NSW Resources Regulator

In-service fires on mobile plant

SEPTEMBER 2017

NSW GOVERNMENT

Document control

Published by NSW Department of Planning and Environment, NSW Resources Regulator

Title: In-service fires on mobile plant

First published: September 2017

RM8 reference: PUB17/566

Amendment schedule		
Date	Version	Amendment

Foreword

The NSW Resources Regulator conducted a review of in-service fires on mobile plant at NSW mines.

The intent of this report is to present data collected from ancillary reports graphically to facilitate industry review. It is hoped that the reader may gain an insight to the broader understanding of fires on mobile plant across the NSW mining industry and prompt a review of the effectiveness of current preventative measures. The report also provides an initiative for the industry to consider a shift of focus towards elimination of ignition/heat sources to drive a step change in occurrence of fires.

Data source

The data for the analysis in this report has been obtained from dangerous incident notifications reported as required by the *Work Health and Safety (Mines and Petroleum Sites) Act 2013* No 54 Part 3 Incident notification clause 14(c) a dangerous incident prescribed by the Regulations.

Work Health and Safety (Mines and Petroleum Sites) Regulation 2014 Part 13 clause 179 defines dangerous incidents:

179 Dangerous incidents

For the purposes of section 14 (c) of the WHS (Mines and Petroleum Sites) Act, each of the following is prescribed as a dangerous incident:

(a) an incident in relation to a workplace that exposes a worker or any other person to a serious risk to a person's health or safety emanating from an immediate or imminent exposure to:

(ii) an uncontrolled implosion, explosion or fire

The equipment base population data and operating hours data is not available for specific deduction of equipment performance or trends. The data records commence September 2014, continuing to the current date of analysis - May 2017.

Reference documents

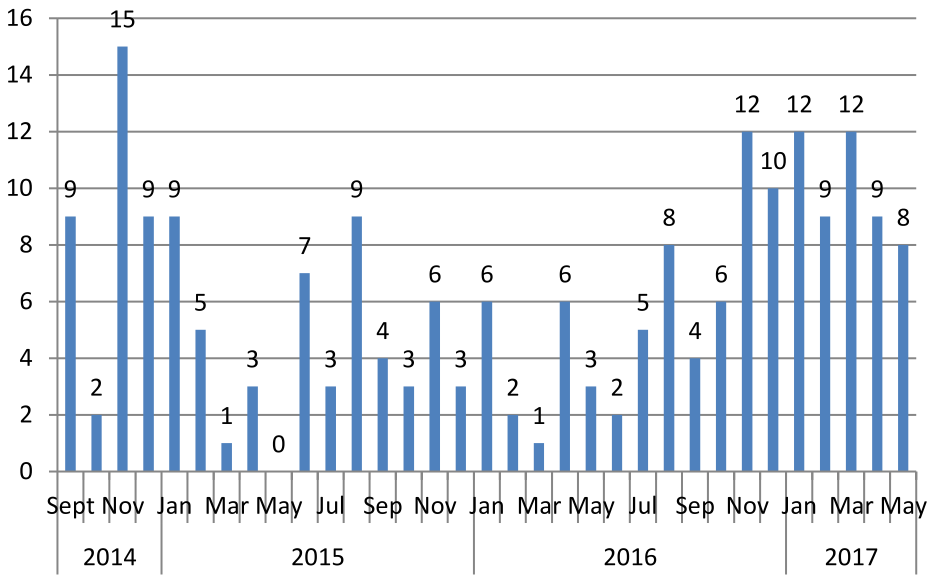
1. MDG 1032 Guideline for the prevention, early detection and suppression of fires in coal mines
2. NIOSH, Ignition of hydraulic fluid sprays by open flames and hot surfaces by Liming Yuan
3. NIOSH IC 9467 Analysis of Mobile Equipment Fires for all US surface and underground coal and metal/non-metal mining categories, 1990-1999
4. MDG15 Guideline for mobile and transportable equipment for use in mines
5. RR980 HSE Generation of flammable mists from high flashpoint fluids

Contents

Data

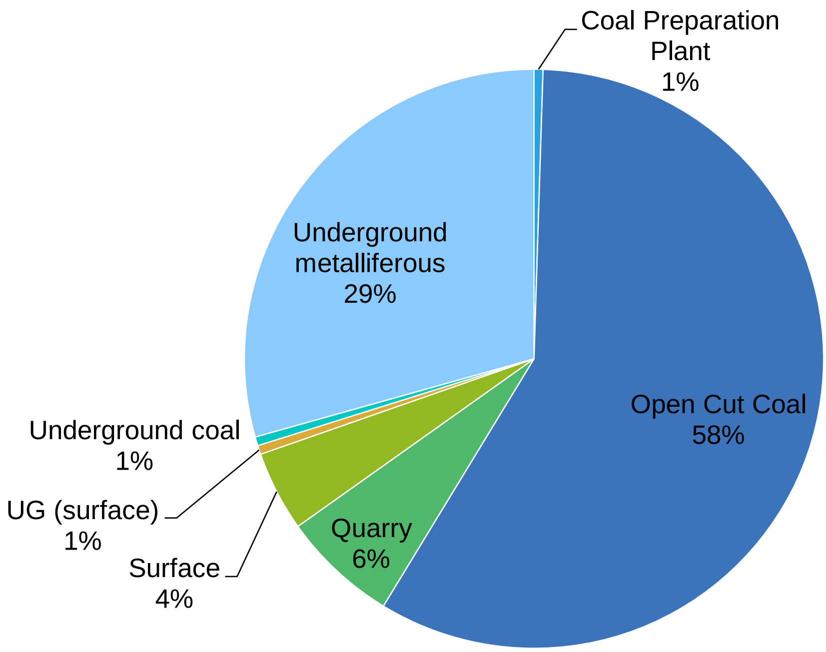
Fire notifications

Figure 1: Fire notifications.



