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Application of fault tree analysis to coal spontaneous combustion

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ABSTRACT: Fault tree analysis is a powerful risk assessment tool for identifying root causes of an unwanted event that can then be managed with appropriate control measures. This method has been applied to the analysis of a spontaneous combustion event for the five year mine plan of the new Abel Mine, Newcastle, Australia. A team of people with diverse backgrounds provided input to the analysis, which was facilitated by a risk management consultant. The team consisted of the Technical Services Manager – Underground Operations, the Project Manager, The Undermanager, the Ventilation Officer, a Mining Technician and Fire Officer (representing the underground operators), a ventilation consultant and a coal spontaneous combustion expert. The resulting fault tree has provided the mine with a clear set of controls that can be incorporated into a spontaneous combustion management plan. This approach sets a new benchmark for the coal industry and produces a generic model that is robust enough to be transferable to any mine by adjustment of the site specific parameters. Some of the branches of the fault tree will be presented in this paper to raise the awareness of the coal industry to the comprehensive nature of this approach to risk management.

INTRODUCTION

All underground coal mines need to assess the risk of a spontaneous combustion event occurring. In New South Wales leading industry practice is the development and implementation of a Spontaneous Combustion Management Plan (SCMP) that complies with the Spontaneous Combustion Management Code (MDG1006). A formal risk assessment is the keystone to developing the SCMP and there are a number of approaches that can be taken to do this. To assist mining operations with this process, the New South Wales Department of Primary Industries and Mineral Resources has issued a Risk Management Handbook (MDG1010) that also incorporates a set of compliance guidelines in the form of a Review Checklist (MDG1014).

In July 2009, the Abel Mine in Newcastle organised a risk assessment session with the objective to identify, analyse and assess the potential for a spontaneous heating event. Hence, the risk assessment considered the risks to Abel Mine and all site personnel associated with a spontaneous combustion event at the mine. It was considered that the most suitable risk assessment method for this task was Fault Tree Analysis (FTA). The focus of the risk assessment was therefore on identifying all possible “direct” and “contributing” causes of spontaneous combustion at Abel Mine, identifying the underlying “root” causes for each and then considering the adequacy of existing controls as preventative measures. The risk assessment covered planned operations in the Upper Donaldson Seam for the next five (5) years, including SMP Area 1, the South Mains to 47c/t and the area to the East. The West Mains were excluded from this risk assessment.

This paper presents a summary of some of the key elements of the fault tree analysis applied to the Abel Mine as it is not possible to present the details of each of the branches determined from the full risk assessment session. The final report for this work was 27 pages long and the completed fault tree is best viewed as an A0 size drawing, which was included as an appendix to the report

RISK ASSESSMENT

Risk assessment team

A spontaneous combustion risk assessment needs to be undertaken as a team effort with input from diverse backgrounds. Leading practice dictates that a risk assessment session should be managed by a facilitator who is expert in risk management methods to ensure that things are done systematically. In the case of the Abel Mine session a mix of site personnel with relevant experience and external consultants were involved (Table 1). The site personnel covered a range from senior management to face personnel.

Table 1: Risk assessment team composition

Position/ Title/ Qualifications	Industry Experience
Senior Consultant Risk Management Facilitator	28 years
Consultant Risk Management Scribe	2 years
Undermanager	23 years
Mining Technician and Fire Officer	11 years
Ventilation Officer	12 years
Ventilation Consultant	34 years
Spontaneous Combustion Consultant	30 years
Technical Services Manager	25 years
Project Manager	32 years

Risk assessment methodology

The risk assessment was undertaken in accordance with the requirements of AS/NZS 4360:2004 and MDG 1014, using a Fault Tree Analysis approach with spontaneous combustion as the "top level" undesirable event. Team members initially held a "brainstorming" session to identify all issues associated with the development of spontaneous combustion. Following this, a fault tree was developed to display the logical structure of events and situations which could lead to a spontaneous combustion event. The "Primary", "Secondary" and "Intermediate" causes were identified and considered by the Risk Assessment Team, with each level in turn further analysed to find the "root" causes in each case.

