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I R M R C

ANALYSIS OF THE CAUSES OF ELECTRICAL SHOCK INCIDENTS IN MINING IN NSW

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Summary

This study involved an in-depth analysis of 110 electric shock incidents reported to the NSW Department of Mineral Resources COMET database. Most of the cases were reported as Notifiable incidents and did not result in serious injury or lost time. Most occurred underground and around two-thirds came from the coal sector. All cases were coded using a classification and coding system developed to look at the causes of occupational fatalities. Evaluation of the reliability of the coding showed good reliability.

The most common patterns of occurrence of the electric shock incidents involved the following:

- Almost all cases involved equipment factors mainly in the form of inadequate design or breakage.
- In almost all cases, the equipment failure was a pre-existing condition. Breakage of equipment just before the electric shock was very uncommon.
- The behaviour of mine workers played a minor role in these incidents. In most cases, the person inadvertently made contact with equipment which was already unsafe electrically. In this way, the person's role was as an indicator that a problem existed, rather than the person making a contribution to the problem occurring.
- Where an error occurred, it was mainly a rule-based error involving failure to isolate or check for dead. In all these cases, there was a pre-existing fault with the equipment which a check would have detected.
- Water was also a factor in a significant minority of cases, especially in the non-coal sector. Where water played a role, however, it always occurred in combination with pre-existing equipment design problems or breakage.

These patterns highlighted directions for prevention of electric shocks in mining. Most obviously, they show that almost all of the incidents could have been prevented by audits, reviews and maintenance of mining equipment. The results show strongly that an on-going safety review system would be the single, most effective intervention to prevent electric shock incidents. The results also point to the need to reinforce among mine employees and contractors the importance of fundamental electrical safety procedures including isolating and checking electrical equipment. This is important both because it is good safety practice, but also because, as the results of this study show, mine employees and contractors cannot be sure that the equipment they are using is safe.

Overall, this project has shown the value of in-depth analysis for identifying the causes of safety-related incidents and the strategies most likely to be successful in preventing them.

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Introduction

One of the areas of concern for safety identified from initial analysis of data held in the Department of Mineral Resource's COMET database was contact with electrical energy. This issue was selected for further analysis. The aim of this analysis was to attempt to gain a better understanding of the circumstances in which these incidents involving electrical energy occur in the mining industry. This information would assist in directing further action to prevent them.

Method

All of the cases involving electrical energy-related outcomes were located in the COMET database. These cases were referred to COMET for a range of reasons mainly relating to Notifiable incidents CMGNR (see Table 1).

After consultation with DMR Electrical Inspectors, a sample of 122 cases was selected for analysis on the basis that they all resulted in an electric shock. Table 1 shows the reasons for reporting the incident to COMET for these 122 cases and the outcomes resulting from these incidents are shown in Table 2. Notifiable incidents constituted around one third of cases reported in the COMET dataset. Analysis of the types of outcomes in the sample showed that relatively few cases resulted in serious injury or lost time, even though around half resulted in some degree of electric shock. Most of the cases occurred underground (51.6%), with the remainder occurring in open cut mines (33.6%) or in processing plants (13.9%). Most of the cases occurred in coal (62.3%) compared to minerals mining (35.9%).

Table 1: Types of incidents reported in COMET database which resulted in contact with or potential for contact with electrical energy.

Types of incidents	**Total sample**	
	n	**%**
*1994 Emergency MIA	5	4.1
*Dangerous Incident MIA	20	16.5
*Serious Bodily Injury CMRA	1	0.8
Dangerous Incident	2	1.7
High Potential Incident	15	12.4
Incidents CMUGR 1999, Cl 34 (2)	17	14.0
Non Spec Acc Ending in Fat/Injury	4	3.3
Notifiable Incidents CMGNR 1999, Cl 83	48	39.7
Missing	9	7.4
Total	122	100.0

*indicates incident type classifications that have been superseded due to changes in regulation and are no longer in use.