- 203 fire events were reported between September 2014 and May 2017 at an average of 6.2 events each month.
- In the past 12 months of data between May 2016 and May 2017 a total of 97 events make the average trending at eight fires each month.

Figure 2: Fires on mobile plant by mine type.



Mobile plant logistics

The mine site mobile plant original equipment manufacturer population data and operating hours data was not available for specific comparison of equipment fire trends by original equipment manufacturer.

Figure 3: Type of machine by event numbers.

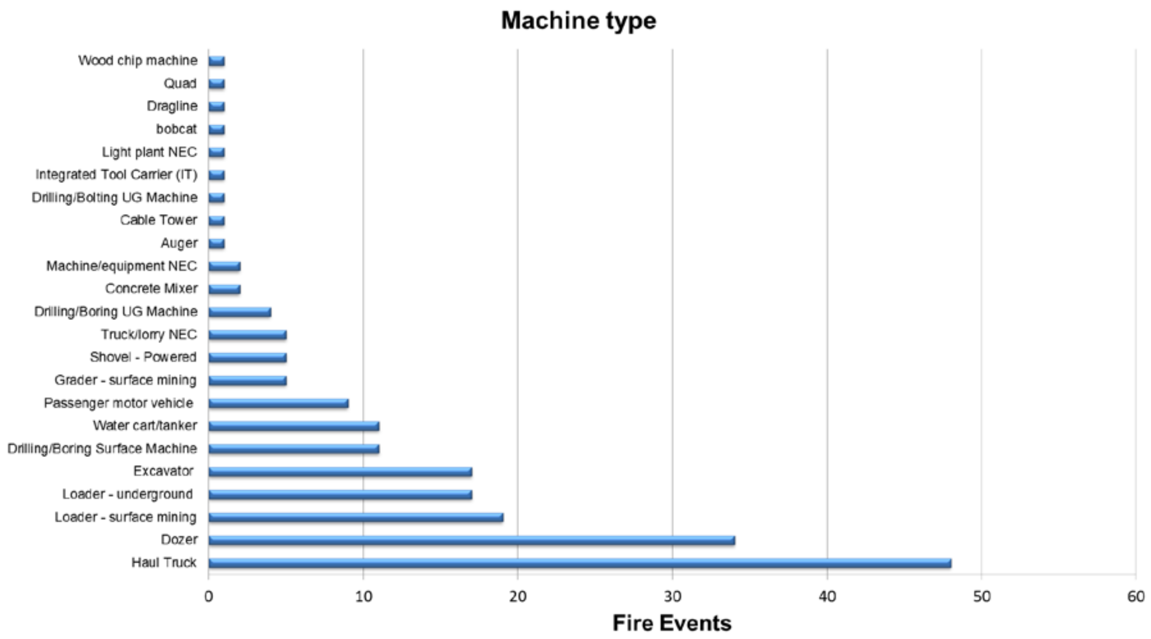


Figure 4: Build year of machines involved in a fire event.

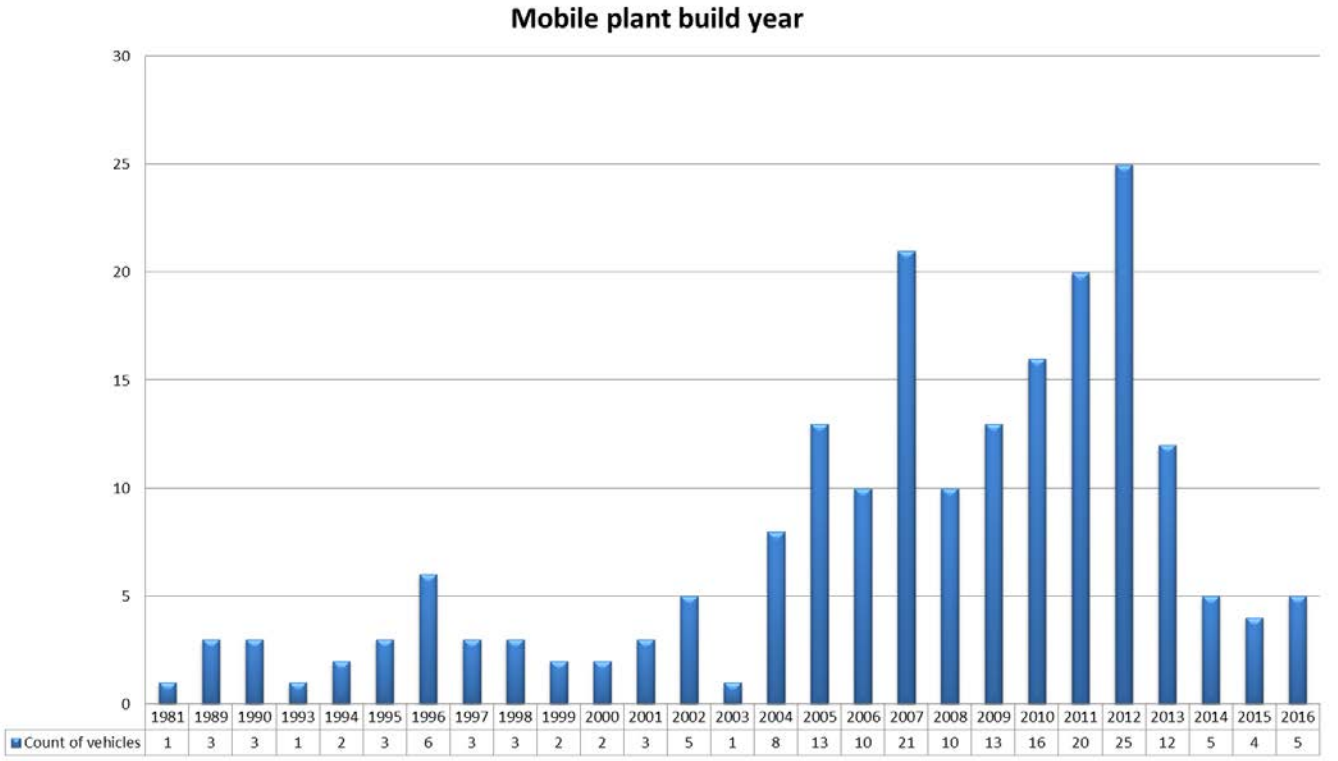


Figure 5: Fire fuel sources are dominated by oils including hydraulic, engine oil and diesel fuel.