At this point the current controls for each root cause were examined to consider their adequacy. Further (additional) risk reduction controls and actions were then identified by the team to reduce the final risk to an acceptable level, or "As Low As Reasonably Practicable" (ALARP).

FAULT TREE ANALYSIS

Primary causes of a spontaneous combustion event

The initial branches of the spontaneous combustion fault tree are shown in Figure 1. Three primary causes of a spontaneous combustion event developing have been identified. These are self-heating (in response to the mining process), less than adequate dissipation of heat and a less than adequate monitoring system. All three of these branches must occur for an event to escalate to a dangerous level – thus requiring the "AND" gate as shown in Figure 1.

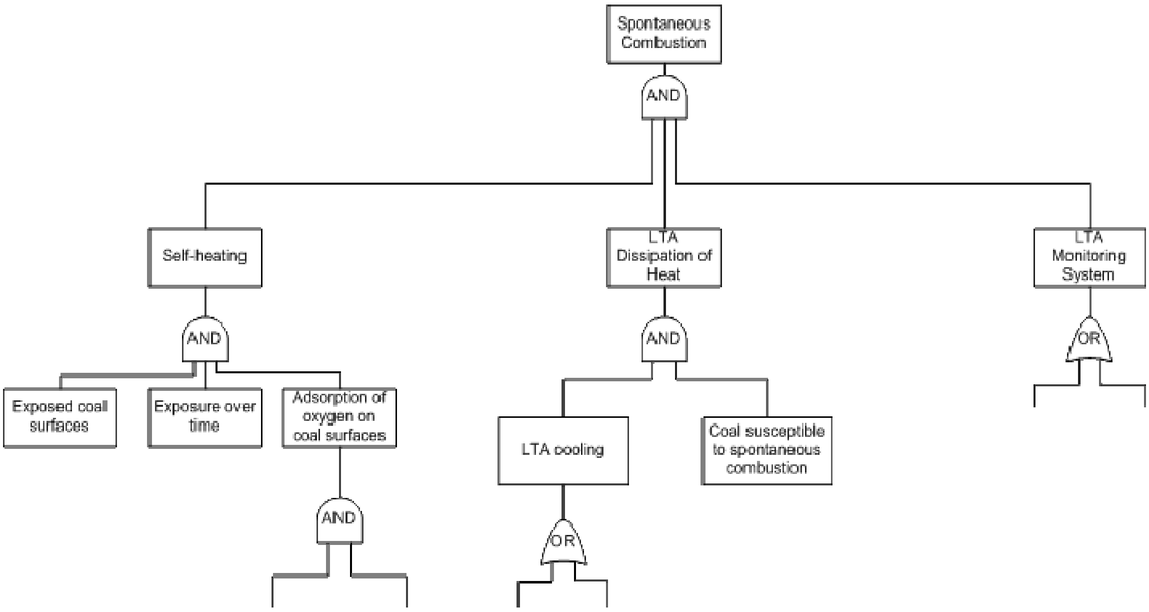

Figure 1- Partial spontaneous combustion fault tree showing primary causes and some of the secondary causes leading to an unwanted event (LTA = Less Than Adequate)

Secondary and intermediate causes of a spontaneous combustion event

For self-heating to occur due to the mining process there are three requirements. These are exposure of coal surfaces to air, sufficient time of exposure for self-heating to take place and adsorption of oxygen by the coal (Figure 1). All three of these must occur for this branch to be part of the root cause of an event (once again designated by the "AND" gate in Figure 1). The mining factors leading to exposure of coal surfaces are coal left in the goaf, accumulation of coal elsewhere in the mine and fractured coal pillars. It only requires one of these factors to be present for the branch to come into play leading to an event (this is represented as an "OR" gate in the fault tree structure). Each of these intermediate causes can be subdivided further. For example fractured coal pillars can be subdivided into the following four root causes:

- Geological anomalies (Fault, dykes, sedimentary channels etc);
- Less than adequate pillar design;
- Pillar life cycle; and
- Pillar loading.

