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TECHNICAL REPORT

EES-100

Electrical Engineering Safety

Underground Coal Mine Electric Cables used in Hazardous Zones

Produced by Mine Safety Operations Branch

Industry and Investment NSW

March 2011

D I S C L A I M E R

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Table of Contents

Table of Contents 3
1. Establishment 5
  1.1 Title 5
  1.2 Purpose 5
  1.3 Scope 5
  1.4 Applicable legislation 6
  1.5 Referenced Gazette Notices 6
  1.6 Referenced Standards and Guidelines 6
  1.7 Acronyms 6
2. Executive summary 7
3. Introduction 8
4 Cables in underground coal mines 10
  4.1 Integrating mining cables and electrical distribution systems 10
  4.2 Australian Standards for coal mining cables 11
  4.3 Australian Standards associated with mining cables 13
  4.4 Repair of mining cables 13
  4.5 Integrating mining cables in the mine's OH&S management system 14
5. Cable arcing incidents in hazardous zones (1984 – 2009) 16
  5.1 Reporting of cable arcing incidents 16
  5.2 Cable arching statistics 1984 to 2009 16
  5.3 Cable arcing statistics 2007 to 2009 18
  5.4 Cable arcing – NERDEC Report C1252 22
6 Cable damage statistics 2000/01 to 2008/09 24
  6.1 Introduction 24
  6.2 Cable damage 26
7. Issues – cable design and manufacture 29
  7.1 Current identified issues 29
  7.2 Emerging issues 29
8. Observations on cable arcing incidents, cable damage and cable design 32
9. NSW production and cable arcing incidents 33
  9.1 Raw coal production for NSW mines 33
  9.2 Raw coal production and arcing incidents for NSW mines 34
10. Appendices 36
  Feedback Sheet 36

I&I NSW Contact details 37

1. Establishment

1.1 Title

This is the Industry & Investment NSW (I&I) Electrical Engineering Safety Technical Report *Underground Coal Mine Electric Cables used in Hazardous Zone.* The author of the report is J.F. Waudby, Senior Inspector of Electrical Engineering.

1.2 Purpose

This Technical Report provides information to enhance industry's understanding of the risk controls associated with electric cables used in underground coal mine hazardous zones and to identify 'emerging issues' that need to be considered from a strategic perspective. The report is of particular relevance to those involved in underground coal mining operations, to cable manufacturers, cable repairers and to OH&S professionals.

The report seeks to enhance industry's ability to protect people and property from:

- electrocution
- electric shock
- electrical burn injuries
- arc blast injuries
- injuries sustained through operation of the apparatus
- unintended operation of the apparatus
- ignitions of flammable mixtures of gas or dust
- fire.

1.3 Scope

This Technical Report extends to all underground coal operations in New South Wales and relates specifically to hazardous zones. It deals with high and low voltage flexible reeling, trailing and feeder cables; with a focus on reeling cables and trailing cables.

This Technical Report is supplemented by:

- Standards as referenced
- Technical Paper (refer to Mine Safety website) - *Earthing Integrity & Associated Protection Part 1 - Controlling Touch Voltages and Arcing in Trailing Cable Circuits* and *Part 2 - Earth continuity of restrained plugs and receptacles.*

1.4 Applicable legislation

Occupational Health and Safety Act 2000

Occupational Health and Safety Regulation 2001

Coal Mine Health and Safety Act 2002

Coal Mine Health and Safety Regulation 2006

1.5 Referenced Gazette Notices

Gazette Notice for Specification of Plant that can be used in a Hazardous Zone.

Gazette Notice for the specification of requirements to be licensed as a cable repair workshop.

1.6 Referenced Standards and Guidelines

AS/NZS 1299:2009 Electrical equipment for mines and quarries – Explosion-protected three phase restrained plugs and receptacles for working voltages up to and including 3.3 kV.

AS/NZS 1300: 2009 Electrical equipment for mines and quarries – Bolted explosion-protected three phase cable coupling devices.

AS/NZS 1802:2003 Electric cables - Reeling and trailing - For underground coal mining purposes.

AS/NZS 1972:2006 Electric cables - Underground coal mines - Other than reeling and trailing cables**.**

AS/NZS 4761.1:2008 Competencies for working with electrical equipment for hazardous areas (EEHA) - Competency Standards.

AS/NZS 4761.2:2008 Competencies for working with electrical equipment for hazardous areas (EEHA) - Guide to assessing competency.

EES 001 Electrical Engineering Management Plan**.**

1.7 Acronyms

AS: Australian Standard

AS/NZS: Australian New Zealand Standard

EES: Electrical Engineering Safety

EMI: Electromagnetic Interference

OH&S: Occupational Health and Safety

SEP: Standard of Engineering Practice

2. Executive summary

Current cable designs based on Australian Standards and manufacture of cables have served the industry reasonably well over the past 25 years (with the exception of cables used on shuttle cars). Cable design has not been identified as a factor in damage scenarios. However, with the increasing productivity demands and increased globalisation of manufacturing, deficiencies in the Australian Standard are becoming apparent. There is a need to revise the Australian Standard AS/NZS1802 to cater for increased performance requirements for mining cables. Until the standard can be revised a process of 'trialling' new designs without requiring exemption from legislation is required. There is also a need for the industry to consider whether third party conformity assessment of mining cables is warranted.

For shuttle cars the use of individually screened power conductors has the potential to reduce the number of arcing incidents due to phase to phase short circuits. The coal industry should consider trialling reeling cables similar to type 280 cables and pursue improved design and manufacture of such cables.

Any increase in utilisation voltage (above 1000 V) for continuous miners could increase the safety risk to mine workers if current cable designs and current cable management practices are employed.

Deficient cable repair has not been a factor in cable damage scenarios, although defective cable repairs were identified in a handful of arcing incidents between 1984 and 2009. The current cable repair arrangements, including licensing of workshops and certification of competent cable repairers, is continuing to serve the industry well. However, this should not stop the regulator from seeking alternative but equal arrangements.

Industry performance with respect to cable arcing incidents has not improved in 25 years, while for continuous miner cables the performance has deteriorated. No reasons are offered to explain this deterioration.

Even when considering the significant improvement over the past two years, industry performance with respect to shuttle car cable arcing incidents has deteriorated. No reasons are offered to explain this deterioration.

Although the rate of damage to shuttle car and continuous miner cables has improved, the damage (including arcing incidents) to shuttle car cables and continuous miner cables is an obvious area for improvement. These are probably the hardest worked cables in a mine and the ones exposed to the highest risk of damage, therefore they are the ones that need particular management attention. Ways to prevent damage to these cables are well known and have been known for many years; however, the ability of the industry to manage these basic factors is in question.

Solutions for the common damage scenarios on longwalls are well known, easily applied and maintained, but despite this failures still occur.

The cables on typical longwall monorail systems are generally well managed.

3. Introduction

Industry & Investment NSW has the following vision for electrical engineering safety:

> "A mining and extractive industry that has eliminated death and injuries from electrically powered and electrically controlled equipment."

Electrical engineering safety encompasses:

- Prevention of electric shock and burns, (electrocution, death or injury as a result of a shock, radiation burns, flash burns, burning particles and plasma)
- Prevention of electrical arcing and surface temperatures that have sufficient energy to ignite gas and/or dust
- Prevention of fires caused by the malfunction of electrical equipment
- Prevention of injury and death from unintended operation, failure to stop or failure to operate, of electrically powered and electrically controlled equipment
- Use of electrical technology to provide safe-guards and monitoring for non-electrical hazards and electrical hazards with a safety integrity level appropriate for the risk.

Supporting this vision is a philosophy of operation which is outlined in the Strategic and Operational Plan for Electrical and Engineering Safety in NSW Mines, which can be viewed at www.dpi.nsw.gov.au. The philosophy of operation embraces a **System Safety Approach,** applying the **Hierarchy of Risk Controls** and the **Risk Reduction Precedence,** and fostering a **Positive Safety Culture.**

Satisfactory electrical engineering safety must be achieved in the context of the mining industry's increasing electricity consumption and the use of electrical technology, with the consequent increases in size (power rating) and complexity. With this comes a changing risk profile. To adequately manage the safety risks posed by electrical equipment and technology, the hazards, risks and risk controls need to be thoroughly understood. This understanding must be at an engineering level.

