FRICTIONAL IGNITIONS IN UNDERGROUND BITUMINOUS COAL OPERATIONS 1983-2005

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ABSTRACT

Frictional ignitions are defined as the ignition of a flammable mixture of methane and air that is initiated by frictional heating. Ignitions created through the addition of energy from open flames and exposed electrical circuits are not included in this analysis. Energy released in a roof fall that creates a spark and ignites a methane mixture would be considered a frictional ignition. Frictional ignitions represent the majority of all ignitions in underground coal mines. Over the study period of 1983 to 2005, a total of 1993 ignitions were reported in underground bituminous coal mines in the United States, of which 1589 were frictional ignitions. Reportable ignitions to the Mine Safety and Health Administration (MSHA) are any unintentional occurrences of flame underground regardless of duration. Frictional ignitions were reported in 155 mines and 13 states. Continuous miners represented the largest source for frictional ignitions with 1090 (68.6% of all frictional ignitions). Longwall mining operations represented the highest concentration of frictional ignitions during this study period with 1365 frictional ignitions (85.9% of all frictional ignitions). The 17 mines with the most frictional ignitions were all longwall mining operations and had 1130 frictional ignitions (307 from the shearer) that represented 71.1% of the total. In 1983, mines with frictional ignitions represented 6.9% of operating underground mines and 36.6% of total underground coal production. The percentage of operating underground mines with frictional ignitions and their total production has increased steadily and in 2005 represented 9.8% of active mines and 46.2% of underground coal production.

The three coalbeds with the highest number of frictional ignitions (Blue Creek, Pittsburgh No 8, and Pocahontas No 3) had 1049 ignitions that represented 66.0% of all frictional ignitions. The three states with the highest number of frictional ignitions were Alabama (710), Virginia (247), and Pennsylvania (242) that represented 75.5% of the total. Frictional ignitions peaked in 1991 with a high of 114. In 2005, only 34 frictional ignitions were reported. If only frictional ignitions that occur at the face are considered, there have been no fatalities since 1983. Since this time, there were 33 ignitions that caused 53 workers to lose a total of 2912 working days. When including ground falls, then there have been four frictional ignitions with one incident causing two fatalities and injuring eight workers.

From 1983-1991, underground productivity and the number of frictional ignitions increased. However, productivity continued to increase from 1991-2000 while total frictional ignitions fell, thereby disproving this connection between productivity and frequency of frictional ignitions. Ninety percent of all frictional ignitions occurred in underground coal mines that liberated more than 393 L/s (1.2 MMcfd million cubic feet per day) of methane through the main ventilation system. Although methane production is not the determining factor for the occurrence of frictional ignitions, it is a good indicator of the anticipated frequency.

INTRODUCTION

A statistical study of available data regarding frictional ignitions in the United States from 1983 to 2005 was conducted by the National Institute for Occupational Safety and Health (NIOSH) to determine and define conditions controlling their occurrence (MSHA, 2006a; MSHA, 2006b; and MSHA, 2006c). A typical frictional ignition is defined as a continuous miner or shearer bit striking a sandstone layer in the coal seam or the surrounding strata, creating a frictional hot spot or spark that ignites a flammable concentration of methane.

Three conditions need to be present to create frictional ignitions: Oxygen, methane or other hydrocarbon (fuel), and a heat source. The concentration of methane at the active face is controlled by many factors including local geology, coalbed characteristics (porosity, permeability, cleat system, and methane content), mining rate, methane drainage, and ventilation controls. The creation of a spark or heating of the cutting bits or the rock face to a significant temperature appears to occur when they strike a hard quartz-rich or sulfur-bearing rock within or surrounding the coal seam.

A statistical analysis and review of all frictional ignitions determined possible controlling factors in frictional ignitions. Various factors were considered and included time of day, month, year, state, basin, coalbed, coal thickness, methane emissions, equipment type, underground location, tonnage and hours worked, productivity, and underground mining method. A detailed description of these factors will be included in a more comprehensive NIOSH Information Circular to be released in 2007 (Krog, 2007). For this paper, only a subset of the various factors listed above will be discussed.

TOTAL IGNITIONS VS. FRICTIONAL IGNITIONS

A total of 1993 ignitions of methane in underground bituminous coal mines were reported to MSHA during 1983-2005, with frictional ignitions being the majority. During the period of the study, 155 mines in 13 states reported a total of 1589 frictional ignitions (79.7% of total) averaging 69 per year. Total ignitions peaked in 1991 with a total of 137, and this corresponded to a peak of 114 frictional ignitions during the same year (Figure 1). The general trend for the occurrence of frictional ignitions has been declining since 1991, with a record low of 34 frictional ignitions in 2005.