Any one of these root causes can lead to an event (once again this would be represented by an "OR" gate in the fault tree structure). Having determined the root causes at the bottom of this branch on the fault tree, controls can be identified for each. The current controls for geological anomalies are exploration to date, development of a geological model and hazard mapping. Additional controls for geological anomalies are update the geological model and maps as the mine develops as well as identification of sheared coal zones as part of the mapping process.

Current controls for less than adequate pillar design are pillars to be designed by a competent geotechnical engineer, strata monitoring and monthly strata management meetings. These same controls also apply to the pillar life cycle and pillar loading.

The mining factors associated with exposure over time are a slow extraction retreat rate, failure to seal quickly and effectively and prolonged ventilation over the goaf. Again any one of these intermediate causes can lead to an event. These factors can also be broken down into root causes and controls identified for each.

Adsorption of oxygen by the coal requires both the presence of an air supply and that the coal is susceptible to oxidation. There are multiple possible sources of air into the underground environment that can lead to a spontaneous combustion event. These are:

- Shallow depth of cover;
- Ventilating over the goaf;
- Elevated oxygen levels in the sealed goaf;
- Less than adequate ventilation appliances;
- High pressure differential; and
- Boreholes.

Current controls to mitigate against shallow depth of cover are no pillar extraction at < 50m and surface subsidence monitoring for cracks and remediation. For any ventilation over the goaf, monitoring for signs of oxidation products would be necessary. The current controls for elevated oxygen levels in the sealed goaf are gas monitoring and analysis; no pillar extraction at < 50m; surface subsidence monitoring for cracks and remediation; and identification of the signs of oxidation. In terms of ventilation appliances, the current controls require that these be rated appliances installed by an external supplier. An additional control is the implementation and maintenance of an individual seal installation permit and history file. High differential pressure areas are currently highlighted by Ventsim modelling and analysis for the five year plan. The borehole status database identifies boreholes that need to be checked for integrity.

Less than adequate heat dissipation is a combination of less than adequate cooling and the coal susceptibility to spontaneous combustion. The control for the latter is to provide a thorough assessment of the coal susceptibility (Beamish and Arisoy, 2008) to cover the five year plan. Less than adequate cooling may arise from broken coal thick enough to provide insulation (reducing heat loss) or reduced ventilation or changing humidity of the ventilation current. The reduced ventilation may stem from either sealing issues, regulator issues or goaf fall issues. Appropriate controls for each of these root causes can be implemented as part of the normal management practice of the mine.

Less than adequate monitoring can contribute to an event as a result of either less than adequate monitoring resources or less than adequate response to alarm conditions. In the case of the latter this can be either failure to respond to an alarm or failure of the alarm itself. All of these branches need careful consideration to ensure appropriate controls are in place. For example, failure of the alarm may be as a result of either hardware or software. Current controls for hardware failure include, appropriate maintenance systems, fit for purpose equipment and adherence to standards of engineering practice. Additional controls for hardware failure are TARP to include procedure in case of failure of part or all of the monitoring system and backup power supply. Additional controls for software failure include confirming the monitoring system purchase includes backup software for rebooting or re-initialising software and access to service personnel. Consideration is also given to training mine personnel in software systems.

CONCLUSIONS

Risk assessment is routinely used in the coal industry to develop plans that are appropriate to the management of hazards. Leading practice at all coal mines requires the implementation of a Spontaneous Combustion Management Plan (SCMP). The initial step in developing this plan should be to identify the root causes of an unwanted spontaneous combustion event. This can be achieved using the Fault Tree Analysis (FTA) risk assessment method. Controls can then be constructed from this analysis to form the SCMP. However, to perform this analysis correctly requires additional input from site personnel to capture the experience and diversity required for identifying site specific conditions and controls, thus obtaining the best possible outcome in terms of risk management. This process has been successfully applied to the new Abel Mine in Newcastle to develop a comprehensive SCMP for the five year mine plan. Three primary causes of a spontaneous combustion event have been identified as self-heating (in response to the mining process), less than adequate dissipation of heat and a less than adequate monitoring system. The root causes of each of these branches on the fault tree have been identified with appropriate current and additional controls as preventative measures.

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