Table 2: Types of outcomes resulting from contact with electrical energy in all COMET cases and the sample of 40 cases

Result of incident	**Total sample**	
	n	**%**
Electric shock	68	55.74
Electrical energy	35	28.69
Lost time injury	2	1.64
Machinery out of control MIA	1	0.82
Potential to cause serious injury	4	3.28
SBI/SI	2	1.64
Burns	1	0.82
Missing	9	7.38
Total	122	100.0

Coding of cases

The wider circumstances of each case in the sample of 122 cases was classified and coded using the information available in the COMET database as well as Electrical Inspectors reports. Further details of the classification and coding framework can be found in the Appendix (Classification and Coding of Electrical Energy Events in Mining). This methodology was based on a framework previously used to classify and code occupational fatalities (Williamson and Feyer, 1990; Feyer and Williamson, 1991; Williamson, Feyer and Cairns, 1996; Williamson and Feyer, 1998). Modifications were made to the framework to make it more suitable for coding the information available on electrical energy events. The framework and modifications were discussed with Electrical Inspectors at three meetings.

Of the 122 cases examined, 12 had insufficient information to code. The analysis that follows therefore is based on 110 cases. One coder coded all cases using the methodology described in the Appendix. The reliability of coding was assessed by a second coder coding a subset of 23 cases. The coding was found to be reliable, with 86.9% cases being coded in the same overall manner by both coders (see further details in Appendix).

Results of classification and coding

1. Contributing Factors:

Contributing factors are defined as factors that made a contribution to the incident occurring but were pre-existing, sometimes for very long periods, in the time before the incident occurred. Table 3 lists the Contributing factors which played a role in the circumstances of the electrical incidents for the subsample from the COMET database.

Ninety percent of cases involved equipment factors in some form. Approaching half of the cases involved equipment alone, mainly due to design features (eg: problems relating to equipment not being fit for purpose) or other aspects of poor design. Design or breakage of equipment were the main problems overall, both as single factors alone and in combination with other factors. In fact poor or inadequate design was a problem in more than half of cases (55.1%) and equipment breakage was a problem in 46.2 % of cases. The most common single patterns of contributing factors were equipment design which accounted for 14.5% of cases, followed by the combination of equipment design and breakage (11.8% of cases).

Equipment problems due to poor installation were less common, and occurred in only 13.6% cases and mostly in combination with other factors especially work practice factors, in particular unsafe or inadequate standard operating procedures. Poor installation of equipment was the sole factor in only three cases.

Work practices were a contributing factor in around one-third of cases overall (31.8%) and were mainly due to unsafe standard operating procedures (23.4%) and, to a lesser extent, problems with housekeeping (9.0%). Work practice problems hardly ever occurred as a sole factor (only 5.5% cases) and mainly involved continuing use of a piece of equipment that was poorly designed or broken, or not doing the housekeeping or maintenance to fix the equipment.

Environmental factors were also important contributing factors and in all of these cases this was due to the presence of water. Notably though, environmental factors only really played a role in combination with equipment factors and not work practice factors. Only two cases involved a combination of a wet environmental and inadequate or unsafe work practices.

Overall, therefore, the main types of Contributing Factors were due to equipment problems, with design factors and equipment breakage being the biggest single factors. Very few cases involved problems due to installation alone, although it was important in a significant proportion of cases in combination with other factors especially unsafe or inadequate work practices. Wet mine environments contributed to the incident almost always in combination with equipment design problems or breakage.

Table 3: Types of Contributing Factors involved in 40 cases resulting in exposure to electrical energy in mining

Type of Contributing Factors	*n*	*%*
Equipment factors only	**45**	**40.9**
Design only	16	14.5
Installation only	3	2.7
Breakage only	10	9.1
Design and breakage	13	11.8
Design and installation	1	0.9
Design, installation and breakage	2	1.8
Equipment and Environment factors	**19**	**17.3**
Design and Environ (water)	7	6.3
Breakage and Environ (water)	6	5.5
Design, Breakage and Environ (water)	4	3.6
Installation, breakage and Environ (water)	2	1.8
Equipment and Work practice factors	**27**	**24.5**
Design and standard operating procedures	6	5.4
Design and housekeeping	1	0.9
Design and supervision/coordination	1	0.9
Installation and standard operating procedures	4	3.6
Installation and housekeeping	1	0.9
Breakage and stand operating procedures	3	2.7
Breakage and housekeeping	4	3.6
Design, breakage and stand operating procedures	3	2.7
Design, breakage and housekeeping	2	1.8
Design, installation and supervision/coordination	2	1.8
Environmental factors only (water)	**1**	**0.9**
Environment and Work practice factors	**2**	**1.8**
Work practice factors only	**6**	**5.5**
Housekeeping	1	0.9
Standard operating procedures	5	4.5
Equipment, work practice and Environment factors	**6**	**5.5**
Design, standard procedures, water	3	2.7
Design, housekeeping, water	1	0.9
Breakage, standard procedures, water	2	1.8
No contributing factors	**4**	**3.6**
Total	**110**	**100**

2. Precursor Events

Precursor Events are defined as the events leading most immediately to the incident's occurrence. They are linked with the incident in time, but they are distinguished by a much shorter time frame than for Contributing Factors.