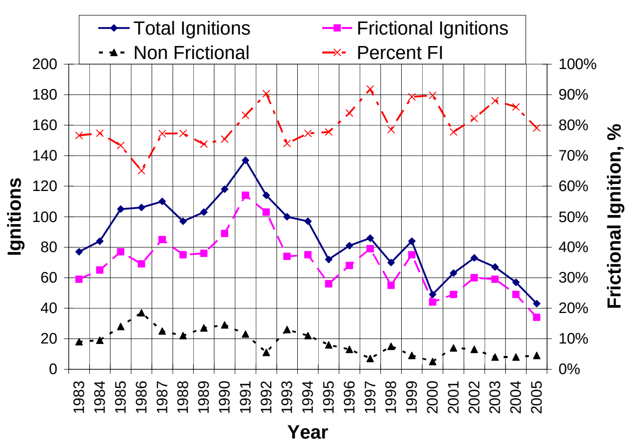

Figure 1 Frictional ignitions as a percentage of total ignitions

COMPARISON BY MINING MACHINE TYPE (CONTINUOUS MINER, SHEARER, ROOF BOLTER, CUTTING MACHINE)

Continuous mining machines represented the largest percentage of frictional ignitions followed by longwall shearers, roof bolters, and cutting machines (Table 1). Continuous miners accounted for 68.6% (1090) of all frictional ignitions, longwall shearers 24.1% (383), roof bolters 3.1% (50), cutting machines 1.2% (19), and unknown equipment causes 1.3% (20). The four ground fall frictional ignitions were given their own classification because their occurrences led to destructive mine fires. The remaining 1.4% (23) of 'other equipment' frictional ignitions represent a wide range of equipment including coal loaders, feeder-breakers, longwall components other than the shearer (e.g. shields), conveyors, hand tools drills, locomotives, and mancars. Machinery directly accounted for 98.5% of all frictional ignitions (1565) with the 20 unknown equipment not counted because no specific equipment was recorded.

Table 1 Breakdown of frictional ignitions by machine types

Year	Continuous Miner	Cutting Machines	Longwall Shearer	Roof Bolter	Unknown Equipment	Other Equipment	Ground Falls	Total
1983	41	5	10	2	1			59
1984	40	2	15	6	1	1		65
1985	64	1	9	2		1		77
1986	45	2	16	2	2	2		69
1987	43	6	30		2	2	2	85
1988	49		19	3	1	3		75
1989	56		18	1		1		76
1990	57	3	26	1	2			89
1991	100		11	2	1			114
1992	75		24	1	2	1		103
1993	67		3	3		1		74
1994	47		25	1	2			75
1995	46		8			2		56
1996	43		20	4		1		68
1997	50		25	2	1	1		79
1998	33		18	1	2		1	55
1999	46		22	3	1	3		75
2000	31		11	1			1	44
2001	36		11	1		1		49
2002	45		10	4		1		60
2003	30		21	4	2	2		59
2004	29		18	2				49
2005	17		13	4				34
Total	1090	19	383	50	20	23	4	1589
Percent	68.6%	1.2%	24.1%	3.1%	1.3%	1.4%	0.3%	100%

COMPARISON BY STATE

During the period of the study, 13 states reported a total of 1589 frictional ignitions (Table 2). Alabama led the nation with 710 frictional ignitions (44.7%), followed by Virginia with 247 frictional ignitions (15.5%), and Pennsylvania with 242 frictional ignitions (15.2%). West Virginia with 132 ignitions (8.3%) and Utah with 113 (7.1%) were fourth and fifth, respectively. The remaining states in decreasing order were Kentucky (62), Ohio (22), Colorado (22), Illinois (19), Indiana (11), New Mexico (5), Oklahoma (2), and Tennessee (2). The reduction in the number of frictional ignitions after 1999 is mainly the result of a few ignition-prone Alabama mines changing cutting sequence or shutting down.

Table 2 Frictional ignitions by state per year

YEAR	AL	CO	IL	IN	KY	NM	OH	OK	PA	TN	UT	VA	WV	Total
1983	23	1			2				11		13	5	4	59
1984	30	4			5				8	2	5	2	9	65
1985	55				3				10		1	5	3	77
1986	25				2		1		13		4	15	9	69
1987	15	2	3		5				8		25	10	17	85
1988	20	2	1		3				13		12	19	5	75
1989	23				3				18		16	13	3	76
1990	33		2	2	16				10		4	16	6	89
1991	62		2	3	1		2		8		3	29	4	114
1992	49				3				8		2	36	5	103
1993	52	2							7		2	9	2	74
1994	43			6	4		1		4		2	14	1	75
1995	29	1					1		5		1	17	2	56
1996	48								8			12		68
1997	38	2	6				1		11		1	17	3	79
1998	38				1		1		5		5	2	3	55
1999	44	2	1		1		6		13		3	4	1	75
2000	10	1					5		15		8	1	4	44
2001	15				2		2	2	13			5	10	49
2002	23				2	2			13			3	17	60
2003	16	2			5	2	2		12		4	7	9	59
2004	7	2	4			1			22		1	3	9	49
2005	12	1			4				7		1	3	6	34
Total	710	22	19	11	62	5	22	2	242	2	113	247	132	1589
Percent	44.7%	1.4%	1.2%	0.7%	3.9%	0.3%	1.4%	0.1%	15.2%	0.1%	7.1%	15.5%	8.3%	100%