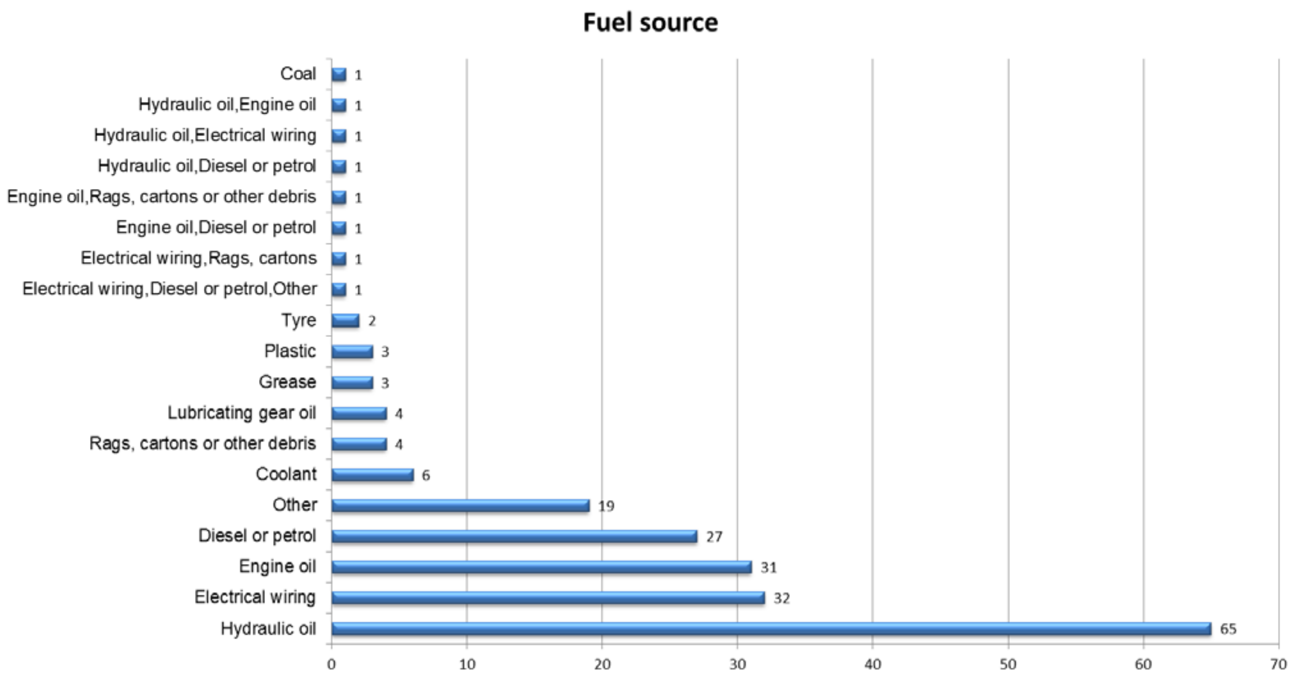


Figure 6: Fire heat sources are dominated by hot surface temperatures of diesel exhaust system components and electrical hot joints.

