Summary of reported incidents

In-Service Failure of Explosion-Protected Diesel Engine Systems (ExDES)

January 2010 - October 2011

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Resources and Energy – Mine Safety

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1. Background

There have been several mine explosions in history where a diesel engine system (DES) may have been the source of ignition. The consequence of such a failure may be multiple fatalities, significant damage to the mine, consequent loss of production, employment and public confidence.

In order to minimise the risk of igniting potential methane atmospheres in underground coal mines, precautions are taken with diesel engines used in such workplaces. In NSW, diesel engine systems in underground coal mines are design registered, with the AS/NZS 3584 series of standards, '*Diesel engine systems for underground coal mines'* being the primary compliance document.

The focus of this report is on the failure of the explosion protection characteristics of diesel engine systems (ExDES failures), as reported under clause 56(1)(m) of the NSW *Coal Mine Health and Safety Regulation 2006* (CMHSR). This document summarises findings for reported incidents between January 2010 and October 2011.

This Report provides an update on information provided in SB10-06, *Failures of explosion protected diesel engine systems*, see www.dpi.nsw.gov.au/minerals/safety/safety-bulletins

2. Explosion hazards

2.1 Reporting requirements

An explosion can occur in an underground coal mine when there is an ignition source within and explosive atmosphere while it exists. In order to build an understanding of this risk, mining legislation in NSW requires various types of incidents to be reported.

Fuel source events must be reported where '*an accumulation of gas that requires the withdrawal of people or results in the tripping off of electric power*' [CMHSR 2006 Clause 56(1)(g)]. This occurs when the concentration of methane in the atmosphere exceeds 1.25%.

Ignition sources and potential ignition sources must be reported, some of which include:

1. mechanical Ex failures [CMHSR Clause 56(1)(m)];
2. electrical Ex failures [also CMHSR Clause 56(1)(m)]; and
3. cable arcing [CMHSR Clause 56(1)(l)].

Figure 1 below shows a graph of the reported numbers of such methane events and incidents from underground coal mines in NSW.

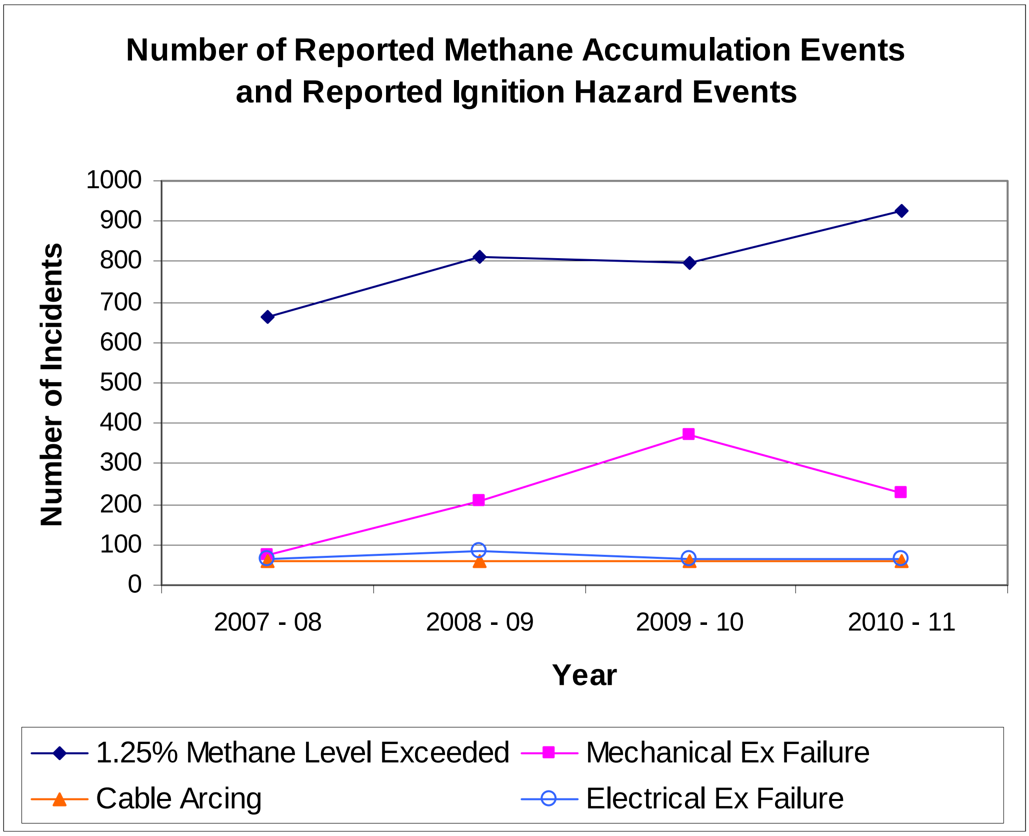

Figure 1

2.2 Failure Rates

Figure 1 shows that the number of reported Ex DES failures (mechanical Ex failures) is significantly greater than the number of reported Ex electrical failures. The figure also shows an improvement in the number of ExDES reported failures in the last 12 months.

Last year there were 230 ExDES failures and 65 Ex electrical failures reported. This conservatively[1] equates to an annual probability of failure of –

- 23% for each ExDES item
- 0.12% for each Ex electrical items

This means last year an individual DES was about 190 times more likely to have failure of its explosion protected characteristics than an individual explosion protected electrical item.

[1] There are about 1030 registered DES's in use at underground coal mines across NSW. The number of reported failures was 230. Each mechanical item had an annual probability of failure of about 23%, i.e. 23 failures per year for every 100 items in service.

A conservative estimate for the number of Ex-protected electrical items in use at an average size underground coal mine in NSW is 2,000. Assuming approximately 30 mines means there would be at least 60,000 Ex electrical items. The number of reported failures was 65. Each Ex electrical item therefore had an annual probability of failure of about 0.12%. i.e. 0.12 failures per year for every 100 items in service.

2.3 Co-Incidence of Gas Accumulation and Ignition Hazard

Based on the information in Figure 1, there was a 1% probability[2] of an in-service failure of an ExDES at a underground coal mine at the same time an accumulation of methane occurred, i.e. a reportable event under, 56(1)(g).

NOTE: The ExDES is only assumed to be somewhere at the mine. It does not necessarily mean at the same location where the accumulation of methane occurred.

Figure 2 below shows it can be reasonably assumed[3] that in NSW last year –

- There was greater than 90% probability that there were 6 or more occasions when a diesel engine was in-service with failed explosion-protection characteristics during a reported accumulation of methane gas in an underground coal mine.
- There was a 10% probability that this occurred 14 or more times.

