

Safety in Mines Research Advisory Committee

Draft Final Report

**Risk assessment of hoisting with
and without a safety detaching hook.**

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Executive Summary

In the late 19th century steam winders with poor control led to literally many hundreds of overwinds per year. The current status on South African mines is that the frequency of overwinds is about five to ten per year, and these are nearly always slow speed overwinds in which no injuries or fatalities occur.

Detaching hooks have two functions. Firstly to detach the rope from the cage in the event of a high speed overwind. This function minimises the damage to infrastructure, but also releases the rope in overwinds at all speeds, including some low speed overwinds. This is not a safety function in that it does not prevent fatalities. The second function is to latch into the spectacle plate once the rope has detached, and provide a means of holding the cage from falling down the shaft. This is a safety function, in addition to the jack-catches, that helps prevent fatalities.

Safety of persons always takes precedence over damage to infrastructure and loss of production, and this study only assesses the risk of serious injury and loss of life. Risk of damage to infrastructure and loss of production is not considered.

Following the Vaal Reefs accident in 1995, in which 104 people died as a result of a locomotive falling down Number Two shaft, the Commission of Enquiry found that the safety detaching hook had opened during the accident and detached the cage from the rope, allowing it to fall approximately 400 m to the bottom of the shaft. Had the detaching hook not opened, the elasticity of the rope would have been sufficient to prevent it from breaking, with the consequence that many of the men, particularly those on the lower deck, are likely to have survived.

Subsequently SIMRAC project GAP340 confirmed that detaching hooks can be fully opened accidentally by a falling object striking only one of the scissor plates at relatively low energy, detaching the conveyance and leaving it free to fall down the shaft. This possibility raised concerns as to the safety risks posed by detaching hooks and the current project investigates the difference in risk between hoisting with and without detaching hooks.

The critical events identified and evaluated in the study were:

- The high-speed overwind (in which the rope would break if not detached).
- The low-speed overwind.
- Objects falling down the shaft.

The results of the project indicate that, as currently implemented in the South African mining industry, safety detaching hooks are likely to cause roughly three times more fatalities than would be caused if no detaching hooks were used.

This conclusion is based on both known occurrences of accidents and estimated risks. Further work on modifications to detaching hooks with a view to eliminating the risk of accidental opening by falling objects could reverse the above situation. On the other hand, if high speed overwinds can be prevented then detaching hooks would become redundant. This project also considers measures to prevent overwinds.

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Table of contents:

| | Page |
|--|------|
| Executive summary | 4 |
| 1 Introduction | 5 |
| 2 Components of this report | 6 |
| 3 Structure of project | 6 |
| 4 Accident statistics | 6 |
| 5 HAZOP study | 8 |
| 6 Event trees | 9 |
| 7 Risk analysis | 9 |
| 8 Measures to prevent overwinds | 11 |
| 9 Results – summary | 12 |
| 10 Recommendations | 13 |
| APPENDICES | |
| Appendix A Accident statistics | A 1 |
| Appendix B AEA Technology HAZOP study report | B 1 |
| Appendix C AEA Technology risk assessment report | C 1 |
| Appendix D Measures to prevent overwinds | D 1 |
| Appendix E Submissions from detaching hook manufacturers | E 1 |

1. Introduction

Safety detaching hooks were developed in the late 1800's primarily as a means of protecting infrastructure in the event of overwinds. Winders at that stage were typically steam driven and difficult to control, and overwinds were common. Furthermore, headgears were usually constructed from wood and often not sufficiently robust to withstand the loads generated during an overwind. Hence there was a strong need to detach the rope from the conveyance in the event of an overwind. Detachment alone serves to protect the headgear and winder from damage but does not protect the cage and its occupants. A further function of the detaching hook is therefore to latch the cage into the headgear and prevent it from falling back down the shaft. This is the primary safety function of the detaching hook.

In order to clarify the objectives of the current investigation it is important to isolate the two functions of the hook. Detachment is to be recognised as a function primarily related to the protection of infrastructure. On most modern headgears the full rope breaking load can be withstood and any infrastructure damage that might occur is unlikely in itself to be a threat to the occupants of a cage. Hence on shafts with a modern headgear the detachment function can be regarded as solely one of protecting infrastructure. In terms of safety the only issue is the maximum survivable deceleration rate.