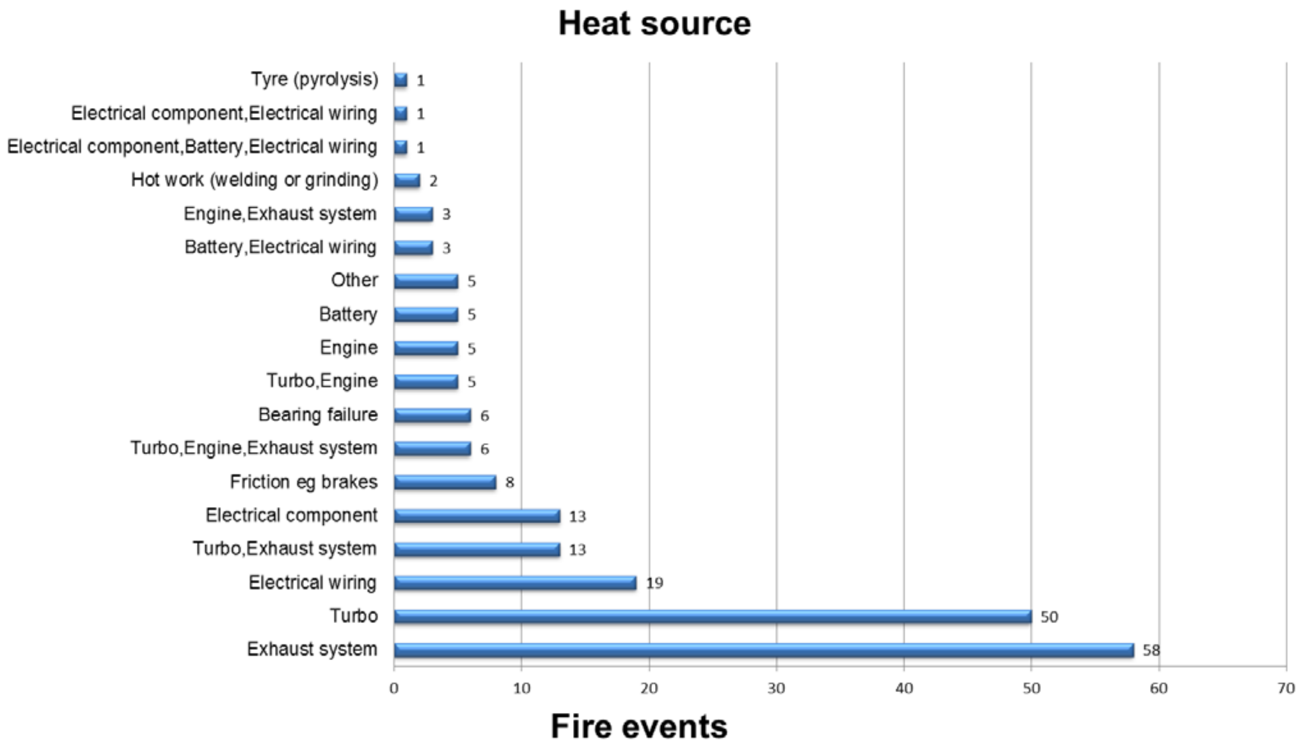


Figure 7: Mechanical hot surface location reported by ancillary form.

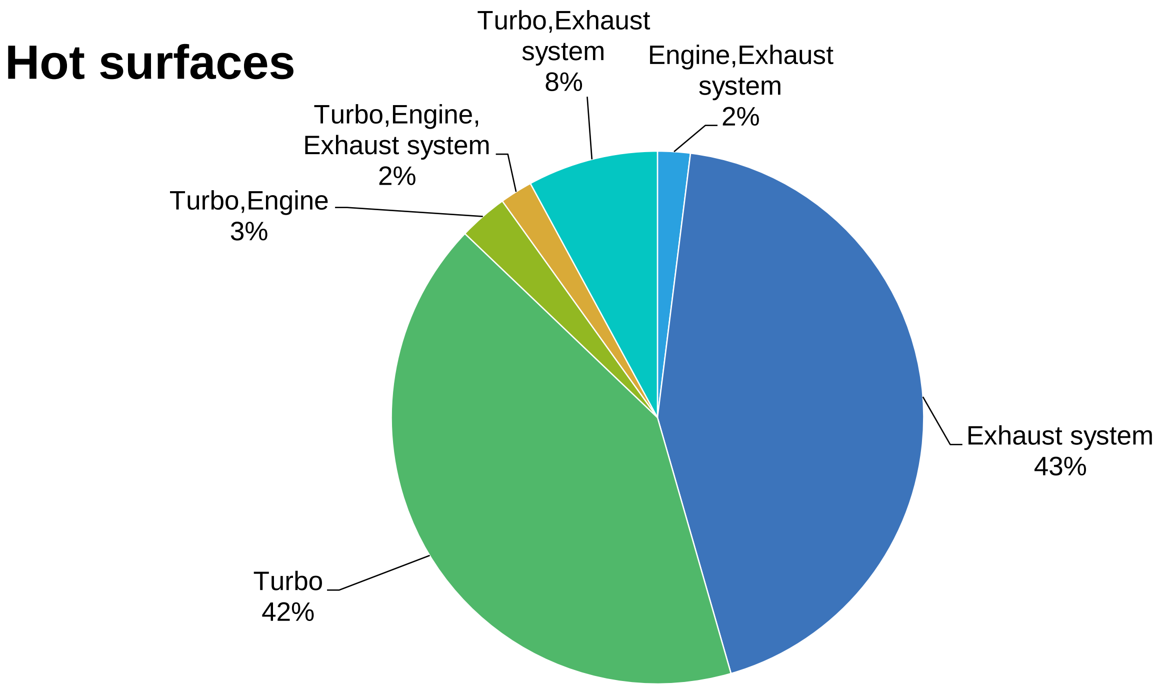
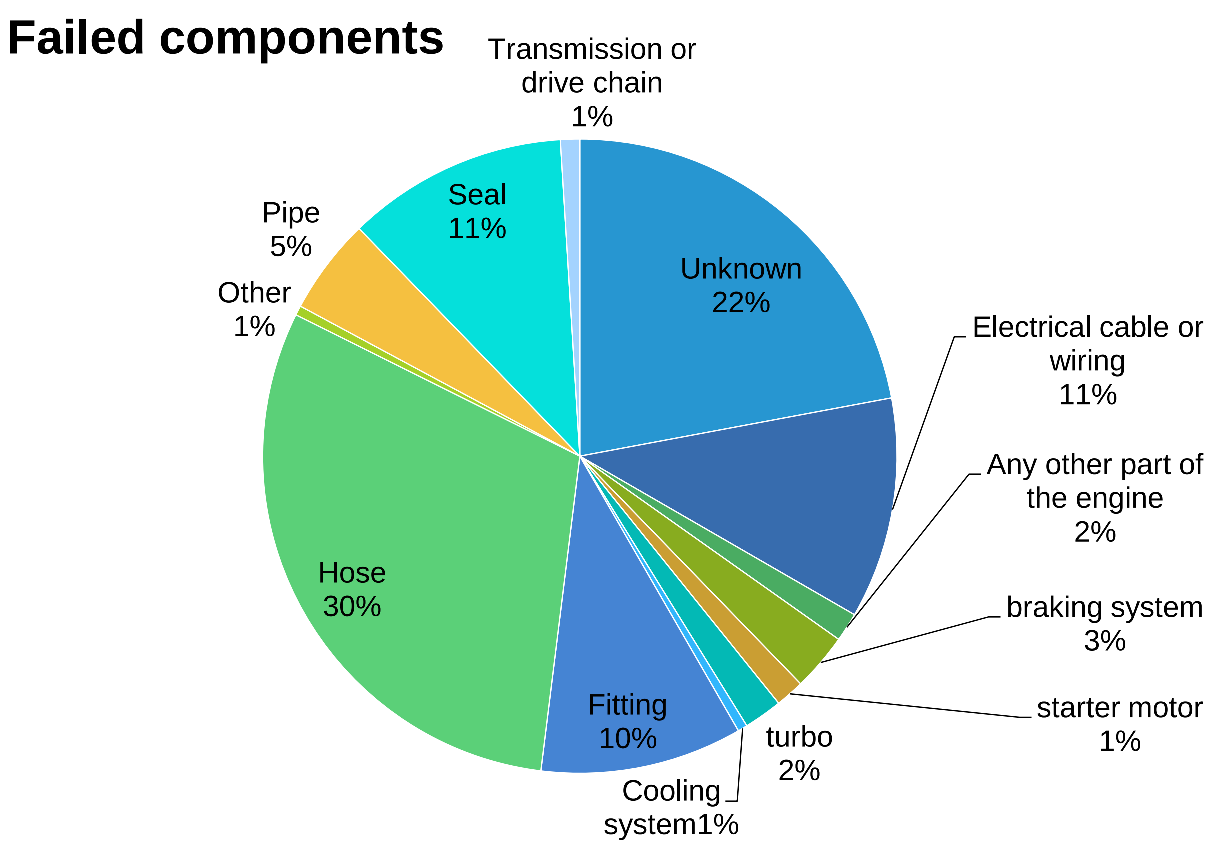


