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REPORT OF INVESTIGATIONS/1989

Use of an In-Seam Tester To Determine Effects of Bit Type on Primary Dust Generation

By Laxman S. Sundae

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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Manuel Lujan, Jr., Secretary

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	m	meter
g	gram	MN	meganewton
gpm	gallon per minute	N/cell	newton per cell
J/g	joule per gram	pct	percent
km	kilometer	s	second
L/min	liter per minute		

USE OF AN IN-SEAM TESTER TO DETERMINE EFFECTS OF BIT TYPE ON PRIMARY DUST GENERATION

By Laxman S. Sundae[1]

ABSTRACT

A U.S. Bureau of Mines designed and fabricated in-seam tester (IST), retrofitted with a dust shroud, was used to establish a respirable dust index (RDI) and to determine cutting forces from a variety of bit types in four coal mines and a salt mine.

Results from cutting tests at four coal mines showed that radial bits required the lowest cutting force and the least specific energy. Generally, for each conical bit the RDI and cutting force increased when the included bit tip angles increased from 70° to 90°.

During field tests it was not possible to measure the total quantity of respirable dust produced by each cut; therefore, attempts were made to determine the amount of dust that became airborne from each test cut. The test results show that the quantity of airborne respirable dust is very erratic and cannot be related to bit type. Two statistical methods were employed to analyze RDI, but no correlation was found between the RDI and bit type. Despite scatter in test results for RDI, significant difference was found in RDI generated in four coal seams. In general, RDI increased with the increased cutting force for each coal seam from mine 1 through mine 4.

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INTRODUCTION

The Bureau has been actively engaged in the reduction of primary dust generation at the coal face since the enactment of the Federal Coal Mine Health and Safety Act of 1969. Some of the early efforts were directed toward fundamental laboratory research to reduce cutting force, specific energy, and dust generation. To support these efforts, an IST was developed for direct measurement of coal cutting forces at the coal face.

The dust measured for this report is defined as the amount of dust produced by the IST test bits during the coal cutting action of the IST that is dispersed into the air by the kinetic energy released by coal, by the bits, and by the fragmented and broken coal hitting the floor. An RDI is used because the amount of dust measured was neither diluted by ventilation, nor totally contained in the shroud. There is no way to determine what percentage of total dust is being measured. The RDI is used to differentiate the mass reading obtained without volume dilution from the more normal mass reading for a given volume dilution. All dust measurements were made in an identical manner for relative comparison.

A significant amount of research has been done on dust generation, dust collection, dust suppression, and the efficiency of various methods to reduce dust levels from the mine air (*1-2*).[2] Research on predicting and isolating primary dust in the mine air has established the relationship between dust generation and the depth of cut (DOC) (*3-5*) and established the relationship of dust and energy to symmetric and asymmetric bit wear (*6-7*). Although some field research has been done, most of this research was done under controlled laboratory conditions.

Further field tests to verify the Bureau's laboratory results were required. The IST was designed and tested for the direct, in situ measurement of coal cutting forces. The IST was retrofitted with a shroud so the amount of airborne respirable dust (ARD) produced at the coal face could be determined. The objective of this field investigation was to determine in situ cutting forces and the RDI for different bit types in several coal seams.

EXPERIMENTAL PROCEDURE

BRIEF DESCRIPTION OF IN-SEAM TESTER AND DUST SAMPLING

An IST was designed and fabricated by the Bureau with the assistance of Ingersoll-Rand Research, Inc., for direct measurement of coal cutting forces in situ (*8*). Results of in situ measurement of coal cutting forces in several seams have already been published (*9-10*). The components of the IST, such as pick mounting, force dynamometer, mast, frame, and frame mounting anchors, have all been described elsewhere (*8-10*). For measurement of respirable dust (RD) at the coal face, the IST may be used with a dust containment shroud while the coal cutting forces are being measured. The IST, without shroud, is shown in figure 1.

The dynamometer was calibrated before and after each field test. There was no change detected in the shape or size of the error curve (hysteresis loop) and the slopes of the curves remained the same during all tests, which indicated that the force measurement device was functioning accurately. The calibration curves made before the field testing are shown in figure 2. Figure 2 (top) also shows the low level of crosstalk between the two channels of the dynamometer.

All dust measurements were made using a GCA RAM-1 with a cyclone on the intake tube.[3] The sampler used a 2-L/min airflow with the cyclone on the intake mounted within 2.54 cm of the bit tip.

General Description of Test Sites and Bits

Ten test sites were used for the results given in this report. Nine test sites were in four coal mines, one site was in a salt mine. For first three mines, each test series used for analysis consisted of a minimum of seven cuts made with each bit type for each DOC.

The first series of tests at four test sites were completed in mine 1, an underground coal mine of the Springfield-Harrison No. 5 Seam located in Logan County, IL. The coal seam in this mine is 137 m deep with a seam thickness of 1.37 m. The coal is mined by the room-and-pillar method with the aid of continuous miners. Three test sites were located in a pillar rib. The last site was located on a pillar face 15.24 m away from the first three. All test sites at mine 1 contained thin layers of shale and hematite uniformly distributed through the test cut area. Occasionally, however, the vertical fractures were filled with calcite and other calcareous material. All of these impurities