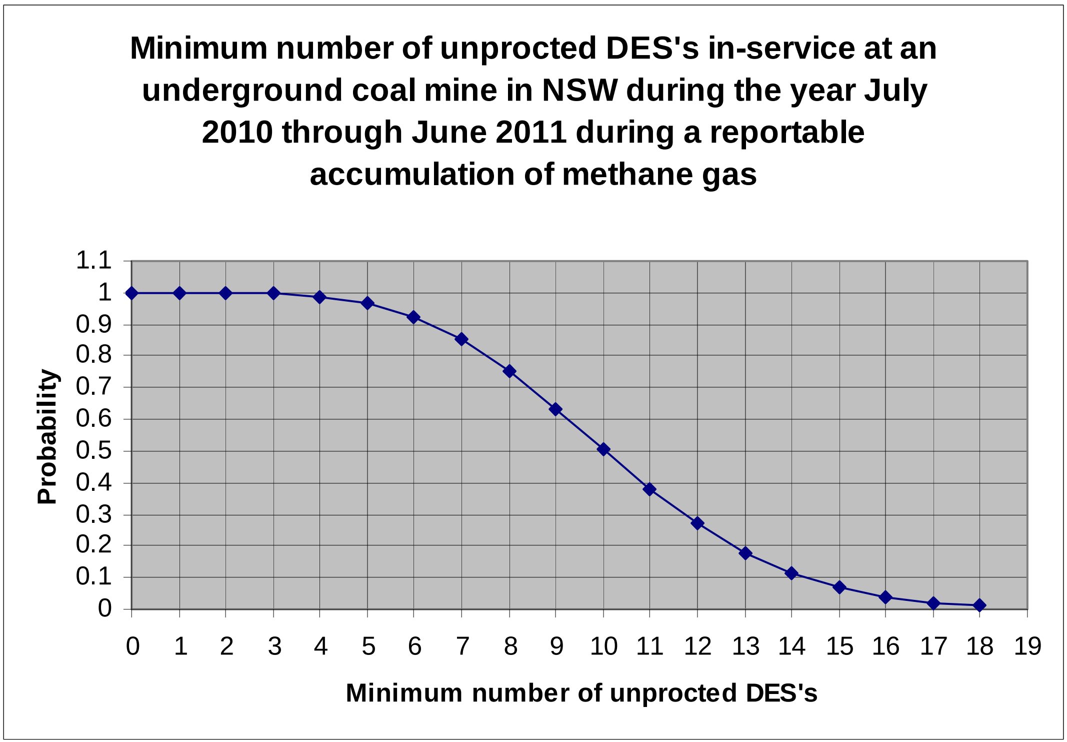

Figure 2

[2] There were about 230 ExDES incidents in underground coal mines in NSW during July 2010 through June 2011 across (approx.) 30 UG coal mines. Hence each mine had an average of nearly 1200 hours between ExDES failures. This calculation assumes most failures are discovered during a daily test. Each incident therefore represents about 12 hours of use in an unprotected state. This is a conservative estimate considering a minority of failures are discovered during weekly or longer period testing. Therefore, each mine had a probability of 1% (or more) that at any moment during that year, a DES with failed explosion protection characteristics was in service somewhere at the mine.

[3] Figure 2 uses foregoing assumptions and also assumes 900 reportable methane accumulations. Values were calculated using the binomial probability equation.

3. Time Trend of Reported ExDES Incidents

Figure 3 below shows the percentage of ExDES's that failed during each year.

The failure rate shows a pleasing decline since 2009[4].

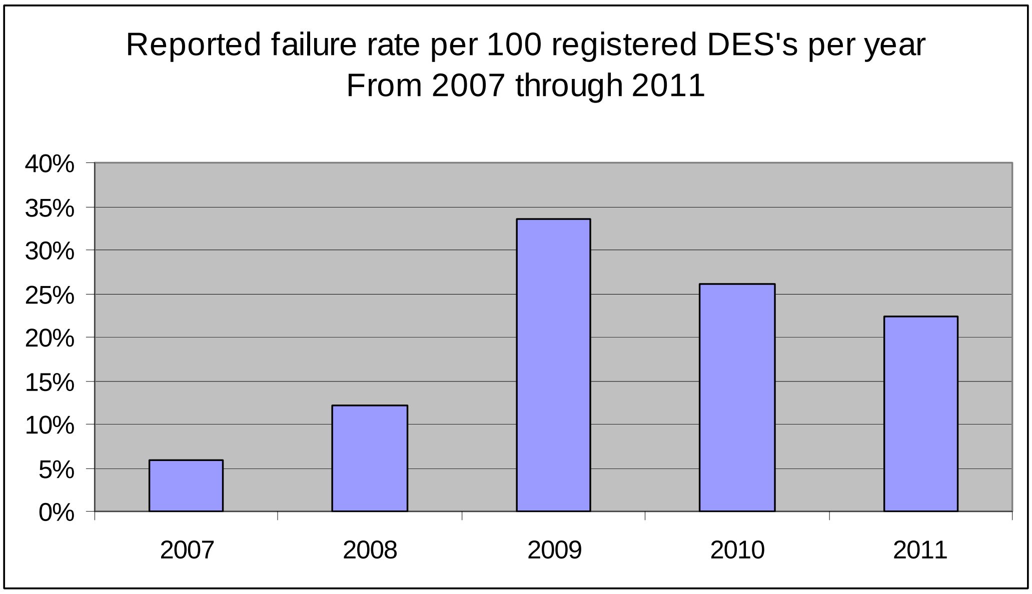

Figure 3

It is believed that from 2007 to 2009, the proportion of actual incidents reported increased. Anecdotal evidence from industry members suggests the number of incidents may still be under-reported.

[4] The value for 2011 is based on 10 months of data normalised for 1 year

4. Regional Reporting

Figure 4 below shows the average number of reported ExDES failures per underground coal mine in NSW by region for 2011. This supports anecdotal evidence that Southern mines are more diligent in reporting actual incidents.

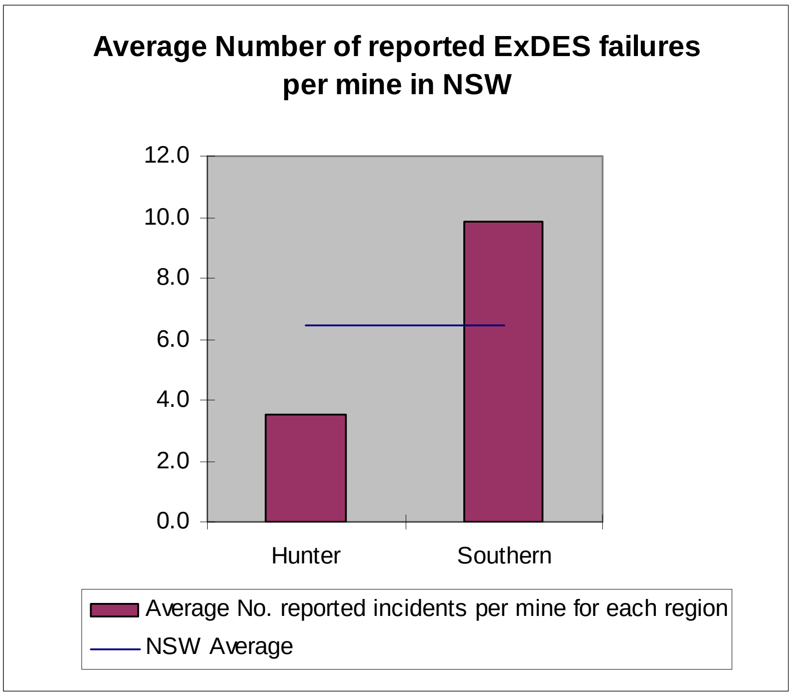

Figure 4 Regional Reporting

Hunter Region

Figure 5 below shows the number of ExDES failures reported by Hunter region mines. Most Hunter region mines report below the industry average number of ExDES incidents. The highest reporting mines report 10 times more incidents than the lowest. Is the high variation due to unreported incidents at the lowest reporting mines?