The pattern of involvement of precursor events is shown in Table 4. The results indicate that most cases involved an environmental event relating to the location of the person at that point in time. In most cases this was related to the person coming into a situation where they could be exposed to electrical energy and this event occurred just before and was most immediately related to incident. A significant number of cases involved water getting into the person's location just before the incident (13.7%). In the majority of cases behavioural failures were not involved at all (80%), although most cases the event sequence occurred when the person's behaviour placed them into the location where they made contact with electrical energy. In these cases, however, the behaviour was not an error.

Table 4: Types of precursor event involved in 110 cases resulting in exposure to electrical energy in mining.

Type of Precursor Event	**n**	**%**
Behaviour only	**7**	**6.4**
Skill-based error	2	1.8
Rule-based error	4	3.6
Violation	1	0.9
Environment only	**84**	**76.4**
Environment voltage	69	62.7
Environment water	8	7.3
Environment water→ Environment voltage	7	6.4
Environment and Equipment	**4**	**3.6**
Breakage → Environment	4	3.6
Environment and Behaviour	**14**	**12.7**
Skill-based error → Environment	3	2.7
Rule-based → Environment	9	8.2
Knowledge-base → Environment	1	0.9
Violation → Environment	1	0.9
Behaviour and Equipment	**1**	**0.9**
Breakage → Rule-based	1	0.9
Total	**110**	**100.0**

For a significant minority of cases the person's error led to them making contact with electrical energy (19.1%). For two-thirds of the cases involving behaviour (66.7% cases involving behaviour), the person made a rule-based error, usually by not isolating the equipment they were working on at the time and consequently making the situation safe. In about one-quarter of these cases (23.8% cases involving behaviour), the error occurred in skilled behaviour where the behaviour being performed did not require conscious control as the person had a great deal of experience in doing it.

The majority of cases occurred without events relating to equipment. Only five cases overall (4.5%) involved a breakage of equipment in the period immediately leading to the incident. This is in contrast to the major role played by equipment problems in the Contributing Factors and shows that equipment problems that led to subsequent contact with electrical energy were almost always pre-existing problems.

3. Patterns of occurrence of Contributing factors and Precursor Events

Table 5 shows a summary of the relationships between Contributing Factors and Precursor Events. By far, the most common pattern involved equipment factors leading to a person inadvertently being exposed to electrical energy. In fact of the 69 cases that ended with an environmental precursor event, virtually all (93%) occurred due to at least one pre-existing equipment factor playing a role in making the environment unsafe.

Unsafe work practices, including poor housekeeping played a much smaller role than equipment overall and there was no specific link between unsafe work practices and any particular types of Precursor Events. Work practice problems contributed to incidents that involved both behavioural and environmental events.

As noted before, behavioural events only played a role in a small percentage of incidents (21 cases). Interestingly, however, the only cases that did not involve at least one Contributor Factor occurred due to events involving an employee’s behaviour. This involved a small number of cases (3.6%), but in most the incident occurred because the person made a skill-based error. Most cases involving a behavioural event involved a rule-based error (11.8%) and for most of these (69%), equipment design and/or breakage at an earlier time made a direct contribution to the incident.

Table 5: Patterns of Contributing Factors and Precursor events showing the number of occurrences of each type of factors for each type of Precursor event.