COMPARISON BY BASIN

The United States was divided into sections using the following primary basins: Northern Appalachian, Central Appalachian, Warrior, Illinois, Western Interior, and Rocky Mountains (Figure 2). The Rocky Mountain Basin is a collection of smaller basins including Uinta, San Juan, Wasatch Plateau, Emery, Book Cliffs, plus a few more. The Warrior basin had the most frictional ignitions with 710 (44.7%), followed by the Northern Appalachian basin with 346 (21.8%), and the Central Appalachian basin with 321 (20.2%), as shown in Table 3. The Rocky Mountain Basin had 140 (8.8%), followed by the Illinois Basin with 70 (4.4%), and the Western Interior basin with 2 (0.1%).

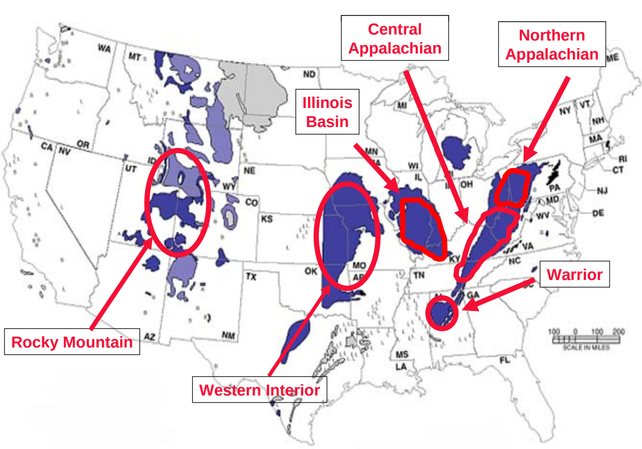

Figure 2 Coal basins in the United States

The basin approach was selected because it gives a better view of the frictional ignitions than a comparison on a state-wide basis since two states are located in two different basins. Eastern Kentucky is in the Central Appalachian basin and Western Kentucky is in the Illinois basin while West Virginia is in both the Northern and Central Appalachian basins.

Table 3 Frictional ignitions by coal basin per year

Year	Central Appalachian Basin	Illinois Basin	Northern Appalachian Basin	Rocky Mountain Basin	Warrior Basin	Western Interior Basin	Total
1983	7	1	14	14	23		59
1984	10	2	14	9	30		65
1985	8	2	11	1	55		77
1986	22	2	16	4	25		69
1987	17	7	19	27	15		85
1988	25	3	13	14	20		75
1989	19		18	16	23		76
1990	22	18	12	4	33		89
1991	32	5	12	3	62		114
1992	41	3	8	2	49		103
1993	10		8	4	52		74
1994	18	6	6	2	43		75
1995	18		7	2	29		56
1996	12		8		48		68
1997	19	6	13	3	38		79
1998	5		7	5	38		55
1999	4	2	20	5	44		75
2000	4		21	9	10		44
2001	6	2	24		15	2	49
2002	4	2	29	2	23		60
2003	9	3	23	8	16		59
2004	3	4	31	4	7		49
2005	6	2	12	2	12		34
Total	321	70	346	140	710	2	1589
Percent	20.2%	4.4%	21.8%	8.8%	44.7%	0.1%	100%

COMPARISONS BY COALBED

A total of 155 mines in 53 coalbeds had a total of 1589 frictional ignitions. The six coalbeds with the highest number of frictional ignitions accounted for 1261 (79.4%) of the total in the United States (Figure 3). These included the Blue Creek coal seam (Warrior Basin) with 623 ignitions from 5 mines, the Pittsburgh coal seam (Northern Appalachian Basin) with 262 ignitions from 22 mines, the Pocahontas No. 3 coal seam (Central Appalachian Basin) with 164 ignitions from 11 mines, the Mary Lee coal seam (Warrior Basin) with 83 ignitions from 3 mines, the Jawbone coal seam (Central Appalachian Basin) with 67 ignitions from 4 mines, and the Springfield coal seam (Illinois Basin) with 62 ignitions from 13 mines.