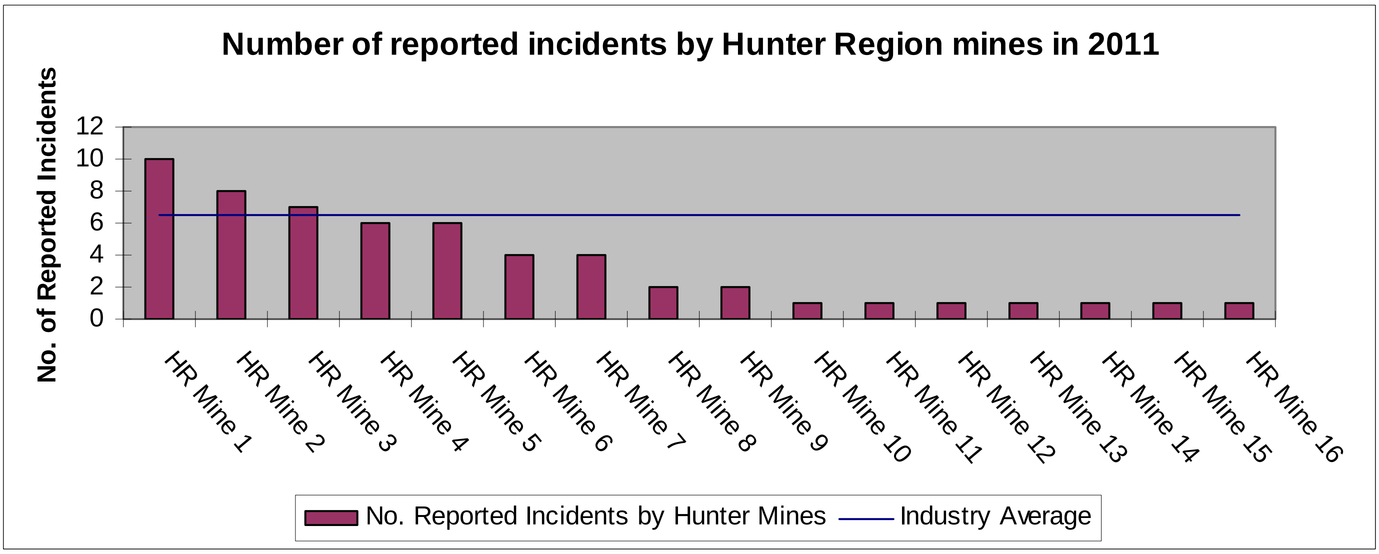

Figure 5 Hunter Region Mine Reporting

Southern Region

Figure 6 below shows the number of ExDES failures reported by Southern region mines during 2011.

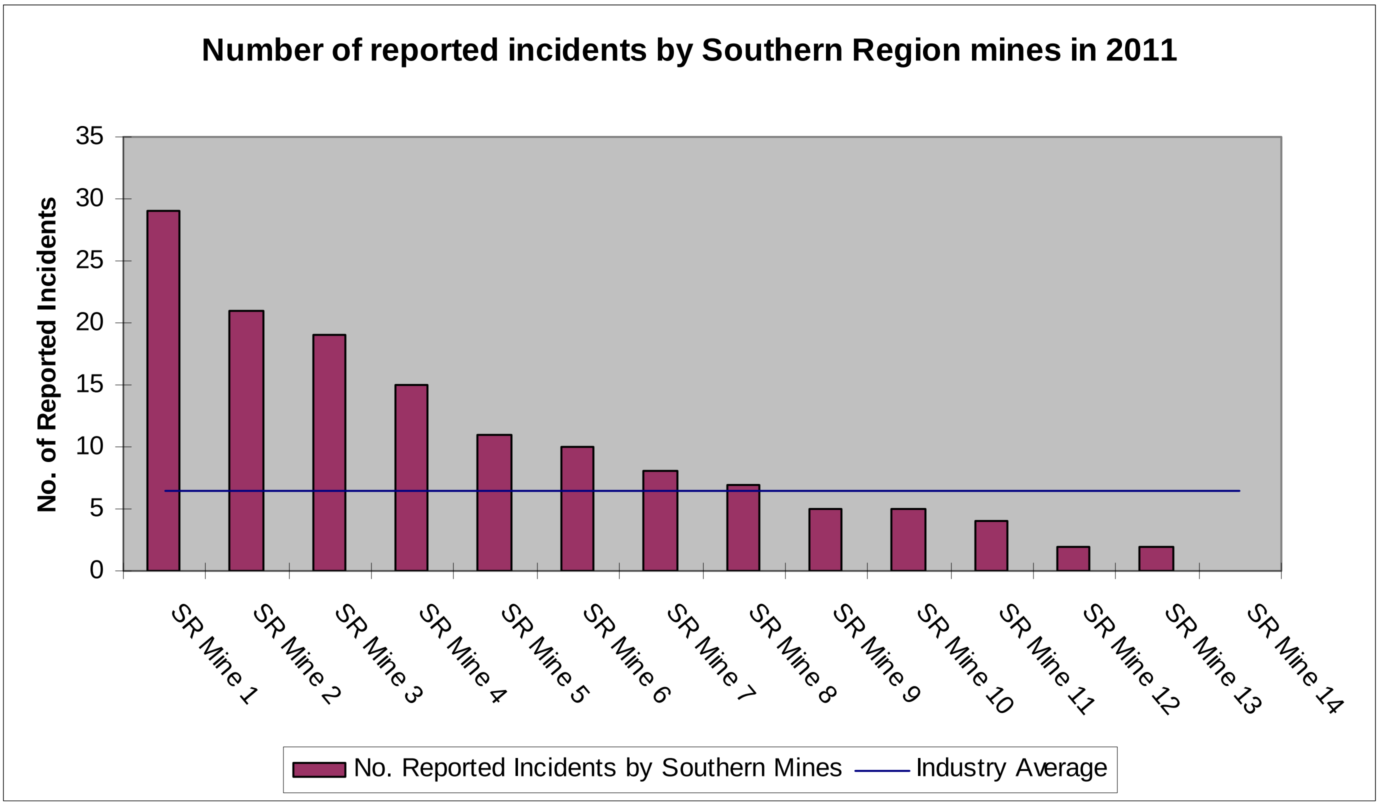

Figure 6 Southern Region Mine Reporting

A majority of Southern region mines have an above average incident reporting rate. The highest reporting mines report over 10 times more incidents than the lowest. Is the high variation due to under-reporting of incidents at the lowest reporting mines?

