INTRODUCTION OF NON FLAMEPROOF DIESEL VEHICLES

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SUMMARY

As the result of development and trials by ACIRL, Moranbah North & Crinum mines, Toyota Landcruisers have been modified and successfully introduced in underground coalmines. This has resulted in improvements in gaseous and particulate emissions, ride, noise and vibration, speed, manoeuvrability, and lighting, while also having the advantage of lowering capital and operating costs. A new class of diesel personnel carriers known as non-flameproof diesel vehicles, has been created

INTRODUCTION

In Australian and UK coal mines the legislation governing the introduction and use of diesel engines in underground coalmines has historically been unambiguous. Irrespective of the use of the engine or the risks to which it is exposed, only flameproof diesel engine packages have been allowed. As the engines were traditionally used in free steered vehicles; their entry into high risk areas was seen as unable to be controlled and consequently had to be safe to use in the most hazardous location. This created one style of engine package and restricted innovation and the development of fit for purpose equipment. Due to the small market in Australia costs have climbed when compared to international competitors like the USA and South Africa.

HISTORY

The drafting of a new Coal Mines Act forced the legislators and industry in Queensland to look closely at the way we do things. The Moura disaster focussed our thoughts to critically examine the risks we all face in mining. This risk based approach created a climate where diesel engine vehicles of a different type to the traditional flameproof ones could be considered. The openly stated duty of care principles encouraged the mining industry, and organisations servicing the industry, to take a more positive role in introducing new technology. This paper traces the introduction of modified Toyota Landcruiser vehicles into underground coalmines.

Under the present legislative regime a diesel engine must be approved for use by the Chief Inspector of coal Mines. The approval process generally in the past has only been for certified flameproof engine packages, although, during driveage of new drifts in stone the Chief Inspector has allowed non flameproof engines to be used within five metres vertically of a coal seam. To trial the non flameproof diesel vehicles (NFDV) in an operating underground coal mine has meant approving non certified engines. This was only allowed after the risks were closely assessed and control measures put in place.

Initially one Toyota Landcruiser was tested by running up and down Mt Cootha in Brisbane, then in a drift at an Ipswich mine and finally it was used for transporting demonstrators and visitors at the jet engine trials at Collinsville No 2 mine. It later went into full trial mode at Moranbah North and shortly after two more Landcruisers were added to the developing fleet. Twelve months later Crinum took delivery of three and Moranbah North two more troop carriers and one tray back vehicle fitted with a HIAB style crane. To date the vehicles combined have covered over 150,000km of travel.

RISKS AND CONTROL

The risks created by the use of diesel engine transports at a mine can be considered to fall into the broad categories of; explosion of flammable gas, fire, emission of noxious gases, collision, noise and vibration. Each of these is examined in more detail below:

Explosion of Flammable Gas – Flameproof engines will not propagate an explosion in gaseous atmospheres. Non flameproof engines will. There is only one control and that is not to allow flammable gas and the engine in the same place. Simple to say, but not so simple to guarantee. We all know that its safe to drive a Toyota up and down the main drift, but how far inbye could it safely go? The modern thrust of legislation is to declare parts of the mine a non-explosive risk zone and other zones as potentially explosive. It is obvious to state that provided the vehicles remains in the non-explosive risk zone we should not be at risk.

How to achieve this and prove its reliability became a key part of the trial of the first Toyota underground

The restriction of location also prevents non flameproof, non-intrinsically safe electrical circuits on the vehicle from entering potentially explosive areas.

Fire – The most successful fire prevention control at present underground is the maximum allowed surface temperature of 150°C. This has been retained for the Toyota. The 'hot spots' were found during the surface trials and dynamometer testing. Sections of the exhaust pipe were found to remain constantly at elevated temperatures and only by modification could this be controlled.
Other components known to reach high temperatures in abnormal situations are monitored, for instance the alternator.
Fuse protected circuitry reduces the possibility of a fire initiated by electrical arcing.
The exhaust gas as it is emitted to the atmosphere is also monitored for temperature.
FRAS drive belts have been fitted in place of the standard supplied product.

Noxious Exhaust – The modern engines are a cleaner burning engine than the older greatly derated ones used in the presently available flameproof engine package. Carbon monoxide was never going to be a problem and NO, NO2 (or NOX) have been adjusted downwards by tuning of the engine while on the dynamometer. The engine can easily meet the gas emissions considered to be safe levels in the flameproof diesel standard AS3584. To cool the exhaust and ensure dilution a new exhaust expansion chamber has been constructed and installed immediately prior to the tailpipe; venturi airflow brings in fresh air to this chamber. Tailpipe exhaust readings have been found to have very low noxious gas levels, dilution is assured, whereas the flameproof engines dilute the gases into the mine atmosphere after leaving the scrubber.