Figure 8: Failure modes reported by ancillary form



Causal factors and design change recommendations typically included routing, fastening, clamping and segregation of hydraulic, lubrication or fuel lines away from hot surfaces.

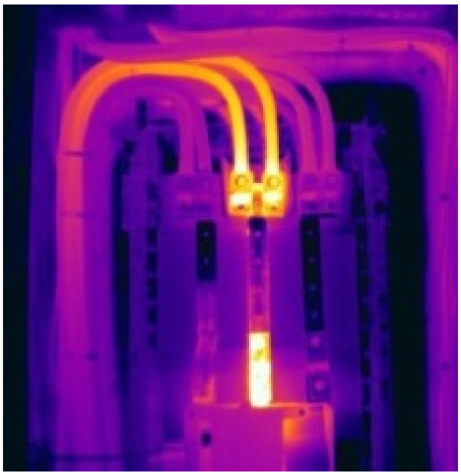
Fifty seven percent of all fires involved the failures of fittings, hoses, pipes, seals or similar fluid system devices.

Analysis

Most of the fires in the data sample can be segmented into two major groups:

- 69% diesel engine related, associated predominantly with hot surface and fluid release
- 20% electrical, associated predominantly with wiring.

Figure 9 and 10: Turbo hot surface and electrical hot joint.



The analysis of fire incident data found an average of 6.2 events per month reported over the 33-month period from September 2014 to May 2017. Previous fire data collected between 2001 and 2008 reported in MDG10032 occurred at an average of 3.1 events per month. In the 12 months between May 2016 and May 2017, a total of 97 incidents were reported at an average of eight fires each month.

Key aspects of the data include:

- Fifty eight (58%) percent of the reported fires occurred at open cut coal mines
- Twenty nine (29%) percent of the reported fires occurred in underground metalliferous mines
- The high temperature diesel engine exhaust and turbo surfaces were the ignition source in 69% of all fires.
- Causal factors and design change recommendations typically included routing, fastening, clamping and segregation of hydraulic, lubrication or fuel lines away from hot surfaces; but did not recommend elimination of the ignition/heat source as a control.
- Thirty three percent (33%) of all fires involved hydraulic oil,
- Seventeen percent (17%) of all fires involved engine oil, and
- Fifteen percent (15%) of all fires involved diesel fuel.
- Fifty seven percent (57%) of failed components were identified as fitting, hose, pipe, seal or similar fluid retention device.
- Approximately half the diesels in the fire events have lagging applied to the turbochargers. Seven percent (7%) of all fires reports contributed blame to the lagging which equates to 18% of lagged turbo installations.
- Fire protection systems were reported to be fitted to 84% of vehicles in fire incidents. Where the fire suppression system was deployed (47% of cases), 10% was automatic and 37% was manual activation.
- Seven percent (7%) of the vehicles had defects recorded at the time of service and at the time of pre-start inspection.
- Maintenance and design improvement recommendations were made on the ancillary forms. Forty six percent (46%) of respondents recommended design changes and 56% of respondents recommended maintenance changes.
    - The OEM was not notified in 19% of cases where a design change was recommended.
    - The OEM was not notified in 23% of cases where a maintenance change was recommended

- Twenty one percent (21%) of fires identified the heat source as being electrical. These fires are associated predominantly with wiring, but also include battery and starter motor events.
- Causal factors for electrical fires apportion blame to hot joint over current short circuit events. Recommendations included attention to routing, termination, connection, fastening and protection.

Recommendations in MDG1032

The recommendations in *MDG1032 Guideline for the prevention, early detection and suppression of fires in coal mines* are reinforced by the current data review and should be considered by all designers and people with management or control of mining plant.

MDG1032 recommendations:

Fire risks should be minimised to the lowest level reasonably practicable and controlled in the following order:

a) *Eliminate the fuel and/or ignition sources, if practicable*
b) *Substitute the fuel and/or ignition source to one of a lesser hazard.*
c) *Segregate the fuel and ignition source, (isolating the hazard).*
d) *Use engineering means to –*
   i. *minimise the risk of initiating a fire;*
   ii. *provide systems for the early detection of fires; and*
   iii. *provide systems to suppress and extinguish a fire.*
e) *Develop emergency procedures for early warning, fire suppression and the safe egress of people.*
f) *Use of personal protective equipment (PPE).*

Note: *A combination of methods may be required to minimise the risk to the lowest level reasonably practicable.*

Maintenance people should proof test all safety functions periodically and ensure adequate regular cleaning of surfaces, repair of any fluid leakage, and security of joints and fasteners.