5. *ExDES Failure Rate by manufacturer (OEM)*

Figure 7 below shows the likelihood of ExDES failures for the major OEM's for the year July 2010 through June 2011.

The industry average is 22%, or 22 failures per 100 machines in service per year.

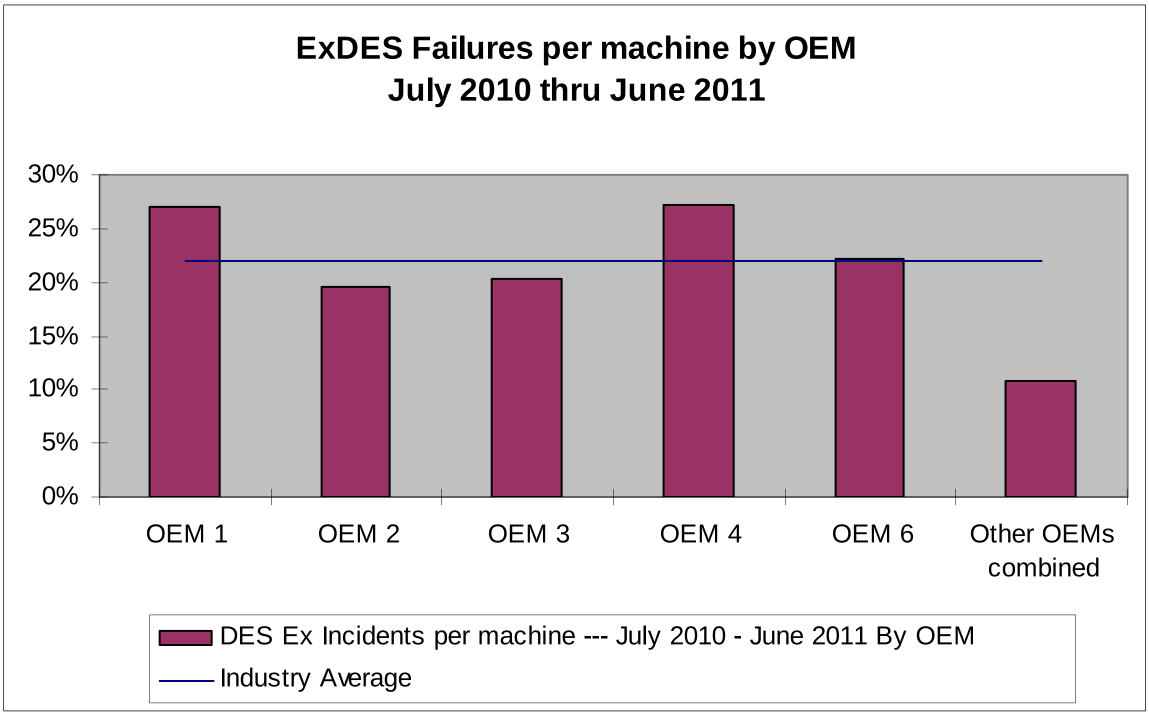

Figure 7 Failure rate by OEM

6. *How did ExDES's Fail?*

Figure 8 below shows a breakup of the reported failures for the year January 2010 through October 2011[5].

- 59% were a failure of the control system to keep the DES in an explosion-protected state.
- 38% occurred in a major DES component.

While not strictly reportable, 3% of reported incidents related to a failure of a strangler valve to shut down the engine.

[5] The following sections looks at the details of how the control system and engine components failed.

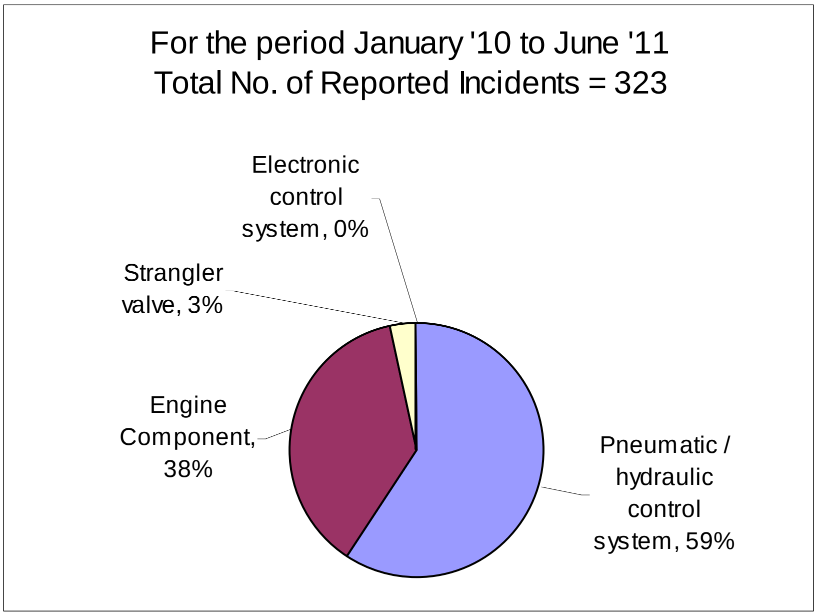

Figure 8

The data contained no reported incidents of the failure of an electronic control system to keep the DES in an explosion protected state. This suggests that if electronic control systems were used in all diesel engine systems, the best part of 59% of failures could be reduced.

7. Control System Failures

7.1 Which Control System Components Failed?

Figure 9 below shows the distribution of failures among control system components[6]:

