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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

°F	degree Fahrenheit
ft	foot
in	inch
in^3	cubic inch
min	minute
psig	pound per square inch gauge
psig/min	pound per square inch gauge per minute

EFFECT OF PRESSURE ON LEAKAGE OF AUTOMATIC SPRINKLERS

By Mark W. Ryan,[1] Alex C. Smith,[2] Richard W. Pro,[3] and Charles P. Lazzara[4]

ABSTRACT

The U.S. Bureau of Mines conducted a study to determine if commercially available automatic sprinklers could withstand the high static pressures in deep underground coal mines without leaking and if exposure to the mine environment affected their leak pressures. New sprinklers and sprinklers exposed to the mine environment were subjected to increasing pressures until leakage occurred. The average leak pressures of the new sprinklers ranged from 640 to 2,300 psig and were significantly different for sprinklers from different manufacturers and for different types of sprinklers.

Generally, standard-response sprinklers withstood higher pressures than fast-response sprinklers. The results indicated that most commercially available sprinklers would withstand the high static pressures in deep underground coal mines; however, they would not provide the same reliability and safety factor as sprinklers used aboveground at or below their rated pressure of 175 psig.

The average leak pressures of the sprinklers exposed to the mine environment ranged from 740 to 1,180 psig. The mine environment affected the ability of 66% of the sprinklers to withstand high static pressures.

New sprinklers were also evaluated at pressures of at least 500 psig for 30 days to determine their ability to withstand long-term exposure to high static pressures; no leakage was observed.

[1]Fire prevention engineer.
[2]Research chemist.
[3]Physical science technician.
[4]Supervisory research chemist.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

INTRODUCTION

Automatic sprinkler systems are the primary method of protecting lives and property from fire in aboveground facilities. The demonstrated effectiveness of automatic sprinkler systems along with their reliability and low maintenance has lead to their increased used in underground mines.

Federal regulations for underground coal mines require that automatic sprinkler systems (wet pipe or dry pipe), deluge-type water spray systems, foam generators, or dry powder chemical systems be installed at all main and secondary conveyor belt drive areas in underground coal mines. Sprinkler systems are required to provide protection for motor drive belt takeups, electrical controls, gear reducing units, and the 50 ft of fire-resistant, or 150 ft of non-fire-resistant, belt adjacent to the belt drive, and sprinklers must be spaced at 8-ft intervals. Each individual sprinkler shall be activated at a temperature of not less than 150° F and not more than 300° F (see reference 1, Part 75, Paragraph 1107-7).

The Federal regulations for underground coal mining state that components of automatic sprinkler systems shall be of a type approved by Underwriters' Laboratories, Inc. (UL), Factory Mutual Research Corporation (*1*).[5] Sprinklers must meet or exceed the performance criteria established in UL Standard 199 to be listed by UL (*2*). In regard to static pressure, UL Standard 199 states that an automatic sprinkler shall not exhibit any visual leakage at 500 psig or less. In this test, the pressure is increased to 500 psig at a rate not to exceed 300 psig/min and held for 1 min. The sprinkler must also be able to withstand, without rupture, an increasing hydrostatic pressure up to 700 psig at a rate not to exceed 300 psig/min and held for 1 min. In addition, to test the long-term ability to withstand high static pressures, UL Standard 199 states that automatic sprinklers shall not exhibit any leakage when subjected to a hydrostatic pressure of 300 psig for 30 days. To test the ability of automatic sprinklers to withstand large, sudden increases in pressure, the standard states that sprinklers shall withstand without leakage, 3,000 applications of a pressure surge increasing rapidly from 50 to 500 psig. Sprinklers that comply with the requirements of UL Standard 199 are rated at 175 psig. Manufacturers designed the sprinklers and the requirements of UL Standard 199 were developed for these conditions. However, the highest pressure that the sprinkler can withstand is not determined. Currently, we do not know if even a listed sprinkler can withstand the high static pressure common in deep underground mines or if different types of sprinklers from different manufacturers can withstand higher pressures than other types of sprinklers and from other manufacturers. Most commercially available sprinklers are designed so that the mechanical pressure normally exerted on the top of the cap or valve over the orifice is many times that developed by the water pressure below, so that the possibility of leakage in aboveground applications is practically eliminated (*3*). Again, this is assuming that the sprinklers will be installed and used under conditions for which they were designed.

However, in a deep underground mine, water supplied from aboveground sources such as ponds, tanks, or reservoirs can result in pressures as high as 1,000 psig because of the water head. The water head is developed at a rate of 0.43 psig per foot of change in elevation. For example, a mine 2,000 ft deep will develop a water head of 860 psig in its water lines. Pressure-regulating valves are sometimes used to control high static and residual or flowing water pressures in water systems in underground coal mines; however, it is very important that the pressure settings for these devices be correctly determined using the manufacturers' instructions. Pressure settings on these devices are either set by the manufacturer or are field adjustable. In either case, the valve inlet pressure, required outlet pressure, and required flow are necessary to correctly set a pressure-reducing valve. Incorrect pressure settings can cause inadequate water pressure and flow for fire-fighting purposes. There are examples where incorrect settings of pressure-reducing valves severely hampered fire-fighting efforts in aboveground installations, such as during the fire at One Meridian Plaza, in Philadelphia, PA, in 1990. This office high-rise fire killed three firefighters and caused millions of dollars in damage (*4*). Therefore, it is very important that pressure-reducing valves be installed, maintained, and periodically tested according to manufacturers' instructions.

