and injuries of the total for all mining sectors over 12 years

3.2 Visits to mines

A total of seven mines, consisting of 5 Coal mines, one Diamond mine and one Gold mine, were visited for this project. A questionnaire was prepared containing a number of questions relating to the technical aspects of the bakkies, as well as the safety procedures and usage. A copy of this questionnaire can be found in Appendix A. The following mines were visited:

- Arthur Taylor (Coal)
- Khutala (Coal)
- Matla (Coal)
- Kriel (Coal)
- Twistdraai (Coal)
- Randfontein Estates (Gold)
- Premier (Diamond)

The response of the mines will be discussed in the following paragraphs, with reference to the questionnaire number, as attached in Appendix A.

3.2.1 General vehicle information (questionnaire paragraph 2.1)

A wide variety of bakkies are currently used on mines. Some of these are flameproof, while others are semi-flameproof or non-flameproof. Since the requirements for bakkies used in
fiery mines and non-fiery mines differ significantly with respect to flameproofing, this section will be divided into the two categories. The following flameproof, semi-flameproof and non-flameproof bakkies were found on the fiery mines:

- Toyota Land Cruiser (flameproof – see Figure 4)
- Toyota Hi-Lux 2,4l diesel (non-flameproof – see Figure 5)
- Ford F250 (flameproof)
- Mazda B-series (semi-flameproof – see Figure 6)

This list is not comprehensive and only indicates the typical type of bakkies found at the mines visited for this project.

Figure 4: Flameproof Land Cruiser bakkie
Four of the five fiery mines visited are already making use of non-flameproof or semi-flameproof vehicles to transport personnel. The one mine not yet making use of non-
flameproof vehicles have a very small fleet (mainly supervisory vehicles) and felt that the development costs of a non-flameproof vehicle would be higher than maintaining their current fleet. Most of the mines still have flameproof vehicles in their fleet, but these vehicles are significantly older than the non-flameproof vehicles. Some of the flameproof vehicles are almost 20 years old and have been extensively modified and repaired due to the harsh corrosive environment in which they operate. Non-flameproof bakkies are much younger models due to this technology being implemented only recently and because of the replacement policy that goes with these vehicles.

The following bakkies were found on the non-fiery mines:

- SVM (Jeep type vehicle – see Figure 7)
- Toyota Hi-Lux 2,8l diesel and 3,0l diesel (see Figure 8)
- Toyota Land Cruiser

Bakkies in the two non-fiery mines are used as supervisory vehicles and for transporting explosives and do not require any flameproofing. Since the supervisory vehicle usually carry only one person, some of the mines are investigating the possibility of using quad bikes. Figure 9 shows a photograph of the quad bike currently being considered as a supervisory vehicle.
3.2.2 Vehicle procurement (questionnaire paragraph 2.2)

At most of the mines, the decision of which type of bakkie to buy lies with the shaft engineer. On only one mine, mine management was involved in the procurement process, while one other mine involved other technical personnel. It can therefore be assumed that vehicle procurement decisions are mostly taken by the responsible shaft engineer.

Generally, the procurement of a vehicle is preceded by a technical investigation, from which a specification is drawn up. A tender is then put out for a bakkie with the required specifications and at least three quotations are required. The procurement decision is then mainly based on financial considerations. Some of the mines followed in the footsteps of
the leaders and did not conduct a thorough study, but only adopted, and slightly modified the bakkie specification drawn up by others.

In most cases the standard exemption procedure is followed in order to obtain the necessary approval. This procedure would include firstly convincing the mines health and safety committee that the bakkie is safe and suitable for use and secondly to apply for exemption from the DME.

3.2.3 Vehicle operation (questionnaire paragraph 2.3)

It was found that only two mines did not wash their bakkies on a daily basis, of which one had only flameproof bakkies and the other was a non-fiery mine. All other mines wash their bakkies on a daily basis, however the quality of the washing differs significantly. Vehicle washing facilities range from automated non-contact washers and pressurised warm water to mine water, with a pH of between 9 and 12. The purpose of the daily washing though is the clear any build up of coal dust on hot surfaces that might ignite.

Most of the mines do not have a formal shut down procedure for non-flameproof bakkies. Shutting down a vehicle forms part of general safety regulations, namely finding a safe parking spot, applying the park brake, cutting the engine, inserting gearlock (if fitted), swiping the smart card (if fitted) and inserting stop blocks behind the wheels (if required by the mine). For flameproof vehicles, an extra (cumbersome) requirement is to ensure that the accumulator is charged, so that the vehicle can be started again. The parking procedure therefore forms part of the general training given to the drivers of bakkies in the underground environment.

Bakkies are used for the following purposes:

- Supervisory vehicle: This vehicle does not carry a heavy load and usually transports the supervisor and two to three colleagues and or visitors. Supervisory vehicles make up a small part of the total number of non-flameproof vehicles.
- Personnel transporter: Many of the bakkies are adapted to carry personnel in standard or pony (bakkie and trailer) configurations.
- Material or equipment transporter: Some bakkies are converted to a mobile workshop, or is assigned to the fitters.
- Explosives transporter: This vehicle is exclusively used to transport explosives into the mine.
- Ambulance: Some mines prepare one or more bakkies to serve as an ambulance.

Unless the bakkie is converted as a dedicated mobile workshop, only small hand held tools are allowed to be transported with personnel. Some of the bakkies are equipped with a stowage facility under the seats, while at other mines tools are placed on the floor, or even on the seat.

3.2.4 Vehicle maintenance (questionnaire paragraph 2.4)

Most of the bakkies have logbooks in which services, faults, checks etc. are noted. All bakkies undergo some form of pre-start check at the beginning of each shift. An example
of this pre-start check is presented in Appendix B. Some of the pre-start checks are logged electronically or monitored by the smart card system.

Service intervals are usually determined in conjunction with the supplier and may be time based, distance based or both. Apart from the daily checks, safety services are usually carried out on a two weekly basis or every 2500km, whichever comes first. Routine maintenance and checks also form part of the conditions for exemption granted to mines using non-flameproof (and flameproof) vehicles in fiery mines.

Due to concern that mine water with a high sulphur content might be used to top up the radiator (which may cause engine overheating), there was enquired whether the sulphur content of radiator water is checked. None of the mines check the sulphur content of radiator water, but all gave the assurance that only fresh water and anti-freeze are used in the radiators.

In most of the mines the particulate emissions are not checked, but the general air quality is monitored by the environmental department. Only one mine do check the particulate emissions during the two-weekly safety service, while another mine’s flameproof vehicles were checked on a six monthly basis by the flameproof suppliers.

None of the mines check derated diesel injection pumps and usually send pumps to the supplier for repair or calibration. Pumps are sealed and calibration certificates are supplied. At some of the mines it is possible to obtain a diesel injection pump from the store, but at most of the mines no diesel injection pumps are kept in stock and all maintenance is subcontracted. The garage foreman is usually responsible for services carried out by the mine, while the driver is responsible for checks, but ultimately the engineer is responsible for a safe working condition of the vehicle.

The brakes of all bakkies are tested on a regular basis, although not all brake tests are the same. One mine makes use of only a test ramp, while two mines use the Simret or Brakcor device, as well as the test ramp, and another two use only the Simret test device. The two non-fiery mines perform a brake hold test, where the service brake is applied with the engine running at wide open throttle in gear (only on automatic vehicles). To pass the test, the vehicle must remain stationary during this test. The Simret device was developed by the British Safety in Mines Research Authority and determines the brake efficiency of the vehicle. A complete description of the device is supplied in Appendix C.