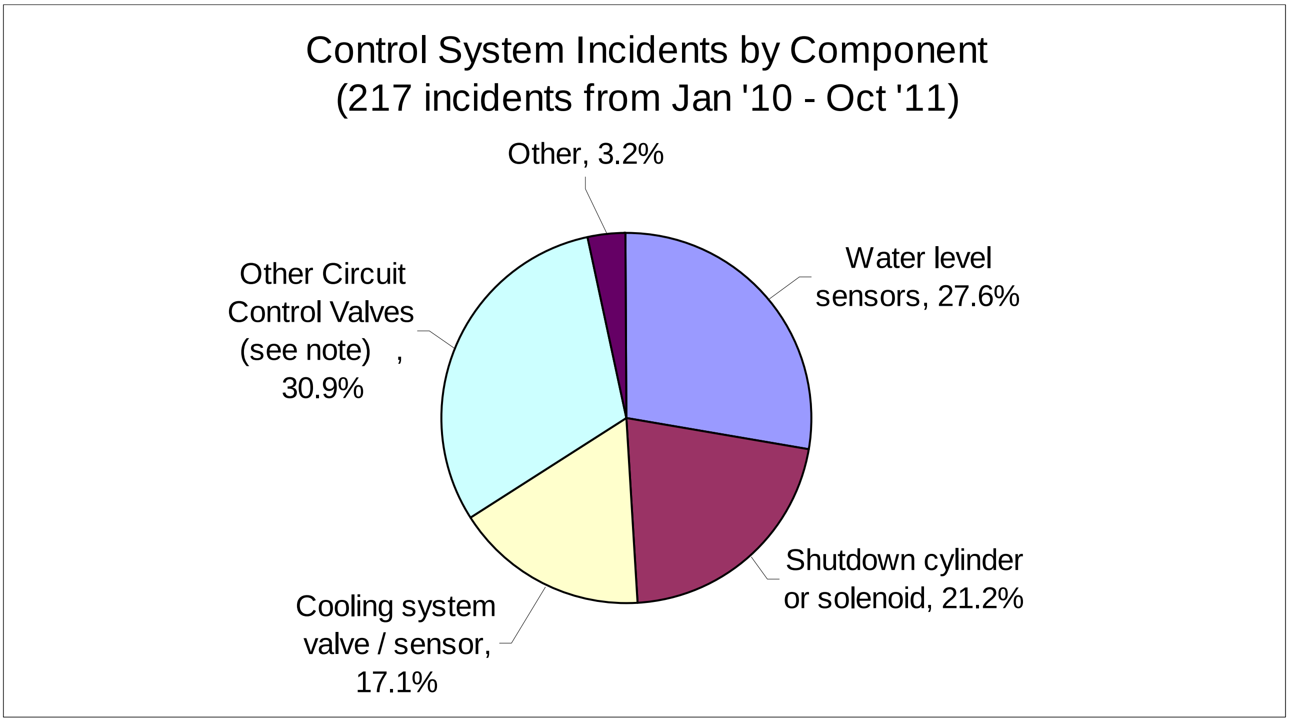

Figure 9

[6] 'Other circuit control valves' include flow control valve, pilot valve, override valve, needle valve, etc.

Water level sensors were the biggest single item among control system components that failed, causing 27.6% of failures. These were mainly Humphrey valve failures. Sometimes this sensor was installed wrong.

The next most frequent location of failure of the DES was at the shutdown cylinder, at 21.2%, mainly by jamming of the cylinder, and sometimes by wrong pressure setting, loose bolts/nuts/studs or bent linkage.

Cooling system valve/sensors contributed 17.1% of failures, mostly by non-operation of the valve/sensor. A couple of failures here were due to wrong installation.

Although contributing 30.9% of failures, “Other circuit control valves” encompassed a number of different functions and types of valves. These included the flow control valve, oil pressure, safety circuit pressure valve, relief valve etc (needle valve, pilot valve etc).

7.2 How did Control System Components Fail?

Figure 10 below shows the distribution of failure modes experienced by the same set of control system components:

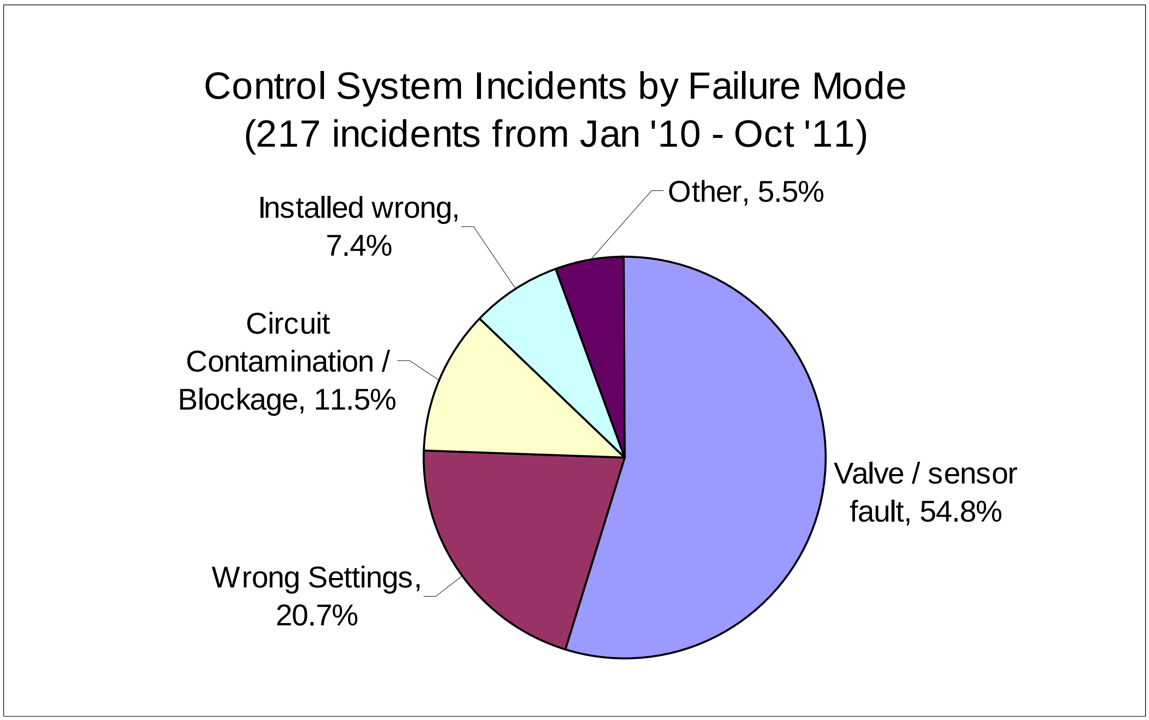

Figure 10

The data suggests that the most significant mode of failure in the pneumatic/hydraulic control system is valve/sensor reliability, accounting for 54.8% of control system failures. Can DES manufacturers control this?

Wrong settings came in next at 20.7% of reported failures. These included both accidental and deliberate deviations from the correct settings, although this was not usually identified in the incident report.

Circuit contamination caused 11.5% of control system failures. Can maintenance or overhaul procedures control this?

8. *Engine Components Failures*

8.1 Which Engine Components Failed?

Figure 11 below shows which engine components are more prone to failure.