In some cases, the water supply to an automatic sprinkler system along a conveyor belt drive is also used to supply water to the mining face for dust suppression and cleanup. To obtain the needed pressures at the mining face, a satellite pump may be used, which can generate several hundred pounds of pressure at the sprinklers. Using commercially available automatic sprinklers that are listed with a working pressure rating of 175 psig in underground mines under high static pressure may result in sprinkler leakage or rupture. If the sprinkler ruptures because of a large water hammer while someone is in the area, there is a possibility of injury due to flying pieces of metal. If the sprinkler ruptures while no one is in the area, or if it leaks excessively, the waterflow alarm would activate, resulting in a false alarm. This decreases the

[5]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this report.

reliability of the sprinkler system, increases maintenance of the system, and discourages the use of automatic sprinkler systems in areas other than those currently required by Federal regulations, such as haulageways and along longwall faces.

In this report, the U.S. Bureau of Mines examined the ability of commercially available sprinklers to withstand the high static water pressures typical in deep underground coal mines. This work is part of a larger program to evaluate the effects of the underground mining environment on the performance of automatic sprinkler systems. The larger program also includes examining the effect of the mine environment, ventilation, response time index (RTI), temperature rating, and fire size on the activation time of sprinkler systems. The results obtained from this program will help the Bureau to improve fire safety in the mining industry, thus enhancing the safety of the Nation's miners.

SPRINKLERS

The leak pressures of 12 different types of new, commercially available automatic sprinklers from four different manufacturers (designated as manufacturers A, B, C, and D) were evaluated. Also, six types of automatic sprinklers that had been exposed to the underground coal mine environment were evaluated. These exposed sprinklers were obtained from nine different mines and had been installed in the mines for different lengths of time, ranging from 1 to 5 years. Table 1 shows the sprinklers that were tested.

Table 1.—Automatic sprinklers tested[1]

Manufacturer	Activation temp, °F	Response type	Comments	No. tested
A	135	S	EH, LT	10
	165	F	LT	5
	212	S	EH	10
B	165	S	LT	5
	165	F	LT	5
	212	S	EH	10
	212	S	WC, EH	10
C	135	S	GB, LT	4
	135	F	GB	5
	165	S	LT	5
D	165	S	EH	10
	212	S	EH	10

EH Exposed sprinklers tested also.
F Fast response.
GB Glass bulb.
LT Long-term tested.
S Standard response.
WC Wax coated.
[1]Unless noted, all sprinklers were fusible type.

Six types of new sprinklers that were evaluated were chosen to correspond to the six types of exposed sprinklers that were received from the operating mines. The other six types were chosen to give a broad range of sprinklers available, as far as response type, activation temperature, activation mechanism (glass bulb or fusible link) and manufacturers. All of the sprinklers had 0.5-in orifices and 0.5-in National Pipe Threads (NPT). All of the sprinklers, except as noted in table 1, were of the fusible type. Fusible-type sprinklers usually use an arrangement of links and levers that are soldered together and held over the sprinkler orifice cap by the frame arm. As the increased temperature of a fire causes the solder to melt, the links and levers separate and release the cap over the sprinkler orifice, allowing water to discharge and strike the deflector. The glass-bulb sprinklers use a frangible bulb that is partially filled with a liquid, leaving a small air bubble. Heat causes the bubble to be compressed into the liquid and the pressure to rise until the bulb shatters. This releases the cap over the sprinkler orifice, allowing water to discharge and strike the deflector. Examples of fusible- and glass-bulb-type sprinklers are shown in figure 1.

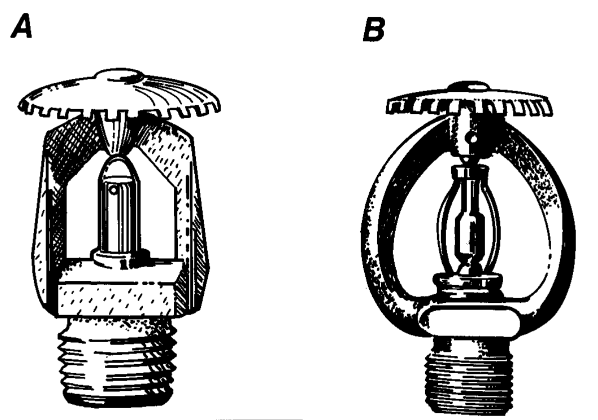

Figure 1.—Examples of glass-bulb (*A*) and fusible-type (*B*) sprinklers.

EXPERIMENTAL APPARATUS

LEAK PRESSURE EXPERIMENTS

The leak pressure experiments were conducted using a hand-operated, high-pressure hydraulic pump with high-pressure hydraulic hose connected to a pressure gauge and sprinkler. The hydraulic pump was capable of generating pressure up to 10,000 psig and had a hydraulic oil reservoir of 462 in^3. The hoses were equipped with high-pressure, quick-connect, spring-loaded fittings. Hydraulic hose ran from the hydraulic pump to the sprinkler and pressure gauge, which was mounted behind a Plexiglas acrylic sheet shield. The hydraulic hose from the pump was connected to a tee fitting. The tee fed a bourdon-tube-type pressure gauge on one end while a section of hydraulic hose with an adaptor and 0.5-in pipe nipple on the other end was used to connect the sprinkler to the hydraulic system. The pressure gauge measured pressures from 0 to 2,300 psig in graduations of 20 psig. A photograph of the leak pressure experimental apparatus is shown in figure 2.

LONG-TERM PRESSURE EXPERIMENTS

The long-term pressure experiments were conducted using an adjustable drop nipple, a bourdon-tube-type pressure gauge, and the sprinkler. The adjustable drop nipple consists of two sections of pipe; one section, smaller in diameter, is threaded into a larger diameter section. An O-ring seals the threaded connection. The open ends of the two sections of pipe have female pipe threads. The end of the smaller diameter pipe is 0.5-in, female NPT so that the sprinkler can be inserted. An adaptor and the pressure gauge were placed on the other end. Three sprinklers were tested simultaneously using three adjustable drop nipples and three pressure gauges. One pressure gauge read from 0 to 2,300 psig with 20-psig graduations, and the other two read from 0 to 1,500 psig with 10-psig graduations. A photograph of the apparatus used in the long-term pressure experiments is shown in figure 3.