Electric cables used in underground coal mine hazardous zones form an integral part of any mining operation and the associated risks and risk controls need to be understood and managed within the context of current mining practices. Risks and risk controls also need to be identified and understood with respect to future requirements, such as increased power consumption, non-sinusoidal electrical supply system, increased harmonics, increased voltage levels, increased equipment utilisation etc.

Electric cables in underground coal mine hazardous zones are subject to an extremely arduous environment that is often very wet. In addition, they are handled regularly by mine workers while energised.

NERDEC Report No. 1252 summarises the risks from cables in hazardous zones when it states:

> *"In addition to adding significantly to the cost of production, cable failures, particularly those involving damage to the outer sheath and conductor insulation, represent a significant risk of:*
>
> - *Ignition of flammable gas*
> - *Initiation of a coal dust explosion*
> - *Initiation of a fire*
> - *Personal injury due to burns, electrocution etc.*
>
> *The severity and consequences of any particular cable failure will depend on the actual circumstances existing at the time of failure. Some of the factors affecting the severity and consequences include the adequacy of the ventilation system, the presence of combustible material such as coal dust and the proximity of personnel to the site of the failure. In a gaseous underground coal mine, for example, cable damage involving open arcing may have disastrous results with the initiation of gas and/or coal dust explosion with a potential for the loss of many lives."*[1]

[1] 'Evaluation of Mine Cable design safety' p.10, NERDEC Report Number 1252, June 1993

4 Cables in underground coal mines

4.1 Integrating mining cables and electrical distribution systems

Electrical distribution systems and cables are designed in such a way that if a cable is damaged the risk of electrocuting someone, causing a major fire, catastrophic failure of the cable or igniting methane gas is minimised. Of particular interest are the flexible cables used to supply machines, electrical distribution centres and onboard machines, as these are most likely to be damaged. When selecting cables the electrical distribution system is an important factor, along with considering the type of application and the harsh mining environment (mining cables are particularly susceptible to damage due to the extreme mechanical stresses, especially on reeling and trailing cables). It must be recognised that high transient voltages can be generated by the power system. [2]

The electrical distribution system protection and method of earthing is particularly important. Selection of an incorrect cable may compromise the safeguards provided by the electrical protection and the earthing. For this reason it is important that advice is sought from a competent electrical engineer before selecting and installing a mining cable.

All underground coal mine electrical distribution systems are designed to limit the amount of current that can flow in the event of an earth fault. Typical values are 5, 10 and 25 amperes, with most commonly 5 amperes at the working face. This means that when a cable is damaged and the fault is from a power conductor to earth, the amount of energy released is reduced significantly from that of a solidly earthed electrical distribution system.

Note:	The energy released is proportional to the square of the current, so this reduction can easily be by a factor of 10,000 or more. Earth fault limitation is also a proven method of controlling touch voltages at mobile machines to a level that is highly unlikely to be fatal.

A key feature of most mining cables is the provision of earthed screens around each individual power conductor. These screens are provided so that if a cable is damaged the most likely type of fault is an earth fault. Combining the earth fault limitation and the fact that the most likely fault is going to be a relatively low energy earth fault, the likelihood of a catastrophic failure of the cable or a major fire is significantly reduced. This arrangement should be considered a fundamental requirement for underground coal mine electrical systems. When combined with fast acting earth fault protection the likelihood of electrocution is also significantly reduced.

[2] 'Evaluation of Mine Cable design safety' p7. NERDEC Report Number 1252, June 1993

4.2 Australian Standards for coal mining cables

Mining machines in the underground coal industry work in a harsh environment. Many of these machines are mobile and often their motive energy is electricity. Because of the harsh environment and special requirements for electrical distribution at mines, cables used on mining machines and to supply mining machines are specially constructed.

Key features of the design of cables are:

- Collective screening around power conductors or individual earthed screens around each individual power conductor.
- Electrical symmetry for cables that can carry high current. This is provided to prevent currents being induced in earth conductors and thus raising the earth potential of individual machines above the normal 0 volts. If this induction is not controlled, then it is possible for one machine to be at a different earth potential to another, and if they touch there will be a spark between the two machines. In a coal mine, this spark has the potential to ignite methane gas and cause an explosion with catastrophic consequences. This is particularly important where rubber tyred machines are used. Along with simple pilot circuit arrangements, it has the benefit of making the pilot circuit relatively immune to the effects of EMI.
- Tough construction:-
    - Outer sheath resistant to abrasion
    - Capable of withstanding pull forces
    - Overall construction to be sufficiently impact resistant
    - All components / elements sufficiently durable for the specified duty.
- Overall construction to maintain all conductors in a stable / relative position.
- Fire resistance of cable sheaths and insulation. If a fire does start, once the ignition source is removed the fire will burn itself out within a short time.
- Outer sheath to be anti-static.
- All components / elements are sufficiently flexible for the specified duty.
- Insulation of conductors suitable for an IT system.
- Insulation of conductors able to be coordinated with equipment Basic Insulation Levels (BIL's).
- Conductors (including earth conductors and screens) have sufficient ampacity.
- Earth conductors and screens are of sufficiently low resistance so that the earth leakage detection systems can reliably operate within the current and timing parameters.
- Capable of being terminated in explosion protected enclosures (for underground use).
- All parts / components / elements capable of being repaired and restored to an 'as new' condition.

These design features are codified in the two most important Standards for mining cables:

- **AS/NZS 1802:2003** *Electric cables - Reeling and trailing - For underground coal mining purposes*
- **AS/NZS 1972:2006** *Electric cables - Underground coal mines - Other than reeling and Trailing*

AS/NZS 1802 is particularly significant because the different types of cables have different constructions and different voltage ratings. They are numbered accordingly. All reeling and trailing cables constructed in accordance with AS/NZS1802 have a number commencing with 2, along with a number that denotes the voltage rating. For example, type 209.1 means a type 209 cable with a voltage rating of 1.1kv. The two most common types of cable used are type 275 for shuttle car reeling applications and type 241 for continuous miner and longwall machine supply. These cables are the most common source of electrical arcing incidents in hazardous zones, that is, reeling and trailing cables used to supply mobile coal production machinery.

AS/NZS 1802 was first developed in Australia as AS C81 in 1941. Subsequently it was significantly revised and type 275 cable appeared for the first time in 1976. This has become the cable of choice for shuttle car and other reeling applications. The latest version of the Standard was released in 2003.

Innovations have occurred with the introduction of type 245 cable which has three pilot conductors (instead of one) and type 241M which is a high flexibility version of type 241 specifically for shearer applications. A significant innovation was introduced for reeling cables with individual screening on power conductors. This innovation permitted individual power conductors to have semi conductive earth screens that were either extruded (type 280A) or laid up with tape (type 280B). However, type 280 cables have not been used at mines and type 280A was removed from the standard in 2003.

The catalyst for type 280 cables was a research project begun in 1989. This was the NERDEC PROJECT C1252. A specific objective was: *"to help reduce the incidence of damage, particularly that involving arcing and burning, to power cables used in mining applications, with particular emphasis given to both heavy duty reeling and trailing cables".*[3]

[3] 'Evaluation of Mince Cable design safety', p.7, NERDEC Report Number 1252, June 1993

4.3 Australian Standards associated with mining cables

Along with these cable design standards are other standards relating to cable plugs specifically designed for fitting to cables constructed to the above standards. These standards are:

- **AS/NZS 1299:2009** *Electrical equipment for mines & quarries – Explosion-protected three phase restrained plugs and receptacles for working voltages up to and including 3.3 kV* (and its predecessors, 1989 and 1993).
- **AS/NZS 1300: 2009** *Electrical equipment for mines & quarries – Bolted explosion-protected three phase cable coupling devices (*and its predecessors, 1973 and 1989).

All the referenced standards, along with the cable repair standard referred to in section 4.4, are interrelated. This means changes in one standard will impact on the other standards. Deficiencies in any one of the standards, particularly considering contemporary and future mining demands, have the potential to reduce mine worker safety and the productivity of the industry.

Note:	Emerging issues with plugs, receptacles, and adaptors were the catalyst for a major revision of the associated standards (AS/NZS 1299 and AS/NZS 1300) to address such matters as increased cross sectional area and bending radii of power conductors and cables compromising the ability to terminate cables into plugs. AS/NZS 1802, AS/NZS 1972 and AS/NZS 1299 are specified in the gazette notice for plant that can be used in a hazardous zone; therefore compliance with these standards is mandatory.