A consequence of detachment is removal of the means of support of the conveyance, hence, upon detachment, latching of the hook in the headgear must take place or else the conveyance can fall down the shaft. The ability to securely hold the conveyance in the headgear therefore represents the primary safety function of a detaching hook. This safety function is backed up by the legislated use of jack catches.

The SIMRAC project GAP340 has shown that movement through the spectacle plate (where latching takes place) is not the only means of opening a detaching hook. It was shown that detaching hooks can be opened accidentally by falling objects with relatively low kinetic energy (the energy required to open the detaching hook is of the order of 27 to 58 kJ), and hence detach the conveyance from the rope, leaving it free to fall down the shaft. This possibility raises concerns as to the safety risks posed by detaching hooks and the current project investigates the difference in risk between hoisting with and without detaching hooks.

The approach adopted was to compare the statistically probable number of fatalities in the South African industry under conditions where detaching hooks are used, as opposed to the scenario that they are not used. Individual failure modes and probabilities were identified by a team of experts in HAZOP sessions. The overall consequences of individual failures were determined by means of event trees that identified five basic scenarios in which there may be a difference in risk between having and not having a detaching hook. The probabilities associated with each of the scenarios were estimated on the basis of statistical evidence combined with expert judgement where appropriate. Given that there have been a limited number of occurrences of the main scenarios identified, a Bayesian statistical approach was used in establishing the best estimates for the underlying frequencies.

The two most important scenarios in determining the balance of risk were found to be accidental detachment of the hook after being struck by falling objects, and high speed overwinds (in which the rope would break in the absence of a hook) with subsequent failure of the jack catches to secure the cage. It is shown that there are likely to be more fatalities associated with the former than the latter hence it is concluded that the risk in using detaching hooks is greater than in not using them.

This conclusion represents the status in general within the mining industry where hoisting takes place, with currently installed equipment, even though this varies widely. The risks and probabilities affecting the assessment could change if various mitigating measures are brought into practice and adhered to. Various mitigating measures have been considered as separate part of the project.

2. Components of this report

This report describes and summarizes the completed study. The larger body of this report contains the Appendices, which are in themselves each self-contained studies. In particular, the main body of the work is contained in Appendix C, which is the report by AEA Technology (AEAT), who were commissioned to conduct the HAZOP study and risk analysis. The AEAT report itself contains a number of appendices.

3. Structure of the investigation

The study was structured as follows:

- 3.1 Collect accident statistics from the Department of Minerals and Energy offices on overwinds.
- 3.2 Conduct a HAZOP study on winder systems.
- 3.3 Analyse the data obtained from the accident statistic records and HAZOP study.
- 3.4 Investigate measures to minimise the risk of overwinds.
- 3.5 Assemble a report on the investigation.

These components are dealt with in more detail below.

4. Accident statistics

Statistics were obtained on mine accidents in which a safety detaching hook could have played a role (mainly incidents of overwinding, but also accidents in the shaft or headgear areas).

The bulk of the required information was extracted from accident records maintained by the South African Department of Minerals and Energy (DME). Limited success was however achieved with this investigation, because records of non-fatal accidents or incidents are only kept for a period of five years before being destroyed. Although the DME have in addition categorised and captured all reportable accidents and incidents on computer since 1988, the computer

records do not show the type of details required for an investigation of this nature.