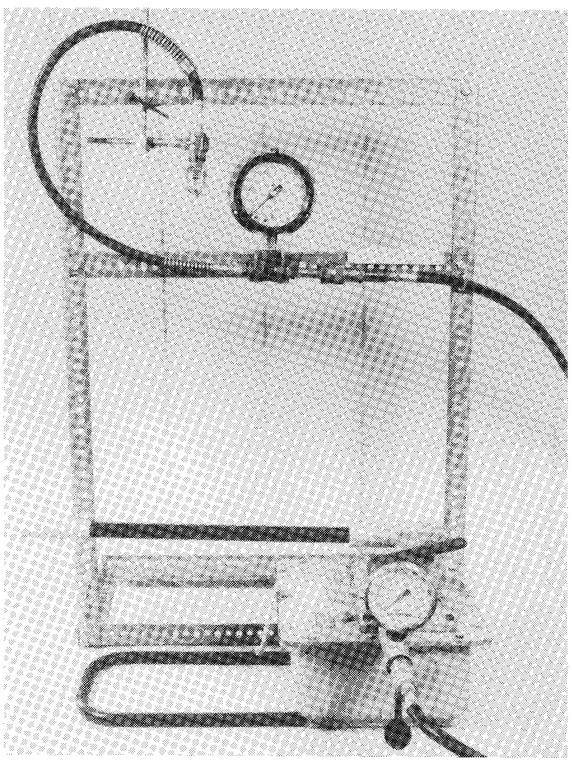

Figure 2.—Experimental apparatus used in leak pressure experiments.

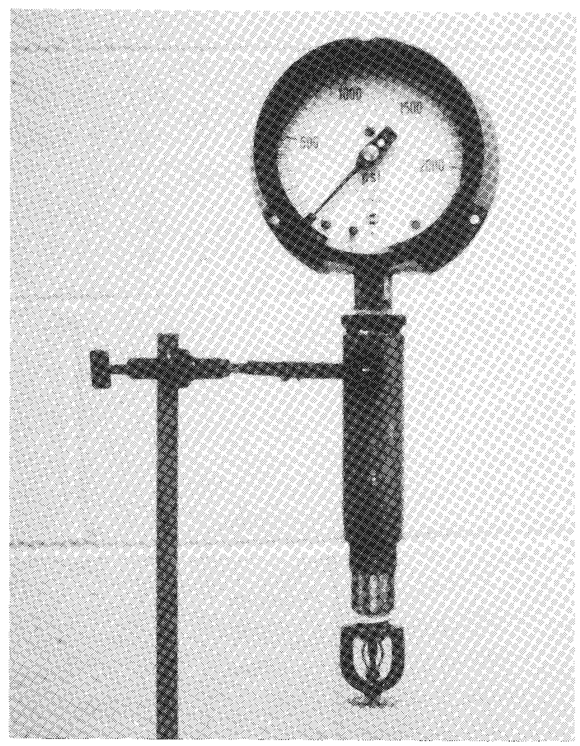

Figure 3.—Experimental apparatus used in long-term pressure experiments.

EXPERIMENTAL PROCEDURES

LEAK PRESSURE EXPERIMENTS

To conduct the leak pressure experiments, the release valve on the hydraulic pump was opened to release any pressure on the system. The quick-connect fitting on the pump side of the tee fitting was disconnected. The disconnected section was filled with water through the fitting for the sprinkler and then the sprinkler was installed. This section was reconnected to the system and the release valve on the hydraulic pump was closed. The pressure was quickly raised in the system to 100 psig and held for 1 min. Thereafter the pressure on the system was quickly raised another 100 psig and held for 1 min and the system was monitored to determine if any leakage occurred. This procedure was repeated until the sprinkler leaked. Leakage was defined as more than one drop of water per minute. At the end of the test, the pressure was released, the end section of the system was disconnected, and the sprinkler was removed. Any water or hydraulic oil in this section was drained. The end section was refilled with water and another sprinkler was installed.

LONG-TERM PRESSURE EXPERIMENTS

To conduct the long-term pressure tests, the pressure gauge was installed in the end of the drop nipple with the larger pipe diameter. The system was filled with water and a sprinkler was installed. The pressure was raised by screwing the smaller pipe into the larger pipe, thereby decreasing the volume and increasing the pressure. The pressure was raised to the desired point and the apparatus was mounted on a stand. The apparatus was inspected daily to check for leakage or change in pressure due to temperature changes. Slight adjustments, if needed, were made to the system to maintain the desired pressure for 30 days or until the sprinkler leaked.

RESULTS AND DISCUSSION

LEAK PRESSURE EXPERIMENTS WITH NEW SPRINKLERS

Experiments were conducted, using the procedure previously described, on each set of new sprinklers to determine their leak pressure. The leak pressure is defined as the maximum pressure the sprinkler could withstand for 1 min without leakage. For example, if the pressure was raised to 700 psig and held for 1 min and the sprinkler did not leak, but did leak while increasing the pressure to 800 psig, or the sprinkler could not withstand 800 psig for 1 min without leakage, then the leak pressure was reported as 700 psig. The data were statistically analyzed to determine the mean, standard deviation, range, and median leak pressure for each type of sprinkler. The results are shown in table 2. The data were also analyzed using Nalimov's Test, for each manufacturer, response type, fusible element type, and activation temperature, to determine if any of the values showing large deviations from the mean value could be classified as outliers. An outlier is defined as a data point that does not fit the data population, because of equipment malfunction, improper readings, human error, or some other unknown reason, and may be removed (*5*). Of the 89 new sprinklers that were evaluated, 5 were classified as outliers and were removed. The data for each type of sprinkler are given in the appendix. The data show considerable variability, especially when comparing similar types of sprinklers from different manufacturers and standard- and fast-response sprinklers from the same manufacturers.