The cumulative total clearly shows that the six coalbeds with the highest number of frictional ignitions account for almost 80% of the total (Figure 4). The Blue Creek coal seam dominated frictional ignition numbers; as more ignitions occurred in this seam than all other coalbeds combined, with the exception of the top three. In other words, the fourth to 53rd coalbeds have a total of 540 frictional ignitions while the Blue Creek coalbed has 623 ignitions.

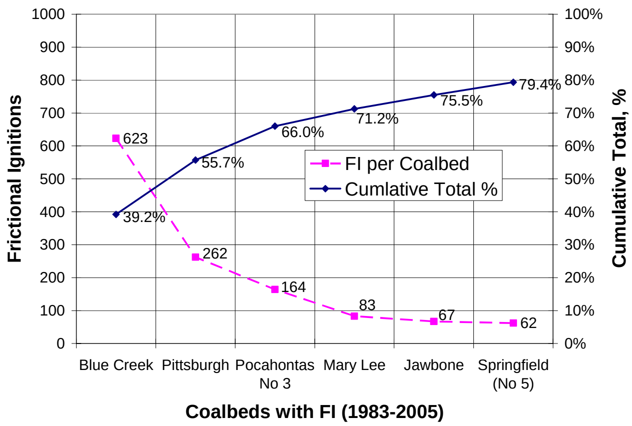

Figure 3 The six coalbeds with the highest number of frictional ignitions

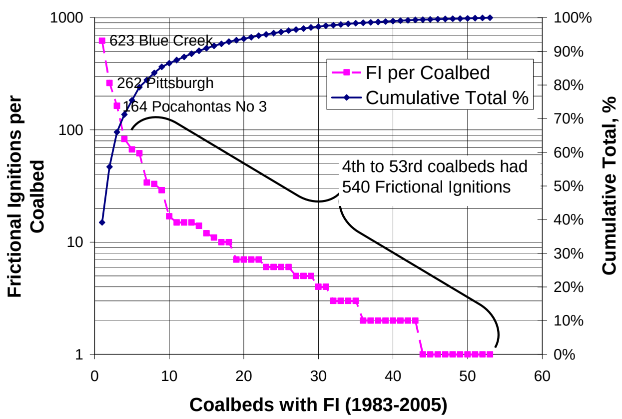

Figure 4 Cumulative frictional ignitions by coalbeds in decreasing order

COMPARISONS BY COALBED PRODUCTION

The number of frictional ignitions in a coalbed is a function of the total coal production from the coalbed. For the time period of this study, 262 and 164 frictional ignitions occurred in the Pittsburgh and in the Pocahontas No. 3 seams, respectively. To infer that the Pittsburgh seam is more prone to frictional ignitions would be incorrect. A total of 1,350 million metric tons of coal was extracted from Pittsburgh seam mines and 260 million tons of coal from Pocahontas No. 3 mines. The ratio of ignitions to tonnage suggests that the Pocahontas No 3 is three times more likely to have a frictional ignition than the Pittsburgh seam on a per-ton-of-coal basis. Table 4 shows all coalbeds that experienced a frictional ignition along with their coal production and frictional ignition rate. The Spring Canyon A and Castle Gate D seams have abnormally high frictional ignition rates due to the presence of unsaturated carbon compounds in the surrounding strata.