3.2.5 Accident statistics (questionnaire paragraph 2.5)

At the time of writing this report, none of the mines could confirm any fatalities caused by accidents involving non-flameproof vehicles. Some minor accidents did however occur, the cause of which was speeding, lack of discipline or unauthorised use.

3.2.6 Modifications to commercial bakkies (questionnaire paragraph 2.6)

All the fiery mines perform only minor modifications to bakkies and usually receive a vehicle that is built to specification from the supplier. The two non-fiery mines are more involved in the modification process and one of these mines performs all modifications in-house. The most common modifications made to non-flameproof vehicles to be used in fiery mines include the following:
• Modification of load box to accommodate people, or the fitting of a fifth wheel to pull a pony trailer.
• Canopy or other form of FOPS
• Gear lock
• Fail safe brakes
• Rubberised load box and chassis
• Smart card system for monitoring access and other parameters such as vehicle speed, engine speed, and temperatures
• Spark arrestor
• Differential breather pipe extended to under load box (to prevent water from entering)
• Lower differential gear ratio
• Governor set to limit engine speed at predetermined value
• Derated diesel injection pump
• “Non-flameproof” sign writing on the doors
• Fire extinguisher
• Sealed lights
• Reverse siren
• Other cosmetic changes to enhance the durability

The following modifications are made to vehicles used in non-fiery mines:
• Vehicle identification number
• Fail safe brakes
• Canopy
• Rotating lights
• Rearward facing spot lights
• Lockout of higher gears
• Locked in permanent 4x4
• Main isolator battery switch
• Stop blocks
• Fire extinguisher
• Bull bars (front and rear)
• ROPS
• FOPS

Modifications to bakkies cost the mines between R15 000 and R100 000, depending on the type of modifications. Approximately half of the mines added additional lights, such as
revolving lights, to the vehicle to make it more visible, while only the vehicles used in the
non-fiery mines were equipped with lights that illuminates the load box. All the bakkies
were fitted with some form of FOPS or canopy, while only the two non-fiery mine vehicles
had a proper ROPS. Most of the vehicles had standard mild steel exhaust systems, unless
they were flameproof or semi-flameproof. Two vehicles were fitted with a spark arrestor
and purifier respectively. None of the non-flameproof vehicles were fitted with special
sealed batteries neither were they inside a protection box.

3.2.7 Service life (questionnaire paragraph 2.7)

The service life of some of the flameproof vehicles are close to 20 years. These vehicle are
modified extensively, or even rebuilt due to the harsh corrosive environment in which they
operate. Due to the high capital cost of a flameproof bakkie, these vehicles are constantly
being modified to be stronger, have thicker body panels and carry more load.

Non-flameproof vehicles, on the other hand remain similar to the standard vehicles and
have an expected service life of 3-5 years. The reason for the shorter service life is that the
vehicles will be sold or bought back by the supplier and replaced with new vehicles. These
vehicles will probably last longer than 5 years due to the extensive maintenance program
an daily washing.

Replacement of vehicles are based on the following factors:

- Operating cost (flameproof and bakkies in non-fiery)
- Reliability
- Financial considerations (resale value vs. replacement cost)
- Availability

3.2.8 Trailers (questionnaire paragraph 2.8)

Only two of the seven mines make use of trailers to transport up to 22 personnel to and
from the mining section. Figure 10 shows a photograph of such a trailer. Also clearly
visible in this photograph is the stop block behind the bakkie’s rear wheel and the air hoses
used for assisted braking on the trailer. Some of the pony trailers are configured as an
ambulance. The vehicle trailer combination is rated to carry the full GCM (Gross
Combined Mass) of 3880kg.
3.2.9 Operating environment (questionnaire paragraph 3.1)

The width of the roads on most mines varies between 6m and 6.5m, while one mine has roads of between 3.5m and 3.8m. The radius of turns inside the mine are between 3m and 5m and in coal mines the turn radius is determined by the pillar spacing. None of the mines makes use of cambered roads to reduce lateral acceleration in turns.

Vehicles are taken into the mine, either by the shaft lift, or are driven down a steep incline. The inclines on most of the fiery mines range between 8% (4.5°) and 10.5% (6°), while the inclines in the non-fiery mines were 29% (16°) and 32% (18°). Since the average gradient on public roads is not more than 10.5% (6°), it is evident that the inclines encountered in the two non-fiery mines are much greater than those found on public roads.

3.2.10 Storing environment (questionnaire paragraph 3.2)

Bakkies are either stored in designated parking areas underground, or on the surface in hangers. No special ventilation is provided in the underground parking areas and normal underground ventilation is used. The ventilation is generally described as good to very good.

3.2.11 Competence of operators (questionnaire paragraph 4)

All the mines have some sort of training program for the designated drivers, including a theoretical and practical exam. Depending on whether the driver needs to negotiate steep inclines, the training program will contain hill descent and hill parking training. Most mines require drivers to have a code 08 drivers’ licence and complete an approved training course.
Drivers are taught about general vehicle maintenance, such as checking fluid levels, tyres and visible damage. Only one of the seven mines allows multiple drivers for one vehicle (anyone with a valid licence), while the others have strict access control to vehicles. This is done by implementing one or more of the following:

- One set of keys, signed for by the driver and kept by the driver at all times
- Gearlock
- Alarm/immobiliser
- Smart card authorisation

3.2.12 Enforcement (questionnaire paragraph 5)

Sometimes the maximum speed that a vehicle can attain is limited by ride comfort, or the quality of the road. All the mines do however have a speed limit, which is prescribed by mine management as a safe speed. Two mines have a speed limit of 15 km/h, one a limit of ±17 km/h (maximum speed in first gear), one a limit of 30 km/h and three mines have a speed limit of 40 km/h. The speed limit is enforced in various ways, of which the smart card system and gear lockout are probably the most effective. The smart card system will sound a warning buzzer when the maximum speed is exceeded and will log an event when the threshold number of warnings is exceeded. Smart card information is downloaded on a regular basis and disciplinary action is taken against drivers that exceed the speed limit. Gear lockout is very effective since the maximum vehicle speed is determined by the maximum geared speed of the highest available ratio. This is a very simple, yet effective system, since no smart card system is required to monitor speeding. In some mines radar is used the catch speed offenders, while others rely only on the discipline of their drivers not to exceed the speed limit.

The 180m safety zone from the face is demarcated with signs and flashing lights, but none of the smart card systems prevent access to this areas, although is should be possible.

3.2.13 Comments on DME requirements (questionnaire paragraph 6)

Most of the mines feel that exemption to use non-flameproof bakkies is very valuable and they will abide by the regulations in order to maintain exemption to use these vehicles. Some of the mines feel that the 200°C temperature limit on all surfaces and exhaust gas may be a bit low and that the origin of the 200°C is not known. Only one mine has commented on the SABS 1589 braking specification, namely that the bakkies comply with road ordinance and would therefore be able to negotiate any gradient on a public road. If the inclines found in the mines are of the same order, it should therefore be able to negotiate inclines found in mines. One of the mines felt that the air velocity meters are unnecessary.