The leak pressures of the different types of new sprinklers were compared with each other using the comparison of means method. The Student's t-test was applied to the hypothesis that the mean of the leak pressures of the two sprinklers being compared were statistically equivalent (*6*). If the hypothesis is accepted for a given confidence level, 100 - p, there is a (100 - p)% probability that the hypothesis is true, or that the average leak pressures were equivalent. If the hypothesis is rejected, there is a (100 - p)% probability that the average leak pressures are not equivalent. The following comparisons used the Student's t-test at a 95% confidence interval.

Table 2.—Results of leak pressure experiments with new sprinklers

Sprinkler				No. tested	Mean, psig	Standard deviation, psig	Range, psig	Median, psig
Manufacturer	Activation temp, °F	Response type	Comments					
A	135	S	NAp	[1]8	1,825	140	1,600-2,000	1,800
A	165	F	NAp	5	>2,300	NAp	>2,300	>2,300
A	212	S	NAp	[1]8	2,050	140	1,800-2,200	2,100
B	165	S	NAp	5	1,140	150	900-1,300	1,200
B	165	F	NAp	5	760	230	400-1,000	800
B	212	S	NAp	[1]9	1,022	83	900-1,200	1,000
B	212	S	WC	10	1,120	65	1,000-1,200	1,100
C	135	S	GB	4	950	310	700-1,400	850
C	135	F	GB	5	640	90	500- 700	700
C	165	S	NAp	10	780	85	700- 900	800
D	165	S	NAp	10	860	150	600-1,100	850
D	212	S	NAp	10	1,060	70	1,000-1,200	1,050

F Fast response.
GB Glass bulb.
NAp Not applicable.
S Standard response.
WC Wax coated.
[1]Excludes outliers.

Comparison of Similar Sprinklers From Different Manufacturers

First, the leak pressures of the automatic sprinklers with the same activation temperature, response type, and fusible element type, but different manufacturers, were compared. Although the fusible element type was the same for sprinklers that were compared, the engineering design, manufacturing process, and materials of the fusible elements were different for each manufacturer. The average leak pressures of the 165° F standard-response sprinklers from manufacturers B, C, and D were 1,140±150, 780±85, and 860±150 psig, respectively. The data were consistent for each set of sprinklers, as indicated by the low standard deviation, indicating good reproducibility within a sprinkler type from the same manufacturer. However, there was a noticeable difference in the average leak pressure of the sprinklers from different manufacturers. The leak pressures of the sprinklers from manufacturers C and D were determined to be statistically equal, while the leak pressures of the sprinklers from manufacturer B were shown to be statistically higher.

The average leak pressures of the 212° F standard-response sprinklers from manufacturers A, B, and D were 2,050±140, 1,022±83, and 1,060±70 psig, respectively. The average leak pressures for sprinklers from manufacturers B and D were determined to be statistically equal. The average leak pressure for the 212° F sprinklers from manufacturer A was double the average leak pressure of the sprinklers from manufacturers B and D.

The average leak pressures of the 165° F fast-response sprinklers from manufacturers A and B showed a significant difference. The sprinklers from manufacturers A and B had average leak pressures of greater than 2,300 and 760±230 psig, respectively. The limit of the gauge used in the test apparatus was 2,300 psig, and all of the sprinklers tested from manufacturer A were able to withstand at least that pressure without leaking. Obviously, the 165° F fast-response sprinklers from manufacturers A and B were determined not to be statistically equal. The 165° F fast-response sprinkler from manufacturer A also had the highest average leak pressure of all the sprinklers tested.

These comparisons show that there is definitely a difference in the ability of sprinklers from different manufacturers to withstand high static water pressure. The difference in their ability to withstand high static pressures is most likely the design of the fusible element and the materials used in the fusible element. The design of the fusible element of the sprinklers and most likely the materials used were different for each manufacturer, as well as different for the standard- and fast-response sprinklers from the same manufacturer. The sprinklers from manufacturer A were able to withstand much larger static pressures than sprinklers from the other three manufacturers. The sprinklers from manufacturers B and D were essentially equivalent to each other; however, they were able to withstand only half of the pressure withstood by the sprinklers from manufacturer A. Sprinklers from manufacturer C had the lowest average leak pressures of the four manufacturers tested.

Comparison of Sprinklers From Same Manufacturer

Next, automatic sprinklers from the same manufacturer with the same response type and fusible element design, but different activation temperatures, were compared. The average leak pressure of the 135° F and 212° F standard-response sprinklers from manufacturer A were 1,825±140 and 2,050±140 psig, respectively. Although these values are very similar and are within 11% of each other, they were not determined to be statistically equal by the t-test. However, the relatively high values indicate that both sprinklers would be able to withstand high static water pressures.

The average leak pressures of the 165° F and 212° F standard-response sprinklers from manufacturer B were 1,140±150 and 1,022±83 psig, respectively. The average leak pressures of these sprinklers were determined not to be statistically equivalent. The average leak pressures of the 165° F and 212° F sprinklers from manufacturer D were 860±150 and 1,060±70 psig, respectively. It was determined that the average leak pressures of these sprinklers were not statistically equivalent.

These comparisons show that different activation temperatures within a particular manufacturer have some effect on the ability of sprinklers to withstand high static pressures. In all of the comparisons, the values were similar and within at least 20% of each other; however, none were found to be statistically equivalent. The small differences were expected because the manufacturer, response type, and fusible element design were all the same. The activation temperatures of the sprinklers were the only variable in these comparisons. The activation temperature is controlled by the small amount of metal alloy that holds the fusible element together, which may have affected the sprinkler's ability to withstand pressure. The melting temperature of the metal alloy can be changed by the composition of the alloy, which may change its strength.