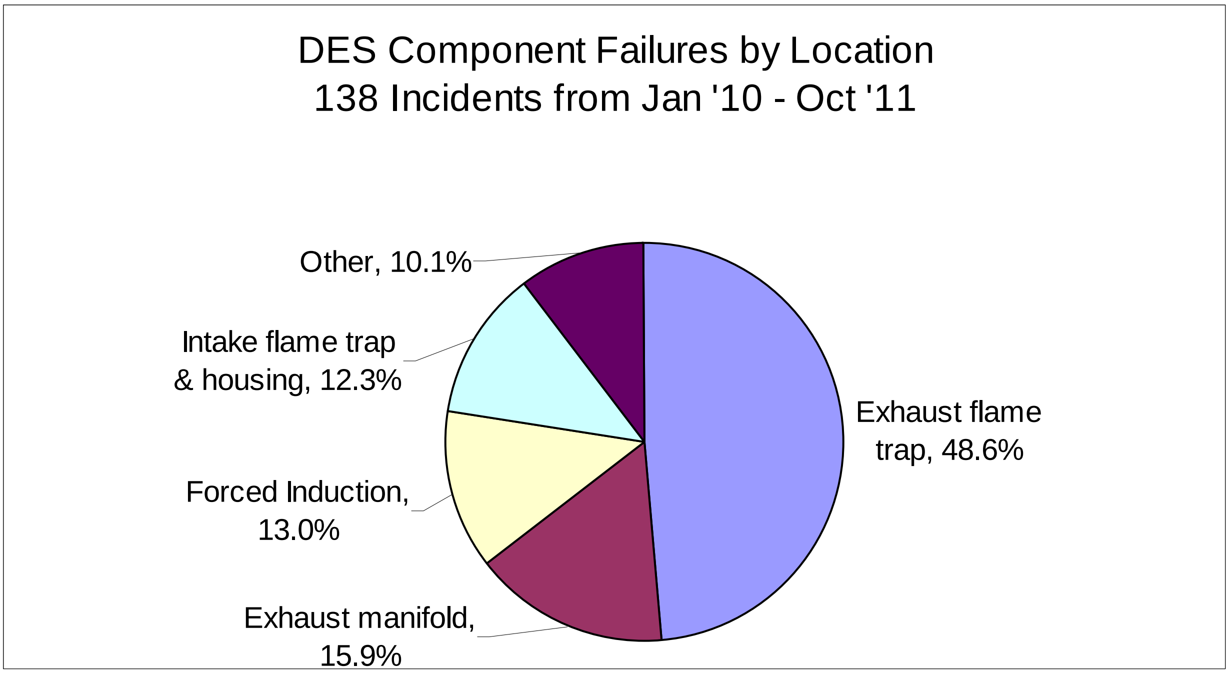

Figure 11

Second to the control system, the next source of failure of diesel engine systems was the exhaust flame trap, contributing 48.6% of non-control-system failures. Most of these were in the wet scrubber.

Lesser contributions were made by the exhaust manifold (15.9%)

8.2 Exhaust Flame Trap Failure Modes

Figure 12 below shows the distribution of failure modes of exhaust flame traps.

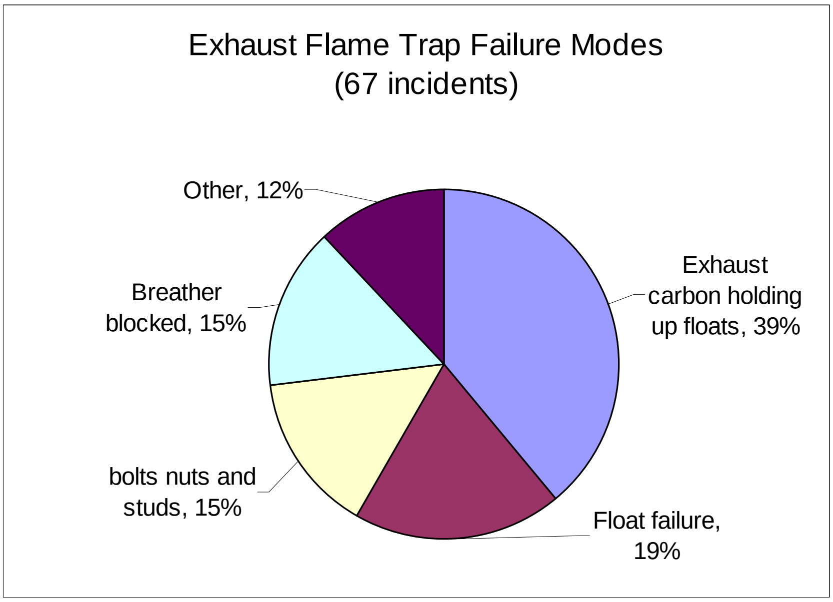

Figure 12

8.3 Exhaust Manifold and Turbo Fixed Connection Failure Modes

Figure 12 below shows the combined failures modes of the exhaust manifold and turbo:

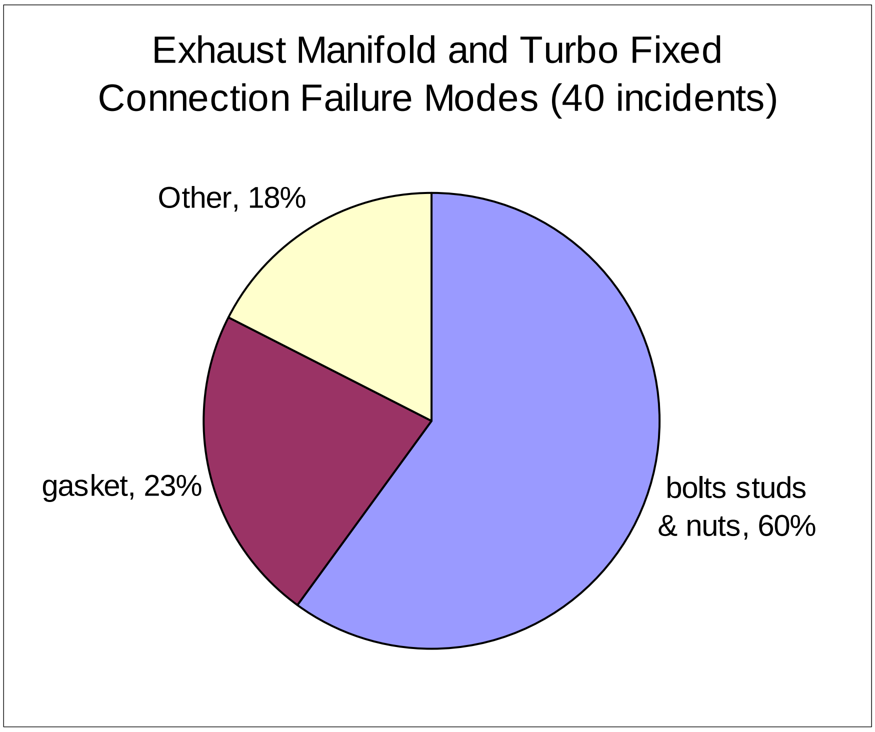

Figure 13

8.4 Intake Flame Trap Failure Modes

Figure 14 below shows the distribution of failure modes of intake flame traps:

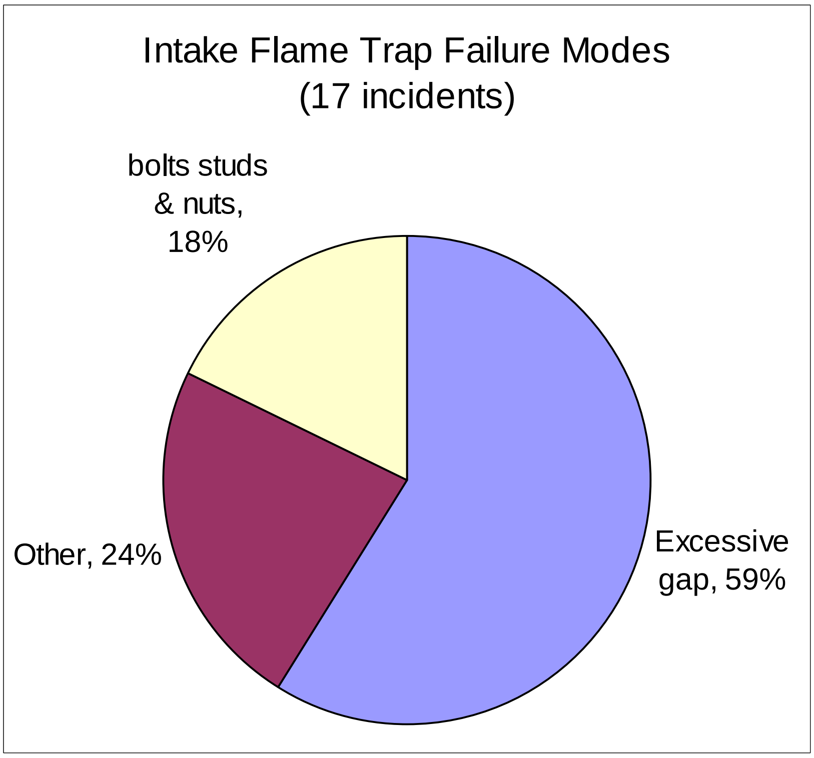

Figure 14

9. *Top 10 Failures*

Figure 15 below shows the top 10 ways a DES was reported to have failed. The percentages quoted are a proportion of the total number of failures and 84% of all failures are shown.

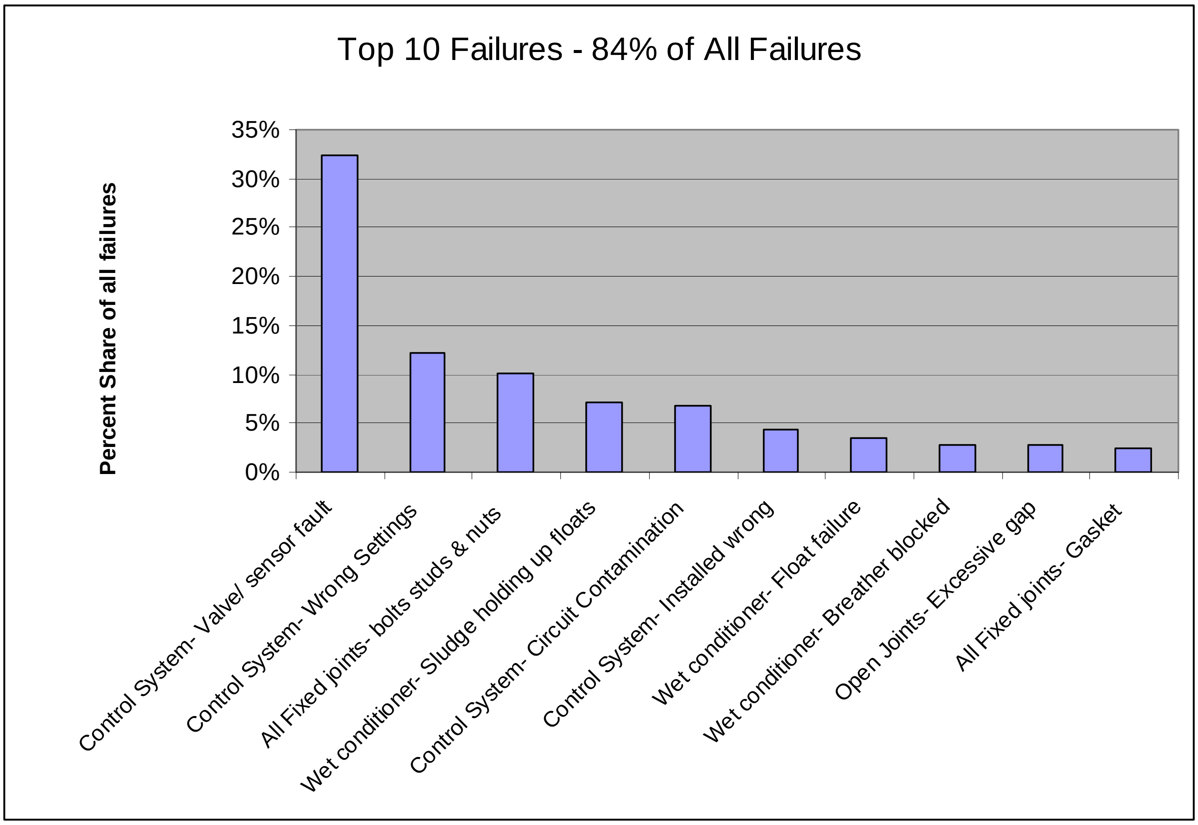

Figure 15

Valve/sensor reliability seems to be the greatest opportunity for improvement and could be improved by use of an electronic control system. The failures due to wrong settings in the pneumatic/hydraulic control circuit may have been due to either deliberate misuse, or insufficient security of the settings; there is currently insufficient information available to determine the split between the two.

Similarly for security of bolts, studs and nuts – OEM's and users may share responsibility for improvement.

10. Strategies for Improvement

In order to reduce the probability of failure of ExDES and to more accurately assess the reliability of diesel engine system designs and maintenance regimes, the Department will -

- Improve the quality of data gathered and has introduced an ancillary report form for all ExDES reported (56)(1)(m) incident, copy attached. This form will allow the data to be directly attributed to each particular diesel engine system design. Common issues can be identified and reduced.
- Provide to each OEM a copy of the data that relates to their DES and require each OEM to review the incidents and provide design solutions, as applicable.
- Require OEMs to critically review and analyse the safety integrity of their shutdown systems and other components.
- Encourage OEMs to review lifecycle inspection, testing and maintenance requirements and encourage users to comply with these OEM lifecycle recommendations in their maintenance management system.

- Publish an update of statistics on an annual basis.
- Continue with the recognised service facility program for the overhaul of ExDES's.
- Encourage all ExDES owners to comply with the requirements of AS/NZS 3584.3:2012 *Diesel engine systems for underground coal mines - Maintenance*.
- Encourage the use of the relevant national competencies for the assessment of people maintaining and overhauling ExDES.
- Phase out all older 'approved' ExDES, currently operating under exemption by the end of 2013.
- Implement a program to improve the quality of the design, manufacture and supply of new ExDES consistent with the electrical Ex certification schemes (certificate of conformity) by 2016.

Ancillary Report – In Service Failure of Explosion Protected Diesel Engine Systems, Clause 56(1)(m)

NSW GOVERNMENT | Trade & Investment

Pursuant to Clause 59 of the Coal Mine Health and Safety Regulation 2006, this form is gazetted and additional to the Coal Notification of Incident Form. This Report must be completed and submitted to NSW Trade & Investment within 21 days for all notifiable incidents subject to Clause 56(1)(m) in relation to explosion protected diesel engine systems.