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

[3]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

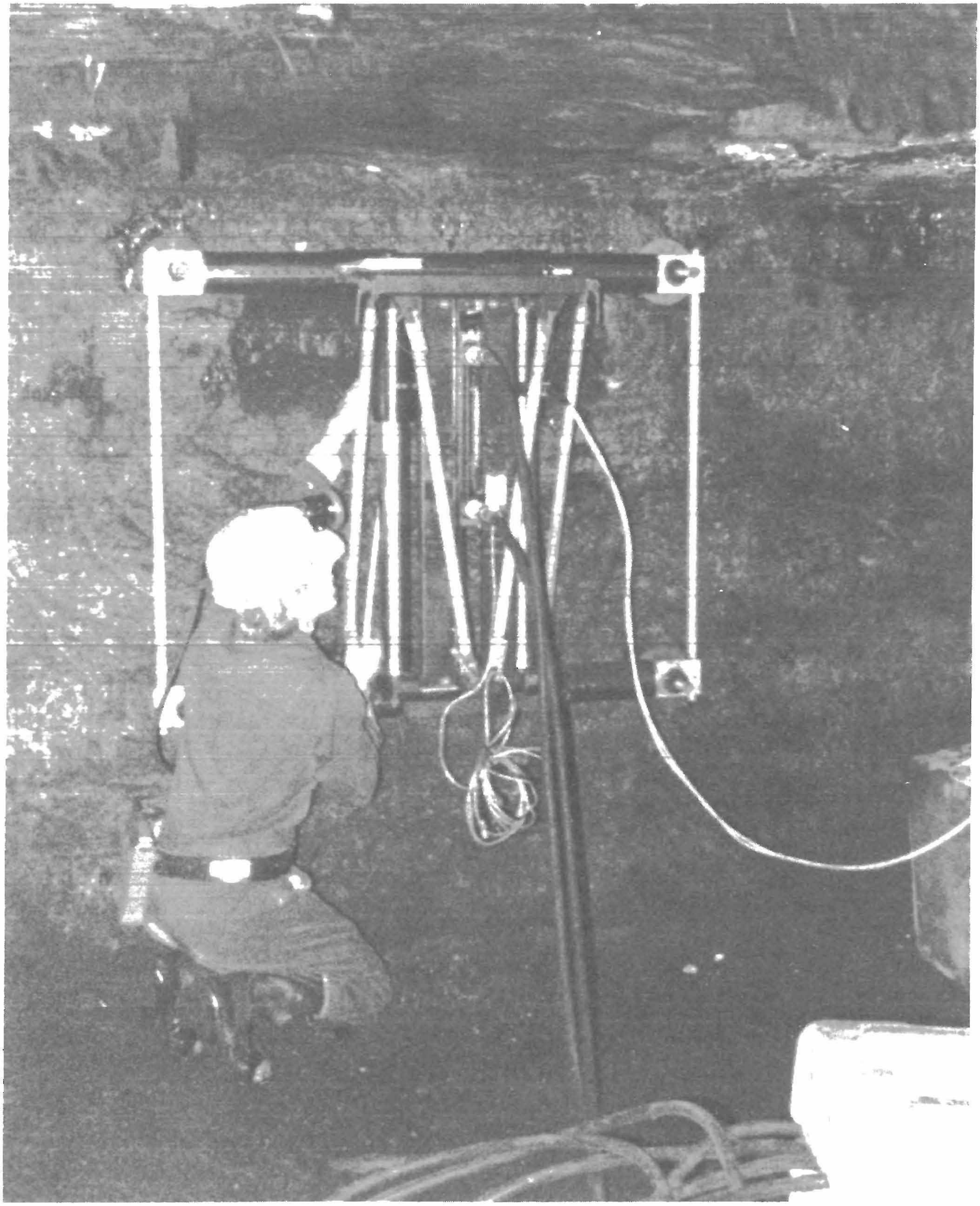

Figure 1.–In-seam tester mounted on coal pillar rib without shroud.