Comparison of Standard- and Fast-Response Sprinklers

The average leak pressures of standard- and fast-response sprinklers from the same manufacturer with the same activation temperature, but different fusible element design, were also compared to determine if there is a difference in their leak pressures. The release mechanisms of fast-response sprinklers are more sensitive to heat, therefore activating in a shorter period of time than standard-response sprinklers at a given activation temperature. The average leak pressures of the 165° F standard- and fast-response sprinklers from manufacturer B were 1,140±150 and 760±230 psig, respectively. The average leak pressures of the standard- and fast-response sprinklers from manufacturer B were determined not to be equal at a 95% confidence level. The average leak pressures of the 135° F glass-bulb, standard-response sprinklers and the 135° F glass-bulb, fast-response sprinklers from manufacturer C were 950±310 and 640±90 psig, respectively. However, the Student's t-test determined that the average leak pressures of these sprinklers were equivalent at a 95% confidence level. This is attributed to the large standard deviation of the standard-response sprinkler. Overall, the fast-response sprinklers had average leak pressures lower than those of standard-response sprinklers. The only exception to this is the fast-response sprinklers from manufacturer A, which at greater than 2,300 psig had the highest average leak pressure of any of the sprinklers tested. The fusible element design of these sprinklers was dramatically different from the other sprinklers, and may have been responsible for the differences in leak pressures.

Comparison of Glass-Bulb- and Fusible-Type Sprinklers

The 135° F standard-response glass-bulb sprinklers from manufacturer C and 135° F standard-response fusible-type sprinkler from manufacturer A were compared to determine if there is a difference in their leak pressures due to the activation mechanism. The average leak pressures of 1,825±140 psig for the sprinkler from manufacturer A and 950±310 psig for the sprinkler from manufacturer C were significantly different. The average leak pressures were determined not to be statistically equivalent. As mentioned above, the sprinklers from manufacturer A had the highest average leak pressures compared with those from the three other manufacturers, so the glass-bulb sprinklers were also compared with other fusible-type standard-response sprinklers with different activation temperatures. The 135° F standard-response glass-bulb sprinklers from manufacturer C were compared with the 165° F standard-response fusible sprinklers from manufacturers B and D. The Student's t-test determined that the average leak pressures of all of these sprinklers were statistically equivalent to each other at the 95% confidence level. Although the leak pressures of the sprinklers were determined to be equal, the high standard deviation of the glass-bulb sprinklers also shows the variability associated with sprinklers of this type and manufacturer.

Comparison of Wax-Coated Sprinklers

The average leak pressures of the 212° F sprinklers from manufacturer B and the wax-coated version of those sprinklers were also compared. They were found to be similar at 1,022±83 and 1,120±65 psig, respectively. The wax coating, as expected, had a minimal effect on the sprinkler's leak pressure.

LONG-TERM PRESSURE EXPERIMENTS WITH NEW SPRINKLERS

In the long-term pressure experiments, six of the different sprinklers were able to withstand at least 500 psig for 30 days without leakage. As mentioned earlier, UL standards require sprinklers to withstand a pressure of 300 psig for 30 days to be listed. The 135° F standard-response and 165° F fast-response sprinklers from manufacturer A were able to withstand at least 1,000 psig for 30 days. The 165° F standard-response sprinkler from manufacturer B was able to withstand at least 1,000 psig for 30 days, while the 165° F fast-response sprinkler from manufacturer B was able to withstand at least 500 psig for 30 days. The 165° F standard-response, fusible sprinkler from manufacturer C was able to withstand 500 psig for 30 days, while the 135° F standard-response, glass-bulb sprinkler from manufacturer B was able to withstand at least 750 psig for 30 days. These experiments also showed the difference between the sprinklers from the four manufacturers, as both of the sprinklers from manufacturer A were able to withstand at least 1,000 psig for 30 days. Also, for each manufacturer, except A, the standard-response sprinkler was able to withstand a higher static pressure than the fast-response sprinkler for the 30-day period.

The results of the leak pressure experiments with the new sprinklers showed that the manufacturer was the most significant factor when comparing an automatic sprinkler's ability to withstand high static pressures typically found in deep underground coal mines. This is probably due to the difference in the design, materials, and manufacturing procedure of the fusible elements. The sprinklers from manufacturer A were clearly superior in their ability to withstand high static pressure. The sprinklers from manufacturers B and D were essentially equivalent to each other; however, they were able to withstand only half of the pressure withstood by the sprinklers from manufacturer A. Sprinklers from manufacturer C had the lowest average leak pressures of the four manufacturers tested. The response type, standard or fast, was also found to have a significant effect on the sprinkler's ability to withstand high static pressures.

LEAK PRESSURE EXPERIMENTS WITH EXPOSED SPRINKLERS

Leak pressure experiments were conducted on automatic sprinklers obtained from nine different operating coal mines. The sprinklers were exposed to the mine environment for periods ranging from 1 to 5 years. The results of these experiments are shown in table 3.

Table 3.—Results of leak pressure experiments with exposed sprinklers

(All sprinklers standard response)

Mine	Sprinkler		Leak pressure, psig	Confidence interval,[1] psig
	Manufacturer	Activation temp, °F		
1 ...	A	135	1,000	1,700-1,950
			1,000	
			1,500	
			1,000	
2 ...	A	212	<100	1,925-2,175
			1,500	
			500	
			300	
			2,000	
3 ...	A	212	900	1,925-2,175
			1,000	
			1,400	
			900	
			1,700	
4 ...	B	212	600	955-1,090
			1,100	
			1,200	
			900	
5 ...	B	[2]212	900	1,075-1,165
			1,100	
			1,100	
			900	
			800	
6 ...	D	165	900	750- 970
			<100	
			1,300	
			600	
			1,000	
7 ...	D	165	1,000	750- 970
			700	
	D	212	1,200	1,010-1,110
			900	
			900	
8 ...	D	212	900	1,010-1,110
			1,000	
			1,100	
			1,100	
			900	
9 ...	D	212	1,000	1,010-1,110
			600	
			900	
			1,100	
			1,000	

[1]Confidence interval of the average leak pressures of the corresponding new sprinklers; confidence coefficient of 95%.
[2]Wax coated.