Table 4 Coalbeds with frictional ignition and production data

Coalbed Name	Basin	Frictional Ignitions	Tons Coal	Frictional Ignitions per Million Tons
Spring Canyon A (Sub. No 3)	RMB	33	889,844	37.09
Castle Gate D	RMB	29	4,361,491	6.65
Blue Creek	WRB	623	185,416,792	3.36
Mary Lee	WRB	83	79,885,318	1.04
Davis	ILB	5	5,202,603	0.96
Jawbone	CAB	67	70,093,801	0.96
Coal Basin B	RMB	6	8,688,575	0.69
Lower Hartshorne	WIN	2	2,909,555	0.69
Pocahontas No 3	CAB	164	260,460,520	0.63
Gholson	RMB	2	3,461,460	0.58
Stearns No 1-1/2	CAB	1	2,005,679	0.50
Elswick	CAB	1	2,074,224	0.48
Upper O'Connor (Castle Gate B)	RMB	15	35,421,423	0.42
Lower Freeport	NAB	34	84,319,214	0.40
Lower Iaeger (Tiller)	CAB	4	11,601,016	0.34
Beckley (Pocahontas No 12)	CAB	14	40,623,537	0.34
Pocahontas No 4	CAB	10	29,831,611	0.34
Apache	RMB	2	6,404,879	0.31
Lower Sunnyside	RMB	6	21,052,968	0.28
Rock Canyon	RMB	7	25,731,494	0.27
Sewell "B" (Greasy Creek)	CAB	2	7,385,694	0.27
Wattis	RMB	7	26,542,319	0.26
Raven (Jewell)	CAB	6	23,868,463	0.25
Cedar (Dorchester)	CAB	11	44,803,077	0.25
Fruitland No 8	RMB	5	21,977,790	0.23
Upper Kittanning	NAB	12	52,801,491	0.23
Pittsburgh	NAB	262	1,350,221,677	0.19
Pocahontas No 5	CAB	1	5,163,664	0.19
Clarion	NAB	17	88,887,943	0.19
Brookville	NAB	1	5,443,716	0.18
Fire Creek (Pocahontas No 11)	CAB	4	32,370,140	0.12
Cameo	RMB	1	8,207,194	0.12
Somerset (B)	RMB	10	91,117,871	0.11
Springfield (No 5)	ILB	62	621,606,355	0.10
Hiawatha	RMB	7	88,593,866	0.08
Blind Canyon	RMB	6	80,187,479	0.07
Upper Freeport (Davis)	NAB	15	233,750,259	0.06
Hazard No 7	CAB	1	16,690,115	0.06
Splash Dam	CAB	3	54,428,415	0.06
Cedar Grove (U. Elkhorn No 3)	CAB	15	287,670,223	0.05
Lower O'Connor (Castle Gate A)	RMB	3	59,108,466	0.05
Pratt	RMB	2	45,299,428	0.04
Redstone	CAB	1	26,456,358	0.04
Elkhorn Leader	CAB	1	26,468,360	0.04
D Seam (CO)	RMB	3	80,872,314	0.04
Lower Kittanning	NAB	5	186,282,689	0.03
No 2 Gas (Imboden, L. Elkhorn)	CAB	7	371,493,244	0.02
Low Splint (Williamson)	CAB	2	127,966,667	0.02
Sewell	CAB	1	65,753,750	0.02
Eagle	CAB	2	165,854,492	0.01
Alma	CAB	2	175,706,990	0.01
Herrin (No 6)	ILB	3	565,824,120	0.005
Hazard No 4 (Fire Clay)	CAB	1	312,230,047	0.003

CAB = Central Appalachian Basin
ILB = Illinois Basin
NAB = Northern Appalachian Basin
RMB = Rocky Mountain Basin
WIN = Western Interior Basin
WRB = Warrior Basin

COMPARISONS BY MINING METHOD

Figure 5 shows that those operations using the longwall method had a greater occurrence of frictional ignitions (1365 ignitions) than those operations using only the room-and-pillar method (224). Although shearers produced 383 ignitions on longwall mining operations, continuous miners produced 906 ignitions, most of these during longwall gateroad development.

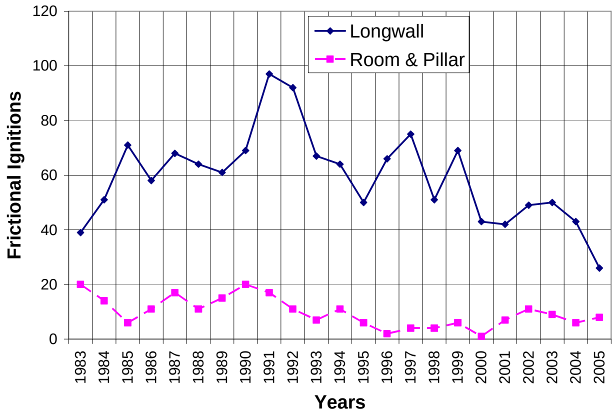

Figure 5 Longwall and room-and-pillar frictional ignitions per year

When individual coalbeds were investigated, there was evidence that longwall mining produced more frictional ignitions on a per-ton basis than room-and-pillar mining (Table 5). There were thirteen coalbeds with frictional ignitions in both longwall and room-and-pillar mining with 10 million tons of production by both methods. Nine of the coalbeds had higher frictional ignition rates for longwall mining operations than room-and-pillar. The Jawbone frictional ignition rate for longwall mining arose from a single operation, so this high rate was viewed with caution. Also, the Pocahontas No. 3 coalbed had many room-and-pillar operations that produced over 41 million tons of coal with only one frictional ignition. Three Western coalbeds had higher frictional ignition rates from room-and-pillar operations than longwall mining operations, although these coalbeds had only a limited number of ignitions from a few mines, so the results were not conclusive. The majority of frictional ignitions from the western Somerset (B) and D Seam (CO) occurred during roof bolting. This uncommon concentration of roof bolting frictional ignitions suggested that the overlying stratum was the controlling factor and that mining the coal itself generated few frictional ignitions. If roof bolting into the overlying strata controlled the frictional ignition rate, then longwall mining would have had a lower rate because fewer roof bolts were required to extract the same amount of coal.