3.2.14 Summary

It is evident from the preceding paragraphs that although four of the five fiery mines do employ non-flameproof vehicles, they all go about it in a different way. This may be due to the way the mine is managed, or the specific technical requirements of each mine. It does however appear that some of the mines did not go through the same development and research effort, as did the pioneers of non-flameproof bakkies. Since all vehicles are not
necessarily equally well suited for deration, or engine modifications, each vehicle will have to be evaluated individually.

All the mines have a good driver training program in place and monitor the use of bakkies carefully. It is also very noticeable that at most mines, although the non-flameproof vehicles are still new, very little accidents and almost no fatalities or injuries were recorded since the introduction of non-flameproof bakkies. From the response of the mines to the questionnaire is can be concluded that the mines will go a long way to retain exemption to use these vehicles.

3.3 Visits to industry

A number of industry role players, including the flameproof equipment manufacturers were visited during this project, e.g.:

- Elgin Flameproofing
- CAE
- Turnkey instruments
- MIH Engineering
- Toyota Secunda

Each of the abovementioned companies will be discussed briefly in the following paragraphs.

3.3.1 Elgin Flameproofing

Elgin is one of the leaders in the flameproofing industry in South Africa. Elgin develops, manufactures, installs and maintains flameproof equipment for mines and is responsible for the flameproofing of many vehicles currently being used.

One very important sub-system of the Elgin flameproof system is the scrubber box. The purpose of the scrubber box is twofold, namely to cool the exhaust gas, as well as to clean the exhaust gas of particulate matter and other emission products. There are currently two basic systems available namely the wet and the dry scrubber. The wet scrubber system is the most common one and works on a principle of circulating exhaust gas through a water filled container. The dry scrubber system uses engine water to cool exhaust gas in a heat exchanger arrangement and do therefore not come into direct contact with the exhaust gas. A diagrammatic layout of the two systems is presented in Appendix D. These are not the only two scrubber concepts, but since the wet scrubber is most commonly used, it is included in this section.

Elgin is very concerned about the use of non-flameproof vehicles, especially regarding the non-flameproof engine, the enforcing of the 180m safety zone, the 200°C temperature limit and the quality of exhaust emissions. Elgin feels that the mines should adhere to the SABS 868 specification and that exemption should only be granted for flameproof vehicles conforming to the SABS 868 standard.
3.3.2 CAE

Stellenbosch Automotive Engineering Pty (Ltd) trading as CAE specialises in vehicle engines and was contracted by Sasol Secunda to derate the first non-flameproof prototype vehicle. This vehicle, a Toyota 2.4l diesel, was successfully derated to within the required temperature limits, with sufficient power left for performing useful work.

Although CAE managed to derate the engine to within the temperature limits, no realistic exhaust emission specification for underground vehicles could be found to date. CAE is however prepared to be part of a committee to establish a realistic derating procedure and exhaust emission specification.

CAE recently conducted tests on a non-flameproof vehicle fitted with a derated injection pump and found that the maximum allowable manifold temperatures are exceeded by up to 50°C. It was concluded from these measurements that the manifold surface temperature may vary significantly at different positions on the manifold. The hottest part of the manifold should be in the region where the individual runners merge into the downpipe. The exhaust manifold temperature may therefore not necessarily be measured in the hottest spot on some of the existing non-flameproof vehicles.

3.3.3 Turnkey Instruments

Turnkey Instruments are the sole suppliers of the SIMRET 3000 device. The SIMRET device is currently used by many of the mines to verify the correct working of their bakkie’s braking system. The SIMRET is based on the ISO 3450:1996 standard and calculates the brake efficiency based on measured data. Similar devices are marketed by Brakecor and Wabco.

Appendix C contains more detailed information on the SIMRET test device.

3.3.4 MIH Engineering

MIH Engineering is based in Evander and is an accredited SABS 868 test authority. They also supply flameproof equipment and fail safe braking systems. Mr. TC Joubert from MIH is one of the committee members assigned to reviewing the current SABS 868 standard.

MIH Engineering feels that there is nothing wrong with the concept of non-flameproof vehicles, but feels that it should be properly regulated. The regulations should include testing procedures / authorities, minimum vehicle specifications, as well as implementation guidelines from the DME.

3.3.5 Toyota Secunda

Toyota Secunda was not willing to share any information regarding non-flameproof bakkies, since they believe that the information they currently have give them a competitive advantage in the market.
3.4 SABS 868

3.4.1 Background

The first edition of the SABS 868 standard was published in 1967 and was amended in 1969, 1970, 1972, 1976, 1977, 1983 and 1988. The title of the 1967 standard was: “Standard Specification for Diesel engines for use in fiery mines”. This document was superseded by the current SABS 868:1997 standard. The current edition consists of two parts namely engine subassembly (SABS 868-1) and adapted engine and ancillary equipment (SABS 868-2). The SABS 868 standard will be discussed in the following paragraphs, with reference to changes made from the 1967 to the 1997 edition, as well as other aspects that are currently being investigated by mines and industry.

3.4.2 Discussion

In essence, the first and second editions of the SABS 868 standard cover the same aspects and in many instances the same wording was used. Parts discussing dry flame arrestors were added and the only major difference between the standards, which is also the topic of debate in the mining community, is the temperature limits.

Temperature limits are assigned to various parts of the engine, as well as the exhaust gas. Table 1 indicates the difference between the first and second edition in terms of temperature limits. From this table, it can be seen that the limits for exhaust gas were increased, while the limit for surface temperature was lowered.

Table 1: Changes in temperature limits from SABS 868:1967 to SABS 868:1997

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Any surface</td>
<td>204°C</td>
<td>150°C</td>
</tr>
<tr>
<td>Exhaust gas</td>
<td>85°C</td>
<td>150°C</td>
</tr>
</tbody>
</table>

Requirements in terms of exhaust gas quality did not change significantly. One addition to the SABS 868:1997 is the specification of the diluted exhaust gas quality.

3.5 SABS 1589:1997

The SABS 1589:1997 braking standard will be discussed in detail in this section. The title of this standard is “The braking performance of trackless underground mining vehicles – Load haul dumpers and dump trucks”. From the title of this publication it can already be speculated whether this document is applicable to commercial vehicles such as bakkies in the underground environment. The service brakes, emergency brakes, park brakes and fail-safe brakes are discussed in the SABS specification. In order to evaluate the braking performance requirements for bakkies as stated by this standard, the specification for vehicles used on public roads will be used as benchmark.

The SABS 1589 standard addresses the following types of brake tests:

- Service braking
• Emergency braking
• Park braking
• Fail-safe braking

According to SABS 1506:1994 (see reference 6.vi), one ton bakkies are classified as class N2 vehicles. This is in accordance with the directives of the European Community (71/320/EEC) and ECE regulation no. 13 with regards to braking. These bakkies are however converted to personnel transporters, which places it in the M2 category, i.e. passenger vehicles with at least four wheels, which carries more than 9 passengers and weighs less than 5 tons.

The braking requirements of M2 vehicles, according to the international standard, are as follows:

Type O test (engine disengaged): braking from 60km/h in less than 36.7m.
mean fully developed deceleration of 5m/s²
braking force of less than 700N

Type O test (engine engaged): test speed 80% of maximum speed, but not more than 100km/h
braking distance less than 111.6m
mean fully developed deceleration of 4m/s²
braking force less than 700N

Type I test (brake fade test): test speed 80% of maximum speed, but not more than 100km/h
brake to half of starting speed
perform 15 cycles with a 55s duration

From SABS 1589 and SABS 1506:1994 it can be seen that the specification for road vehicles are more strict in terms of stopping distance and mean fully developed acceleration. The SABS 1506 does, however, not address fail-safe brakes.