The leak pressures of the exposed sprinklers were compared with the confidence interval of the average leak pressure of the corresponding new sprinklers. The confidence interval method determines a confidence interval for an experimental mean for an associated confidence coefficient (*6*). For example, if a sample of 10 sprinklers were leak pressure tested, the confidence interval with an associated confidence coefficient could be calculated. If the confidence coefficient is 95%, then there is a 95% probability that the true average leak pressure would fall in the confidence interval. The upper and lower limits of the confidence interval, I, were calculated from the expression

$$I_u = \bar{X} + t_p \frac{s}{\sqrt{n-1}},\ I_L = \bar{X} - t_p \frac{s}{\sqrt{n-1}},$$

where I_u is the upper limit of the confidence interval, I_L is the lower limit of the confidence interval, $\bar{X}$ is the mean of the leak pressures of the corresponding new sprinklers, t_p is the Student's statistic at the 100 - p confidence interval, s is the standard deviation, and n is the number of samples. This method was used to calculate the confidence interval for the corresponding set of new sprinklers for each type of sprinkler that had been exposed to the mine atmosphere. If the individual leak pressure of each exposed sprinkler did not fall into the confidence interval of the corresponding new sprinklers, then there is a 95% probability the exposed sprinkler was subjected to conditions in the mine that reduced its ability to withstand high static pressure. Each exposed sprinkler was evaluated individually since it could not be assumed that all of these sprinklers were subjected to the same conditions, even if they were from the same mine. Several of the exposed sprinklers had been physically damaged and some were extremely corroded. All were standard-response sprinklers. Photographs of a few of the exposed sprinklers are shown in figure 4.

The exposed sprinklers from mine 1 were 135° F standard-response sprinklers from manufacturer A. These sprinklers were in service in the mine for approximately 3 years. Three of the five sprinklers had deflectors that were slightly damaged. This was probably the result of being struck by a hard object, which could have also jarred one of the linkage components that hold down the orifice cap. The average leak pressure for the new sprinklers was 1,825 ± 140 psig. The confidence interval for the new sprinklers was from 1,700 to 1,950 psig. None of the leak pressures of the exposed sprinklers fell into this range. The leak pressures of the exposed sprinklers ranged from 1,000 to 1,500 psig. They were all mildly corroded and all of the fusible elements were coated with a layer of caked rock dust. The leak pressures of four of the five exposed sprinklers were at least 40% lower than the average leak pressure of the new sprinklers. This shows that exposure to the environment at this particular mine had a significant effect on the ability of these sprinklers to withstand high static water pressure.

Mines 2 and 3 sent sets of exposed sprinklers that were 212° F rated from manufacturer A. The set of exposed sprinklers from mine 2 had been in service in the mine about 3 years and had a range of leak pressures from < 100 to 2,000 psig. The deflector of the exposed sprinkler that leaked before 100 psig could be applied was slightly damaged but there was no other visual damage that would indicate that the sprinkler could not hold 100 psig. The sprinkler that held only 300 psig had no visual damage and the sprinkler that held 500 psig had corroded to the point where a reddish rust had started to form on the metal surface. The two sprinklers that held 1,500 and 2,000 psig were in the best condition of the sprinklers received from this mine. The confidence interval for the new 212° F sprinklers from manufacturer A was from 1,925 to 2,175 psig. Only the sprinkler that held 2,000 psig fell in the confidence interval for the corresponding new sprinklers. Three of the five exposed sprinklers were able to withstand less than 25% of the average leak pressure of the corresponding new sprinklers. The mine environment had a significant effect on the ability of these sprinklers to withstand static pressure.

The set of 212° F rated sprinklers from mine 3 were from manufacturer A. They had been in service in the mine about 2 years, and all of the sprinklers appeared to be in good physical condition. The leak pressures ranged from 900 to 1,700 psig. The three sprinklers that were able to hold 900 and 1,000 psig had more rust and accumulations in the orifice and were only able to withstand less than half of the average leak pressure of the corresponding new sprinklers.

The set of sprinklers from mine 4 were 212° F rated sprinklers from manufacturer B. The 95% confidence interval for the corresponding new sprinklers ranged from 955 to 1,090 psig. Two of the exposed sprinklers in this set fell in the confidence interval for the corresponding new sprinklers, and all of the leak pressures of the exposed sprinklers were relatively close to the average pressure of the corresponding new sprinklers. All of the sprinklers were in good physical condition except for the sprinkler that held only 600 psig, which had a damaged deflector. Excluding this sprinkler, the remaining sprinklers were able to withstand at least 88% of the average leak pressure of the new sprinklers.

The sprinklers received from mine 5 were 212° F wax-coated sprinklers from manufacturer B. The exposed sprinklers had been in service for approximately 5 years and were in good condition with little or no sign of damage. The confidence interval for new sprinklers of the same type was 1,075 to 1,165 psig. Two of the exposed sprinklers fell in the confidence interval, while the other three sprinklers were only able to withstand about 70% of the average leak pressure of the corresponding new sprinklers.