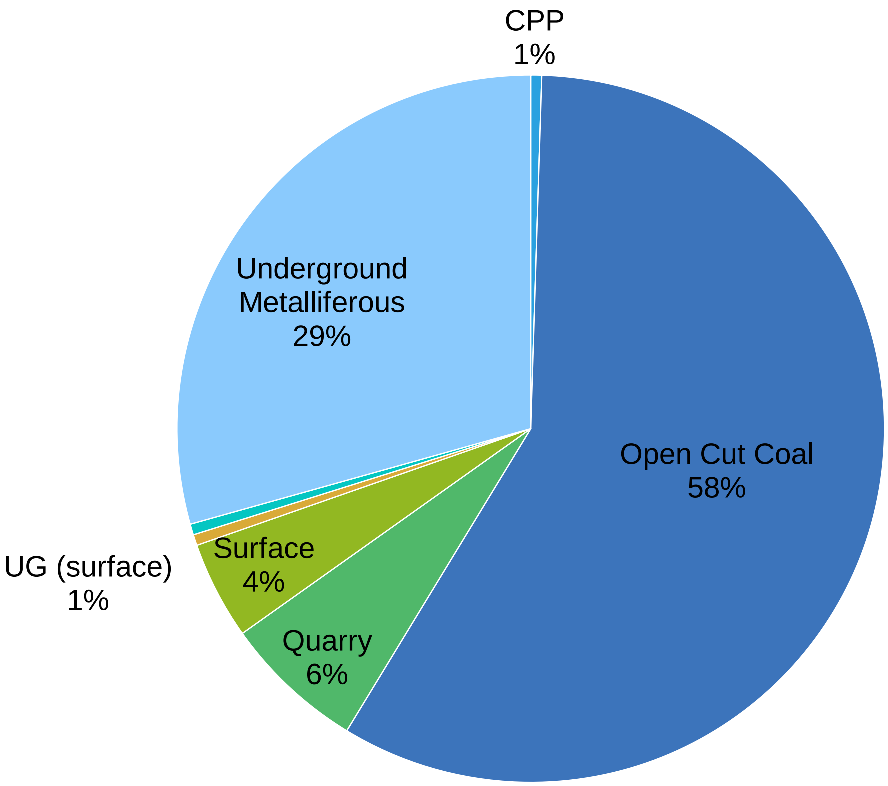
Designs should include fire protection analysis and information to maintain the design intent with regard to fire hazard assessment.

Observations

Figure 11: Fires on mobile plant by mine type

Underground coal – 1 (tyre pyrolysis)

Underground coal- diesel surface temperature is limited to 150°C



The data sample includes all mining and quarrying operations in NSW. Of the larger 116 operating mines and quarries there are 28 underground coal mines (24% of operations). Diesel engine systems are registered in underground coal mines; there are approximately 900 registered diesel engine systems in underground coal mines. There are no fires reported on the 900 diesel engine systems used in underground coal mines.

Factors - underground coal diesel design:

- Surface temperature is controlled to be less than 150°C for all modes of operation – exhaust manifold, turbo, exhaust pipes, and compressor are cooled by water jacket
- Explosion protection techniques including Ex d and Ex i are used for electrical systems – heavy duty protection of cables and connections
- Start systems are pneumatic – no batteries, starter motors or high current draw.
- Brakes are oil immersed totally enclosed – surface temperature less than 150°C.

All of the above robust design features are fundamentally integrated by mechanical and electrical design. The design of the underground coal vehicles eliminates (by design) the presence of hot surfaces and sparks. The statistics in this sample show that these methods are more than 99% effective in the elimination of fires on this type of diesel mobile plant. These techniques are proven engineered solutions; elimination of fires on mobile plant is achieved for underground coal. Visibility to *Target Zero* for fires on mobile plant is within the capability of mechanical and electrical engineers.

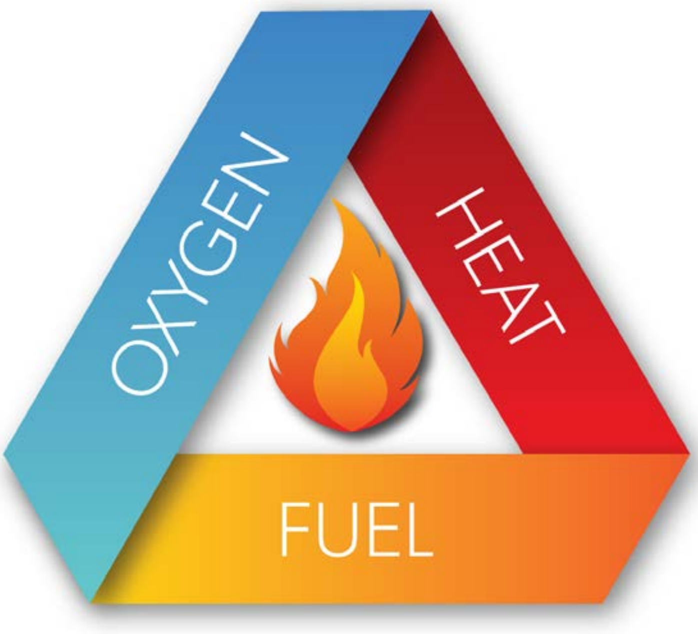
Hypothesis

A step change reduction in the occurrence of fire events can be made by the control of diesel engine surface temperature.