### 3.6 DME documentation

Documentation generated by the DME regarding underground commercial vehicles will be discussed in this section. The documents are discussed in chronological order and comments will be made on each document based on the information currently available. The following documents are discussed:

i Minimum requirements for the transport of persons and material by means of a vehicle propelled by a non-flameproof compression ignition (diesel) engine in a location other than the hazardous location underground in a fiery mine, 1 November 1999.

ii Non-flameproof compression ignition engine requirements, 10 November 1999.
3.6.1 Minimum requirements for the transport of persons and material by means of a vehicle propelled by a non-flameproof compression ignition (diesel) engine in a location other than the hazardous location underground in a fiery mine, 1 November 1999.

This document was intended as a guide to the person responsible for personnel/material transport with non-flameproof bakkies. The document addresses issues such as the engine, brakes, ventilation, maintenance, logbooks and washing. Although this document touches on the most important matters and states specific requirements, details are lacking in some areas. This includes amongst others that the maximum exhaust manifold temperature must not exceed 200°C, but it is not specified where on the manifold this temperature should be measured. The temperature may vary significantly from place to place on the manifold.

This document was a good starting point to make potential users of non-flameproof vehicles aware of the basic requirements, although sufficient information and/or guidelines needed to implement non-flameproof vehicles are not supplied.

3.6.2 Non-flameproof compression ignition engine requirements, 10 November 1999.

This document is based on document 3.6.1. The technical content of the document did not change much, with the only major changes to the document title and the trailer brakes section. The title of this document is much shorter and more understandable than the previous one.

3.6.3 Non-flameproof compression ignition engine and vehicle requirements, 24 November 1999.

This document is based on document 3.6.2, and includes changes made by employees of the DME. The title was changed to include vehicle and not just engine requirements. Changes were also made to the paragraph about the deration of injector pumps, which require all vehicles, except prototype vehicles to be derated by an accredited testing authority and SABS 0166 permit holder. Minor changes were made to the ventilation section namely that the person on duty, who is a valid gas testing certificate holder, must permit the restart of an engine after it has been shut down due to a hazardous condition.

3.6.4 Non-flameproof compression ignition LDV engine approval requirements, 14 February 2000.

This document is an update of document 3.6.3. In the title of the document, the term vehicle was replaced with LDV (Light Delivery Vehicle). The title therefore signifies that the document is only about the engine requirement and only engines of LDV’s. Although
the scope paragraph was reduced to two lines, the objectives remained unchanged. Extensive modifications were made to the paragraph about minimum standards for non-flameproof transporters (safety devices) and the paragraph about brake requirements were removed.

The paragraph concerning the requirements for safety devices now only states that a fail-to-safe device is required that will cut the fuel supply to the engine when the exhaust manifold surface temperature exceeds 200°C. No mention is made of engine temperature, exhaust gas temperature, or engine water level. The exact location of the manifold temperature measurements is still not supplied.

Reference to the SABS 868 specification concerning emission levels was removed. The document now only states that vehicles should comply with regulation 10.6.6. The requirement for vehicles to be equipped with adequate fire extinguishing equipment was also removed. Other minor changes to the wording include replacing the word vehicle with LDV.
4. Results

4.1 Vehicle requirements

A number of vehicle related requirements that would improve safety will be discussed in the following paragraphs.

4.1.1 Lights and lighting

Lights and lighting is a very important aspect of underground vehicles, since lights enable the driver to see the road, obstacles and pedestrians, as well as to make the vehicle visible to other road users and pedestrians. Lights on flameproof vehicles are very small and do not provide the same luminescence, as do the lights on bakkies. All commercially available bakkies comply with SABS 1376 and SABS 1046, which are standards pertaining to vehicle lights and lighting.

The headlights of the vehicle should therefore be more than adequate for underground use, compared to flameproof vehicles. One area in which the lighting of non-flameproof vehicles can be improved is lighting for passengers that have to alight from the rear of the vehicle. Only the two non-fiery mines provided additional lights to illuminate the rear of the vehicle.

The visibility of bakkies can therefore be improved by the addition of revolving lights and the load area can be illuminated to ease access for passengers.

4.1.2 Traction

Traction forces are generated between the tyre and the road and transmit the tractive effort generated by the engine to the road. The amount of tractive force that can be transmitted to the road may be limited by either available engine power or by the available traction between the tyres and the road. Figure 11 shows the front (Fxf) and rear (Fxr) tractive forces that a vehicle can generate. If the available traction is exceeded the tyres will start spinning and the tyres will be unable to generate side force. This may lead to the vehicle becoming unstable and loose steerability.
Traction is very important when vehicles are driven up or down steep inclines. Four wheel drive vehicles have the advantage over two wheel drive vehicles that all four wheels are used to transmit the traction force to the ground. From the mine visits, it was found that the mines with steep inclines make use of 4x4 bakkies.

The road surface determines to a great extent the traction coefficient and for gravel roads this coefficient may vary between 0.3 and 0.6. This means that the vehicle will only be able to transmit between 30% and 60% of the vehicle weight as traction force.

Appendix E contains tractive effort graphs of some of the bakkies currently being used in the mines. These graphs indicate the amount of tractive effort available from the vehicle in each gear, as well as the traction limits for traction coefficients ($\mu$) of 0.3 and 0.6 (traction limits for only a levels surface is shown). The magenta lines indicate the required traction force to overcome rolling resistance, air resistance as well as the gradient resistance (gradients of 0°, 5°, 10° and 15° are indicated).

Form these graphs it can be seen that for many of the bakkies, the tractive supply in first and even second gear is more than the tyre ground interface can handle, i.e. the supply exceeds the available traction (engines not derated yet). This means that it would be possible to spin the wheels on this surface by driving at wide open throttle. The tractive effort diagrams can also be used to determine beforehand if a vehicle with a derated engine will be able to negotiate the inclines found in the mine.

It must however be noted that the graphs supplied in Appendix E are for engines that have not yet been derated. The tractive performance of the derated engine will have to be determined, in order to perform a tractive effort analysis like this. This should form part of the HIRA for using the vehicle in the mine.

Traction can be improved by one or more of the following:

- 4x4 instead of 4x2
- better road surface on inclines (higher traction coefficient)
- tyres with more grip (higher traction coefficient)
• more ideal torque split between front and rear wheels (more torque on tyres that are carrying more load)

4.1.3 ROPS

The SABS 1563:1992 standard prescribes the requirements for a ROPS (see also ISO 3471). From the tests prescribed in this standard and visual assessment of bakkies seen at the mines, it can be concluded that only a few bakkies would comply with this standard. Many of the non-flameproof bakkies do not have an adequate ROPS.

The ROPS on bakkies used to transport personnel should be designed in accordance with the SABS 1563 standard, otherwise the overhead structure would provide no protection in case of a roll-over and might even pose a danger to the occupants.

4.1.4 FOPS

Most of the bakkies were fitted with some form of FOPS. The FOPS may form part of the ROPS and should at least be able to protect occupants from falling debris within reasonable limits. The ISO 3449:1992 standard states the requirements for FOPS on earth moving machinery.

4.1.5 Ergonomics

Bakkies are manufactured on a very large scale and the manufacturer can afford to spend money on the design of a good ergonomic layout. The flameproof personnel transporters, on the other hand, are manufactured in limited quantities and often are not well designed in terms of ergonomic considerations.