1 About the coal operation where the incident occurred:

Name of coal operation:	
Date of incident:	Mine Identification No. (if known):

2 Machine identification

MDR[1] or MDA[1]:	MIR[1]:
Machine Manufacturer:	Machine Model:
Machine Owner:	

3 Last inspections

Date of last Code D:	Registered Service Facility (RSF) No.:
Date the failed component / part of system was last inspected or tested:	

4 Type of Ex Failure:

There was potential for, or there was evidence of: (only tick the most likely one)

☐Spark external to engine ☐Flame external to engine ☐Surface temperature to exceed 150 deg C

5 Location of failure – Diesel engine system component OR Control system:

Which part of the diesel engine system failed? (tick one – root cause only)

☐Exhaust flame trap (wet/dry) ☐Exhaust manifold ☐Intake flame trap & housing ☐Forced induction (turbo / supercharger)	☐Engine block & cylinders ☐Intake manifold ☐Exhaust pipe(s) ☐Engine head	**If one of these components is selected, go to 6 below.**
☐Pneumatic/hydraulic control system	☐Electrical control system	**If one of these control systems is selected, go to 7.**

6 Failure Mode of Engine Component

Which major component failed? Tick one from this column:	**How did the major component fail?** Tick one only (initial cause) from the same row:	
☐ Wet flame trap (conditioner):	☐ Exhaust carbon holding up floats ☐ Float failure issues ☐ Structural failures	☐ Water below LWCO[2] when engine stops ☐ Blocked breather ☐ Excessive backpressure ☐ Other
☐ Fixed connection (issues):	☐ Bolts, nuts & studs ☐ Gaskets ☐ Thread issues	☐ Surface flatness ☐ Damage ☐ Other
☐ Open joints (issues):	☐ Surface flatness / finish ☐ Excessive gap ☐ Thread issues	☐ Bolts, nuts & studs ☐ Damage ☐ Other
☐ Positive flame trap element:	☐ Damage ☐ Excessive internal clearances	☐ Other
☐ Structural failures:	☐ Fatigue / Cracking ☐ Corrosion ☐ Physical contact damage	☐ Catastrophic failure ☐ Turbo seal failure ☐ Other
☐ Excessive surface temperature:	☐ Cooling system failure	☐ Other
☐ Other (please specify the component and how it failed)		

Go to Question 8.

[1] MDR – Mine Design Registration number. MDA – Mine Department Approval number. MIR – Mine Item Registration number.
[2] LWCO – Low Water Cut-Out.

7 Control system failure

Only answer this question if directed to do so from Question 5.

Which component failed? (tick one from this column)	**How did the control system fail?** (tick one from this column)
☐ Water level sensors ☐ Shutdown cylinders or solenoid ☐ Cooling system sensors ☐ Exhaust temperature sensors ☐ Engine oil pressure sensors ☐ Other circuit control valve failure ☐ All or multiple sensor failure	☐ Valve/sensor faults ☐ Wrong settings ☐ Circuit contamination or blockage ☐ Installed wrong ☐ Loose valve/sensor mounting ☐ Hose failure
Other (please specify)	Other (please specify)

8 Recommendations for prevention

Causal factors:

If more space is required, please attach additional page(s)

Would a **design** change prevent or minimise failure? ☐ Yes If yes, describe how below ☐ No

If more space is required, please attach additional page(s)

Would a **Code D overhaul** change prevent/minimise failure? ☐ Yes If yes, describe how below ☐ No

Would a **maintenance / testing** change prevent/minimise failure? ☐ Yes If yes, describe how below ☐ No

If more space is required, please attach additional page(s)

9 Other Comments

If more space is required, please attach additional page(s)

10 Signature

Have you informed the manufacturer of this failure? ☐ Yes ☐ No

Signature of Manager of Mechanical Engineering:	Name: Date signed:

COA-AR ExDES Ancillary Report Form.doc Page 2 of 3

NOTES

1. Clause 56(1)(m) of the *Coal Mines Health and Safety Regulation 2006* requires notification of any incident or matter involving the '*in-service failure of the explosion protection characteristics of explosion protection plant*'.

   This Ancillary Report is to provide a consistent approach for all underground coal mines.

2. The AS 3584.2 standard stipulates the explosion protection characteristics and defines the components (characteristics) which form part of an explosion protected diesel engine system.

3. All '*diesel engine system used in underground mines at a coal workplace*' must be both design and item registered under Part 5.2 of the *OHS Regulation 2001* before use.

4. For the purpose of clarifying the above provisions, the Department requires the following to be reported –
   '*Any incident or matter where it is evident an explosion protected diesel engine system has been (or is likely to have previously been) operating in a* ***non-explosion protected condition***'.
   A **non-explosion protected condition** means a condition which has potential to ignite either; coal dust on the surface of the engine; or methane in the surrounding atmosphere.

5. Examples of **matters which must be notified** include, (but are not limited to) –

   a) any explosion protection characteristic failures when discovered during use, routine maintenance or overhaul;

   b) the failure of a diesel engine system to shut down when required by the control sensors, for example – loss of water in the scrubber; excessive system temperature (above 150^0C); failure of engine cooling system, etc;

   c) a catastrophic failure of the diesel engine system which protrudes external to the engine, such as turbochargers, superchargers, piston, valves, connecting rods, etc.;

   d) the failure of a primary and backup control sensor, for example temperature, floats, etc;

   e) the failure of an explosion protected open joint which exceeds the specified dimensions for explosion protection;

   f) looseness of any explosion protected fixed joint (gasket joint);

   g) deterioration or significant damage to any dry type flame trap;

   h) the failure or loosening of any screw type explosion protection joint;

   i) the failure to replace any explosion protected component, such as a cap, plug, flame trap or other like component, after carrying out maintenance activities;

   j) any evidence of a fire or spark external to the explosion protected joints, flametrap or water conditioner ;

   k) any catastrophic failure of a turbo in a dry type exhaust system;

   l) failure of the cooling system, and/or sensors such that the external surface temperature of the diesel engine and /or exhaust gas temperature at the flametraps appears to have exceeded 150^0C;

   m) evidence of thermal degradation of an exhaust filter; and

   n) the water level not being at or above the minimum safe water level when the diesel engine shuts down automatically.

6. Examples of **matters which are not required to be notified** include, (but not limited to) –

   a) the failure of a single sensor where backup sensors are installed, functional and the diesel engine system is not in a un-explosion protected condition; for example –

      (i) a single exhaust float failure where a backup float is fitted and functional;

      (ii) a single temperature sensor failure where a backup sensor is fitted and functional;

   b) the failure of an engine to start;

   c) stopping of the engine system because a sensor has operated;

   d) failing of the engine cooling system where the engine shuts down; and

   e) any other failure which does not render the diesel engine system in an un-explosion protected condition.

Please contact your local NSW Trade and Investment office if you require assistance completing the form.

NSW Trade and Investment Offices located in coal mining regions

Hunter Region

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