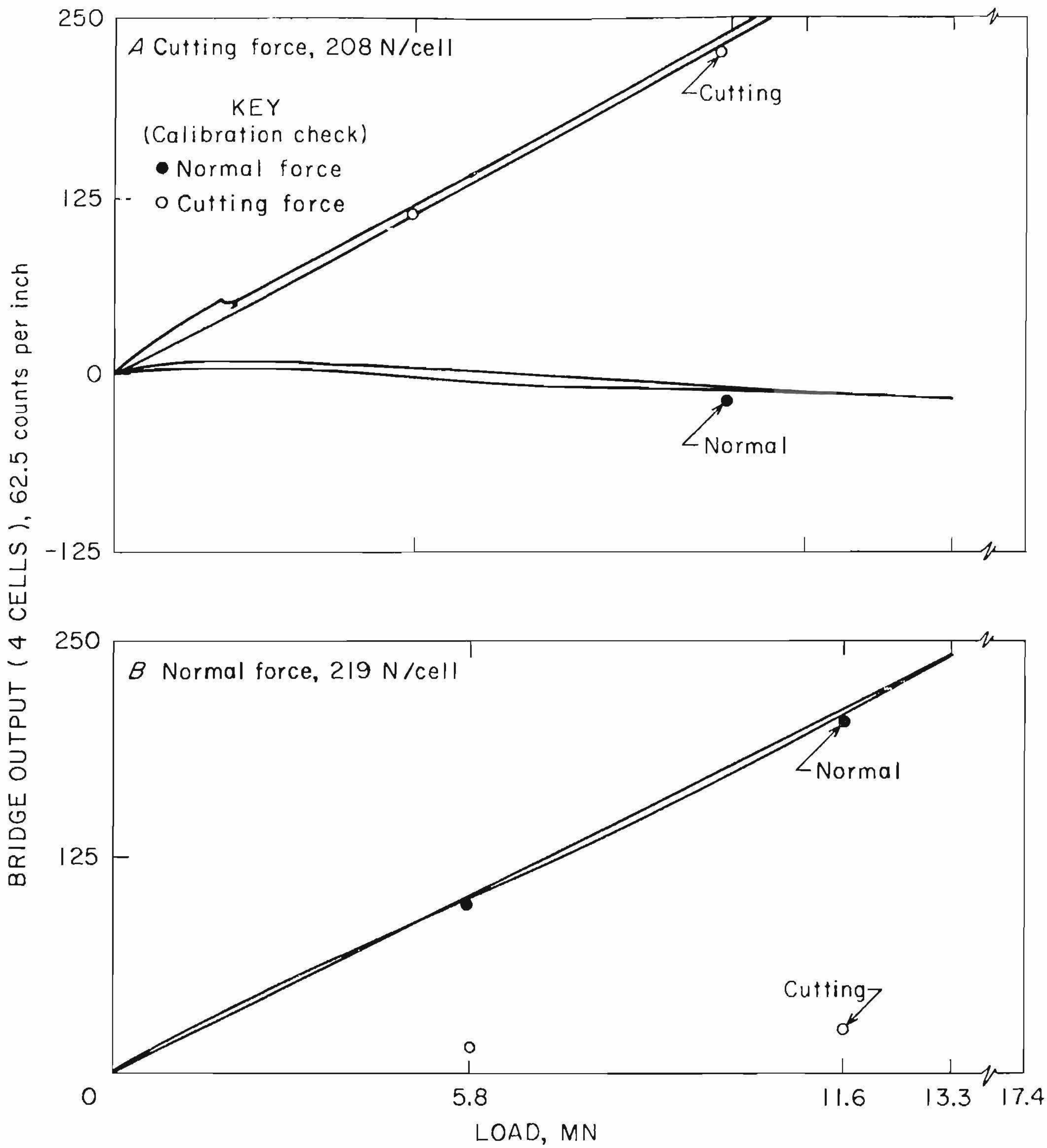

Figure 2.–Calibration curves for cutting and normal forces made prior to field testing.

appeared stronger than the bituminous coal mined and may have influenced the average cutting force values slightly. At mine 1, 87 cuts were made with the IST. The number of cuts per bit are shown in table 1.

Table 1.–Summary of field test results

Bit type and number of cuts	DOC, cm	Spacing, cm	Force, N: Average H	Force, N: Average N	Force, N: Average R	Force, N: Peak H	Force, N: Peak N	RDI Mean	RDI SD	Material cut, g	Specific Energy, J/g	Specific Dust
MINE 1												
Radial:												
14 cuts	1.27	2.54	412	234	476	2,319	890	2.62	1.37	113	1.0176	0.02319
7 cuts	2.54	5.08	1,227	310	1,266	6,037	1,462	11.06	5.93	419	.8401	.02640
Plumb bob:												
75°:												
15 cuts	1.27	2.54	582	747	948	2,817	2,402	4.19	1.539	108	1.5248	.03879
8 cuts	2.54	5.08	1,451	1,473	2,067	5,950	4,115	16.47	8.183	440	.9438	.03743
90°:												
13 cuts	1.27	2.54	1,466	2,702	3,073	3,969	5,988	3.75	2.002	131	3.2666	.02863
8 cuts	2.54	5.08	3,416	5,051	6,096	8,396	9,341	22.02	3.467	467	2.0813	.04726
Cigar, 80°:												
14 cuts	1.27	2.54	711	886	1,139	2,874	2,840	4.45	2.213	109	1.7798	.04028
8 cuts	2.54	5.08	1,944	2,019	2,803	5,839	4,671	18.47	3.906	412	1.3521	.04483
MINE 2												
Radial:												
8 cuts	1.27	2.54	447	222	503	2,002	391	2.42	1.239	177	[1]1.17	.01341
	2.54	5.08	1,098	236	1,125	5,560	725	6.52	3.575	705	.72	.00868
Plumb bob:												
70°:												
8 cuts	1.27	2.54	664	569	876	2,615	1,913	2.34	1.26	107	[1]1.99	.01715
	2.54	5.08	1,995	1,561	2,535	6,783	4,226	16.67	5.393	617	1.49	.02734
75°:												
8 cuts	1.27	2.54	737	787	1,076	2,669	2,446	1.97	.804	166	2.09	.07220
	2.54	5.08	2,227	2,006	3,002	6,894	5,062	29.58	11.908	570	1.79	.05194
90°:												
8 cuts	1.27	2.54	959	1,228	1,557	3,225	3,558	2.81	1.673	179	[1]2.55	.01714
	2.54	5.08	2,916	3,389	4,479	7,228	7,175	32.56	11.179	674	1.98	.07674
MINE 3												
Radial, 8 cuts	1.27	2.54	494	240	552	2,780	890	2.46	1.0	153	1.52	.01634
Plumb bob:												
70°, 8 cuts	1.27	2.54	1,777	1,828	2,553	6,285	4,782	6.28	3.89	237	[2]3.52	.02627
75°, 7 cuts	1.27	2.54	1,280	1,370	1,873	4,226	4,226	3.67	1.07	166	3.66	.02268
90°, 8 cuts	1.27	2.54	2,248	2,865	3,643	5,894	7,673	5.97	2.64	212	[3]5.23	.03040
MINE 4												
Radial, 6 cuts	1.27	2.54	722	294	783	4,372	1,632	23.46	9.461	198	1.77	.11867
Plumb bob:												
70°, 6 cuts	1.27	2.54	1,108	1,005	1,499	5,636	4,448	9.14	2.561	215	2.52	.04287
75°, 6 cuts	1.27	2.54	1,345	1,575	2,073	5,560	5,262	14.95	4.45	209	3.08	.07095
90°, 7 cuts	1.27	2.54	2,245	3,087	3,816	6,832	7,468	9.74	2.246	206	[4]5.30	.04799
MINE 5												
Radial:												
2 cuts	1.27	2.54	1,119	445	1,205	5,561	2,447	([5])	([5])	NA	2.7175	ND
	1.27	5.08	1,989	625	2,085	6,895	2,669	([5])	([5])	NA	2.9611	ND
Round nose:												
8 cuts	1.27	2.54	2,668	873	2,808	7,173	2,559	([5])	([5])	NA	4.2709	.00108
4 cuts	1.27	5.08	4,421	1,472	4,659	11,010	4,671	([5])	([5])	NA	4.5076	.000519
V-shaped:												
8 cuts	1.27	2.54	1,211	260	1,239	4,393	890	([5])	([5])	NA	2.1736	.000674
4 cuts	1.27	5.08	2,341	528	2,400	6,561	1,557	([5])	([5])	367	2.9810	.000371
Plumb bob:												
60°:												
16 cuts	1.27	2.54	1,888	1,764	2,585	4,699	3,892	([5])	([5])	NA	3.3771	ND
4 cuts	1.27	5.08	3,431	3,065	4,601	7,674	7,229	([5])	([5])	NA	4.0975	ND
90°:												
16 cuts	1.27	2.54	3,748	5,938	7,023	6,561	8,925	([5])	([5])	NA	6.6675	ND
4 cuts	1.27	5.08	5,634	8,089	9,859	10,232	12,344	([5])	([5])	NA	5.9599	ND

DOC Depth of cut.
H Horizontal.
N Normal.
NA Not available.
ND No dust.
R Resultant.
RDI Respirable dust index.