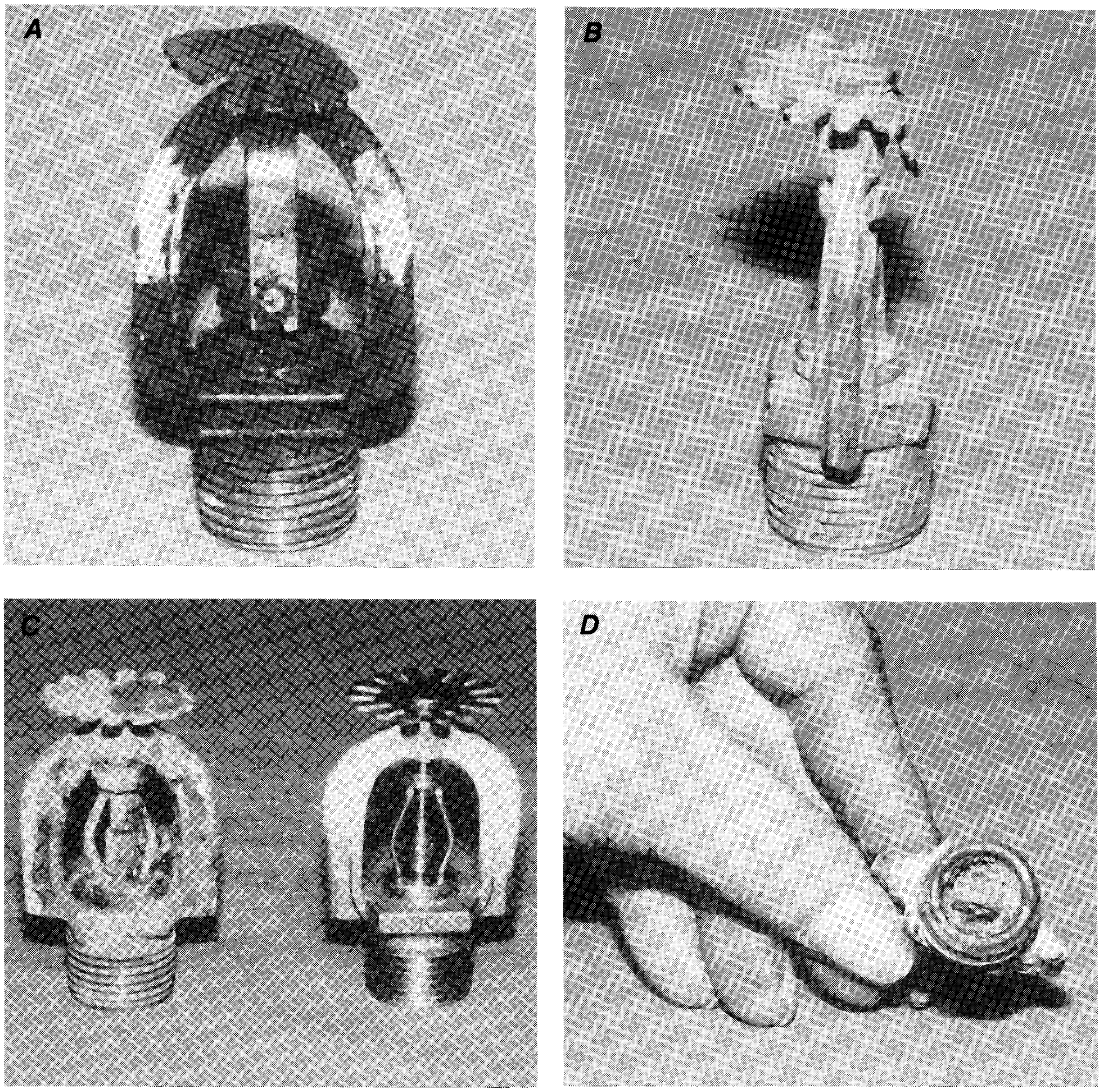

Figure 4.—Examples of exposed sprinklers. *A*, Damaged sprinkler; *B*, damaged sprinkler; *C*, exposed sprinkler (left) versus new sprinkler (right); *D*, sprinkler plugged with pipe scale, stones, and/or other foreign material.

Mines 6 and 7 sent sets of exposed 165° F standard-response sprinklers from manufacturer D. Mine 6 sent five sprinklers and mine 7 sent two sprinklers. The confidence interval for the new 165° F standard-response sprinklers from manufacturer D was from 750 to 970 psig. In the set with five sprinklers, the leak pressures ranged from <100 to 1,300 psig. The sprinkler that leaked before 100 psig could be applied had a damaged deflector and damage and rust around the orifice cap and upper portion of the threads. This indicates that this sprinkler may have been leaking while in service in the mine. The deflector of the sprinkler that was able to hold only 600 psig was severely damaged and could be made to spin on the frame arm. The leak pressures of the other three sprinklers were 900, 1,000, and 1,300 psig, which either fell in or exceeded the pressures specified by the confidence interval. These sprinklers were in good condition. Unless physically damaged, exposed sprinklers from this mine were not affected by the mine atmosphere. The two 165° F sprinklers from mine 7 were in relatively good condition and either came close to the lower limit or exceeded the confidence interval.

Mines 7, 8, and 9 provided sets of exposed 212° F standard-response sprinklers from manufacturer D. The confidence interval for the new 212° F sprinklers from manufacturer D was between 1,010 and 1,110 psig. The set from mine 7 contained three sprinklers and all were in good condition. The leak pressure of one of the sprinklers exceeded the confidence interval, while the other two were close to the lower limit of the interval. The effect of the environment of this mine on these sprinklers was minimal.

In the set from mine 8, the leak pressure of two of the five sprinklers fell in the confidence interval and the other three were close to the confidence interval. These sprinklers had been in the mine approximately 2 years and all were in good condition. The effect of the mine environment on the performance of these sprinklers was not significant.

In the set from mine 9, one of the sprinklers fell in the confidence interval; however, one of the other four sprinklers was able to withstand only 600 psig. The deflector on this sprinkler was severely damaged, which could be the reason for its poor performance. The mine environment was definitely a factor in the performance of this sprinkler, although the effect on the rest of sprinklers was not as obvious.

Overall, the leak pressures of 66% of the sprinklers received from underground mines did not fall into the confidence interval for their corresponding new sprinklers, indicating a reduction in their ability to withstand high static water pressure. For seven of the nine mines from which sprinklers were obtained, the sprinklers that did not fall into the confidence interval had leak pressures, on the average, 20% less than the average leak pressures of their corresponding new sprinklers. Considering that these sprinklers had been installed in the mine for no more than 5 years, and on the average 2 or 3 years, the mine environment had a significant effect on the automatic sprinklers' ability to withstand high static pressure.