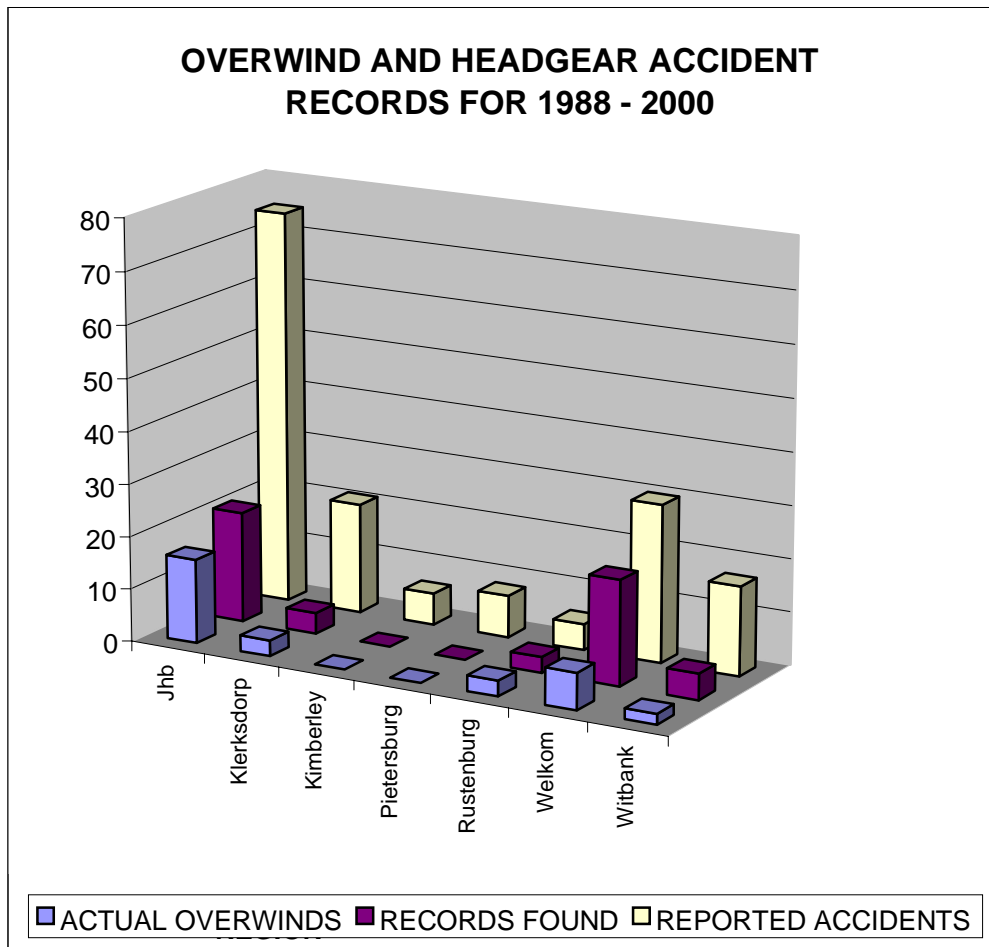


Figure 4.1 Record of overwind and headgear accidents.

A total of 166 non-fatal overwinds, shaft or headgear accidents and incidents have been recorded on the DME computer system since 1988. Hard copies of only 53 reports on these incidents (32 per cent) could be retrieved from the relevant regional archives of the DME, since most of the records older than five years have been destroyed. A summary of the information obtained from these records is shown in Table A1 in Appendix A. Figure 4.1 shows these results graphically. Only 31 of these non-fatal incidents (58 per cent) were overwinds of conveyances in the headgear, while the others were so-called “underwinds” (i.e. an “overwind” of a descending conveyance into the bottom of the shaft) or incorrectly categorised accidents, as indicated in Table A1.

Records on fatal accidents are stored for an indefinite period by the DME, and it was somewhat easier to retrieve the reports on past overwind accidents that resulted in fatalities. However, indexes at the regional DME archives where these reports are kept, mostly do not show the accident category or description, and were therefore not very useful during the search for accident information or statistics. In some instances overwind accidents recorded did result in injuries to personnel, but the relevant accident reports or information could not be found in

the archives. The number of overwind accidents reported in South Africa per year are shown in Figure 4.2.