4.4 Repair of mining cables

As a result of the need to regularly repair mining cables and the special design of mining cables and associated plugs, it has been necessary to develop an Australian Standard for the repair of cables. The standard was originally published in 1975, revised in 1993 and the latest version was released in 2003.

The standard is:

- **AS/NZS 1747:2003** *Reeling, trailing and feeder cables used for mining - Repair, testing and fitting of accessories*.

Because of the special construction of mining cables and the associated specialist repair techniques, test devices and repair materials; organisations that undertake repair of these cables require a high degree of competence, proper facilities and detailed work processes to ensure cables are restored to a fit for purpose condition. Therefore, flexible reeling, trailing and feeder cables that are used in a hazardous zone must only be repaired at a licensed facility. Clause 19(1)(e)(ii) of the Coal Mine Health and Safety Regulation 2006 states:

> *'(e)(ii) the repair of flexible reeling, trailing and feeder cables for use in a hazardous zone being carried out only by a person licensed to carry out those repairs.'*

Information on how to obtain a licence is available on the I&I website at:

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/157903/EES-007-Licensing-of-Cable-Repair-Facilities.pdf

The list of licensed cable repair workshops is available from the I&I website at: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/203968/Register-of-cable-repairs-licences---v3-090108.pdf

Workshop licensing requirements specify the employment of competent persons. Previously, examinations were conducted with Mine Safety Operations personnel acting as examiners. Competency assessment criteria and a procedure have been developed for cable repairer competencies. Competency assessment is now mainly conducted by the workshop, with an oral examination conducted by a panel of examiners, including at least one independent examiner. Mine Safety Operations personnel often observe the process. The competency requirements have also been incorporated in AS/NZS 4761.

Details of the competency requirements and process are on the I&I website at:

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/115443/EES-012-Assessment-and-Registration-of-Competency---Cable-Repairer.pdf

Note:	Gazette Notice for the specification of requirements to be licensed as a cable repair workshop. EES007 NSW DPI Technical Reference for the Licensing of Cable Repair Facilities for Reeling, Trailing and Flexible Feeder Cables used in NSW Underground Coal Mine Hazardous Zones.

4.5 Integrating mining cables in the mine's OH&S management system

Electrical engineering decisions for the use of cables are critical to achieving safe production at mine sites, therefore these decisions must be of the highest quality. A model for quality decision making can be found in the *Minerals Industry Risk Management Model* (MIRM Model - refer: www.mishc.uq.edu.au).

The quality of the decision depends on the quality of the engineering and management process that designs, purchases, installs, commissions, operates, maintains (including repair and overhaul), modifies, trains, standardises and otherwise defines the nature of the day-to-day work process involving an interaction with cables. All of this must be present and effective at every stage of the cables' life cycle and must be effectively supported by the organisational culture. If any element is deficient, or there is ineffective support from the organisational culture, safe production cannot be guaranteed.

In particular, flexible cable management in a hazardous zone should be addressed in mine site *Standards of Engineering Practice* (SEP's) and include[4]:

- Transport and storage of spare cables
- Testing and inspection of cables in the operation
- Standards for installation of cables and associated responsibilities defined
- Defined responsibilities for inspecting and reporting on the status of cable installations and management
- Removal of power when SEP's are not met
- Damaged cable reporting and investigation
- Reporting and investigation of arcing in a hazardous zone
- Cable replacement practices – licensed cable repair workshops give repaired cables a condition score: the lower the score. The worse the overall condition. Cable replacement should be identified as being required when a cable condition score falls below the operation site standard.

Note: The management of cables will be the subject of mine site assessments in 2010/2011.

[4] EES 001 Electrical Engineering Management Plan, p40, I&I Technical Reference, July 2009

5. Cable arcing incidents in hazardous zones (1984 – 2009)

5.1 Reporting of cable arcing incidents

The data presented here is based on analysing the reported instances of arcing in a hazardous zone from 1984/1985 to 2008/2009 as reported to Industry and Investment NSW, Mine Safety Operations (I&I), in accordance with requirements of the coal mining safety legislation. The data is derived from the annual Chief Inspectors' report for each of the years 1984/1985 to 1998/1999 and from the COMET database for the years 1999/2000 to 2008/2009.

From 1 September 1999 to 1 October 2003 there were no legislative requirements for the reporting of arcing in a hazardous zone, although a number of mines continued to report these incidents. For the year 1999/2000 the data includes arcing incidents reported in accordance with the 1984 legislation for the period 01/07/1999 to 01/09/1999. On 1 October 2003 the *Coal Mines (Underground) Regulation 1999* was amended such that Clause 34B (1) (a) required the reporting of evidence of arcing on cables in a hazardous zone. The *Coal Mine Health and Safety Regulation 2006* maintained the requirements for reporting of these incidents. Clause 56(1)(l) of the Regulation states:

> *'(l) an event that occurs in a hazardous zone in the underground parts of the coal operation and from which an electric arc is observed or that leaves visible evidence on an electric cable of arcing having occurred.'*

5.2 Cable arching statistics 1984 to 2009

Figure 1 on the next page shows the number of arcing incidents per year, while Figure 2 shows the number of arcing incidents per million tonnes of raw coal mined.

Figure 1: Cable arcing incidents

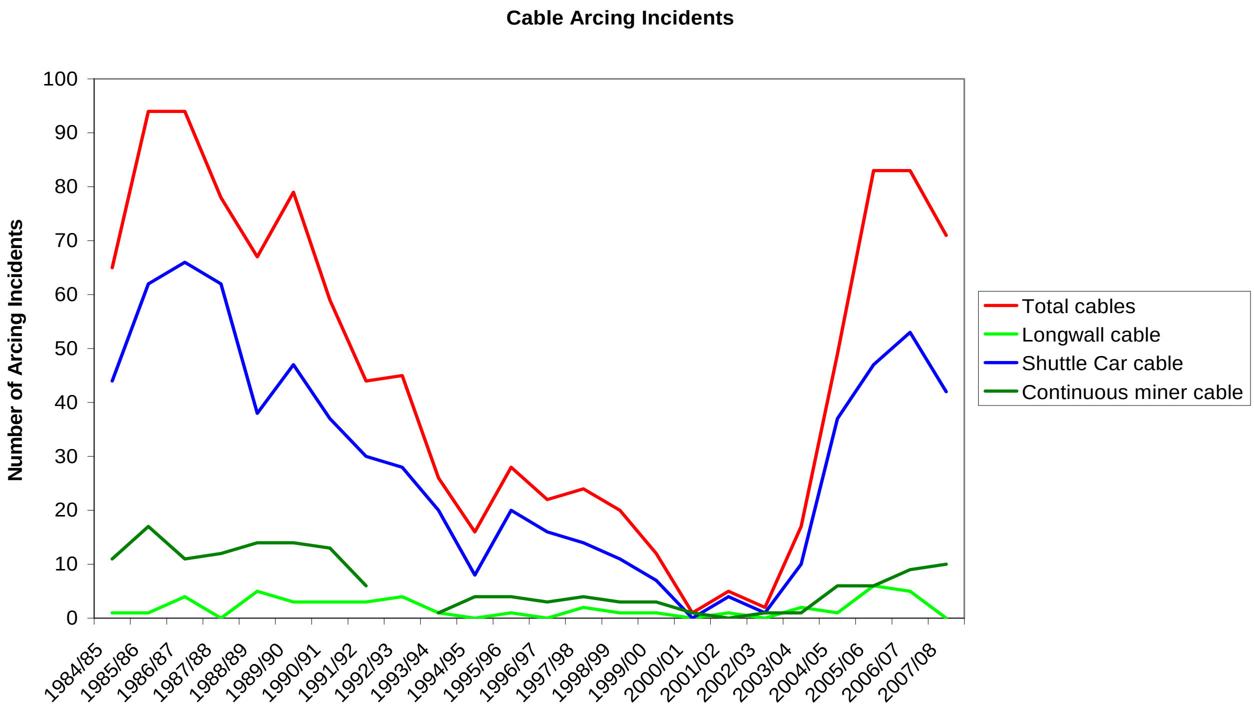
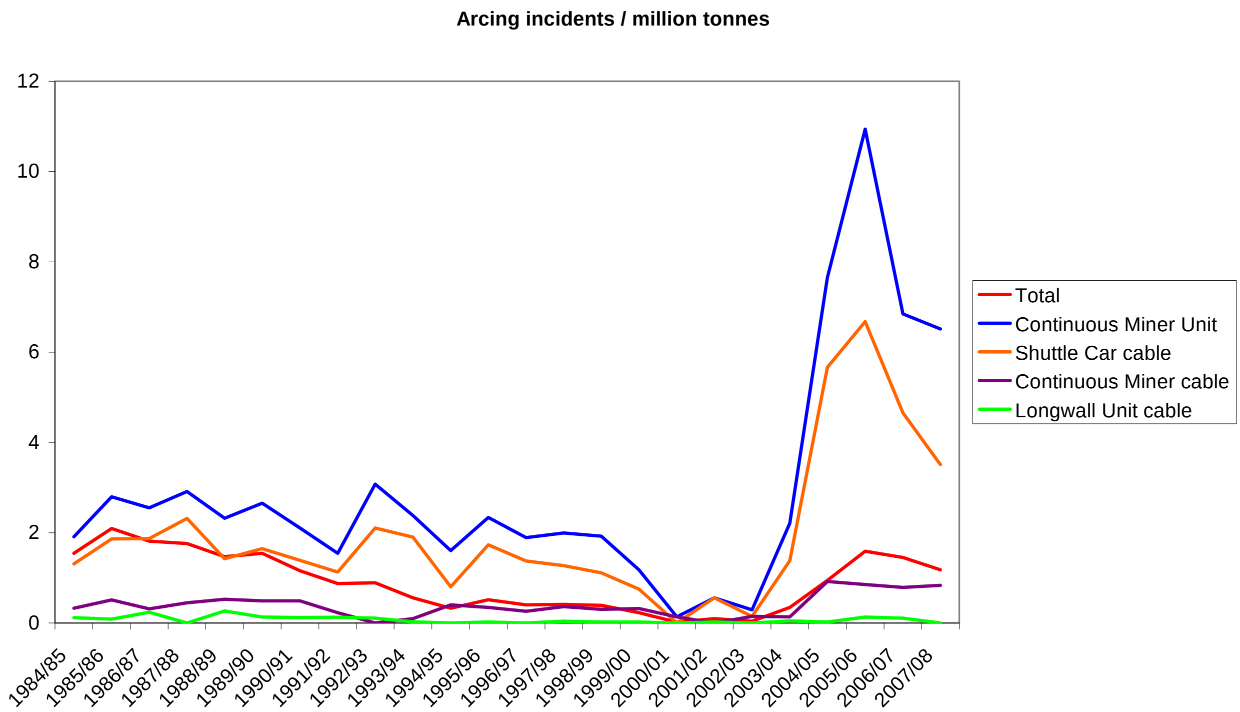