Collision - I mention this because the Toyota may travel at 45kph underground. This speed has been attempted underground but only the finest of pavements can allow it safely and comfortably. All of the vehicles have been reset voluntarily down to 35kph. Collisions at this speed are a distinct possibility and injury to any person hit by the vehicle would be severe.

Controls for this are a mixed bag. The headlights are the standard Toyota halogen bulbs; underground these are very bright and act as an approach warning. The horn has been changed to a 95dbA air horn. All mine personnel have been made aware of the extent of the Toyota travel roads and the results, so far, are no injuries and very little body damage to the vehicles.

Noise and Vibration - When you ride in a Toyota underground for the first time you are amazed. It's quiet, vibration is absent, the ride smooth. These, above all other points that I have mentioned have created the acceptance of the vehicle by the workforce. Traditional vehicles will be found parked on the go pad but all of the Toyota vehicles are in use. I mentioned the air horn as a control measure and the reason for this is that the engine noise level is so low that personnel have no audible warning of the approach of a vehicle other than a loud air horn. This I am sure is the envy of flameproof engine vehicle manufacturers. I find it ironic that the lack of noise had to be considered as a hazard.

Vehicle modifications

A typical specification for a non flameproof vehicle is attached as Appendix 1.

Location control

On board the Toyota and integral with the machine is a microprocessor. Located on the rib at the most inbye point of travel are three or four transmitters. When the microprocessor receives a signal from one of these, it initiates action dependent on how far inbye the vehicles have gone. The first transmitter, called the Yellow Zone, causes a warning alarm in the cab that cannot be stopped until the vehicle reverses back outbye of the transmitter. Approximately 25 metres inbye is a second, Orange Zone, that signals to the Toyota that it has now entered the danger zone and has 30 seconds to reverse out or the engine will shut down, provided the vehicle is taken outbye of the Yellow zone the computer resets to normal. Inbye again is the Red Zone, entering this causes immediate engine shut down. The red zone engine shut down warning on the computer screen cannot be removed, or the engine restarted, without a defeat key. This key is not handed over unless a full investigation is carried out with the possible result of punitive action. Have we had red tag violations? Yes, six of them, all for different reasons. I don't see this a failure of the system but as a benefit.

The system has been tested under genuine operating conditions and proven to be a successful method of control. Signs, warning of the end of the Toyota travel area are now at the third version, they are large, reflective and unique.

One of the mines has chosen to fit a fourth transmitter outbye of the Yellow zone; this is also a warning tag but has the added feature of restricting the vehicle speed to 10 kph, they have also chosen to put a Red tag at the entrance doors to the mine ventilation return. Attempting to enter the return will shut the engine down without providing a warning period, it was felt the sign and the action of opening a door was sufficient warning. To prove the system is 'live' at all times there is also a check transmitter on board the vehicle, if the computer does not see this signal it assumes it is not operating correctly and shuts the engine down.
This system has evolved over the 18 months of trial, it didn't just happen.

Exhaust protection

Tests, on a dynamometer during preparation of the vehicle found the first part of the exhaust pipe exceeded 150°C. The only control method for this problem is the same as has been used in the flameproof engine standard AS 3584. The exhaust manifold and the first length of pipe has been water jacketed, using the vehicle cooling system for the water flow, the intermediate pipe has been air jacketed to increase the surface area for radiation and convection cooling of the metal surfaces. Coolant loss and temperature monitors are fitted into the system.

Brakes

Standard brakes on a Toyota are open discs that can reach glowing red temperatures. Imagine riding the brakes going down the drift. The ideal control method was the fitment of totally enclosed liquid immersed brakes, but reliability and speed restriction had to be trialed.

Two versions of the brakes have been fitted. One Toyota has a fail-safe brake fitted that is capable of speeds up to 80kph, these appear to be the better brake but unfortunately are not commercially available. The other type is off the shelf items and is fitted to the other eight vehicles. They have experienced early seal failure and deterioration of the seal mating faces. The supplying company is aware of the implication of these vehicles being used at many of the underground mines in the future and has worked to improve the reliability and service. This type is restricted to 45kph.

The faster speed version has the advantage that it can use the increased speed for surface travel or for driving into the nearest town. A transmitter tag can be located at the mine drift entrance that signals to the computer to set the maximum allowed speed for surface or underground operation depending on direction of travel. This facility has not been used in the trial.

