# The Status of Mine Fire Research in the United States

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ABSTRACT: During the time period from 1990-2007, 1601 reportable fires occurred in the U.S. mining industry (an average of 89 fires per year). The leading causes of U.S. mine fires were flame cutting and welding operations, frictional heating and ignitions, electrical shorts, mobile equipment malfunctions, and spontaneous combustion. The fact that mine fires continue to occur with an alarming regularity reinforces the importance of recognizing and eliminating the potential hazards and the overall need for improved fire control and suppression technology to ensure the best possible outcome during a mine fire. The National Institute for Occupational Safety and Health (NIOSH) is conducting an evolving comprehensive program of research that is addressing mine fire prevention, detection, management and suppression. This paper presents a summary of recent research accomplishments and provides an overview of the next phase of the NIOSH mine fire research program.

## 1. INTRODUCTION

The U.S. mining sector employs approximately 331,000 people and has one of the highest fatality rates of any U.S. industry. Fatalities, injuries, and disasters, although less frequent than in the past, continue to occur with alarming regularity (NRC, 2007). From 1990-2007, 1601 reportable fires (an average of 89 fires per year) occurred in the U.S. mining industry (figure 1). The leading causes of U.S. mine fires include flame cutting and welding operations, frictional heating and ignitions, electrical shorts, mobile equipment malfunctions, and spontaneous combustion (NIOSH, 2008a).

The overarching goal of the NIOSH fire research program is to reduce the risk of mine fires through the development of new or improved strategies and technologies for mine fire prevention, detection, control and suppression. To accomplish this goal, NIOSH is conducting research aimed at ensuring that fire-safe materials are used, that combustibles are properly handled and stored, that mechanical and electrical equipment is properly used and maintained, and that personnel are adequately trained and educated in fire safety practices. NIOSH research is developing rapid and reliable fire sensing systems, guidelines for selecting and using these systems, investigating the principles of fire dynamics and the interaction of gaseous or chemical agents with an expanding flame. In addition, research is addressing the role that ventilation plays in fire control and extinguishment, and how different fire and smoke mechanisms can impact these interrelationships (NIOSH, 2008b).

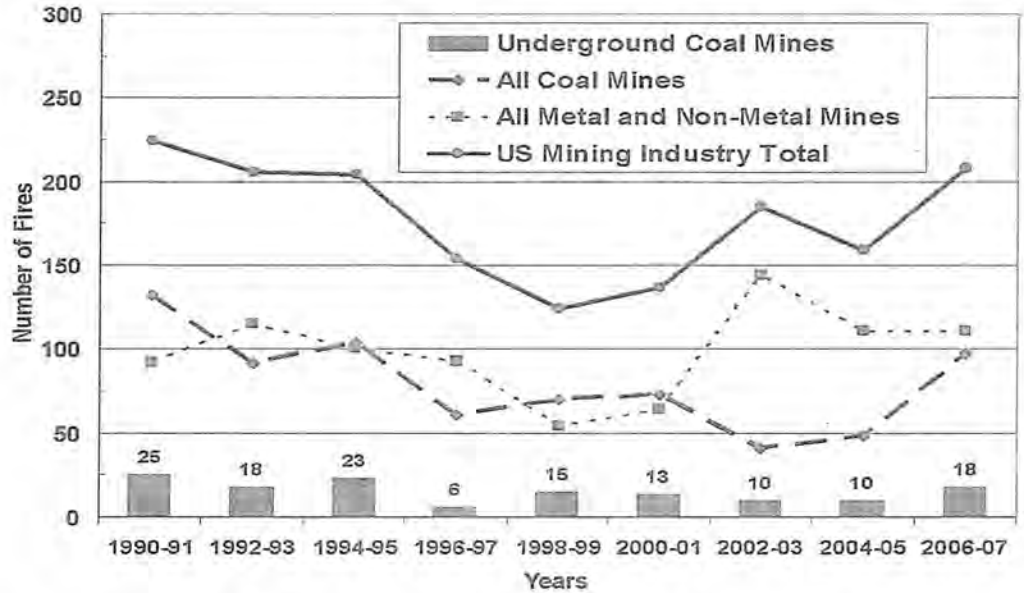


Figure 1. Reported fires for the U.S. mining industry from 1990 to 2007 (DeRosa, 2008).