Figure 2: Cable arcing incidents per million tonnes of raw coal mined



With regard to continuous miner production, there has been a significant decrease in the number of shuttle cars in use since 1984/1985. This is mainly due to the move towards longwall methods. Also since the late 1990s battery powered coal transporters have been introduced at some mines and the carrying capacity of shuttle cars has increased significantly. These factors need to be kept in mind when interpreting the graphs showing the trend in the number of cable damages, the damage per million tonnes of raw coal mined, and the number of arcing incidents per million tonnes of raw coal mined. In calculating the rates of cable damage and cable arcing, the number of tonnes of raw coal mined is the number using that particular mining method. For example, the production figure used for shuttle cars is the continuous miner unit production figure.

5.3 Cable arcing statistics 2007 to 2009

18 longwall and 11 Bord and Pillar operations[5] were in production between 2007 and 2009. The population of longwall face cables considered in this data is 54 - number of mines x 3 cables (Shearer and Armoured Face Conveyor T/G and M/G cables). The number of continuous miner cables in operation at any one time is roughly estimated at 100 and a shuttle car cable population of 200.

The cable arcing data from COMET was analysed for the two years from 2007/2008 to 2008/2009

There were a total of 143 arcing incidents reported. The type of cable involved is shown in Table 1.

Table 1: Arcing incidents – cable type (function eg shuttle car cable, feeder breaker cable etc)

Type of cable	Number of incidents
Shuttle car	90
Continuous miner	23
Longwall Face (Shearer / AFC)	3
Cable on a M/C	7
Mobile roof bolter	10
Breaker line support	2
Other (Chock Mover etc.)	0
Unknown	5
Breaker Feeder	3

[5] 2009 New South Wales Coal Industry Profile, Department of Primary Industries

From Table 1 it can be seen that arcing incidents mainly occur on shuttle car cables, continuous miner cables and mobile roof bolter cables. All of these cables are exposed to potential damage with no additional physical protection. It is obvious that shuttle cars are the hardest worked and most exposed to potential damage, followed by continuous miners and mobile roof bolters.

Cables on longwall faces have significant cable protection which is provided by enclosing cables in metal guarding along the AFC and in flexible cable handler for the shearer cable, colloquially called a “bretby”. The low number of arcing incidents could indicate that cable management on longwall faces is generally satisfactory and reflects the significant amount of ‘engineering control’ provided by physical guarding.

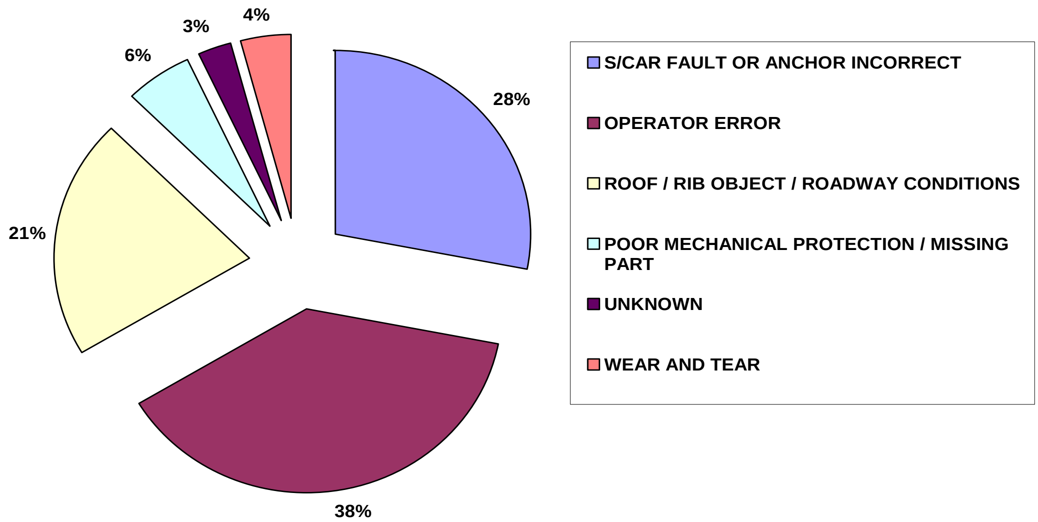
Even when considering the number of cables, the performance on longwall faces is significantly better than for continuous miner units. The difference between the two methods of mining arises from the significant engineering controls exercised on longwalls. In continuous miner units the focus is on ‘cable management’ because of the mining method and dynamic environment.

The data was further analysed to determine the main causal factors. The results are shown in Table 2, while Figure 3 uses a pie chart to show the percentage breakdown.

Table 2: Arcing incidents – main causal factors

Causal factor	Number of incidents
S/car fault of anchor incorrect	40
Operator error	55
Roof/rib object/ roadway conditions	30
Poor mechanical protection / missing part	8
Unknown	4
Wear and tear	6

Figure 3: Main causal factors 2007 – 2009 (ALL types of cables)



S/Car Fault or Anchor Incorrect – This includes defective cable reels, outriggers, sheath rollers, back spooling devices, steering and incorrect anchor location.

Operator Error – This excludes those incidents caused by secondary factors. For example, the roadway conditions caused the car to slide into the rib.

Roof / Rib Object / Roadway Conditions – This includes roof fall causing damage to a cable or rib bolts, rib mesh sticking out and fouled the cable, pot holes in the road etc.

Poor Mechanical Protection / Missing Part – This mainly relates to cables on machines, such as cutter motor cables, shuttle car conveyor cables etc.