Electrical

The electrical circuits have not been modified except where it has been found necessary to do so. The unchanged circuits are designed to Australian Design Rules for road going vehicles. Significant examination from the standpoint of sparking and arcing under fault and abnormal conditions has been conducted. Original wiring has been sealed at some of the connections using a silicon sealant and more positive terminations than the simple spade connections in others. Any additional circuits, monitoring, shutdown etc have been installed to AS4242, the surface earthmoving standard. This was considered to give the most relevant protection level.

Battery isolators, a shunt relay operated from the computer, additional fuse protection and a manual switch have been fitted. The starter circuit carries high currents in normal operation, these are difficult to distinguish from fault currents by fuse protection, twenty seconds after the ignition key is turned on the power from the circuit is disconnected; a timed relay is used to do this.

HAZARD MANAGEMENT

Communication

Good communications are an essential part off everything we do. The two mines trialing the vehicles have the PED system, this is a one way system that transmits messages to the vehicle from the main control room. The driver can take appropriate action on receipt of a message informing of a main fan stoppage or unplanned ventilation event for instance.

A two-way communication method where the driver can respond to the control room would be a further improvement and the next mine that uses the NFDV's may have such a system.

Methanometer

A methanometer has been fitted to one of the vehicles. A non dispersive infra red detector used in the petrochemical industry was chosen for its capability to withstand the vibration, its low response time at the levels of methane approaching the lower explosive limit and the infrequent need to calibrate. Its output can be an input to the onboard computer, although for the trial period it has been used for its alarm characteristic and has not been coupled to provide engine shut down. So far it appears to be reliable. This is a needed control for situations where gas levels may be present that have not alerted the mine monitoring system, such as travel roads that contain methane drainage pipes, the vehicle may be travelling in the roadway when a significant leakage of methane occurs outbye that would pass the vehicle before reaching a mine monitoring detector.

Fire suppression

As well as a fire extinguisher an AFFF fire suppression system has been installed in the engine bay of all vehicles. A pressurised tube, fail safe type was initially trialed but it was unable to hold pressure in the tube and spurious initiations of the suppressant occurred. The type presently fitted is a twenty litre AFFF bottle, with multiple heads located under the bonnet at locations designed to smother the areas most likely to cause fire. Activation of the system also shuts the engine down to prevent foam dispersal by the engine fan, restarting of the engine is not possible until the bottle has been recharged, as the stored pressure is monitored. Fire suppression is seen as the reactive component whereas the fire prevention technique is seen as a proactive measure.

Roll bars

Roll bars installed internally in the passenger compartment were fitted as a precaution as the Toyota does not have the rugged strength of traditional underground transports. With the lack of body damage and the small likelihood of a roll over, the protection is not seen as a highly important requirement. However its use as a grab rail to assist in exiting the vehicle has been proven, it is awkward to lift oneself from the seat whilst wearing all of the belt accessories modern miners now wear.

Roads

The non flameproof diesel vehicle will almost likely always be commercially available and modified to suit; it is unlikely that a custom built machine would be able to match the cost advantage. The suspension and body panels would not be the 'bullet proof' design expected of custom built machines. The road surfaces the non flameproof vehicles will need far exceed present construction standards. The roads that the Toyota Landcruisers have been using were upgraded from their intended standard and since in operation at both mines the roads have undergone further upgrading. The speed available is 45kph but the reasonable maximum for the road construction, the tight turns and the many intersections has been set at 35kph. This is considerably faster than the usually travelled speeds in the mine. The Main Roads Department have written standards for the roads they administer, it is suggested the mines construct their underground non flameproof vehicle travelling roads to the same standard as would be used for a 50kph dirt road.

An unforseen advantage of introducing these vehicles and the subsequent road standard improvement is the change in the remaining flameproof fleet; because these also use the well constructed pavement, their maintenance costs have fallen, you do not need to repair what you have stopped damaging!

Temperature and Humidity

The Queensland perfect weather tends to be quite warm in the six or seven months of summer and the humidity at many mines rises to a barely tolerable level. An airconditioner was fitted into one of the Landcruisers. The trial was to test the change in comfort levels but more importantly to discover the effects of a further power drain on the engine, it was perceived that emission levels may increase or the available power to climb the drifts would be dramatically reduced.

The power reduction is noticeable but not to an unacceptable level. The winner from the trial has been the climate control experienced, the more comfortable conditions has created a demand for this vehicle in preference to the others.

When you wish to go underground you can find a flameproof transport on the 'go pad', you may find a Toyota but in the warmer weather you are not going to find the airconditioned model because it is in almost constant use.
If we have the unfortunate experience of having to transport an injured person to the surface, what better conditions to transport that person than a climate controlled vehicle?

Management system

A committee with representatives from both of the participating mines, ACIRL, the miners union and the Department of Mines and Energy has had the task of trialing the vehicles. They have examined the efficiency of controls; reacted to emerging situations and generally ensured the non flameproof vehicle introduction has been done in a safe and professional manner.