COMPARISONS BY PRODUCTION

Total underground coal production in the United States ranged from a low of 265 million tons (1983) to a high of 380 million tons (1990) and was 334 million tons in 2005 (Figure 6). The number of active underground coal mines has dramatically decreased from 1950 operating in 1984 to only 557 in 2003. This steady downward trend was due to the consolidation and competition within the coal industry. The low total production in 1993 relative to other years was due to a coal workers' strike.

Table 5 Frictional ignition rates for thirteen coalbeds with frictional ignitions by both longwall and room-and-pillar operations

Coalbed	Room-and-Pillar Frictional Ignitions	Longwall Frictional Ignitions	Room-and-Pillar Million tons Coal	Longwall Million tons Coal	Room-and-Pillar Frictional Ignitions per Million tons Coal	Longwall Frictional Ignitions per Million tons Coal	Longwall to Room-and-Pillar Ratio of Frictional Ignitions per Million tons Coal
Jawbone	9	58	58	12	0.15	4.95	32.14
Pocahontas No 3	1	163	41	220	0.02	0.74	30.07
No. 2 Gas (Imboden)	2	5	297	74	0.01	0.07	10.00
Pittsburgh	2	260	64	1286	0.03	0.20	6.47
Upper Freeport	3	12	142	92	0.02	0.13	6.18
Lower Kittanning	2	3	136	50	0.01	0.06	4.11
Mary Lee	10	73	25	54	0.40	1.35	3.40
Clarion	1	16	11	78	0.09	0.20	2.16
Springfield (No 5)	41	21	445	176	0.09	0.12	1.29
Cedar Grove (U. Elk.)	14	1	269	19	0.05	0.05	1.03
Somerset (B)	2	8	11	80	0.19	0.10	0.54
D Seam CO	1	2	10	71	0.10	0.03	0.28
Rock Canyon	6	1	10	15	0.58	0.07	0.11

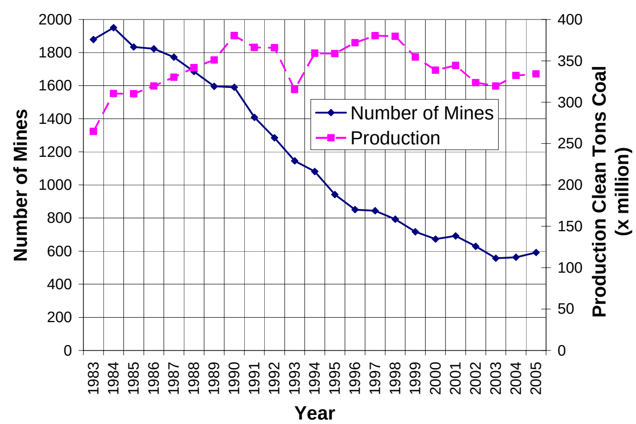

Figure 6 Number of mines and total production

COMPARISONS BY PRODUCTIVITY

As productivity increased from 1983-1991, so did frictional ignitions, which suggested a link between increasing productivity and the increasing number of frictional ignitions (Schatzel, 1995). However, productivity continued to increase from 1991-2000, whereas total frictional ignitions fell during this time. The initial hypothesis that frictional ignition increases between 1983 (59) and 1991 (116) were the result of increasing productivity was not supported by Figure 7 for the data after 1991. Productivity, expressed as clean tons per worker-hour, increased consistently from 1.74 tons/worker-hr in 1983 to 4.85 tons/worker-hr in 2000. Productivity from 2001 to 2005 declined from 4.65 tons/worker-hr to 4.15 tons/worker-hr. Productivity in 2005 (4.15 tons/worker-hr) closely matched the productivity in 1996 (4.13 tons/worker-hr). Increases in productivity were not indicators of increased frictional ignitions.