Wear and Tear – This includes cables that have sheaths that have been abraded (rubbed through) or sustained pin holes.

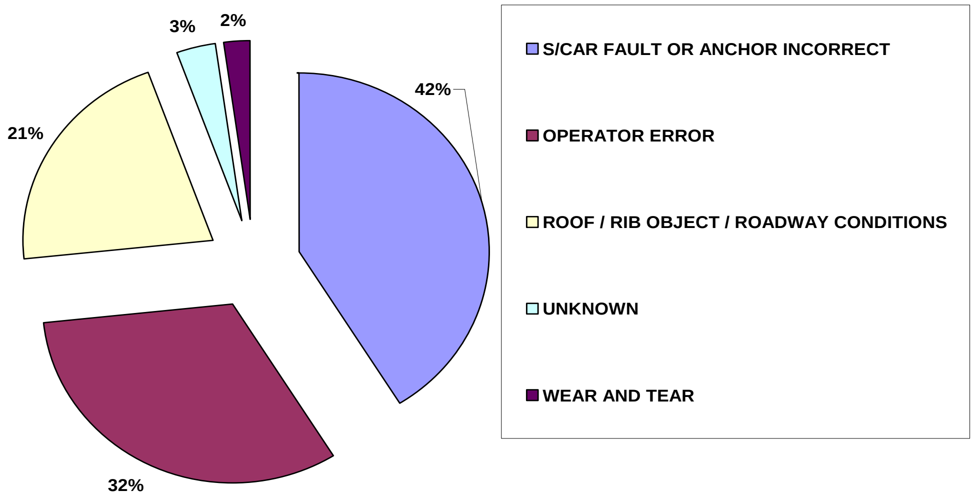
5.3.1 Shuttle car cable arcing incidents

The data was further analysed to only look at shuttle car cable arcing incidents. The results of this analysis is shown in Table 3, while the pie chart in Figure 4 shows this data as a percentage of shuttle car cable arcing incidents.

Table 3: Shuttle car cable arcing incidents - main causal factors

Causal factor	Number of incidents
S/car fault of anchor incorrect	37
Operator error	29
Roof/rib object/ roadway conditions	19
Unknown	3
Wear and tear	2

Figure 4: Main causal factors 2007 – 2009 – Shuttle car cables



5.3.2 Continuous miner and mobile roof bolter arcing incidents

The data was further analysed to focus on continuous miner and mobile roof bolter cable arcing incidents. The results of this analysis is shown in Table 4, while the pie chart in Figure 5.

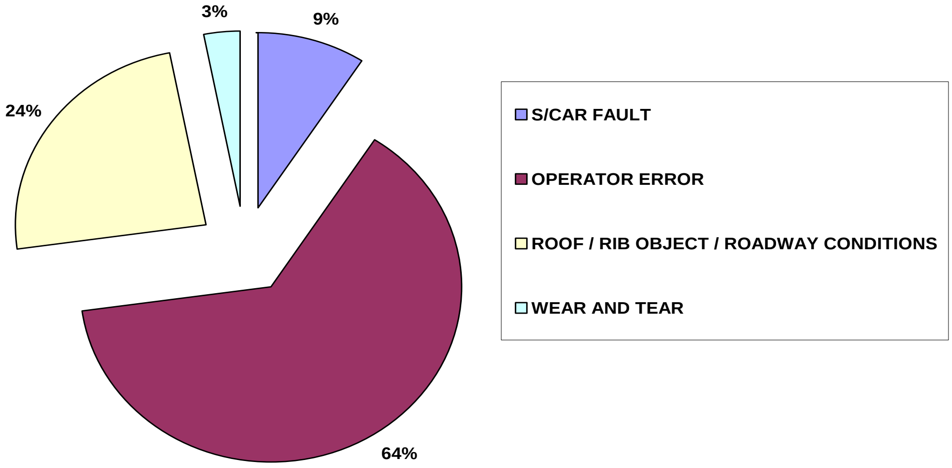
Table 4: Continuous miner and mobile roof bolter cables – cable types

Type of cable	Number of incidents
Continuous miner	23
Mobile roof bolter	10

Table 5: Continuous miner and mobile roof bolter cables – main causal factors

Causal factor	Number of incidents
S/car fault	2
Operator error	21
Roof/rib object/ roadway conditions	8
Wear and tear	1

Figure 5: Main causal factors 2007 – 2009 (Continuous miner and Mobile roof bolter cables)



Operator error, roof / rib / roadway conditions and defective shuttle cars are clearly the main causal factors.

It should also be kept in mind that these causal factors may interact. For example, poor roadway conditions will adversely impact on shuttle cars and the worse the roadway conditions the more maintenance and repairs are required on such things as cable reels, back spooling shoes, outriggers etc. This may also be the case for operator errors.

5.4 Cable arcing – NERDEC Report C1252

Findings from the NERDEC report released in 1993 still have relevance to contemporary operations. However, in considering these findings it must be kept in mind that the statements relating to the design of cable reeling devices have not been verified in developing this present report and that some types of cables manufactured today may use materials that improve the capabilities of the cable and go beyond the minimum requirements specified in AS/NZS1802. There has been no investigation of this aspect during the development of this report.

The NERDEC report on page 15 states[6]:

> *'Section 2.3 Cable Systems*
>
> *The majority of cables involved in reportable incidents in New South Wales are the heavy duty reeling cables of the semi-conductive screened type…..*
>
> *It has been established that some aspects of the design of present heavy duty reeling cables are based on compromise. This has risen principally as a result of the need for the cable to be very flexible in operation and the perceived need to be compatible with the design of the cable reeling device. Little attention appears to have been given to the design of the reeling device itself other than minor alterations to the pinion gears and Archimedes screw to suit different cable diameters. As a result a number of potential problems exist with the design of the cables, as follows:*
>
> - *Little or no earth screen exists between the individual power conductors particularly where the cable is subjected to squashing forces, such as being run over, or bent sharply around sheave and guide rollers, deflection plates or corners of ribs. The consequence of this is that the electrical fault most likely to occur will involve two power conductors with a consequential increase in the severity of the resulting damage.*
> - *The semi-conductive screening existing between the individual power conductors and the external sheath has only a minimal thickness and is physically bonded to the outer sheath material. In situations where the outer sheath is torn or cut it is probable that the effectiveness of the overall screening will be significantly impaired.*
> - *The semi-conductive materials used have only limited current carrying capacity. During fault conditions localized burning of the semi-conductive material can occur to an extent that the fault will self clear during the operating period of the protection equipment.'*

These three points may still be relevant to cables manufactured today.

[6] "Evaluation of Mine Cable design safety", p15, NERDEC REPORT NUMBER 1252, June 1993

6 Cable damage statistics 2000/01 to 2008/09

6.1 Introduction

The major causes of failure of mining cables used in hazardous zones arise from physical damage.

The NERDEC REPORT C1252 states[7]:

'The causes of mechanical damage essentially covers all areas of mining activity but the following have been identified as being the most significant:

- *During transport and storage cables are frequently subjected to rough handling. In particular cables when stored underground are subjected to physical damage due to inadequate storage methods and rough handling. Cables are frequently stored in locations where they are subject to falls of the rib and damage from passing vehicles.*
- *In use cables are frequently stressed beyond their design limits. This includes elevated operating temperatures particularly where excessive cable lengths are operated in coils or stored on reeling drums. In addition poor maintenance of cable reeling and anchorage devices, cable location and mining conditions appear to be significant contributing factors.'*

Anecdotal evidence suggests that handling and storage of cables has improved since 1993. Elevated operating temperatures have not been identified as a major issue. However, analysis of cable arcing incidents indicates poor maintenance of cable reeling and anchorage devices, cable location and mining conditions are still significant contributing factors.

The NERDCC REPORT C1252 also states[8]:

The physical stresses that deteriorate cable can be identified as:

- ***Tension***

  During each shuttle car load-haul dump cycle, the cable experiences maximum instantaneous tensions averaging between 310 and 1170 pounds and in some instances exceeding 2000 pounds. Tension being highest during backspooling.