In general, the non-flameproof vehicles are ergonomically well designed for passengers, as can be seen in Figure 13. From this figure, it can be seen that the passengers have easy access to the vehicles loadbay and that each passenger has his own a grab handle.

4.1.6 Braking

The SABS 1506:1994 standard incorporates the EEC directives concerning braking devices of motor vehicles and their trailers, as well as several other EEC directives. Although underground vehicles do not form part of the scope of the SABS 1506 specification, the non-flameproof vehicles are designed, tested and homologated according to this specification (for above ground use). Applying the SABS 1589 braking standard to non-flameproof bakkies would therefore not be appropriate. It is therefore recommended that SABS 1506:1994 braking standard be applied to all bakkies (flameproof and non-flameproof), as well as semi-trailers (poni bus) used in the underground environment.

4.1.7 Add on devices

Most of the mines listed a lack of discipline as the cause of accidents and injuries. It is therefore recommended that add-on devices such as the smart card system be considered for controlling and monitoring access to the vehicle. The following items can be considered for add-on extra’s that would improve safety:

• Smart card system
• Gear-lock
• Spark arrestor
• Reverse siren
• Fire extinguisher
• Extra lighting or rotating lights
• Stop blocks (if steep inclines are negotiated)

4.1.8 Surface temperatures

To determine the ignition and combustion properties of pulverised coal for typical South African conditions, Technology Services International, a subsidiary of ESKOM Enterprises, developed tests procedures using the Relative Ignition Temperature Apparatus (RITA). This apparatus is used in combination with a pilot scale combustion commonly termed a Drop tube furnace Apparatus for Combustion Kinetics (DACK). This apparatus is capable of combusting a single coal particle in a very well controlled environment which can be considered one-dimensional and non-turbulent, and allows the determination of very accurate time and Temperature histories (see reference 6.vi).

Van der Riet (reference 6.vii) indicated that, based on test work with the apparatus described above, “the sustained ignition temperature for Grootegeluk (upper Ecca) coal is 630°C, for New Vaal coal to be consistently above 550°C and the Witbank coals all grouped around 600°C.” Van der Riet cautioned that “all these temperatures represent cloud ignition with an external heat source, and therefore do not represent the condition under which coal dust packs onto a vehicle exhaust system. Because heat could not build up in the packed coal dust scenario at the same rate, cloud ignition offers far better conditions for a coal to ignite. This would primarily be due to less oxygen diffusion limitations. The cloud ignition temperature should therefore be lower than the packed coal dust ignition temperature.”

The origin of the current 200°C surface temperature limit is thought to be either adopted from some British regulation or from the specification for “Electrical apparatus for explosive gas atmospheres” (SABS IEC 60079-0, see reference 6.v). Unofficial coal dust surface ignition temperatures were obtained from a Norwegian gas explosion consultancy named GexCon. The ignition temperatures for coal dust layers (of Derner coal) is indicated in Table 2.
Table 2: Minimum coal dust surface ignition temperatures for Derner coal

<table>
<thead>
<tr>
<th>Layer thickness</th>
<th>Ignition temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>5mm</td>
<td>260°C</td>
</tr>
<tr>
<td>10mm</td>
<td>240°C</td>
</tr>
<tr>
<td>15mm</td>
<td>210°C</td>
</tr>
<tr>
<td>30mm</td>
<td>195°C</td>
</tr>
<tr>
<td>50mm</td>
<td>170°C</td>
</tr>
</tbody>
</table>

From Table 2 it can be seen that the layer thickness has a big influence on the ignition temperature. It must however be noted that these temperatures are also a function of the induction time.

4.1.9 Exhaust gas quality

The wet scrubber system is effective for removing exhaust gas pollutants, when it is well maintained. The wet scrubber system is often cumbersome to maintain properly since the water levels have to be checked and topped up regularly. Since the flameproof transporters are very heavy they have large diesel engines, compared to the bakkies. Most bakkies already comply with strict emission levels, and if well maintained, should be safe for use in a well ventilated (standard mine ventilation as required by law) underground area.

4.1.10 General

In general, bakkies are safer than previous modes of transport, such as tractor trailers, busses etc. Figure 12 indicates a vehicle previously used for personnel transport and Figure 13 displays the layout of a non-flameproof personnel transporter. The old transporter is heavy, expensive to maintain, unreliable, difficult to manoeuvre, ergonomically poorly designed for the driver, as well as passengers and required numerous non-standard parts. The non-flameproof bakkie is inexpensive to maintain, ergonomically well designed, equipped with standard safety features such as seat belts, crumple zones, effective brakes etc.

Apart from the fact that the bakkie is not flameproof, the bakkie is safer than the old transporter in almost all other respects.
Figure 12: Fermel personnel transporter

Figure 13: Non-flameproof bakkie
4.2 Process requirements

4.2.1 Servicing

Most of the mines have very good maintenance schedules and apart from the daily pre-start inspection, service their bakkies on a two weekly basis. This frequency of the service interval seems high enough to detect and rectify any major mechanical fault that might occur during this time.

4.2.2 Washing

Until more detailed information regarding the surface ignition temperature of coal dust becomes available it is recommended that non-flameproof vehicles be washed on a daily basis, especially in places where coal dust is likely to accumulate on hot surfaces.

4.3 Financial implications

All the mines implementing non-flameproof bakkies indicated that the capital expenditure, as well as the maintenance cost of their personnel transporter fleet decreased dramatically. Although the capital and running cost of non-flameproof vehicles might be lower than that of flameproof vehicles, other costs for better washing facilities, warning devices, the smart card system and a more in-depth training might be more. It is recommended that a detailed financial impact study be performed prior to the implementation of non-flameproof vehicles. If only a very small fleet of flameproof bakkies are used, it might make financial sense to maintain the flameproof vehicles rather than develop and implement non-flameproof vehicles.