## 2. NIOSH MINE FIRE RESEARCH

Current NIOSH research is focused on understanding and controlling spontaneous combustion, the causes of flame cutting and welding fires and injuries, the effects of ventilation on conveyor belt fire suppression systems and remote methods for addressing coal mine fires. The goal of this work is to reduce the number of fires and to improve mine fire control and suppression technology to ensure the best possible outcome during a mine fire. A report on the status of each program area follows.

**Spontaneous Combustion** – Spontaneous combustion continues to be a hazard for U.S. underground coal mines, particularly in western U.S. where the coal is generally of lower rank. For the period 1990 – 2006, more than 20 underground spontaneous combustion fires occurred. Spontaneous combustion occurs when the heat that is produced by the low temperature reaction of coal with atmospheric oxygen is not adequately dissipated through conduction and/or convection, resulting in a net temperature increase in the coal mass. Coal oxidation is an irreversible exothermic reaction and its reaction rate increases with temperature. The increase in temperature leads to higher oxidation rate. If not averted with an appropriate action, this process results in the thermal runaway and a fire ensues. The spontaneous heating of coal often occurs in a gob area and may not be easily detected. The risk of an explosion ignited by a spontaneous combustion fire is also present in those mines with appreciable levels of accumulated methane gas. In fact, three of the mine fires mentioned above also resulted in subsequent methane gas explosions. The incidence of such fires and the associated explosion hazard is expected to increase with the projected increased mining of lower rank coals, deeper mines with more methane gas, and the growth in the size of longwall panels.

A computer model has been developed from existing computational fluid dynamic (commonly called "CFD") codes to describe the ventilation pathways through the immediate gob. Simulations have been conducted for a variety of bleederless and bleeder ventilation scenarios to evaluate the effect of methane emission rate and ventilation on self-heating in longwall gob areas. This work can be used to assist in the design of ventilation systems where spontaneous combustion risk is high.

**Flame Cutting and Welding** – To determine the causes of the fires and injuries caused by flame cutting or welding operations, accident investigation reports were scrutinized, workers were interviewed, and flame cutting and welding operations at several underground coal mines were observed. The data from these investigations was analyzed to determine the root cause of flame cutting and welding fires in the coal mining sector. Promising direct interventions to prevent the root causes of flame cutting and welding fires were identified and evaluated in field tests at operating underground coal mines. Existing training methods and procedures were examined and improvements to these methods and procedures were developed and tested in the field. A safety awareness training toolbox, "Tame the Flame," is planned for release in the near future.

**Conveyor Belt Fire Suppression** – NIOSH, in partnership with the Mine Safety and Health Administration (MSHA), initiated a test program to determine the effectiveness of fire suppression systems on conveyor belt fires in entries with high-velocity air flow (figure 2). Full-scale experiments evaluated the effectiveness of dry powder chemical suppression systems, water sprinkler systems, and water deluge systems in conveyor belt entries at air velocities of 0, 2.5 and 7.1 m/sec (0, 500, and 1400 ft/min). The data from this work will be used to develop guidelines for the installation and use of fire suppression systems in ventilated belt entries. In late 2007, the scope of this research was modified to include the recommendations made by the Technical Study Panel on the utilization of belt air and the composition and fire retardant properties of belt materials in underground coal mining (Mutmansky, 2007).