  Many parameters besides backspooling can have a significant effect on instantaneous cable tensions. These parameters can be summarised as:

  - *Reel hydraulic pressure*
  - *Type of cable anchor used*

[7] "Evaluation of Mine Cable design safety", p8-9, NERDEC REPORT NUMBER 1252, June 1993
[8] "Evaluation of Mine Cable design safety", p23, NERDEC REPORT NUMBER 1252, June 1993

- *Location of the car in the mine section*
- *Shuttle car speed*
- *Direction of shuttle car travel*
- *Mine-bottom roughness and wetness*
- *Anchor point location with respect to shuttle car tram path*
- *Quantity of cable stored on the reel*

- ***Temperature Extremes***

  Cable heating problems primarily on machines that utilise cable storage reels have been reported on numerous occasions. The effect from this may result in fire on the cable and significant deterioration of the conductor insulation which may ultimately manifest in an electrical fault.

- ***Flexure and Twisting***

  These stresses are extremely prevalent with shuttle cars. Where the cable is almost constantly bent around sheave wheels, frame edges, mine props and so on. Although the minimum bending diameter recommended for trailing cables is sic times the cable diameter, but actual bending diameters are often less and also the bending at point of contact may be sudden. The surface diameter of the object contacting the cable may be small and, consequently, relatively intense cable stresses may occur.

  The locations where bending and twisting stresses occur repetitively during every shuttle car hail cycle are summarised as follows:

  - *Cable reel*
  - *Cable layering guide*
  - *Machine frame edges*
  - *Cable reel to sheave wheel*
  - *Sheave wheels and brackets*
  - *Rib corners*
  - *Anchor point*

- ***Abrasion***

  Abrasion of reeled cables occurs frequently at cable flexure points inbye the tie point. Cable layering guide, machine frame and sheave bracket edges are typical examples of abrasion points. Drag cables abrasion occurs primarily along the machine floor and at rib corners.

- ***Crushing***

  Cable damage frequently results from crushing or pinching. In addition to rock falls and rib falls, movement of equipment in the mine significantly contributes to the damage. The equipment is often mistakenly driven over the cable.

The most common type of cable crushing probably occurs when a machine runs over or pinches its own cable. Shuttle cars often run over or pinch their own cable in several ways:

- *Run over as the machine backspools the cable*
- *Run-over as the machine trams towards the anchor point*
- *Crushed between the machine frame or bumper and the rib or the mine bottom as the machine backspools the cable*
- *Crushed between the sheave wheel and the rib.*

It should be noted that:

- There have been no reported incidents of over temperature of cables on cable reels for many years.
- Backspooling, as an identified contributor to cable arcing, has been minimal over the past few years, although it still does occur.

In April 2001 I&I and the workshops commenced gathering cable damage data. This data is available at: http://www.dpi.nsw.gov.au/__data/assets/file/0005/215339/UG-coal-mine-hazardous-zone-cable-damage-TOTAL-DATA-2001-2009.xls

Work is continuing on gathering cable damage data for the underground coal mining industry. This data indicates that for every cable that ceases to function there are a number of sheath damages. There are approximately three sheath damages per single cable. This is greater than four per miner cable and greater than two per shuttle car cable.

From this, it can be inferred that there are cables in operation with damaged sheaths. This damage increases the risk to mine workers of electric shock, arc burns and explosion. The issue is particularly severe with continuous miner cables and shuttle car cables. Any increase in utilisation voltage (above 1000 V) for continuous miners could increase the risk even further if current cable designs, cable management practices and electrical protection arrangements are employed.

6.2 Cable damage

Figure 6 shows the number of cable damages for the period 2001/2002 to 2008/2009.

It should be noted that for the sake of brevity other types of cable damage, such as longwall control and lighting cables, pump cables, feeder cables, longwall feeder cables and other ancillaries, are not included in the graphs shown in Figures 6 and 7.

Figure 6: Number of damaged cables

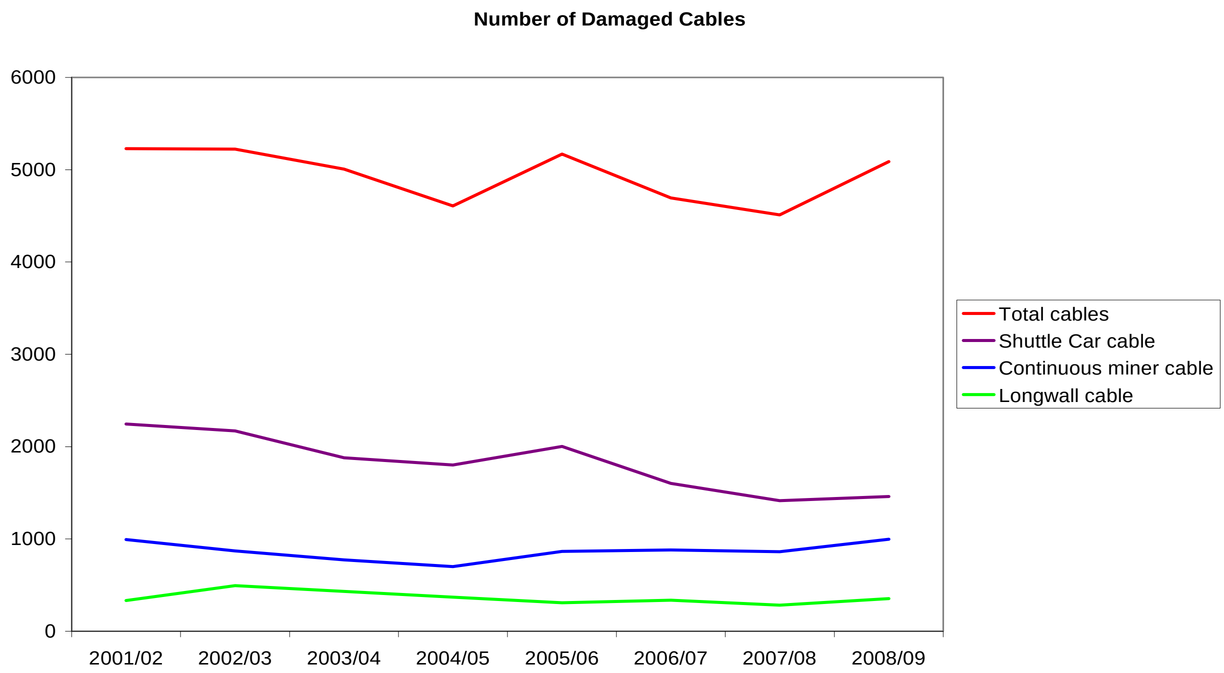
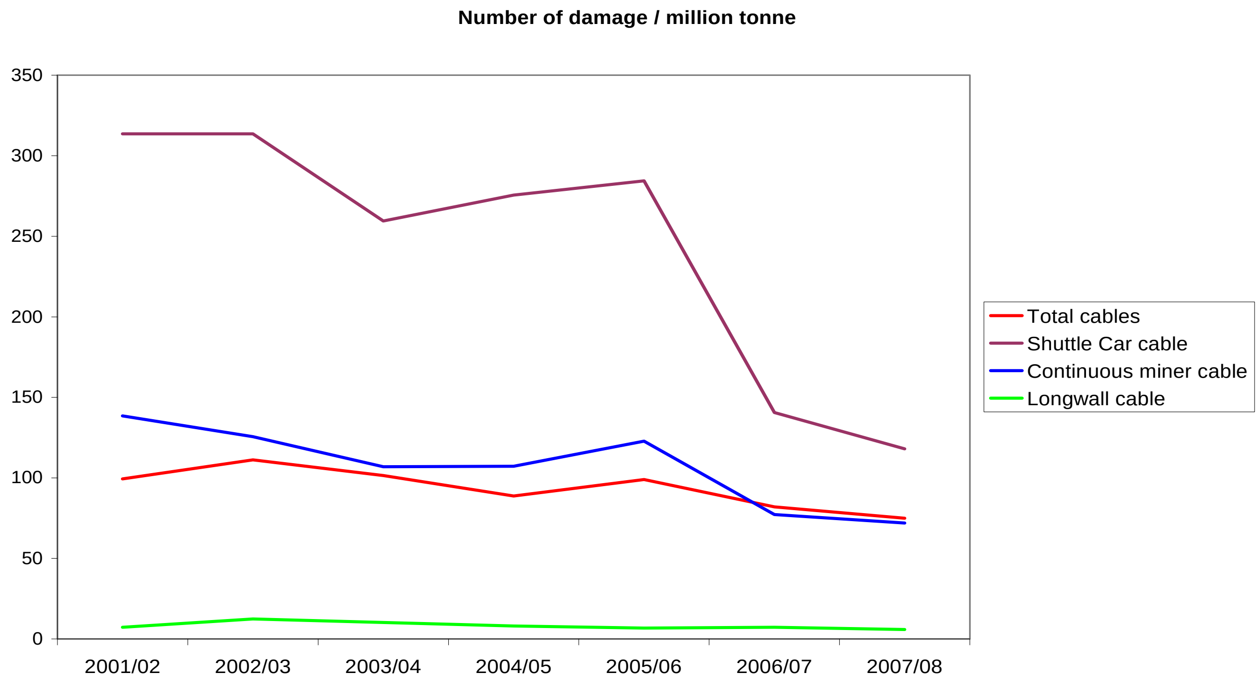


Figure 7 shows the number of damaged cables per million tonnes of raw coal mined for the period 2001/2002 to 2007/2008.