4.4 Hazard Identification and Risk Assessment (HIRA)

In order for any mine to obtain exemption to use non-flameproof vehicles a Hazard Identification and Risk Assessment (HIRA) has to be completed. The purpose of this assessment is to identify significant hazards and then to state how these risks can be removed, contained or minimised. Table 3 indicates a typical HIRA for the use of a non-flameproof bakkie in a fiery mine. In this table, risks unique to non-flameproof bakkies are supplied, since hazards pertaining to vehicles in general should already be addressed. The information supplied in Table 3 is by no means comprehensive and should only be used as guidelines. Each mine should perform a HIRA for its own circumstances and should score the probability and impact of the events based on the conditions in the mine.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Hazard</th>
<th>Criteria for safe use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine overheating</td>
<td>Ignition of coal dust</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Engine temperature indicators and warning devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Monitoring of engine temperature and shutdown on overheating</td>
</tr>
<tr>
<td>Exhaust surface temperature</td>
<td>Ignition of coal dust</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td>exceed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3: Example of HIRA for non-flameproof bakkies
<table>
<thead>
<tr>
<th>Condition</th>
<th>Hazard</th>
<th>Criteria for safe use</th>
</tr>
</thead>
<tbody>
<tr>
<td>temperature exceed safe limit</td>
<td></td>
<td>• Exhaust surface temperature warning devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Shut down of engine when exceeding safe limits</td>
</tr>
<tr>
<td>Exhaust gas temperature exceed</td>
<td>Ignition of coal dust</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td>safe limit</td>
<td></td>
<td>• Exhaust gas temperature warning devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Shut down of engine when exceeding safe limits</td>
</tr>
<tr>
<td>Sparks form exhaust system</td>
<td>Ignition of coal dust</td>
<td>• Fitment of spark arrestor</td>
</tr>
<tr>
<td>Speed limit exceeded</td>
<td>Accident</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Visual and audible warning devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Smart card event logging and disciplinary action against offenders</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lock-out of high gears</td>
</tr>
<tr>
<td>Maximum load capacity exceeded</td>
<td>Accidents</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Load sensing and warning devices</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Smart card event logging</td>
</tr>
<tr>
<td>180m safety boundary exceeded</td>
<td>Ignition of coal dust</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Electronic prevention by cutting the engine</td>
</tr>
<tr>
<td>Steep inclines</td>
<td>Runaway vehicle</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Good quality road surfaces on inclines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• 4x4 drive vehicles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lock in low range (on 4x4 vehicles)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lock-out of high gears</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Accidents and ignition of</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td>coal dust</td>
<td>• Log books and maintenance schedules</td>
</tr>
<tr>
<td>Daily washing of vehicles</td>
<td>Ignition of coal dust</td>
<td>• Driver training and discipline</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Smart card monitoring of wash bay usage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Part of pre-start inspection</td>
</tr>
<tr>
<td>Poor visibility</td>
<td>Accidents</td>
<td>• Fit vehicles with additional lights</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Illuminate load bay area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fit rotating lights</td>
</tr>
<tr>
<td>Non-derated injection pumps</td>
<td>Ignition of coal dust</td>
<td>• Control issuing of pumps at store</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Control at maintenance level</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Part of weekly checks</td>
</tr>
</tbody>
</table>
### 4.5 Decision making process

The research would be worthless if some kind of decision-making strategy was not proposed. An elementary process for choosing a suitable vehicle is outlined in Appendix F. It must however be stressed that this quick reference provides only guidelines and is greatly simplified. The quick reference guide is also intended to sensitise the responsible shaft engineer to various very important issues to be considered when choosing or developing a non-flameproof vehicle. The actual process requires a much more detailed process plan for the successful implementation of non-flameproof vehicles.
5. Conclusions and Recommendations

5.1 Conclusions

The following conclusions can be made:

i.) Many mines have already successfully implemented non-flameproof vehicles.

ii.) Although statistics indicate that vehicle related injuries account for a significant part of the total number of accidents, injuries and fatalities, it was found that accidents involving non-flameproof vehicles were minimal.

iii.) Initial indications are that well developed non-flameproof vehicles are safe to use in non-hazardous areas in fiery mines.

iv.) The standard safety specifications of commercially available bakkies in most cases exceed those found on flameproof personnel transporters.

v.) Non-flameproof bakkies are less expensive than flameproof bakkies in terms of procurement cost and maintenance, although the development cost might be more.

5.2 Recommendations

It is recommended that:

i.) The current SABS 868 standard be updated to include the specific requirements of non-flameproof bakkies.

ii.) Guidelines for compiling a COP regarding the use of non-flameproof vehicles in underground fiery mines be drafted, that addresses all aspects of the vehicle (not just the engine) (refer to MHSA paragraph 9).

iii.) The coal dust surface ignition temperature of coal form different mines be tested and the relevant specifications be amended.

iv.) The SABS 1589 braking standard for underground machinery be amended with specific requirements for LDV sized vehicles or the SABS 1506:1994 standard be applied to these vehicles.

v.) A HIRA be performed before the introduction of any non-flameproof vehicles (refer to MHSA paragraph 10).

vi.) Proper training programs should be compiled in the use and maintenance of non-flameproof vehicles (refer to MHSA paragraph 10).
6. References


viii.) Van der Riet, M. Personal communication, June 2000, Technology Service International (Pty) Ltd, a Subsidiary of Eskom Enterprises, Cleveland, Gauteng.
APPENDIX A: Questionnaire (5 Pages)
### QUESTIONNAIRE FOR MINES WITH REGARDS TO THE USE OF BAKKIES FOR TRANSPORTATION OF PERSONNEL AND GOODS UNDERGROUND.

<table>
<thead>
<tr>
<th></th>
<th>General information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><strong>Details of person completing this questionnaire</strong></td>
</tr>
<tr>
<td>1.1</td>
<td>Name</td>
</tr>
<tr>
<td>1.1.1</td>
<td>Surname</td>
</tr>
<tr>
<td>1.1.2</td>
<td>Title</td>
</tr>
<tr>
<td>1.1.3</td>
<td>Position</td>
</tr>
<tr>
<td>1.1.4</td>
<td>Telephone</td>
</tr>
<tr>
<td>1.1.5</td>
<td>Fax</td>
</tr>
<tr>
<td>1.1.6</td>
<td>e-mail address</td>
</tr>
<tr>
<td>1.1.7</td>
<td>Postal address</td>
</tr>
<tr>
<td>1.2</td>
<td><strong>Mine information</strong></td>
</tr>
<tr>
<td>1.2.1</td>
<td>Name of mine</td>
</tr>
<tr>
<td>1.2.2</td>
<td>Owner of the mine</td>
</tr>
<tr>
<td>1.2.3</td>
<td>Location of mine</td>
</tr>
<tr>
<td>1.2.4</td>
<td>Main mining product</td>
</tr>
<tr>
<td>1.2.5</td>
<td>Name of the mine manager</td>
</tr>
<tr>
<td>1.2.6</td>
<td>Production per year</td>
</tr>
</tbody>
</table>