SD Standard deviation.
[1]7 tests for dust data.
[2]7 tests for dusta data, DOC 1.27 cm.
[3]2 cuts, DOC 1.27 cm.
[4]6 tests for dust data.
[5]No measurable RDI generated.

Tests at two sites were conducted in mine 2 located in the Illinois No. 6 Seam near Farmersville, Montgomery County, IL. The two test sites were selected near an active mine face. Both were in a pillar rib in a crosscut between a belt entry and haul road. The thickness of the coal seam averages 2.29 m, but varies considerably; the top rock is shale, which usually falls. Both sites contained face and rib cleats, some of which contained calcareous deposits that appeared stronger than the coal. Several thin shale partings were also present, as well as a few thin lenses of pyrite. The physical properties of the Illinois No. 6 coal are such that it was possible to make both 1.27- and 2.54-cm-deep cuts. At mine 2, 64 cuts were made.

Mine 3 is located in the Dorchester Seam in Wise County, VA. Seam thickness in this mine is 1.22 m, with a shale parting of 5 to 15 cm present in the upper portion of the seam. Coal is mined by two Joy LS-3 shearers. Because the coal is unusually dusty, 70 gpm of water is injected under the bit tips to alleviate the dust. The test sites were located approximately 180 m below ground level in the head section of a longwall panel. Thirty-one test cuts were made in mine 3. Deep cuts were not possible because of the coal strength.

Mine 4 is located in the Taggart Seam in Wise County, VA, where seam thickness is 1.65 m. Because of excessive ground pressure, the coal surfaces on the sides of the pillar crumble easily, making the choice of suitable test sites very difficult. One test site was ultimately located in the intake air of a development section, where 25 test cuts were taken with the same bits used at mines 2 and 3. Deep cuts were not possible at mine 4 because of coal strength.

Mine 5, located in Ellsworth County, KS, was selected because the deposit contains no impurities, cracks, flaws, or other defects to impair the test results. Because considerable scatter is found in test results for both forces and dust from coal mines, a decision was made to conduct tests in a noncoal mine where the test material could be monomineralic and homogenous. The salt is mined by the room-and-pillar method from a depth of 259 m. No water is added to any cycle of mining operation to avoid adding moisture or humidity to the mine air. The salt is crystalline in nature with crystal size variation from 5 to 8 cm.

The IST test site was located approximately 30 m away from an active mine face where drilling, blasting, and mucking operations were taking place. All tests were conducted in the midsection of 18.3- by 18.3-m pillar to avoid the stress concentration effect from the pillar corners. Because of the hardness of the salt, several attempts were needed to make the first independent clearing cut, even at the shallow depth of 1.27 cm. Therefore, it was not possible to determine the mean and peak forces for independent cuts. A single test site was used to compare the RDI and cutting forces required to make dependent or interacting cuts.

A summary of test results from mines 1 through 5 is given in table 1.

Test Bits

Prior research (*9-10*) by the Bureau has shown that 60° and 90° plumb bobs, 80° cigar bits, and V-shaped radial bits exhibit differences in the cutting force required to make the same types of cuts. Therefore, these four bit types were tentatively selected to be tested at mines 1 through 4.

In cooperation with the operators at each mine, the tentatively selected bits were replaced by one or more of the bits routinely used in each of the test mines to accommodate the operator's needs. At mine 1, the 60° plumb bob was replaced with a 75° plumb bob; at mines 2, 3, and 4, the 60° plumb bob and 80° cigar bit were replaced by 70° and 75° plumb bobs; and at mine 5, the 80° cigar bit was replaced with two radial bits. Thus, the tentative list of test bits was expanded substantially in the field.

The relative shapes and sizes of the eight bits used are shown in figure 3. These bits were new and were used for the first time during field testing. A radial bit; 70°, 75°, and 90° plumb bob bits; and an 80° cigar bit were used in the coal mines. A radial bit, 60° and 90° plumb bob bits, a 90° V-shaped radial bit, and a 90° round-nose radial bit were tested in the salt mine. It should be noted that in figure 3 the radial bits are shown with round mounting shanks. This was done for convenience in the field to avoid having to change blocks on the IST. The face of a radial bit cuts with the bit axis parallel to the drum radius in the normal manner. All of the plumb bob bits were mounted with a 45° attack angle.

Test Procedure

Weathered and/or loose coal and any extraneous material on the test site surfaces was removed by making seventeen 2.54-cm-deep clearing cuts placed 2.54 cm apart at each coal test site. (Where the coal was too hard to make 2.54-cm-deep cuts, 1.27-cm-deep cuts were used.) After these site preparation cuts, the IST was covered with the shroud and a background reading for the RDI was started with the RAM-1. When equilibrium was reached with the RD in the mine air, a test cut was taken. After completion of the test cut, the RAM-1 would be left on until equilibrium was reached again with the RD in the mine air. The RAM-1 was then turned off and the shroud was opened to clean out any broken coal and fines left on the IST. Cutting force data, weight of broken coal, and RD were recorded and preparations were made for the next cut. The IST was covered again with the shroud and the entire procedure was repeated to make the next cut using predetermined spacing. This procedure was repeated until the entire first layer of 8 to 17 cuts were made. The number of cuts per layer was dependent on the spacing used. To make test cuts on successive layers, the surface was cleared again by repeating the clearing cuts used initially.