Figure 7: Cable damage per million tonnes of raw coal



It is important to note that total cable damage per million tonnes is decreasing and there has also been a dramatic reduction in shuttle car cable damage per million tonnes. A significant driver in this reduction is the fact that, on average, the physical condition of cables has improved (note that: as part of the repair process, the cable condition is assessed and categorised) and there are also more new cables in use. Anecdotal evidence suggests there has been a significant increase in the purchase of new cables in the last three to four years compared to previous years.

Experience has shown that newer cables suffer less damage for the first third of their life, probably because the mechanical stresses placed on the cable physically weaken it over time. There is also anecdotal evidence that the electrical stresses on cables have increased. This seems obvious as increased productivity requires increased power delivery to machines and improved utilisation. The requirement for more power requires improved voltage levels at motors, with the simple and often crude voltage regulation at mines, there is an increased risk of an elevated 'no-load' voltage which can exceed equipment design requirements.

Damage to shuttle car cables and continuous miner cables (including arcing incidents) is an obvious area for improvement. These are probably the hardest worked cables in a mine and the ones at the highest risk of damage. Therefore, they need a great deal of management attention. The methods for preventing damage are well known and have been known for many years.

For AFC T/G drive cables, a cable pulling out of the restrained plugs is a recurring issue. It should be noted that the cable gland of the plug is unlikely to be able to withstand the pull forces exerted on a cable without proper restraining. It is well known that cables will be pulled out of plugs when there is a differential movement of the AFC and AFC cable and where plug couplers are fastened to the AFC without effective cable restraint.

The shearer cable has a section along the AFC and a section that 'follows' the shearer. Invariably, this is physically protected by a flexible cable handler, colloquially called a 'bretby'. Generally, if well maintained the bretby affords excellent physical protection. The shearer cable is flexed up and down the face many times during the life of a longwall. On a typical 250 metre wide longwall block that is 2-3 kilometres in length, it can be expected that the shearer cable will get severely stretched and stressed and will need replacing after just one longwall block (although it may still be suitable for less arduous applications).

Cables on typical longwall monorail systems are rarely subject to severe damage, with the most likely damage being minor sheath damage.

7. Issues – cable design and manufacture

7.1 Current identified issues

Little or no earth screen exists between the individual power conductors of Type 275 cables (shuttle car cables), particularly when the cable is subjected to squashing forces, such as being run over or bent sharply around sheave and guide rollers, deflection plates or corners of ribs. As a result, the electrical fault most likely to occur will involve two power conductors with a consequential increase in the severity of energy released and associated damage.

For other types of cable:

- The semi-conductive screening existing between the individual power conductors and the external sheath has only a minimal thickness and is physically bonded to the outer sheath material. In situations where the outer sheath is torn or cut it is probable that the effectiveness of the overall screening will be significantly impaired.
- The semi-conductive materials used have only limited current carrying capacity. During fault conditions, localised burning of the semi-conductive material can occur to an extent that the fault will self-clear during the operating period of the protection equipment.
- After crush damage, it is possible that semi-conductive screening can separate from the insulation it covers and may not be detected as a fault. This separation of the semi- conductive screening can become a potential location for initiating a phase to phase fault instead of a phase to earth fault.

7.2 Emerging issues

AS/NZS 1802 was originally focussed on continuous miners and shuttle cars, the main production method of the day, along with the associated technology and manufacturing arrangements. From this the other related standards evolved (AS/NZS 1299, AS/NZS 1300 and AS/NZS 1747). The standards served the industry well. Indeed AS/NZS 1802 cables were successfully applied to other mining methods not just continuous miner/shuttle car operations. This success was partly due to a reasonable similarity in electrical characteristics, such as voltage, power of machines, diversity factors and voltage regulation. As power requirements have increased and with the advent of increased utilisation voltages at the face, the use of better control for induction motors and the use of technology that can be sensitive to interference, the suitability of AS/NZS 1802 is emerging as an issue, much like it did for AS/NZS 1299 and AS/NZS 1300.

Modern insulating materials, sheathing materials and other component parts of cables have made significant advances over the intervening years and may provide for improved cables, even though they may not conform to the requirements of AS/NZS 1802.

The issue becomes more important with the advent of globalisation of mining cable manufacture. The relationship between the cable manufacturing method and the performance characteristics (both electrical and mechanical) of the constituent parts of cables is evident in that certain materials are suited to certain manufacturing methods. It is also known that changes in chemical formulas for cable insulation, semi conductive screening and sheathing can change performance characteristics. If this is done in an uncontrolled manner there is a possibility of adverse impacts on the safety of mine workers. Consideration of third party conformity assessment of mining cables may be necessary. This conformity assessment would need to include design verification and surveillance of manufacturing by third parties.

The productivity increases that drive increased electrical and mechanical stress on cables means that the accepted useful life of cables that has been used to help determine capital expenditure budgets may no longer be valid. As such, cables could be used beyond their useful productive life (ie they may still be suitable for less arduous applications).

Key features that are becoming important but are not necessarily catered for in current designs include:

- Electromagnetic Interference (EMI) into pilot conductors not to cause malfunction, maloperation or unplanned movements.
- EMI into pilot conductors not to compromise IS ratings of IS components related to pilot circuits.
- EMI into ancillary conductors (data systems) not to corrupt the data in an unsafe manner.

Other matters that are likely to emerge in the near future are:

- Increased voltage levels and associated increased capacitance of cables and the impact on earth leakage protection and earth fault limitation requirements.
- Impact of VVVF drives and circulating harmonic currents.

The selection of type 241 cable for certain applications, and perhaps its very suitability, is an emerging issue. The key design feature of type 241 cable is its high degree of flexibility and the use of semi-conductive power screens. Recent testing has shown that such cables can sustain major crush damage without an earth fault occurring. The crush damage deforms and often damages the conductor insulation and as this occurs it is possible that a high energy short circuit fault between phases is more likely than a low energy earth fault. This likelihood of a high energy short circuit could increase with higher utilisation voltage.

Note: This increase in likelihood has not been established by research or tests.

AS/NZS 1802 needs urgent revision in light of modern insulating and sheathing materials, use of different construction cables (even the consideration of flat cables), and the use of enhanced screening by the use of combined semi conductive and metallic screening.

8. Observations on cable arcing incidents, cable damage and cable design

Basically, industry performance with respect to cable arcing incidents has not improved in 25 years. For continuous miner cables the performance has deteriorated. No conclusions are offered as to why this deterioration has occurred.

Industry performance with respect to shuttle car cable arcing incidents has deteriorated even taking into consideration the significant improvement over the past two years. Again no conclusions are offered as to why this deterioration has occurred.

Damage (including arcing incidents) to shuttle car cables and continuous miner cables is an obvious area for improvement. These are probably the hardest worked cables in a mine and the ones at the highest risk of damage. Therefore, they need a great deal of management attention. The methods for preventing damage are well known and have been known for many years. However, the ability of industry to manage these basic factors is in question.

The known remedies for the common damage scenarios on longwalls are well known, easily applied and maintained, yet failures still occur.

The cables on typical longwall monorail systems are generally well managed.

Cable design has not been an identified factor in damage scenarios. Although for shuttle car cables the lack of individual phase screens may contribute to the number of arcing incidents.

Cable repair has not been a factor in damage scenarios, although defective cable repairs have been identified in a handful of arcing incidents over the period 1984 to 2009.