### Vehicle data

<table>
<thead>
<tr>
<th></th>
<th>General vehicle information</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Make of Bakkies used in mine</td>
</tr>
<tr>
<td>2.1.1</td>
<td>Model of Bakkies used in mine</td>
</tr>
<tr>
<td>2.1.2</td>
<td>Number of each make and model of Bakkie used in mine</td>
</tr>
<tr>
<td>2.1.3</td>
<td>General comments on vehicle performance (with de-rated pumps)</td>
</tr>
<tr>
<td>2.1.4</td>
<td></td>
</tr>
<tr>
<td>2.2</td>
<td>Vehicle procurement</td>
</tr>
<tr>
<td>-------</td>
<td>---------------------</td>
</tr>
<tr>
<td>2.2.1</td>
<td>Who makes decisions during the procurement of Bakkies?</td>
</tr>
<tr>
<td>2.2.2</td>
<td>What procedure is followed when procuring commercial Bakkies?</td>
</tr>
<tr>
<td>2.2.3</td>
<td>What procedure is followed when applying for approval to use non-flame proof commercial vehicles?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.3</th>
<th>Vehicle operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.3.1</td>
<td>Are vehicles washed after each day’s work? If no, at what intervals?</td>
</tr>
<tr>
<td>2.3.2</td>
<td>What is the shut down procedure for Bakkies?</td>
</tr>
<tr>
<td>2.3.3</td>
<td>State list of general tasks in daily use of Bakkies</td>
</tr>
<tr>
<td>2.3.4</td>
<td>Are tools and/or equipment transported with personnel? If yes, are the tools and/or equipment fastened or stowed?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.4</th>
<th>Vehicle maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4.1</td>
<td>Is a logbook kept for each vehicle?</td>
</tr>
<tr>
<td>2.4.2</td>
<td>What is the service interval for vehicles?</td>
</tr>
<tr>
<td>2.4.3</td>
<td>Is the manufacturer’s service schedule followed, or is a revised service schedule implemented?</td>
</tr>
<tr>
<td>2.4.4</td>
<td>Is the sulphur content of radiator water checked during services? If yes, who does this and how is it done?</td>
</tr>
<tr>
<td>2.4.5</td>
<td>Is particulate emissions checked during services? If yes, who does this and how is it done?</td>
</tr>
<tr>
<td>2.4.6</td>
<td>Is the calibration of diesel pumps checked during services? If yes, who does this and how is it done?</td>
</tr>
<tr>
<td>2.4.7</td>
<td>What is the issuing procedure for diesel pumps from the storing facility?</td>
</tr>
<tr>
<td>Section</td>
<td>Question</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>2.4.8</td>
<td>Who is responsible for the maintenance of vehicles?</td>
</tr>
<tr>
<td>2.4.9</td>
<td>How is the braking system of the vehicles tested?</td>
</tr>
<tr>
<td>2.5</td>
<td>Accident statistics</td>
</tr>
<tr>
<td>2.5.1</td>
<td>Number of accidents involving Bakkies over the past 10 years.</td>
</tr>
<tr>
<td>2.5.2</td>
<td>Number of injuries over the past 10 years.</td>
</tr>
<tr>
<td>2.5.3</td>
<td>Number of fatalities over the past 10 years.</td>
</tr>
<tr>
<td>2.5.4</td>
<td>Major causes of accidents involving Bakkies.</td>
</tr>
<tr>
<td>2.6</td>
<td>Modifications to commercial Bakkies</td>
</tr>
<tr>
<td>2.6.1</td>
<td>Who makes modifications to commercial Bakkies (mine or sub-contractors)?</td>
</tr>
<tr>
<td>2.6.2</td>
<td>What type of modifications is made to the vehicles? Specify.</td>
</tr>
<tr>
<td>2.6.3</td>
<td>What costs is involved in modifying commercial Bakkies? Specify</td>
</tr>
<tr>
<td>2.6.4</td>
<td>Are vehicles equipped with reverse sirens?</td>
</tr>
<tr>
<td>2.6.5</td>
<td>Are additional lights fitted to the vehicle to make it more visible? Supply details.</td>
</tr>
<tr>
<td>2.6.6</td>
<td>Are lights fitted to the vehicle to illuminate the rear for passenger access?</td>
</tr>
<tr>
<td>2.6.7</td>
<td>Are vehicles fitted with canopies? Supply details (Make, model, material, dimensions)</td>
</tr>
<tr>
<td>2.6.8</td>
<td>Are vehicles fitted with methanometers?</td>
</tr>
<tr>
<td>2.6.9</td>
<td>Are vehicles equipped with ROPS (Roll Over Protection Structure)?</td>
</tr>
<tr>
<td>Section</td>
<td>Question</td>
</tr>
<tr>
<td>-----------</td>
<td>--------------------------------------------------------------------------</td>
</tr>
<tr>
<td>2.6.10</td>
<td>Are vehicles equipped with FOPS (Falling Object Protection Structure)?</td>
</tr>
<tr>
<td>2.6.11</td>
<td>Are vehicles equipped with special exhaust systems?</td>
</tr>
<tr>
<td>2.6.12</td>
<td>Is the battery inside a protection box? Supply details (construction, material etc.)</td>
</tr>
<tr>
<td>2.6.13</td>
<td>Are special sealed batteries used? If yes, state the make and type of batteries used.</td>
</tr>
<tr>
<td>2.7</td>
<td><strong>Service life</strong></td>
</tr>
<tr>
<td>2.7.1</td>
<td>What is the expected service life of a Bakkie in the mine? [years, kilometres]</td>
</tr>
<tr>
<td>2.7.2</td>
<td>What is the phasing out policy for Bakkies?</td>
</tr>
<tr>
<td>2.7.3</td>
<td>What is the main reason for the phasing out of a bakkie?</td>
</tr>
<tr>
<td>2.8</td>
<td><strong>Trailers</strong></td>
</tr>
<tr>
<td>2.8.1</td>
<td>Are trailers used with bakkies in the mine?</td>
</tr>
<tr>
<td>2.8.2</td>
<td>What makes of trailer are used?</td>
</tr>
<tr>
<td>2.8.3</td>
<td>For what purpose are trailers used in the mine?</td>
</tr>
<tr>
<td>2.8.4</td>
<td>What is the payload of the trailers?</td>
</tr>
<tr>
<td>2.8.5</td>
<td>Does the trailer have its own brakes, and what is the policy regarding trailer brakes?</td>
</tr>
<tr>
<td>3</td>
<td><strong>Environment</strong></td>
</tr>
<tr>
<td>3.1</td>
<td><strong>Operating environment</strong></td>
</tr>
<tr>
<td>3.1.1</td>
<td>Average width of roads used by Bakkies [m].</td>
</tr>
<tr>
<td>3.1.2</td>
<td>Maximum inclines to be negotiated by Bakkies [° or %].</td>
</tr>
</tbody>
</table>
### 3.1.3 Average radius of turns [m].

### 3.1.4 Are sharp turns cambered? If yes, specify camber angle [°].

#### 3.2 Storing environment

- **3.2.1** Where are vehicles stored?
- **3.2.2** What type of ventilation is provided in the storage area?

#### 4 Training & Education

##### 4.1 Operation of vehicles

- **4.1.1** Are drivers given hill decent training?
- **4.1.2** Are drivers given hill-parking training?
- **4.1.3** Are drivers given general training on the maintenance of vehicles? If yes, specify the type of training.

##### 4.2 Are designated drivers certified by a responsible person?

#### 5 Enforcement

- **5.1** What is the speed limit for Bakkies underground?
- **5.2** How is the speed limit enforced?
- **5.3** How is the 180m safety zone from the mining face enforced?

#### 6 Comments on DME requirements

- **6.1** What is the mine's position on the specified maximum exhaust temperature of 200°C?
- **6.2** Comments on SABS868.
- **6.3** Comments on SABS1589.
- **6.4** General comments.
APPENDIX B: Example documentation (2 Pages)
<table>
<thead>
<tr>
<th>Section</th>
<th>VEHICLE ID</th>
<th>HR. METER READ SOS</th>
<th>HR. METER READ EOS</th>
<th>OPERATOR NAME (PRINT)</th>
<th>COY. NO.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift</td>
<td>Date</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTE:**

I hereby declare that I have inspected this vehicle and am satisfied that it is roadworthy.