Discussion

Surface temperature controls are not implemented by original equipment manufacturers (OEMs) to the same extent as applied to underground coal vehicles for the metalliferous and surface mine vehicles. Lagging and double skin options are used. Attempts to control fuel are made by methods that are well designed and effective most of the time, however upon failure of containment of the fuel a fire will occur on contact with the exhaust system surface.

Effective reduction of fires on mobile plant should address both fuel and heat.



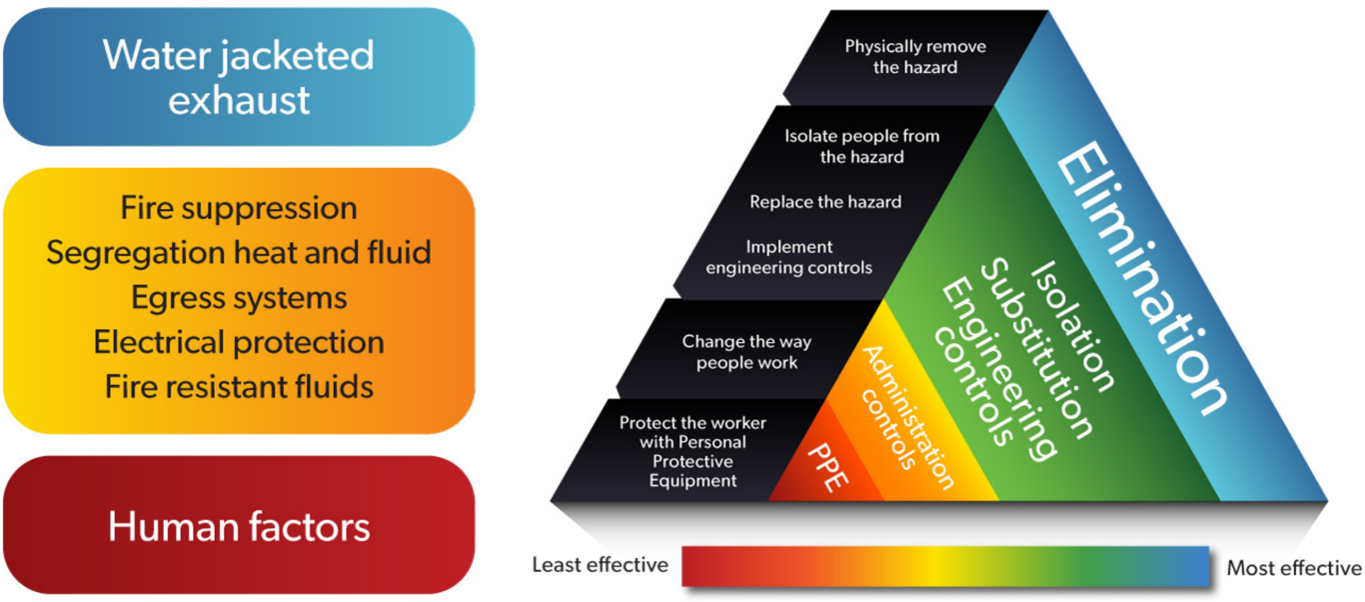
Fire that is initiated by the spray of oil onto a hot surface does not start gradually and build; the fire ignites the atomised fluid in a powerful propagation. Such a fire may be fed by fuel from a substantial system/reservoir under pressure while the vehicle system is operating, and after until accumulators are discharged. The radiator fan feeds such a fire with oxygen. An engine shutdown delay is often programed to allow the operator to safely bring a heavy vehicle safely to rest. Fire suppression may not have sufficient effect to extinguish a fire with an ongoing fuel load, oxygen supply and ongoing surface temperature generation.

Fire suppression is employed as a control to suppress a fire. Fire suppression nozzles are not aimed at the fuel tank, hydraulic tank or tyres, the nozzles are positioned about the hot surface of the diesel engine exhaust – surface temperature is the issue.

For underground coal applications, surface temperature control to less than 150^{0}C targets the spontaneous ignition temperature of some volatile layered coal fines. Surface temperature control to 150^{0}C may not be essential for elimination of 69 percent of fires of the analysed statistical sample that involve oil and fuel. The vehicles involved in the reported fire events typically have dry exhaust systems that operate up to or above 500^{0}C. The minimum hot surface ignition temperatures for diesel fuel (330~370^{0}C) and Hydraulic oil (440 ~480^{0}C) published by NIOSH (Ignition of hydraulic fluid sprays by open flames and hot surfaces) presents a significant fire risk.

Surface temperature controlled diesel engines are commercially available for industries where fire must be controlled such as marine and petroleum applications. Many of the engines used in the mining vehicles are available in wet (water jacketed) exhaust configuration that typically controls engine surface temperature adjacent to water jacketed areas to 200 ~ 250^{0}C.

Figure 12 and 13 : Control measure hierarchy.

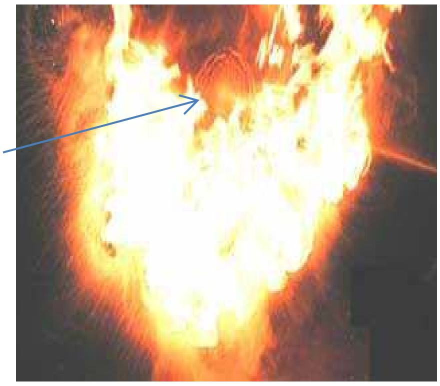


Where surface temperature control is used for mobile plant by robust design methods such as water jacketing, the fire risk associated with hot surface is largely eliminated by design when NIOSH experimental data is considered. The table below shows NIOSH results of MHSIT as conducted by Yuan using flat plate apparatus.

Table 1: MHSIT for fluids (NIOSH Ignition of hydraulic fluid sprays by open flames and hot surfaces.