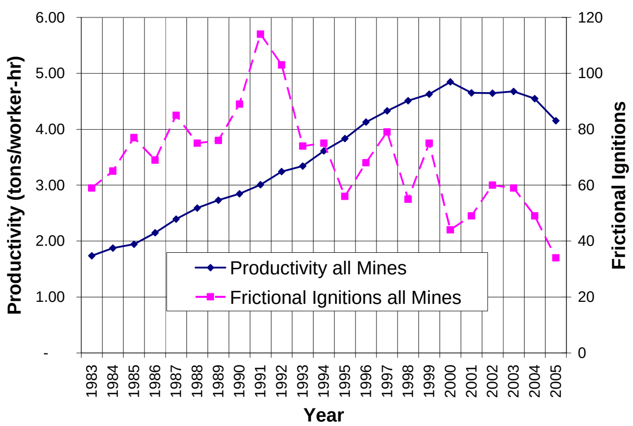

Figure 7 Productivity and Frictional ignitions

FRICTIONAL IGNITION RATES

Frictional ignition rates increased when compared to hours worked, but frictional ignitions per million tons produced decreased (Figure 8). This means that while total frictional ignitions per ton of coal decreased over the timeframe of the study, the productivity per working hour increased at a greater rate, so frictional ignitions on a per-hour-worked basis increased. The 2005 frictional ignition rates for both hours worked and tons produced were below the normal averages because of the low frictional ignition total of 34 in 2005. The 2005 frictional ignition rate per 2 million hours worked (0.85) was less than half of 2003 (1.73).

COMPARISONS BY MINING MACHINE AND MINE TYPE

Mine machinery and its utilization underground differ between longwall and room-and-pillar operations. Although continuous mining machines account for the majority of all frictional ignitions in longwall and room-and-pillar operations (Figure 9), their methane environments differ. Coal production from continuous miners in room-and-pillar sections generally exceeds that for continuous miners in longwall gateroad sections. A continuous miner working a 7-entry section in a room-and-pillar mine generates more coal on a per-shift basis than a continuous miner developing a 3-entry longwall gateroad. A continuous miner developing gateroads at a longwall mining operation is typically operating up to two miles in virgin coal seams and developing quickly and deeply into the coalbed methane reservoir. Methane bleeds into gateroads from the virgin coal on both ribs and face while a 7-entry room-and-pillar section will have a barrier pillar as one of the ribs that most likely has already been degassed of methane. The lateral development rate of a 5-7 entry room-and-pillar section or main/submain section will be less than the rate of a 3-4 entry gateroad section and will have more time to degas. Methane generation of up to 328 L/s (1 MMcfd) in headgate development is not uncommon. Continuous miners account for 82% of all frictional ignitions in room-and-pillar operation and 66% in longwall mining operations (Figure 9).

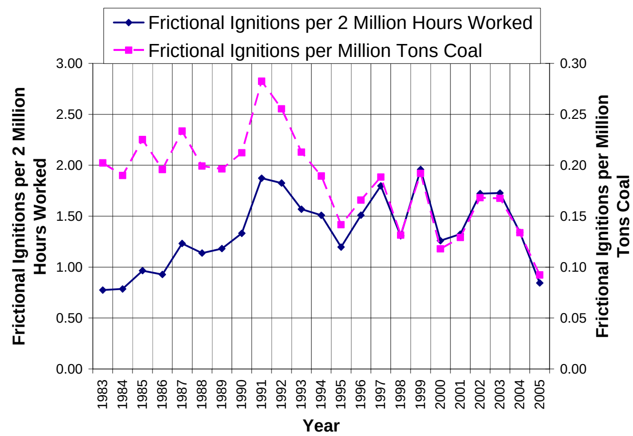

Figure 8 Frictional ignition rate per 2 million hours worked and per million tons coal

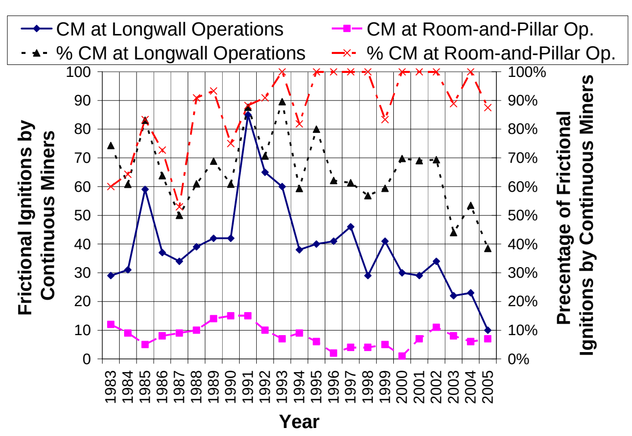

Figure 9 Continuous miner frictional ignitions totals and percentage of total by mining method

COMPARISONS BY TOTAL MINE EMISSIONS

MSHA collects quarterly gas emissions from each mine's main ventilation system. This methane emission data was collected sporadically by the former US Bureau of Mines (USBM) for the following years: 1985, 1988, and 1990. The Environmental Protection Agency (EPA) started collecting this information from 1993 onwards and maintains an up-to-date spreadsheet for each year (Bergamo, 2006). This yields a total of 953 frictional ignitions, where corresponding methane emission data is available. Only the main ventilation systems are measured (main exhaust, bleeder fans). Methane drainage quantities from pre-drainage, gob vent boreholes (GVB), cross member holes, and in-seam holes are not included in the total methane emissions of the mine, although the existence of such drainage systems is noted by the EPA.