In several cases, the exposed sprinklers that did not withstand high static pressures were physically damaged, while in other cases the sprinklers looked no different than the other sprinklers from that mine. Because of the poor visibility and cramped conditions in an underground coal mine, sprinklers installed in mines are more susceptible to being struck by various objects. Sprinkler guards are available and should be used where this is a problem. Also, the sprinklers may be subjected to large water hammers in an underground water system. This may reduce their ability to withstand high static pressures while causing no visible physical damage to the sprinkler. If the sprinklers are physically damaged, they should be replaced as soon as possible. For some of the exposed sprinklers, in addition to the poor performance in the leak pressure experiment, the physical damage of the deflector would have adversely affected the discharge pattern of the sprinkler.

PRESSURE RATINGS

The average leak pressures of the new automatic sprinklers evaluated in this study were much greater than their rated pressures. However, the average leak pressures were not high enough to provide sprinklers used in deep underground mines the same safety factor as sprinklers used aboveground at or below their rated pressures. For a sprinkler to be UL listed with a 175-psig maximum working pressure rating, it must withstand 500 psig without leakage. To provide the same safety factor, a sprinkler with a 400-psig maximum working pressure rating would have to withstand at least 1,145 psig without leakage. Of the 12 types of new sprinklers evaluated in this study, only 4 sprinklers had an average leak pressure of at least 1,140 psig. It is safe to assume that the remainder of these sprinklers would not be able to withstand the pressure needed to be listed with a 400-psig maximum working pressure rating.

CONCLUSIONS

Experiments were conducted to evaluate the effects of high static water pressure on the performance of commercially available automatic sprinklers. Different types of new automatic sprinklers from four different manufacturers were compared as well as automatic sprinklers that had been exposed to the mine environment. The average leak pressures of the new sprinklers ranged from 640 to 2,300 psig and showed a statistically significant difference between sprinklers from different manufacturers, as well as between different types of sprinklers. Generally, the standard-response sprinklers were able to withstand higher static pressure than the fast-response sprinklers. The average leak pressures of the standard-response sprinklers ranged from 780 to 2,050 psig, the fast-response sprinklers from 640 to >2,300 psig. In addition to the leak pressure experiments, six types of sprinklers were able to withstand at least 500 psig for 30 days without leaking.

The leak pressures of 66% of the sprinklers received from nine underground coal mines did not fall into the confidence interval for their corresponding new sprinklers. In addition, several of the sprinklers obtained from the mines were physically damaged and would have not operated as designed. The mining environment had a significant effect on the ability of these sprinklers to withstand high static pressures.

The results of the leak pressure experiments indicate that most of the automatic sprinklers evaluated would not leak when subjected to pressures found in deep underground mines. However, automatic sprinklers installed in deep underground coal mines can be exposed to three times their rated pressure of 175 psig. This leaves only a small safety factor between the average leak pressure and the pressure to which the sprinkler is exposed. The sprinklers are exposed to an environment where physical damage and harsh atmospheric conditions are likely. Because of these factors, consideration should be given to developing performance standards for existing sprinklers that can withstand high static pressure or designing new sprinklers to be used under high static pressures in underground coal mines. This would ensure that sprinklers used underground provide the same reliable, low-maintenance fire protection that they provide aboveground.

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APPENDIX

Table A-1.—Leak pressures of new sprinklers

Sprinkler			Leak	Sprinkler			Leak
Manufacturer	Activation temp, °F	Type	pressure, psig	Manufacturer	Activation temp, °F	Type	pressure, psig
A	135	S	2,000	B	212	S,WC	1,200
A	135	S	1,900	B	212	S,WC	1,100
A	135	S	[1]100	B	212	S,WC	1,100
A	135	S	1,700	B	212	S,WC	1,100
A	135	S	[1]700	B	212	S,WC	1,100
A	135	S	1,800	B	212	S,WC	1,200
A	135	S	1,800	B	212	S,WC	1,000
A	135	S	1,600	B	212	S,WC	1,100
A	135	S	2,000	B	212	S,WC	1,200
A	135	S	1,800	B	212	S,WC	1,100
A	165	F	>2,300	C	135	S,GB	1,400
A	165	F	>2,300	C	135	S,GB	700
A	165	F	>2,300	C	135	S,GB	900
A	165	F	>2,300	C	135	S,GB	800
A	165	F	>2,300	C	135	F,GB	700
A	212	S	1,800	C	135	F,GB	700
A	212	S	2,200	C	135	F,GB	600
A	212	S	2,100	C	135	F,GB	500
A	212	S	2,200	C	135	F,GB	700
A	212	S	1,900	C	165	S	700
A	212	S	2,100	C	165	S	800
A	212	S	[1]1,100	C	165	S	900
A	212	S	2,000	C	165	S	800
A	212	S	[1]1,500	C	165	S	700
A	212	S	2,100	D	165	S	700
B	165	S	1,300	D	165	S	900
B	165	S	900	D	165	S	600
B	165	S	1,200	D	165	S	800
B	165	S	1,200	D	165	S	1,000
B	165	S	1,100	D	165	S	800
B	165	F	400	D	165	S	1,100
B	165	F	800	D	165	S	900
B	165	F	900	D	165	S	1,000
B	165	F	700	D	165	S	800
B	165	F	1,000	D	212	S	1,000
B	212	S	1,000	D	212	S	1,100
B	212	S	[1]100	D	212	S	1,000
B	212	S	1,200	D	212	S	1,100
B	212	S	1,000	D	212	S	1,000
B	212	S	1,000	D	212	S	1,000
B	212	S	1,100	D	212	S	1,000
B	212	S	1,000	D	212	S	1,200
B	212	S	1,000	D	212	S	1,100
B	212	S	900	D	212	S	1,100
B	212	S	1,000				

F Fast response.
GB Glass bulb.
S Standard response.
WC Wax coated.
[1]Outlier.