Contributing factors	*Precursor Events*	*n of factors*	*%*
Equipment factors		**91**	**45.1**
Design		40	19.8
Installation		10	5.0
Breakage		41	20.3
Environmental (water)	→ **Environment (voltage)**	**19**	**9.4**
Work practice	(125 factors and 69 cases)	**24**	**11.9**
Housekeeping		9	4.5
Standard operating procedures		16	7.9
Supervision/Coordination		2	0.9
Equipment		**9**	**4.5**
Design	→ **Environment (water)**	5	2.5
Breakage	(9 factors and 8 cases)	2	0.9
Standard operating procedures		2	0.9
Equipment		**11**	**5.4**
Design		4	2.0
Breakage	→ **Environ (water) → Environ (voltage)**	4	2.0
Work practice		**2**	**0.9**
Housekeeping	(13 factors and 7 cases)	2	0.9
Equipment		**6**	**3.0**
Design		4	2.0
Installation	→ **Equipment (breakage) → Environ (voltage)**	2	0.9
Work practice		**1**	**0.5**
Housekeeping	(8 factors and 4 cases)	1	0.5
Environment (water)		**1**	**0.5**
Equipment		**7**	**3.5**
Design		5	2.5
Breakage		2	0.9
Work practice	→ **Behaviour only**	**2**	**0.9**
Standard operating procedures	(10 factors and 8 cases)	2	0.9
Environmental (water)		**1**	**0.5**
No contributing factors		**3**	**1.5**
Equipment		**12**	**5.9**
Design		6	3.0
Installation	→ **Behaviour → Environ (voltage)**	1	0.5
Breakage		5	2.5
Environmental (water)	(23 factors and 13 cases)	**5**	**2.5**
Work practice		**6**	**3.0**
Housekeeping		1	0.5
Standard practices		5	2.5
Equipment design	**Behaviour → Environ (water)** (2 factors and 1 case)	**1**	**0.5**
Total		**202**	**100.0**

*Note that this Table shows the number and % of times each type of Contributing Factor was coded and as many cases had two factors, the factors do not sum to the number of cases.

Table 6: Main groups of Contributing factors for electric shock incidents for each type of mine operation showing percentage of cases with the specific Contributing factor for each type of mine operation.

	Type of mine operation				
Contributing factors	**Coal open cut**	**Coal under-ground**	**Coal other**	**Non-coal open cut**	**Non-coal under-ground**
Equipment	32.4	40.0	29.4	42.9	39.5
Environment	0	4.0	0	0	0
Work practice	5.9	0	11.8	0	5.3
Equipment + Environment	20.6	8.0	23.5	0	15.8
Equipment + Work practice	26.5	16.0	29.4	14.3	21.1
Environment + Work practice	0	4.0	0	14.3	3.1
Equipment + Environment + Work practice	8.8	0	0	14.3	3.1
n of cases	34	25	17	7	38
Total %	100	100	100	100	100

Analysis of the patterns of contributing factors for each type of mine operations (see Table 6) shows that equipment factors both alone and in combination with other factors were the more common contributing factor. Work practices were far less common for each type of mining operation. Overall it seems that the same sorts of factors contribute to the occurrence of electric shocks in each type of mine operation.

As shown in Table 7, the most common type of event leading most directly to the electric shock was Environment – voltage which related to the person coming into contact with a source of electricity. For the non-coal sector, the second most common event also involved the environment, but related to water occurring in the immediate period leading to the incident. For the coal sector, a behavioural event in the form of a misapplied rule was the second most common type of event leading most directly to the electric shock.

Table 7: Type of Precursor event 1 for each type of mine operation showing percentage of cases with each type of precursor event 1 for each type of mine operation.

	Type of mine operation				
Precursor event 1 code:	**Coal open cut**	**Coal under-ground**	**Coal other**	**Non-coal open cut**	**Non-coal under-ground**
Environment – voltage	91.2	76.0	76.5	57.1	76.3
Environment - water	0	4.0	5.9	28.6	13.2
Behaviour - skill	2.9	0	0	0	2.6
Behaviour - rule	2.9	8.0	11.8	0	2.6
Uncoded	2.9	12.0	5.9	14.3	5.3
n of cases	34	25	17	7	38
Total %	100	100	100	100	100

Discussion

The distinguishing feature of most cases involved a person being in an environment that caused them to come into contact with electricity and this led most immediately to the electrical incident. In fact in all of these cases the person's involvement provided the indicator that an electrical problem existed. This unfortunately, in two cases, resulted in lost time or serious injury. In most cases, however, this environmental event occurred because of pre-existing problems usually with equipment. The greater majority of cases involved equipment problems, almost always due to a pre-existing problem with equipment rather than the equipment breaking or malfunctioning just before the electrical incident. In fact, less than five percent of cases occurred because of breakage of equipment just before the electrical energy contact.