<table>
<thead>
<tr>
<th>Daily Operations Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work</td>
</tr>
<tr>
<td>FROM</td>
</tr>
</tbody>
</table>

**Legend:**

- **BD** = Breakdown
- **PM** = Planned Maintenance
- **S/BY** = Standby
- **WORK** = Working

**Signatures:**

- [ ]

**DE BEERS CONSOLIDATED MINES LIMITED - PREMIER MINE**
Simret 3000
Portable Brake Tester with Printer

Quick & Easy One Man Operation
Display Indicates Brake Efficiency
Built in Printer for Permanent Records
Internal Memory saves up to 50 Tests
Simret 3000 portable brake tester

The Simret 3000 brake tester simplifies the routine testing of heavy vehicle and machine braking systems to ensure compliance with Health and Safety Regulations.

| Range          | 0 to 100% g  
g = 9.81 metres/sec/sec |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>±0.5%</td>
</tr>
<tr>
<td>Display</td>
<td>alphanumeric LCD with backlight, 2 lines of 16 characters</td>
</tr>
<tr>
<td>Printer</td>
<td>built-in 40 column dot matrix type with graphics</td>
</tr>
<tr>
<td>Memory</td>
<td>32k bytes with battery backup, saves up to 50 brake tests</td>
</tr>
<tr>
<td>Clock</td>
<td>accurate to 1 minute per month, months and leap years adjust automatically. All tests are timestamped.</td>
</tr>
<tr>
<td>Battery</td>
<td>sealed lead acid, rechargeable, 12 hours operation from a full charge</td>
</tr>
<tr>
<td>Size</td>
<td>220 x 140 x 110mm</td>
</tr>
<tr>
<td>Weight</td>
<td>4.5kg nett</td>
</tr>
<tr>
<td>Bar code</td>
<td>for plant and operator identification</td>
</tr>
<tr>
<td>Pedal Force Transducer</td>
<td>allows SIMRET to record and print the applied pedal force, 1500 Newtons max.</td>
</tr>
<tr>
<td>PC-Link and WinSim</td>
<td>transfers stored brake tests to your PC to allow further graphical analysis and database creation. Requires PC with Windows 3.1 or Windows95.</td>
</tr>
</tbody>
</table>

Many heavy vehicle accidents are due to defective brakes. Using Simret regular brake testing will identify deteriorating brakes before an accident occurs but, before Simret, there was no reliable method to allow operators to carry out accurate tests on-site. Judging distance between marker posts is not accurate because errors in speed or when the driver applies the brakes give widely differing results.

Now the Simret 3000 brake tester solves the problem by giving an accurate printed record of brake efficiency regardless of vehicle speed, ground conditions or slope. All printouts show the time and date of the test and your plant and operator details can be added, plus hard copy evidence of the test taking place.

Looking back over previous printouts of a vehicle will show deterioration in the brakes so that action can be taken before it’s too late.

Simret 3000 is supplied as a complete ready to use kit which includes leather carrying case for the instrument and its accessories, mains powered battery charger, a trigger pad and full instructions. Available as extras are the Pedal Force Transducer, PC-Link and WinSim, and bar code kit which includes wand and customised bar code tags for your plant.
APPENDIX D: Elgin wet and dry scrubber systems (2 Pages)
APPENDIX E: Traction graphs (5 Pages)
Nissan Hardbody 3.2D 4X4 (High range)

Vehicle speed [km/h]

Traction force [N]

1st
2nd
3rd
4th
5th
mu=0.3
mu=0.6
Resistance

Toyota Hilux 2.4D 4X2

Vehicle speed [km/h]

Traction force [N]

1st
2nd
3rd
4th
5th
mu=0.3
mu=0.6
Resistance
APPENDIX F: Quick Reference guide (2 Pages)
GEN 702
CRITERIA FOR THE SAFE USE OF COMMERCIAL VEHICLES IN THE UNDERGROUND MINING ENVIRONMENT

Quick Reference Guide For Acquisition Of Vehicles

This quick reference guide contains information obtained from research done into the use of commercial vehicles in the underground mining environment. It should be noted that the mine must still apply for exemption from the Department of Minerals and Energy to use non-flameproof vehicles and that this quick reference guide is only intended as a guideline.

Typical factors to consider:

1. SAFETY
2. Operating environment and application. (Supervisory vehicle, transporter of material equipment, explosives or personnel)
3. Acquisition-, Operational- and Disposal Costs
4. Reliability
5. Service intervals (Kilometres / Hours service)
6. Service life
7. Availability of spare parts
8. Ergonomic layout
9. Emission levels
10. Driver training
11. Four wheel- or two wheel drive

Typical additional modifications to commercial vehicles:

1. Modify load box to carry people or the fitment of a 5th wheel to pull a pony trailer.
2. Fitment of roll over- and falling object protection systems [ROPS & FOPS]
3. Fitment of fail safe brakes.
4. Rubberise load box and chassis.
5. Smart card system for monitoring access and other parameters such as vehicle speed and temperature.
6. Fit spark arrestor.
7. Differential breather pipe extended to under loadbox (to prevent water entry)
8. Lower differential gear ratio
9. Governor to limit engine speed to predefined value.
10. Derated diesel injection pump (To obtain specific temperatures & emissions.)
11. “Non-Flameproof” sign-writing on doors.
12. Fire extinguisher
13. Additional lighting (Rotating lights and illumination of loadbox)
14. Reverse siren
15. Stop blocks if vehicle will be used on steep inclines
16. Bull bars (front & rear)
17. Lockout of higher gears
18. Gearlock and or alarm immobiliser
19. Brake testing device or test incline.
20. Traction: i. Better road surface on inclines ii. Tyres with more grip iii. More ideal torque split between front and rear wheels
21. Separate compartment to store tools when same vehicle is used to transport both personnel and equipment.

Reference to applicable standards and documents:

i. Criteria for the safe use of commercial vehicles to transport personnel in the underground environment (GEN 702)
ii. Department of Minerals and Energy documentation regarding non-flameproof vehicles.
iii. SABS 868 "Flameproof compression ignition engines for use in hazardous areas in mines."
   Part3: “Non-flameproof vehicle requirements.” (Not yet released)
v. SABS 1207:1990 “Motor vehicle safety standard specification for braking.”
vi. SABS 1563:1993 “Requirements for roll over protection systems”
vii. ISO 3449:1992 “Earth moving machinery – Falling object protective structures – Laboratory tests and performance requirements”
viii. SABS 0267:1996 “Homologation of motor vehicle models”

Typical process requirements:

1. Daily washing of vehicle to clear coal dust from hot surfaces.
2. Keep logbook with service detail.
3. Daily, weekly, monthly inspections.
4. Remove coal deposits on exhaust pipe and manifold surfaces.
5. Routine brake tests.
Inclines more than 10.5°

Identify operating environment
- Gradients
- Type of road surface
- Road roughness
- Corrosion
- Speed limitations
- Temperatures
- Moisture

Identify vehicle application
- Personnel transporter
- Supervisory vehicle
- Maintenance vehicle
- Explosives transporter

Make and model decision

Non-flameproof vehicle
- Is deration possible?
  - yes: Derate and fit control devices
  - no: Decide on vehicle make and model

Flameproof vehicle
- Suppliers of Flameproof vehicles
- Conform to SABS 868

Additional modifications
- Passenger seats
- ROPS
- FOPS
- Rubberising
- Smart Card system
- Spark arrestor
- Differential breather pipe
- Alternative differential gear ratio
- Engine speed governor
- Deration of diesel injector pump
- Non-flameproof sign writing
- Fire extinguisher
- Rotating lights
- Loud area lighting
- Reverse sirens
- Stop blocks
- Bull bars
- Lockout of higher gears
- Toolbox or stowage compartment

Brakes OK
- Fail-safe brakes and 4x4 drive

Test and verify

HIRA (MHSA §11)
COP's (MHSA §9)
Training programs (MHSA §10)
Maintenance schedules

Bakkie requirement

Identify vehicle application

Identify operating environment

Brakes OK

Fail-safe brakes and 4x4 drive

Conform to SABS 868

Suppliers of Flameproof vehicles

Derate and fit control devices

Inclines more than 10.5°

Test and verify

Maintenance schedules

Identify operating environment

Identify vehicle application