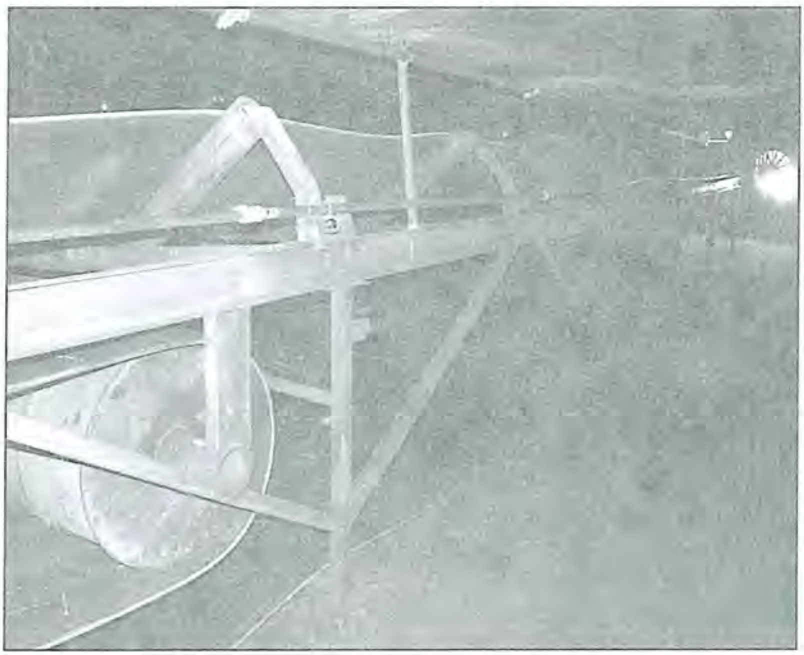

Figure 2. Conveyor belt fire suppression system set-up at the NIOSH Fire Suppression Facility (Rowland, 2008).

In a related study, conveyor belt, typical of the type used in metal/nonmetal mines, where no mandatory fire resistance standards apply, were evaluated for their fire resistance. The results clearly showed the hazards of using non-approved conveyor belting and demonstrated that the use of approved conveyor belting can significantly reduce potential fire hazards.

**Remote Methods for Addressing Coal Mine Fires** – The ability to remotely address coal mine fires can reduce worker exposure to hazardous situations. The objective of this work is to evaluate, improve or modify remote fire-fighting technologies, including remotely installed mine seals (ventilation barriers), and fire control and suppression technology. This research effort is being conducted with active industry participation and with the input from MSHA technical specialists serving as research partners. Full-scale remote mine seal installation experiments have been conducted to evaluate cement-based and rigid-foam based materials at the NIOSH Lake Lynn Experimental Mine (LLEM). The LLEM (located approximately 97 km (60 mi) southeast of Pittsburgh, Pennsylvania) is a world-class, highly sophisticated underground facility where large-scale explosion trials and mine fire research is conducted. This work has resulted in new understandings of the limitations of the technology and development of novel downhole tools to facilitate accurate placement of mine seal materials. Preliminary research on nitrogen gas-enhanced foam (foam resulting from commingling of nitrogen gas, water and a specialized foam concentrate) shows that foam can be stable in the mine opening and can accumulate and flow through mine workings (figure 3).

Figure 3. Compressed air gas-enhanced foam accumulating behind and moving through crib block sets at the LLEM.

## 3 FURTURE NIOSH MINE FIRE RESEARCH

Planned work under the NIOSH mine fire research program will continue the spontaneous combustion modeling effort. The work will focus on western U.S. coal mines by simulating longwall gob areas and collaborating with western U.S. coal mine operators to collect spontaneous combustion data to calibrate the CFD model. CFD modeling will also be used to investigate nitrogen gas injection strategies to prevent the spontaneous heating in coal mines using bleederless ventilation systems and to suppress the spontaneous heating in coal mines using bleeder ventilation systems. It is hoped that this work will result in improved understanding of the conditions that lead to heating events and should also result in new ventilation practices and technologies to reduce the risk and number of fires.