Nearly half of the cases (44.5%) involved behavioural events and/or behavioural contributing factors (usually unsafe standard work practices including poor housekeeping or maintenance), although behaviour played a much smaller role in the electrical incidents than did equipment failures. In some cases the behaviour, most immediately preceding the electrical incident involved no error and simply played the role of indicating, through the incident, that there was a problem with other factors in the work setting, especially equipment problems.

It is clear that equipment-related problems were by far the most common problems identified in this analysis and that they had occurred much earlier in time than the reported incident. This pattern indicates that most cases could have been prevented by action that corrected the design fault or breakage or lack of attention to maintenance. The analysis also suggests that action that focuses on behavioural factors such as training are not the most immediate need for preventing these electrical contact incidents. The analysis suggests that the main role of behavioural interventions would be in improving work practices such as housekeeping and maintenance. However since many of the problems identified relate to equipment design features it may be that many of these problems would not be solved or prevented by routine maintenance. Rather they would require specific action and may involve specialist advice.

While the involvement of behaviour was not very common in the events leading to the incident, the patterns revealed provide some insights into the most appropriate approaches to prevention of error in this cases. Rule-based errors, mostly failure to isolate or to check isolation of equipment, were the most common and they occurred in combination with equipment-based problems. In most cases the equipment failure was the prime cause of the incident, however, action to reinforce the importance of checking and isolating electrical equipment would still be advisable, especially due to the very large proportion of incidents that involved equipment failures. In fact, employees and contractors working in mining should be alerted to the relatively high probability that electrical equipment in mining is not safe due to design, breakage and maintenance problems as clearly shown in this study.

Uncovering these patterns reveals some common problems across different types of mine operations in NSW. The analysis also provides useful insights into the most appropriate approaches to preventing electric shocks. Clearly attention needs to be directed towards reviewing the electrical safety of existing equipment and better ways of choosing new equipment that is suitable for the mining environment.

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Appendix

Classification System

The classification system has been described in detail elsewhere (Feyer and Williamson 1991; Williamson and Feyer 1990). Briefly, the system was designed to code events in terms of their nature, their relative location in the accident sequence and their relative causal importance in the accident sequence. It allowed coding of up to three events immediately preceding the accident which led directly to the fatality, as well as coding of any further pre-existing factor that made a direct contribution to the occurrence of the accident or fatality. These were titled **precursor events** and **contributing factors**, respectively. For purposes of coding, the time before the accident referred to the relative sequential order of events leading up to the fatality. The time separating the events could have varied from seconds, to minutes to hours or perhaps even days. Not all accidents involved the full range of precursor and/or contributing factors

Precursor events were classified into one of four categories: environmental, equipment, medical and behavioural. Behavioural events were further coded in terms of whether the behaviour constituted an error. Errors were subsequently classified according to the behaviour-based classification system proposed by Rasmussen (1982). This system classifies error in terms of the type of behaviour occurring at the time; from skill-based behaviour, in which behaviour is automatic and does not require conscious thought or control, to rule-based in which behaviour is generated through application of memorised rules, to knowledge-based behaviour which is generated by problem-solving and interpretation of existing information. Errors are classified according to the functional level of behaviour during which they occurred, yielding three categories: slips or lapses that occurred during skill-based behaviour, errors that occurred during rule-based behaviour and errors that occurred during knowledge-based behaviour.

Contributing factors were classified into one of eight categories: Environmental, equipment, work practice, supervision, training, task error, medical and other. The work practice category, consisted of factors involving ongoing poor or risky standard operating procedures, in contrast to errors, which were defined as a single incorrect performance of standard operating procedures. Work practice factors, including supervision and training factors, were further classified according to whether the unsafe practice involved housekeeping or maintenance, unsafe or inadequate standard operating procedures or supervision or coordination of work.

Reliability of coding:

The reliability of the coding was evaluated by using multiple coders. Two coders read, classified and coded a sequence of 23 cases chosen at random from the dataset. In all but three cases (13.0%), the two coders had identical coding of the Precursor Event sequence. For 15 cases (65.2%), the two coders had identical Contributing Factors and for the remainder of cases, only one factor was different between the two coders. In two cases, the difference occurred because a factor was left out rather than a different factor being coded. In the remaining 6 cases, the coders differed on one factor, but the meaning of the coding was usually very similar. For example, in three of these cases the alternative coding was equipment breakage being interchanged with housekeeping/maintenance failure. Overall, the level of similarity between coders indicated that the coding was reliable.