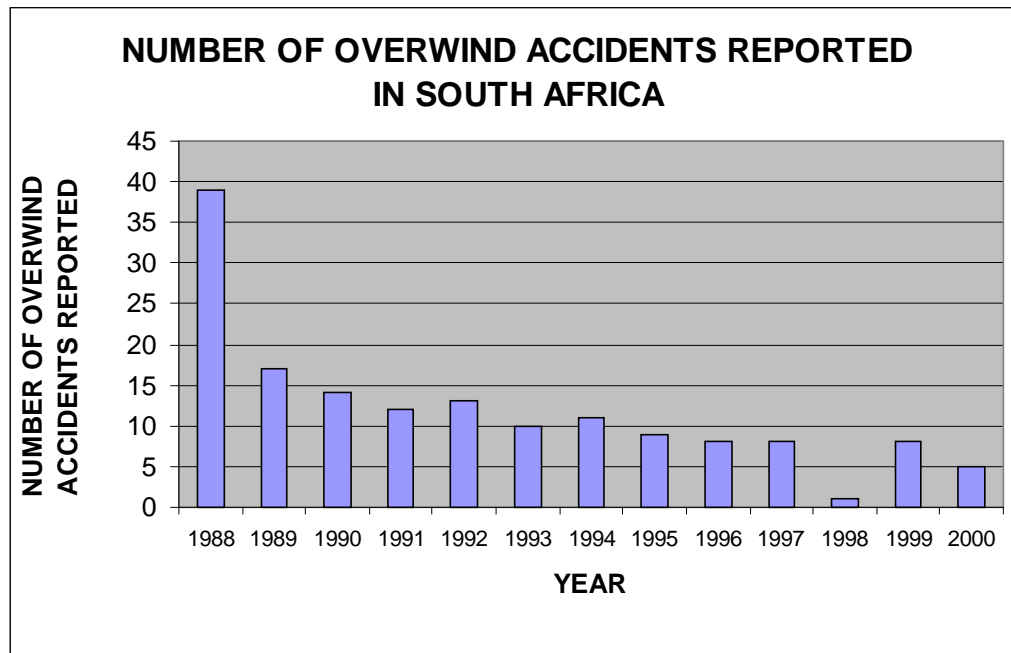


Figure 4.2 Record of overwind accidents reported.

Some information was also obtained on serious overwind accidents that occurred in the United States of America and the United Kingdom, and the details are provided in Appendix A.

5. Hazop study on winder systems

AEA Technology were subcontracted to conduct a study, the outcome of which would assess the risk of hoisting with and without a safety detaching hook. This study is contained in Appendix B. The first step in this task was to conduct a HAZOP (Hazards and Operability) study. (As applied to this study the focus was only on hazard identification, and not operability).

The objectives of the HAZOP study were:

1. To identify all functional failures that could influence the risk related to hoisting with and without detaching hooks.
2. To determine the probability of each failure.
3. To determine the consequences of each failure.

The first step of the HAZOP study was to subdivide a typical winder system into various units such as the conveyance, attachments, detaching hook, shaft, headgear, winder, and a number of others – these can be found in the first column of the HAZOP report, contained within Appendix B as Table B1.

The HAZOP study was conducted by AEA Technology together with a panel of persons from the South African mining industry highly experienced in various aspects of winder systems. AEAT defined the type of data required as input

from the panel. The panel consisted of persons with extensive experience in operational and design aspects of winder systems. The results of the statistics on accidental overwinds were also used as inputs to the HAZOP study.

The result was a table listing all equipment failures identified as relevant (or possibly relevant) to the overall study, together with estimates of the frequency of each failure in South African mining over the past 50 years (based on expert judgement) and an indication of the consequences of each failure. The results are presented in Appendix B, Table B1, of this report.

6. Event trees

All of the faults identified in the HAZOP as potentially affecting the balance of risk in hoisting with or without detaching hooks were identified as being relevant only in the context of three basic event trees. These are:

- High-speed overwind (in which the rope would break if not detached)
- Low-speed overwind
- Objects falling down shaft

The event trees show the inter-relationships between the different faults identified in the HAZOP study. Event trees are dealt with more fully in the AEA Technology report contained in Appendix C, and are shown in Figures 1a to 3b of the same report.

7. Risk analysis

The construction of event trees, based on the HAZOP study (See the AEAT report in Appendix C for details), identified five basic accident scenarios in which the detaching hook plays a part.

The table below shows the statistically probable number of fatalities for each of the basic accident scenarios. (Refer AEAT report, Appendix C).