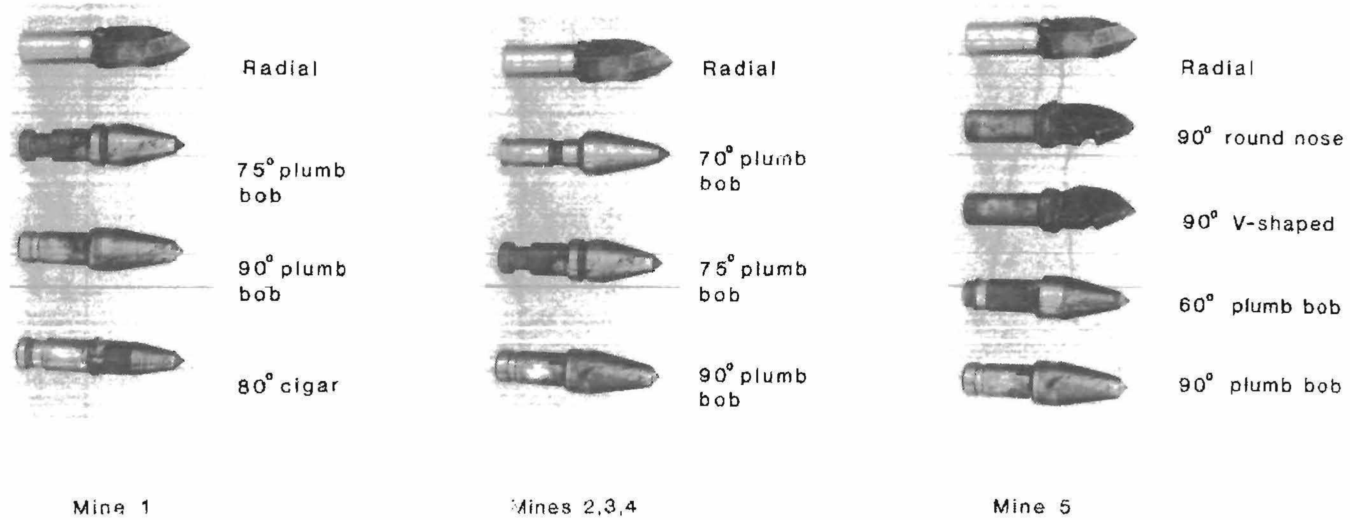

Figure 3.–Test bits.

The field testing was designed to compare the RDI in different coal seams located in the Illinois and Virginia coalfields. In mines 3, 4, and 5 it was not possible, because of the strength of the coal, to make 2.54-cm-deep cuts.

Respirable Dust Measurements

Extra precautions needed to be taken to avoid the effect of airflow on RD measurements even though the IST was shrouded. This meant locating the IST in low-velocity air.

It was not possible to measure the total quantity of RD (airborne and nonairborne) produced by each cut, therefore, attempts were made to determine the amount of dust that became airborne during each test cut. The dust measurements were conducted by enclosing the entire cutting assembly of the IST under a 120- by 91- by 43-cm custom-made shroud. A cyclone-type dust sampler was mounted near the bit tip to sample the RD generated by coal cutting. The RD was passed through a 2-m-long, 0.6-cm-diam intake tube to the RAM-1. The sampler had a flow rate of 2 L/min. Cutting duration was about 1.5 s; however, the dust measurement period varied from 30 to 50 s, depending on dust decay time after each cut.

The sampler was turned on before the start of each test to obtain a background count for the mine air. As soon as the sampler indicated that mine air background equilibrium was reached, the cutting cycle could be started. The equilibrium at the start of the test and equilibrium after the test was completed was defined as zero dust. Thus, only the difference in dust generated by cutting and the background (baseline) is reported. Sampling continued after the completion of the cutting until the initial RD particle equilibrium was reached again. The sampler was then turned off and preparations made for the next test cut.

Figure 4 shows typical variation in the amount of dust generated by four successive cuts for one bit type at mine 1. The background RD in the mine air is shown as zero.

Figure 4 illustrates the considerable variation in the RDI between tests. This variation makes it impossible to see the effect of bit type on mass versus time curves with individual test cuts. This suggests that many more replications must be made in future testing to obtain a reliable bit-dust relationship.

It is shown by figure 4 that no newly generated RD is left under the shroud covering the IST after completion of any test cut. However, it is very likely that some of the RD particles have been deposited on the cutting assembly, coal surface, or the interior surface of the shroud. Therefore, the RDI data must be used as an indicator of relative amounts of RD generated under these test conditions, rather than the absolute quantity produced.

Because there was minimal movement around the shrouded area in mines 1, 2, and 3, however, the assumption is made that no RD was leaking from the shroud before dust particle measurement was completed. Also, because each test was made in an identical manner, if leakage did take place, the relative effect would be the same for each test cut. This was not true in mine 4, however, because the tests had to be made in intake air.

Discussion of Test Results

Mine 1

To determine cutting force, specific energy, and RDI, 87 tests were conducted in the Illinois No. 5 coal seam. The radial bit, 75° and 90° plumb bob bits, and 80° cigar bit used are shown in figure 3. Test results are given in table 1; resultant force, specific energy, and RDI for the