As seen in the foregoing parts of the paper, the vehicle fleet requires better management than the present fleets receive. A management system must be put in place to control the road surfaces, both in construction and maintenance, the vehicles should be regularly checked to ensure the safety features (shut down system, monitoring etc) are in full operating condition.

Procedures written and used for installing, moving to a new location and checking of the transmitter tags that prevent the vehicles from leaving the non explosive risk zone of the mine, are a key element of any system.
The workforce at the mine are the same as any other mine, the amazement at seeing a Toyota underground is universal. Awareness that non flameproof vehicles are going to be travelling the mine roads and the controls on the vehicles need to be given to all persons at the mine, before a vehicle is allowed underground. Training for operators on the safety features, the extent of travel and any other mine inspired controls need to be carried out in the same manner as authorising operators of any other class of underground machine. These form the basis of the 'soft controls' for the NFDV fleet at the mine and have no less importance than the engineering or 'hard controls'.

Future moves

What are we likely to see in the future, both immediate and long term? This is crystal ball stuff.

I think it certain that there will be a proliferation of this vehicle, initially an increase in Toyota numbers but later other models will be introduced. May I mention here that consideration must be made of the four-wheel motorcycle for single use or one passenger use and the minibus for transporting multiple crews to a central reporting station for dispersal to their work locations.
The trial and introduction has been restricted to light vehicles, I can see pressure from parts of industry to repeat the trial for a heavy vehicle, such as a grader, road roller, front end loader or stationary engines for major pumping installations.

New South Wales have seen the vehicles on trial and also visited locations overseas; they are developing a similar trial to ours. It has uncharitably been suggested that they are only duplicating the work that has been done in Queensland, this is a parochial view and one that is completely incorrect. Their trial will feature a totally different location control system, alternative control measures for perceived risks added at the vehicle construction phase will be used. I look forward to their findings because I know that the Queensland trial has not found all the answers and if we stop learning from others we will stop learning.

The committee convened to oversee the trial will have another life, they will continue and change membership to include mine personnel who are introducing the new class of vehicle, and this committee will be the repository of knowledge and experience.

Conclusions

The trial has run its course, no new risks have emerged in recent times, and controls appear to be working. The total distance travelled has been enough to identify the reasons why these vehicles may or may not continue to operate in an underground coal mine.
My belief, both as a Mines Inspector and as a member of the NFDV introduction committee, is that this new class of vehicle should become a standard class, no different to the PJB or SMV vehicles in present use. As the regulations are written for the new Coal Mines Safety and Health Act, they can incorporate the NFDV's.

The NFDV's will evolve further with alternative control measures and new models.

At last the blinkers have been removed and we can see a new way of doing the things we do. This trial has only been the beginning; a new way of thinking is emerging, where traditional methods are going to be questioned. I ask all those people who cannot see the need for change to join me at the barbecue when the 'sacred cows' meet their end.

ACKNOWLEDGMENTS

I would like to thank my fellow members of the NFDV committee for the thoroughly professional and competent work they have done in overseeing the safe introduction of these vehicles. Only the brave or foolish are ready to move into areas where no one has travelled before.
Especially T O'Beirne, C Jacobson and A Vaughan.

APPENDIX 1

GENERIC GUIDELINES FOR N.F.D.V.

- Design risk assessment to be carried out on the diesel engine vehicle to evaluate risks associated with that type of vehicle
- Temperature control system to limit the surface temperatures to 150°C
- Those surfaces that should be temperature monitored must be identified in the risk assessment. These surfaces must be monitored and the vehicle shutdown if the surface temperature reaches 150°C. The need for continuous monitoring may be eliminated if it can be shown that normal operating and credible fault conditions cannot generate 150°C.
- Location control system to prevent access to hazardous zones by shutting the machine down automatically.
- Permanently mounted vehicle engine area fire suppression system with appropriate minimum B:E rating.
- Hand held fire extinguisher to be fitted.
- Enclosed braking system, which limits surface temperature to below 150°C.
- The vehicles electrical system must conform to the original OEM standard as at the date of manufacture and to the Australian Standard AS4242.
- Any electrical circuit modification is to conform to AS4242.
- Vehicle to be fitted with battery isolation system.
- Enclosed battery case to limit access.
- Horn to be rated minimum 95 dBA.
- Audible reversing alarm.
- Permanently mounted headlights and reversing lights.
- Alternative engine stop/isolation switch.
- Vehicle road speed monitoring and controlling system.
- Powered fuel solenoids.
- Unprotected electrical circuits to be isolated when not required.