Summary of differences in risk for different scenarios

| Scenario Number | Scenario description | Probable fatalities per yr | |
|-----------------|---|----------------------------|--------------|
| | | With hook | Without hook |
| 1 | Hook opened completely by objects falling down shaft | 4 | 0.0 |
| 2 | Hook opened on one side by falling objects or slack rope; subsequent dynamic loads cause hook to open fully | 0.024 | 0.0 |
| 3a | High speed overwind of cage carrying men, hook detaches rope, hook fails to catch in spectacle plate and jack lugs fail to catch cage | 0.29 | 0.0 |

| | | | |
|----|--|-------|------|
| 3c | High speed overwind of cage carrying men, rope breaks and jack lugs fail to catch cage. | 0.0 | 1.68 |
| 4 | Slow speed O/W of cage carrying men, hook detaches rope but fails to catch in spectacle plate; lugs fail to catch cage | 0.067 | 0.0 |
| 5 | Slow speed O/W of any conveyance; hook detaches and rope kills bystanders on bank area as it lands | 0.033 | 0.0 |
| | Total (Retaining 3 significant figures) | 4.41 | 1.68 |

Scenario 3b was identified but not assessed because the risk would be negligible and is therefore not included in the above table. This scenario is: "High speed overwind of cage carrying men, hook fails to detach, rope breaks, and jack-catch lugs fail to catch cage." This scenario is exactly the same as the next one (3c), except that 3b requires additional failure that the hook must fail to detach (since if it detaches it becomes scenario 3a). Since the probability of a hook failing to detach is very small (there have been no recorded events of failure to detach), the expected fatalities from this scenario are only a small fraction of those from scenario 3c, and can be ignored in comparison.

In the above table the probable number of fatalities per year is an average taken over the relatively long period of 50 years. The events in the scenarios listed in the table are not regular events. Rather they are infrequent events with low probability of occurrence, but high consequence when they do occur.

In most safety studies the objective is to show that the risk from accidents is sufficiently small, and so conservative estimates of accident frequency are derived using more classical statistical methods. Typically this involves determining or estimating probabilities which are then multiplied by the likely consequences to quantify risk. In this study, however, the estimate must not deliberately err in either direction, since this would prejudice the outcome of the study towards a particular conclusion (for example, a conservative estimate of the frequency of detachments caused by falling objects would cause the disadvantage of the detaching hook to be over-estimated). Since a best estimate mean value is needed, a Bayesian method is appropriate. This is dealt with more fully in the AEA Technology report in Appendix C.

Given that there have been a limited number of occurrences of the main scenarios identified, a Bayesian statistical approach was used in establishing the best estimates for the underlying frequencies.

The results show that the balance of risks is primarily a balance between the benefit of the hook in a high speed overwind and the disadvantage of a hook when objects fall down the shaft. The risk in other scenarios is insignificant in comparison. The AEAT report discusses these results in detail and also sets out the calculation procedure used in each scenario. The above table shows that the use of a detaching hook increases the likelihood of fatalities roughly by a factor of three compared to hoisting without one.

The risk analysis only considers differences in risk between hoisting with and without a detaching hook. Where risks are common between the two situations, that risk has not been included. For example the risk of structural failure of a detaching hook is the same as that of other attachments since they are made of

the same type and grade of steel and are designed to the same safety factors. The presence or absence of a detaching hook makes no difference to the risk of structural failure in the suspension chain (other than to the extent that there is an extra link in the chain). There is therefore also no difference in the probable number of fatalities per year. As a further example, if a falling object does not strike and open the detaching hook, then this would result in the same damage and therefore the same risk to life and injury as if no detaching hook were present. The risk is common to both situations and is not included in the above table.

It must be noted that the risk analysis reflects the status of detaching hook designs as at the time of the Vaal Reefs number two shaft accident in 1995. Since then, it is claimed by the manufacturers, over half of the detaching hooks in service and standby have been modified in an attempt to prevent them from being opened by objects falling down shafts. While these measures are likely to have reduced the risks, and possibly even the balance of risks, this has not been conclusively demonstrated.

The AEAT findings deal with the situation at the time of the Vaal Reefs two shaft accident. This is because the design modifications, although well known, have not been tested at impact energy levels anywhere close to that which would be encountered by a locomotive falling down a shaft for some hundreds of meters. As a consequence the effectiveness of the modifications under similar circumstances is unknown. Although an improvement in the situation is acknowledged, the risk remains un-quantified at the relevant energy levels.