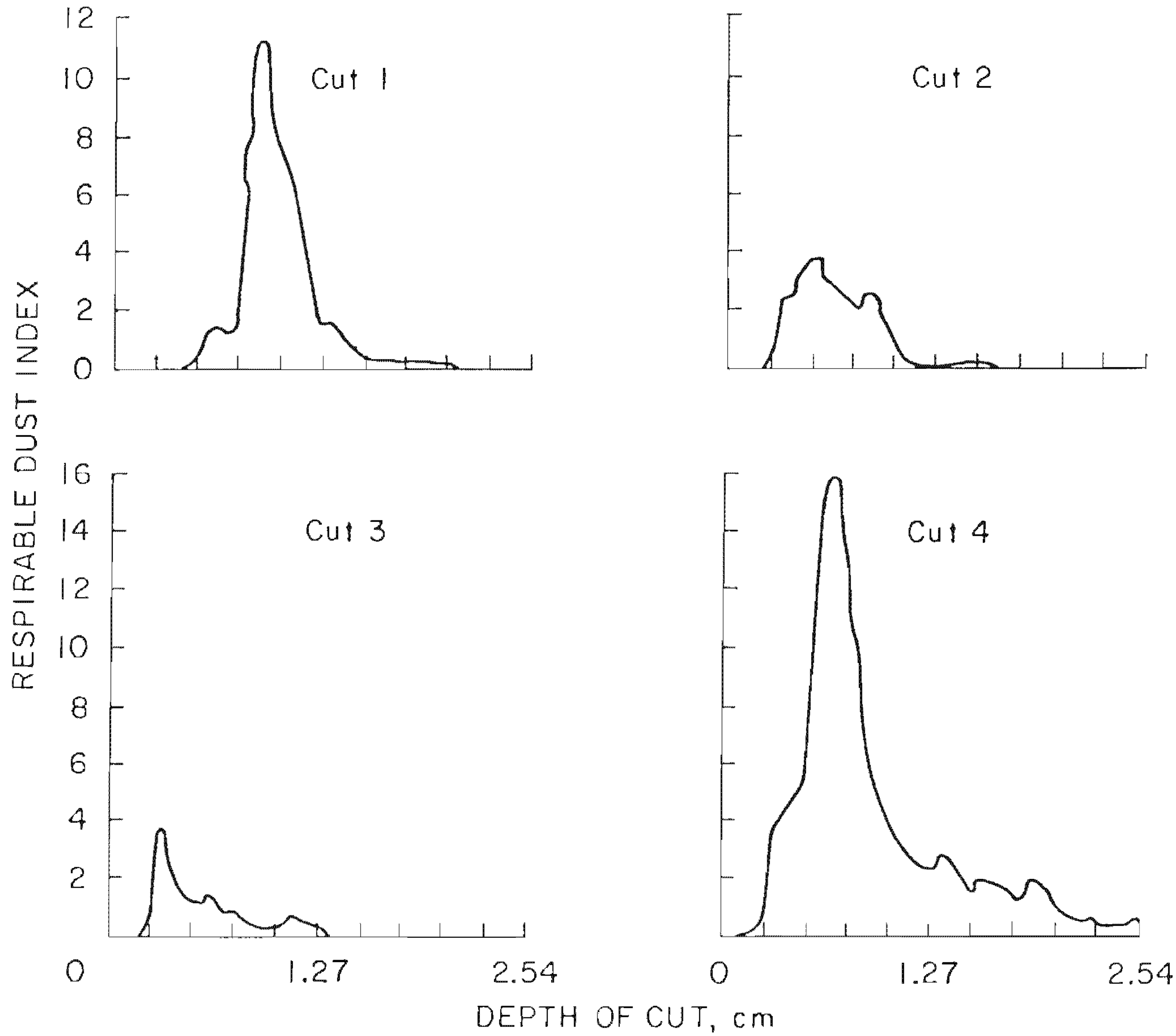

Figure 4.–Profile of respirable dust generated by one bit type during four successive cuts at mine 2, with background respirable dust in mine air at zero.

bits are graphically illustrated in figures 5, 6, and 7, respectively.

Test results for mine 1 show that at 1.27-cm DOC, the radial bit, 75° plumb bob, and the 80° cigar bit required 16, 31, and 37 pct of the resultant cutting force, used 31, 47, and 55 pct of the specific energy, and produced 70, 112, and 119 pct of the RDI in comparison to the 90° plumb bob. At 1.27-cm DOC, the RDI generated by the 75° plumb bob and the 80° cigar bit is higher than that generated by the 90° plumb bob at the same DOC. This anomaly cannot be explained, but it could be attributed to the nature of the coal and an insufficient number of replications. There was considerable scatter in the test results, which precludes results being used to relate dust to bit type.

For a 2.54-cm DOC, when compared to the 90° plumb bob, the radial bit, 75° plumb bob and 80° cigar bits required 21, 34, and 46 pct of the resultant cutting force, used 40, 45, and 65 pct of the specific energy, and generated 51, 75, and 84 pct of the RDI, respectively.