Hydraulic fluid	Minimum hot surface ignition temperature, °C
ATF	350-360
Compressor oil	350-370
AW 32	390-430
AW 46	390-450
AW 68	440-480
Premium 46	420-450
THF	430-460
AW 68*	400-450
Diesel fuel	330-370

Figure 14: Hydraulic oil *minimum hot surface ignition temperatures* (MHSIT) testing.



Minimum hot surface ignition temperature (MHSIT) is affected by a number of factors including fluid stream and surface configurations and confinement. Worst case results suggest MHSIT can be as low as the fluids Auto Ignition Temperature (AIT). The American Petroleum Institute guidance (API 1991) states that hot surfaces are liable to ignite fuel vapour if the surface temperature exceeds the AIT by 200^{0}C. The NIOSH investigation results are more conservative than this API guidance. A literature review by HSE concludes that the measured MHSIT of unconfined sprays is typically more than 60^{0}C above the AIT. Based on this conclusion and diesel AIT of 204^{0}C, a surface temperature target of 250^{0}C would support a step reduction in the occurrence of fires on mobile plant.

Further safety is obtained if vehicle surface temperature is controlled to ISO AS/NZS 60079 temperature class T3 (200^{0}C). This figure is coincident with diesel fuel AIT and moves the surface temperature closer to the proven control established by the 150^{0}C underground coal limit.

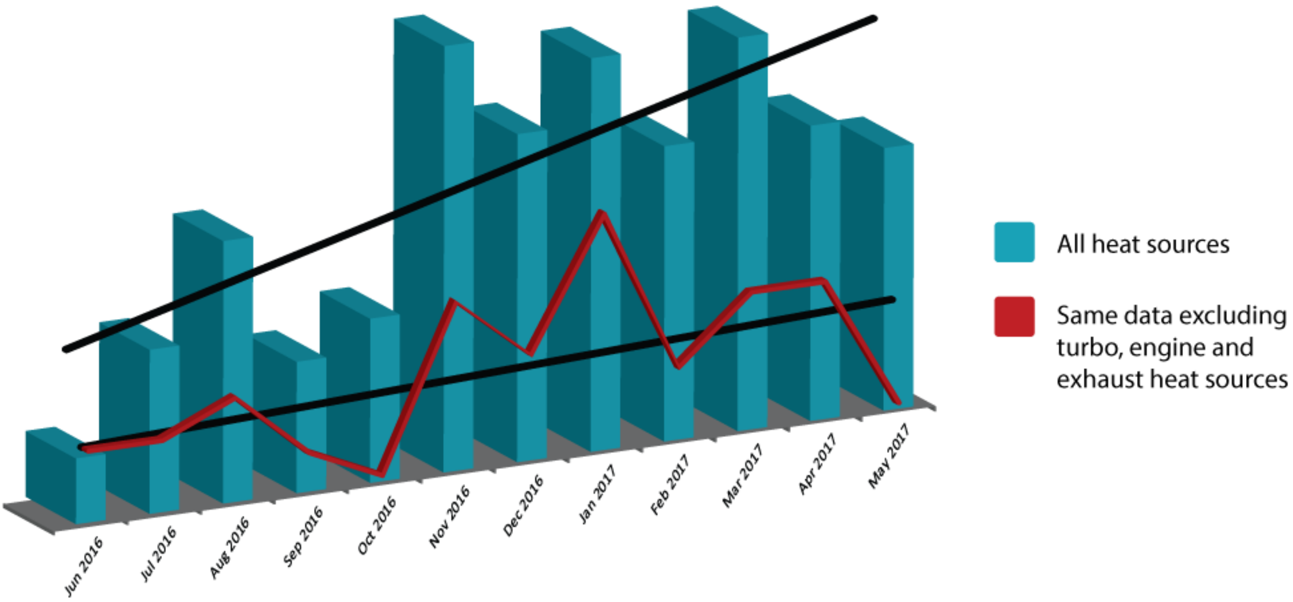
Liquid soaked into porous insulating material such as lagging can ignite at temperatures below the AIT by oxidative self heating (OSH). Fire resistant fluids should be considered where practicable including engine coolant.

Statistics do not adequately share the experience of an operator who is subject to a fire on a vehicle. The ongoing high frequency of fire events makes it more likely that a serious burn, intoxication, asphyxiation, fall or fatality may occur. US statistics show that 89 mobile equipment fires at US metal/non-metal mines were caused by hydraulic fluids (from 1990 ~ 2001), resulting in 46 injuries and 3 fatalities.

Underground mine fires extend the immediate danger of the fire to the inbye crew as toxic emissions and smoke engulf the ventilation passages of the underground mine.

Insurance statistics show that fire and explosion is a leading cause of business interruption by both the number of claims and by the value of claim. A business case that accounts for business interruption costs should be considered for new and existing plant.

Figure 15: Projected fire data with surface temperature controlled engines.



Conclusion

There is a need to continue to improve the reliability of the fire protection characteristics of mining plant.

Data

Currently, eight fire events per month are reported to the NSW Regulator. Engineering technology is available to virtually eliminate fires on mobile plant as demonstrated by underground coal mobile plant statistics.

Surface temperature control

There continues to be clear indication that hot surface and inadvertent release of combustible fluid is a dominant condition causing fires on mobile plant at mines. Surface temperature control by water jacketed turbos and exhaust manifolds as typically available on marine application engines, or other methods, should be considered as a means to eliminate hot surface ignition sources.

The data shows that step progress can be made to reduce mine site fires on mobile plant by reducing engine exhaust system surface temperatures and increasing the protection level of electric wiring.

Information back to industry

The Resources Regulator has the objective to work with industry to develop a strong systematic approach based on risk management principles and performance outcomes supported by a sound safety culture prevailing in the industry.

The information disseminated to industry in this report shares statistical information gathered by the Resources Regulator. The data has been analysed and presented to show patterns that lead to or contribute to fire events on mobile plant