The Buxton tests did not closely replicated the Vaal Reefs two shaft accident because the impact energy obtainable was not nearly sufficient, and in addition the mass of the falling striker was far less than that necessary to provide proper representation even at the required energy.

The impact tests on detaching hooks at Buxton (SIMRAC project GAP340):

- were not a full set of type tests designed to verify the integrity of the hooks against opening. They were intended to gain insight towards understanding how detaching hooks behave, in the event that they open.
- were tested only against objects falling at energy levels of about 150 kJ and with a mass of only about 200 to 300 kg. In the Vaal Reefs number Two Shaft accident the energy of the falling object was about 20 000 kJ and had a mass of about 5000 kg.

None of the makes of detaching hook, including modified designs, have been shown, either by test or analysis, to resist opening under the effect of these higher levels of energy and mass. Until the risk has been shown not to exist, it must be assumed, in the interest of safety, that the risk does exist.

It should be noted that the risks apply to hoisting man cages and do not apply to skips.

8. Measures to prevent overwinds

As a separate part of the project, measures to reduce the number of overwinds occurring per annum have been investigated.

A committee, comprising members of the SIMRAC GAP 701 team and representatives from the suppliers and users of winding plant, was formed to investigate the electrical and mechanical causes of winding system overwinds and suggest mitigating measures that could be employed to minimise or eliminate these.

The main areas as identified in the HAZOP study and the fault tree analysis were used as the topics. The committee was requested to recommend generic minimum standards and “good practice” for the industry where possible.

It was agreed that, whilst the main SIMRAC GAP 701 investigation was concerned with the safety of persons and thus focussed on man winding and high speed overwinds, that the mitigating measures investigation should be wider and look at man and rock winding, high and low speed over and underwinds. It would not however deal with friction winders. The various winder technologies from the simple 1950’s to the most modern winders should also be addressed.

Winder system overwinds were analysed under normal and abnormal (cutting ropes ends, testing etc) winding conditions.

It was recognised by the committee that it is difficult to make generic recommendations and that the risk on each winder needs to be assessed individually. The committee identified that human interference and error was the major cause of overwind incidents.

It was generally agreed that implementation of automation and electronic controls, and their further development, were the most promising approach in the drive to prevent overwinds.

The results of this investigation are summarised in Table D1 contained in Appendix D of this report.

9. Results – summary

The conclusions of the study are listed below:

- 9.1 From the point of view of risk to life, the main accidents in which the detaching hook plays a role are the accidental complete hook opening (as in the Vaal Reefs 2 Shaft accident) and the high-speed overwind, when these involve a cage carrying passengers.
- 9.2 In the double-sided hook opening scenario the hook is a disadvantage because its presence allows the accident to happen. In the high-speed overwind, the hook is an advantage, because if it were not present the rope would break anyway. The catching of the hook in the spectacle plate provides an additional protection against the cage subsequently falling down the shaft, when otherwise there would only be the jack-catches in present shaft arrangements.
- 9.3 On the basis of the data available to this study, the hook is more likely to be a disadvantage than an advantage, and is estimated to cause roughly three times as many deaths as it saves.

The main reasons for this are that:

- 9.3.1 Double-sided detachments are estimated to be more likely than high-speed overwinds in which the jack-catches fail.
- 9.3.2 The fact that some passengers are killed in the initial impact with the crash beams following a high-speed overwind means that fewer are left to be saved by the detaching hook.
- 9.4 The main uncertainty in the assessment concerns the real number of accidental detachments that have occurred. It is statistically unlikely that the Vaal Reefs 2 Shaft and BCL accidents were the only incidents to date, because only one in 17 such events would normally involve people. The study therefore assumes that other detachments have occurred but have gone unreported because there were no fatalities. If this is not so (i.e. if the Vaal Reefs 2 Shaft and BCL accidents were really the only incidents of double-sided hook opening to date) then the balance of risks would be in favour of retaining the hook.
- 9.5 Other uncertainties have been assessed, and are considered unlikely to affect the conclusion that the hook is, on balance, a disadvantage with respect to safety. Even if the estimated frequency of hook openings is halved, this would not change the conclusion.
- 9.6 The susceptibility of detaching hooks to accidental opening by falling objects can be reduced by various modifications. One of these modifications has been applied to over 50 percent of detaching hooks since the 1995 Vaal Reefs disaster. These modifications have been implemented voluntarily by the industry without any requirement by legislation. The modified design however has only been subjected to a limited number of low energy strike tests, and although improvements are indicated, these have not yet been thoroughly demonstrated.
- 9.7 Work can also be done to improve the survivability of high speed overwinds in the absence of a detaching hook, which would strengthen the conclusion that it is safer to hoist without a detaching than with one.
- 9.8 If a detaching system could be constructed that was demonstrably unable to open accidentally due to falling objects, then the balance of risk to safety would favour their retention. This is because overwinds continue to occur. However in all likelihood other risks would be introduced due to its inherent opening mechanism.
- 9.9 On the other hand if overwinds could be eliminated then detaching hooks would be redundant. Reducing the number of overwinds that occur, on a sustainable basis, could reduce the level of risk to the point where the balance of risk to safety would favour hoisting without detaching hooks, even if hooks are modified or redesigned to totally prevent accidental opening due to falling objects.

10 Recommendations

10.1 Detaching hooks:

- 10.1.1 This report should be submitted to the Department of Minerals and Energy for review in the light of current legislation.

- 10.1.2 For detaching hooks to be acceptable they must be shown not to open under impact energy levels of 20 MJ and masses of 5 ton, similar to the mass and energy of a typical locomotive falling a few hundred meters down a shaft.
- 10.1.3 SIMRAC project GAP340 should be expanded to prove the effectiveness of design modifications that have been implemented by manufacturers to circumvent detaching hook openings due to falling objects. This should include both physical testing and analytical work.

10.2 Measures to prevent overwinds:

- 10.2.1 Written procedures should be implemented on all shafts to control the process of setting equipment, tests and checking, such as for limit switches, Lilly controllers etc. In general a separate procedure is required for each winder taking into account the specific equipment installed. On many shafts such measures are already in place, but this needs to be expanded to all shafts.
- 10.2.2 The work above should only be performed by experienced trained people. Their work should be cross-checked by supervision and each step in the procedure should be signed off.
- 10.2.3 The control and overwind protection systems should be designed to fail safe, to cross-check themselves and to cross-check the winder to the actual shaft position.
- 10.2.4 A risk assessment should be carried out on every winder to review the safety of the design and the equipment suitability for the specific application.
- 10.2.5 On restoring the winder to operation following disconnection or alteration of the overwind control and protection systems, the winder should be operated at creep speed to move the winder to the end of wind positions so as to verify that the control and protection systems are operable.

All of these measures reduce the risk of injury or fatalities in overwinds and as a consequence, if implemented successfully on a sustainable basis, also reduce the balance of risk in favour of retaining detaching hooks. The main cause of overwinds is human error. Even when procedures are documented and implemented reliance on human action is still required for these to be carried out with full integrity.

10.3 Measures to improve survivability of high speed overwinds:

- 10.3.1 Provide sufficient overrun for cages. A minimum of 7,5 m overrun from the end of wind limit switches should be provided. Strictly no exemptions to this requirement should be given.
- 10.3.2 If detaching hooks are retained, suspend the cage at some distance below the hook by a flexible element, either rope or chain. This distance should be sufficient to slow the cage down under gravity, and would require the installation of longer jack-catches. This is the practice in England.

- 10.3.3 Provide arresting devices to decelerate the cage over some distance rather than having the cage decelerate violently by crashing into crash beams. It should be noted however that this measure would be unnecessary if 9.3.2 were implemented, but would be second choice if insufficient shaft length were available to implement a flexible suspension element.
- 10.3.4 Provide protection in cages to prevent head and neck injuries due to sharp decelerations in a high speed overwind. This type of measure would be necessary both for deceleration under gravity or by gravity plus arrestors. The requirements when arrestors are used will be more stringent because of the higher deceleration involved.

It is recommended that these issues should form the basis of a further study. Any such measures reduce the risk of injury or fatalities in a high speed overwind and as a consequence also reduce the balance of risk in favour of retaining detaching hooks.