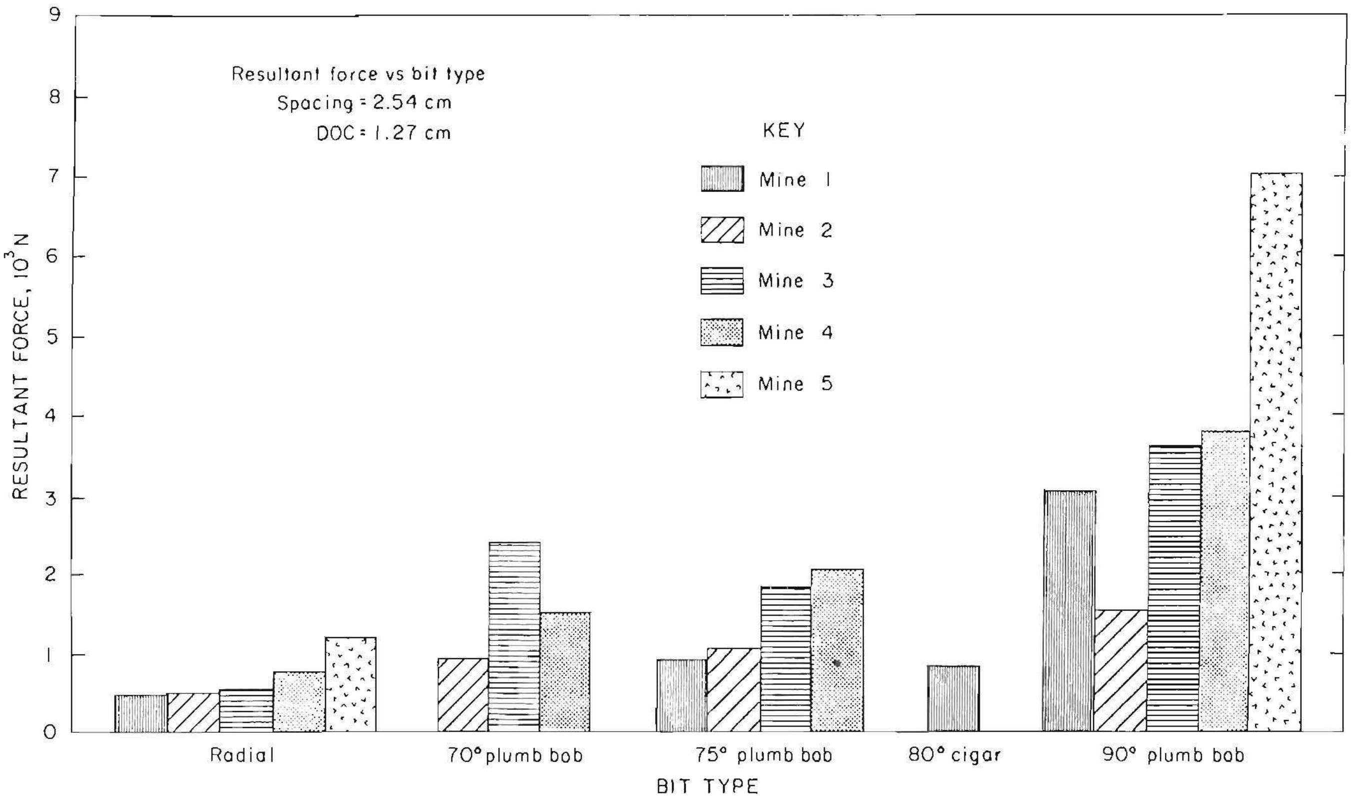

Figure 5.-Comparison of average resultant cutting forces for bits used.

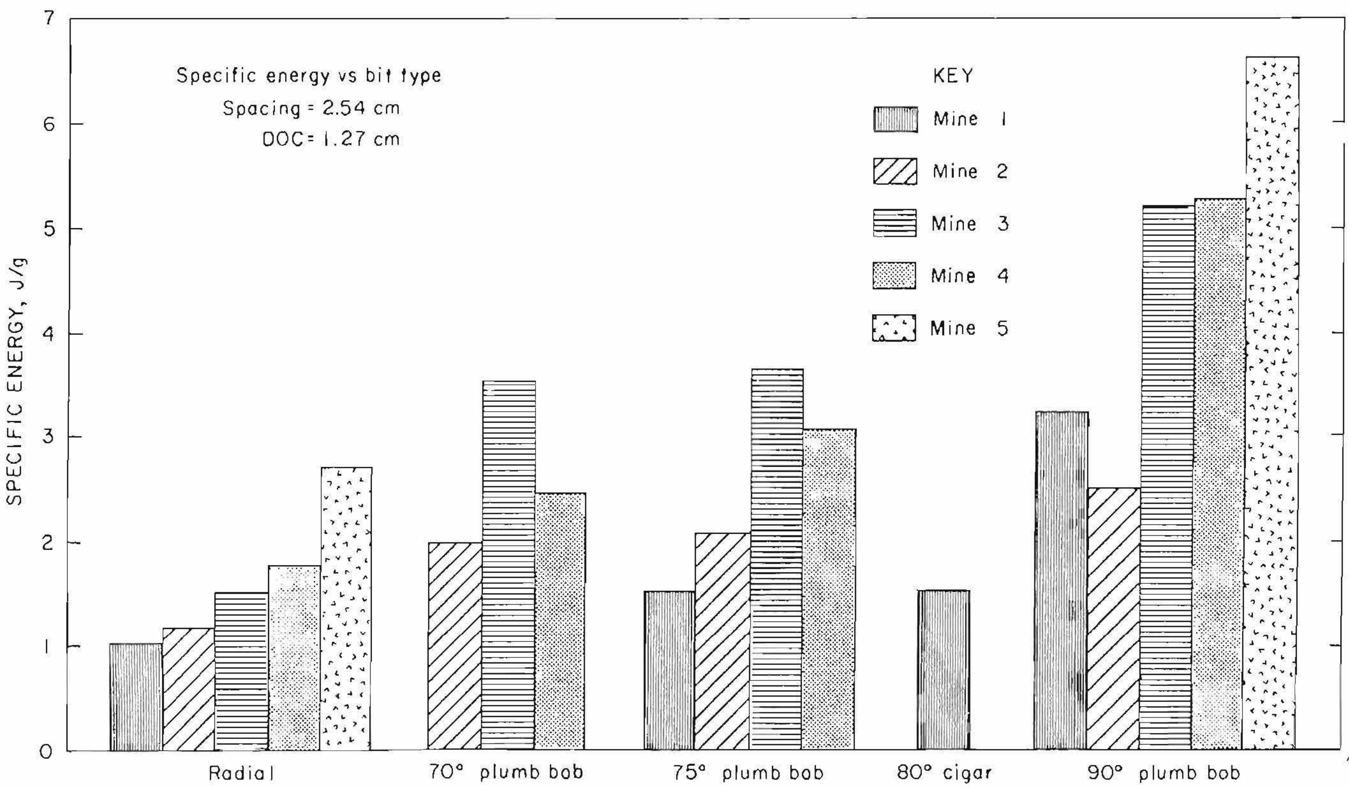

Figure 6.-Specific energy comparison for bits used.