The conveyor belt fire suppression program will focus on the reduction of the hazards of underground coal mine fires, particularly in conveyor belt entries, by applying recent technological advances in the areas of fire-resistant and fireproof belt materials, belt fire suppression systems, atmospheric monitoring systems, and computer codes for predicting and assessing in real-time the impact of fire on the mine ventilation system. In addition, the work will include an overall evaluation of the flammability of conveyor belts, modeling of conveyor belts fires, modeling of contaminant spread, fire risk assessment, and training and maintenance. It is expected that the research output from this work will substantially reduce the number of fires and injuries/fatalities due to conveyor belt fires and will significantly improve the level of fire safety in mines.

Remote mine fire suppression research will continue and will involve the testing of injected inert gas and gas-enhanced foam to extinguish large-scale, deep-seated coal and coal-wood crib fires. During each fire, fire gases, and heat build-up and release will be continuously monitored as each suppression technology is applied to determine fire suppression mechanics and if technology modifications are needed. Included in the work plan is a test of jet engine exhaust technology for mine fire suppression. A controlled, large-scale, deep-seated coal fire will be built underground and a jet engine will be coupled to the LLEM mine ventilation system via the fan shaft or a drift opening so that the jet engine exhaust gases pass over the fire. The complete suite of jet engine exhaust gases will be monitored along with fire heat build-up and release. In addition, heat build-up and moisture loss will be monitored in the rock mass (or via instrumented samples placed near the jet engine exhaust) to determine the effects of heat on mine void and rock mass degradation. Finally, inflatable temporary ventilation control devices will be evaluated through deployment, multi-day inflation and air leakage tests at the LLEM to define the capability and limitations of these devices in a simulated coal mine setting (figure 4). It is thought that these devices could be used by the U.S. coal mining industry to temporarily close an underground mine area in response to a fire or spontaneous combustion heating event and to temporarily redirect mine ventilation during longwall equipment moves or during stopping construction.

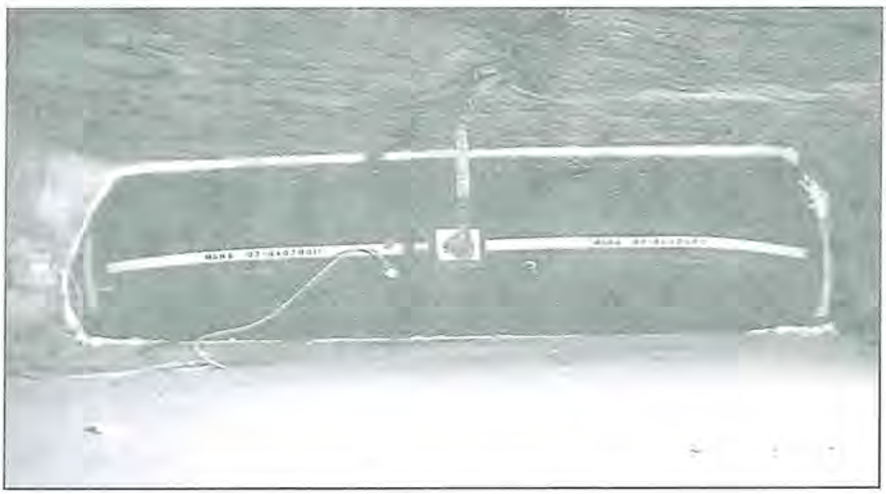

Figure 4. Testing of an inflatable temporary ventilation control device.

## 4. SUMMARY

Mine fires represent one of the greatest threats to those working in the underground mine environment. NIOSH mine fire research is addressing a wide spectrum of problem areas facing the U.S. mining industry. The intent of the research is to provide the mine operator and miners with an understanding of the conditions that could lead to a fire, the capability to detect unusual heating or fire conditions, and the technology to suppress and extinguish a fire to ensure the best outcome possible. Research papers that discuss much of the work presented in this article are available through the NIOSH mining website. A discussion and description of the NIOSH Mining Research Program and copies of all NIOSH published mining research work can be obtained by browsing to http://www.cdc.gov/niosh/mining.

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