For each frictional ignition, arranging the average total methane emissions in ascending order yields a fairly linear trend (Figure 10). This graph shows that half of all frictional ignitions occur with methane emission of 3048 L/s (9.3 MMcfd) or greater. It should be noted that 90% of all frictional ignitions occurred at mines with methane emissions of at least 393 L/s (1.2 MMcfd), while only 31.6% of underground coal mines, that reported methane emission, were that high (Krog, 2007).

While there is a correlation between the number of frictional ignitions and the emission rate, no correlation is apparent when normalizing methane emissions by production for mines operating in the same coalbed. There is a correlation among operations in the same coalbed where mines having higher emission rates have higher yearly frictional ignition rates. However, this arises because larger mines in the same coalbed have more production and a greater likelihood of frictional ignitions. Once the mine emissions were normalized for production, there was no correlation. Previous US Bureau of Mines work on mine methane emissions determined that daily methane emissions were usually 6 to 9 times higher than the methane contained in the removed coal [Kissell, 1973]. Mine methane emissions might not be an accurate representation of methane levels at the face because the effect of methane pre-drainage of a coal seam can be over-shadowed by other strata emissions. Mines that practice aggressive pre-drainage to reduce the methane emission at the development faces may not record a significant reduction in their methane emission level.

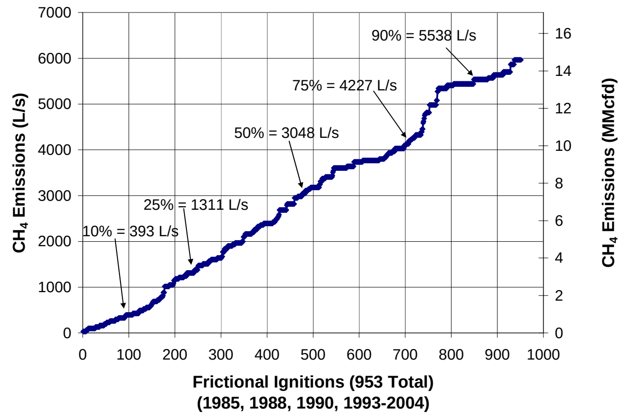

Figure 10 Annual methane emissions from coal mines for each frictional ignition in ascending order (data not available for all years)

CONCLUSIONS

Frictional ignitions in underground coal mines are a concern to the safety of workers because of the potential for fires and explosions that may result in injuries and fatalities. While most frictional ignitions are small and short-lived, the possibility exists that a frictional ignition could be the precursor to a more violent fire or secondary explosion. The coalbed mined and the overlying and underlying strata are the major controlling factors for the occurrence of frictional ignitions in the United States. The Blue Creek coalbed located in Alabama had the highest reported frictional ignitions total as well as the highest frictional ignition rate per million tons of coal mined, except for two minor coalbeds.

There were 1589 frictional ignitions between 1983 and 2005. Reported frictional ignitions have decreased from a high of 114 in 1991 to a record low of 34 in 2005, which was primarily the result of a few ignition-prone Alabama mines changing cutting sequence or ceasing production. While the general trend for the occurrences of frictional ignitions has been declining since 1991, the record low of 34 frictional ignitions in 2005 was most likely a statistical anomaly. Continuous miners represent 68.6% of all frictional ignitions (1090) and longwall mining operations represent 85.9% of all frictional ignitions (1365), while machinery directly accounts for at least 98.5% of all frictional ignitions (1565).

Productivity is not a controlling factor in frictional ignition rates. The number of frictional ignitions did increase from 1983 to 1991 along with productivity. Frictional ignition rates have decreased since 1991, while productivity has continued to rise until 2000.

When individual coalbeds are investigated, there is evidence that longwall mining operations produce more frictional ignitions than room-and-pillar mining on a per-ton basis. Operations using the longwall method had a greater occurrence of frictional ignitions than the room-and-pillar method. Although 383 ignitions were reported on shearers at longwall operations, 906 ignitions were reported on continuous mining machines, mostly during gateroad development. Continuous miners developing gateroads for longwalls are deeply piercing into virgin methane reservoirs at a higher advance rate than continuous miners at room-and-pillar operations. Consequently, methane emission rates can be higher during gateroad development.

While total frictional ignitions on a per-ton-coal basis have decreased over the timeframe of the study, the rise in productivity per working hour has increased at a greater rate so that frictional ignitions on a per-hour-worked basis have increased. There is a correlation between methane emissions and the number of frictional ignitions. However, methane emissions normalized by production for mines operating in the same coalbed showed no correlation with the number of frictional ignitions. Therefore, the coalbed mined, and not the mine's methane emissions, is the determining factor for the occurrence of frictional ignitions.

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