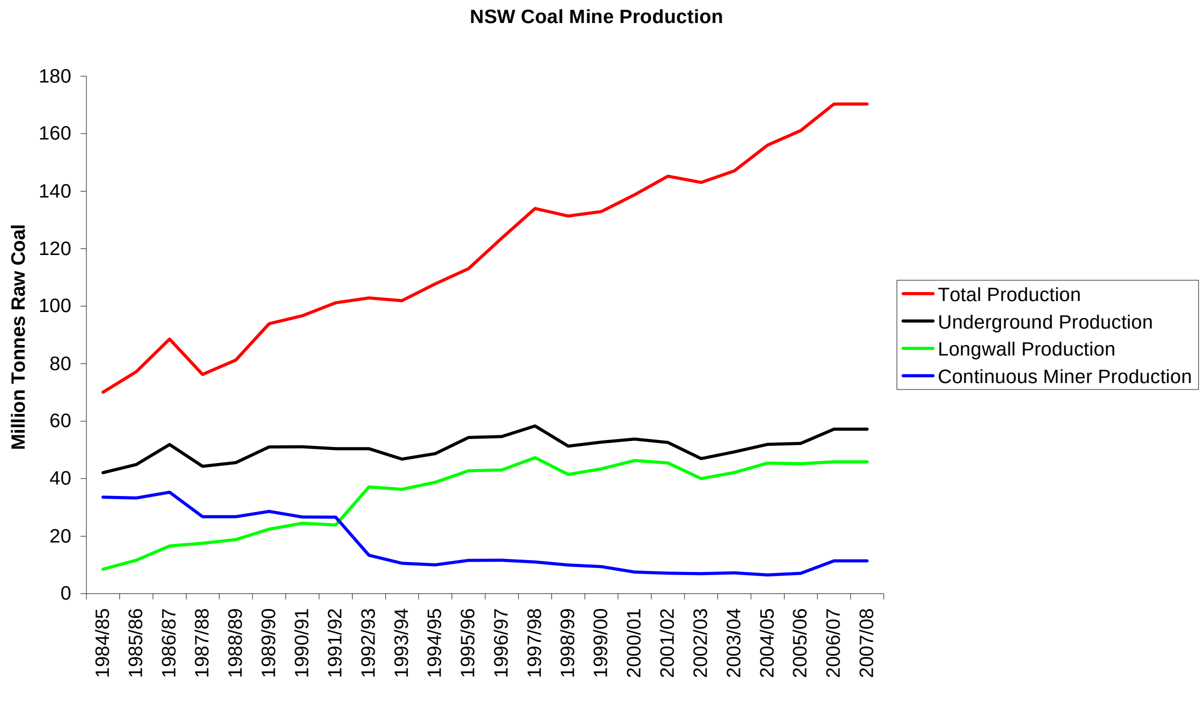
9. NSW production and cable arcing incidents

9.1 Raw coal production for NSW mines

In chapters 3 and 4 cable arcing incidents and cable damage statistics were analysed with respect to raw coal production. The production figures are based on information contained in the annual *Coal industry Profile* published by Industry & Investment NSW. The coal mine production figures for non-longwall underground production (continuous miner production) is derived by subtracting longwall production from total underground production. This correlates with the longwall and non-longwall production figures published in the *Coal Industry Profile*. Details are given in Chapter 8.

Figure 1 shows raw coal production for NSW mines. The total production is for open cut and underground.

Figure 8: NSW coal mine production



9.2 Raw coal production and arcing incidents for NSW mines

	1984/85	1985/86	1986/87	1987/88	1988/89
Total Production	70.034	77.186	88.506	76.268	81.272
Underground Production	42.058	44.918	51.843	44.324	45.597
Longwall Production	8.513	11.647	16.567	17.543	18.85
Continuous Miner Production	33.545	33.271	35.276	26.781	26.747
Underground employment	15121	15469	15152	12587	12520
Number of underground mines	68	66	60	52	51
Total cable arcing incidents	65	94	94	78	67
Continuous Miner Unit arcing incidents	64	93	90	78	62
Longwall cable arcing incidents	1	1	4	0	5
Shuttle car cable arcing incidents	44	62	66	62	38
Continuous miner cable arcing incidents	11	17	11	12	14

	1989/90	1990/91	1991/92	1993/94	1994/95
Total Production	93.9	96.69	101.17	101.95	107.78
Underground Production	51.05	51.13	50.4	46.79	48.7
Longwall Production	22.45	24.47	23.85	36.29	38.74
Continuous Miner Production	28.6	26.66	26.55	10.5	9.96
Underground employment	12352	11988	11007	9072	8959
Number of underground mines	53	52	50	46	45
Total cable arcing incidents	79	59	44	26	16
Continuous Miner Unit arcing incidents	76	56	41	25	16
Longwall cable arcing incidents	3	3	3	1	0
Shuttle car cable arcing incidents	47	37	30	20	8
Continuous miner cable arcing incidents	14	13	6	1	4

	1995/96	1996/97	1997/98	1998/99	1999/00
Total Production	113.089	123.678	134.009	131.381	132.896
Underground Production	54.314	54.642	58.299	51.318	52.763
Longwall Production	42.76	42.99	47.263	41.425	43.402
Continuous Miner Production	11.554	11.652	11.036	9.893	9.361
Underground employment	8869	9044	8143	6063	5846
Number of underground mines	46	44	41	40	35
Total cable arcing incidents	28	22	24	20	12
Continuous Miner Unit arcing incidents	27	22	22	19	11
Longwall cable arcing incidents	1	0	2	1	1
Shuttle car cable arcing incidents	20	16	14	11	7
Continuous miner cable arcing incidents	4	3	4	3	3

	2000/01	2001/02	2002/03	2003/04	2004/05
Total Production	138.779	145.228	143.066	147.046	156.039
Underground Production	53.719	52.591	46.957	49.355	51.907
Longwall Production	46.267	45.43	40.04	42.119	45.376
Continuous Miner Production	7.452	7.161	6.917	7.236	6.531
Underground employment	5641	5652	5238	4948	5286
Number of underground mines	32	32	29	27	28
Total cable arcing incidents	1	5	2	17	49
Continuous Miner Unit arcing incidents	1	4	2	16	50
Longwall cable arcing incidents	0	1	0	2	1
Shuttle car cable arcing incidents	0	4	1	10	37
Continuous miner cable arcing incidents	1	0	1	1	6

	2005/06	2006/07	2007/08	2008/09	2009/10
Total Production	161.14	170.324	177.167		
Underground Production	52.232	57.241	60.22		
Longwall Production	45.193	45.851	48.24		
Continuous Miner Production	7.039	11.39	11.98		
Underground employment	6201	6739	7031		
Number of underground mines	30	29	29	29	
Total cable arcing incidents	83	83	69	74	
Continuous Miner Unit arcing incidents	77	78	69	72	
Longwall cable arcing incidents	6	5	0	2	
Shuttle car cable arcing incidents	47	53	43	47	
Continuous miner cable arcing incidents	6	9	11	12	

10. Appendices

Feedback Sheet

Your comment on this Technical Report is essential for its review and improvement.

Please make a copy of this Feedback Sheet and send your comments to:

The Senior Inspector of Electrical Engineering
Mine Safety Operations
Industry and Investment NSW
PO Box 344
Hunter Region Mail Centre NSW 2310
Phone: (02) 4931 6641
Fax: (02) 4931 6790

How did you use (or intend to use) this technical report?	
What did you find most useful about the technical report?	
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Thank you for completing and returning the Feedback Sheet.

I&I NSW Contact details

I&I NSW offices located in coal mining regions.

North East Area
Maitland
516 High Street Maitland NSW 2320 PO Box 344 Hunter Regional Mail Centre NSW 2310 Phone: (02) 4931 6666 Fax: (02) 4931 6790
Singleton
Level 1, 1 Civic Avenue Singleton NSW 2330 PO Box 51 Singleton NSW 2330 Phone: 02 6572 1899 Fax: 02 6572 1201

South East Area
Lithgow
Suite 1, 1st Floor, 184 Mort Street Lithgow NSW 2790 Phone: (02) 6350 7888 Fax: (02) 6352 3876
Wollongong
Level 3, Block F, 84 Crown Street Wollongong NSW 2500 PO Box 674 Wollongong NSW 2520 Phone: (02) 4222 8333 Fax: (02) 4226 3851