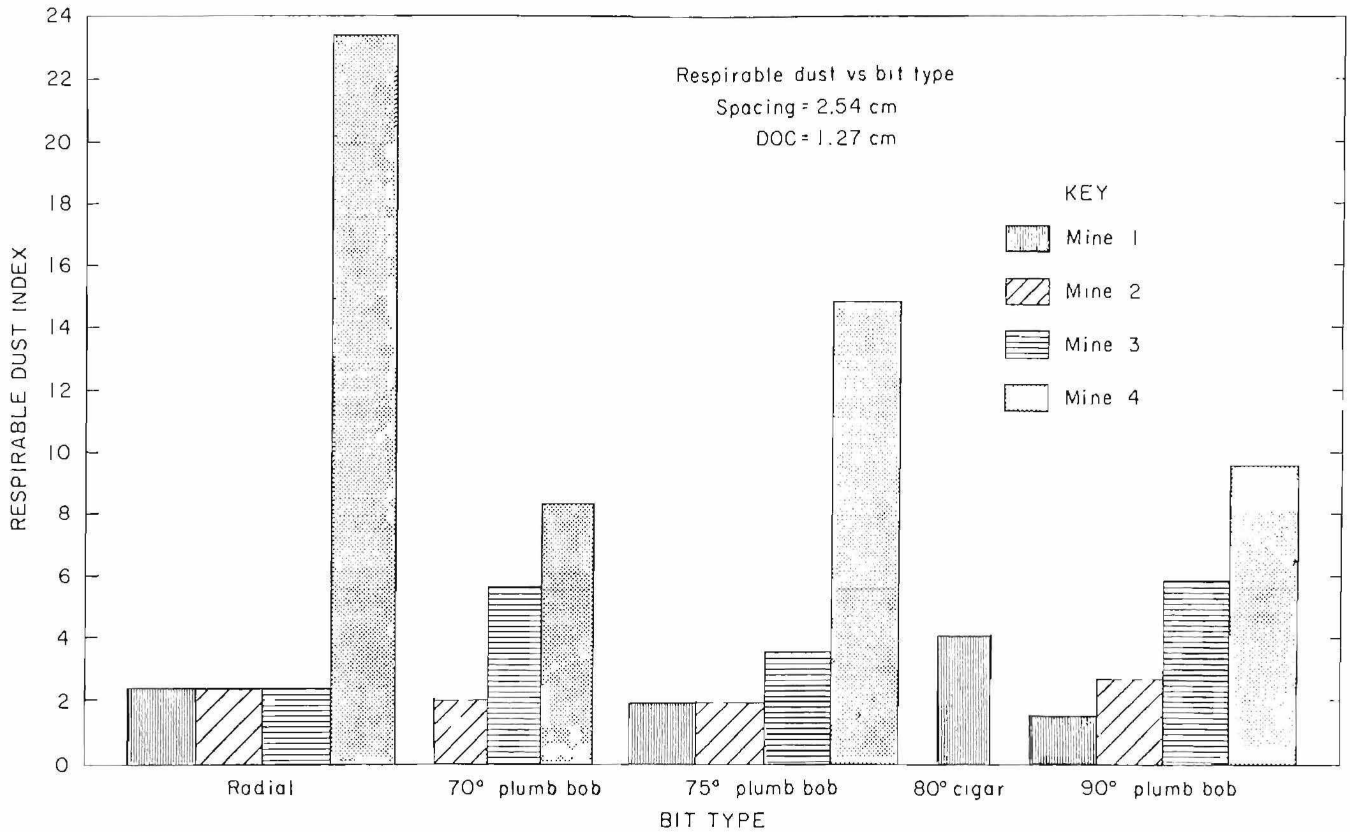

Figure 7.–Comparison of respirable dust index for various bits used.

Mine 2

At mine 2, 64 tests were conducted in the Illinois No. 6 Seam. A summary of test results is found in table 1 and figures 5, 6, and 7. The physical properties of the Illinois No. 6 coal seam are such that both 1.27- and 2.54-cm DOC's were possible. Each series consisted of 16 cuts made with a given bit, 8 cuts at the 1.27-cm DOC and 8 at 2.54-cm DOC. Four bits, a radial and 70°, 75°, and a 90° conicals were used.

Figure 5 illustrates the average resultant cutting forces produced at 1.27-cm DOC. The radial bit used the least force, while the conical bits needed progressively greater values as the included tip angles increased. These results are consistent with past experience (*10*).

A summary of observations made during testing in mine 2 reveals that the RDI cannot be directly related to bit type. Larger quantities of RD are simultaneously ejected when larger fragments of coal are produced during deeper cutting. Although deeper cuts use less specific energy, they require greater total energy, thereby creating relatively greater quantities of RD with the greater kinetic energy released. The larger chips formed at 2.54-cm DOC are ejected a greater distance, thus carrying relatively more dust with them.

Increasing the included tip angle of the conical bits appears to require progressively greater resultant forces to cut the coal, forming chips with greater kinetic energy and hence higher RD generation. However, observations show that the radial bit appears to cut coal with a ploughing action that produces fewer large chips and less RD. Laboratory tests were not conducted to verify or refute these observations.

Mines 3 and 4

Field tests in the Dorchester and Taggart Seams, mines 3 and 4, respectively, were conducted during one field trip. Because the test results are very similar, the tests for mines 3 and 4 are discussed together. In these mines, which are located 15 km apart, 31 and 25 tests, were made, respectively.

Even though the results are similar, geological conditions in each of these mines are distinctly different; development pillars and longwall panels are fairly intact in mine 3, while the same are heavily fractured in mine 4 because of excessive ground pressure. Fracturing of pillars and longwall panels in mine 4 takes place as quickly as mine openings are made. The problem was so critical that it was not possible to find a 2- by 2-m face to mount the IST in dead air. The tests in mine 4 had to be made in intake air. Coal in both mines was too strong to make 2.54-cm-deep cuts. Despite these differences, the cutting force required to make a 1.27-cm-deep cut is nearly the same in both mines as can be seen from table 1 and figure 5. The 70° plumb bob required approximately 60 pct more cutting force in mines 3 than in mine 4. In general, however, tests in mines 3 and 4 required much higher cutting forces and specific energy than either mine 1 or 2.

Table 1 shows that the horizontal components are similar for the radial bit and the 75° and 90° plumb bob bits in mine 3 and 4. Despite these similarities, significantly higher RD was recorded in mine 4. When mounted in the intake airway of mine 4, the IST was in high-volume, relatively high-velocity airflow. A possible explanation for the large increase in measured RD is turbulence inside the shroud caused by the higher air velocity in the entry; however, this was not verified.

Mine 5

Test results are given in table 1, average resultant cutting force, and specific energy are shown in figures 5 and 6, respectively, Test results show that for 1.27-cm DOC and 2.54-cm spacing, the radial bit, round-nose radial, V-shaped radial and 60° plumb bob bit, required 17, 40, 18, and 37 pct, respectively, of the resultant cutting force and used 41, 64, 33, and 51 pct of the specific energy required by 90° plumb bob. At 1.27-cm DOC and 5.08-cm spacing, these bits required 21, 47, 24, and 47 pct of the resultant cutting force and 50, 76, 50, and 69 pct of the specific energy required by the 90° bit, respectively. For each bit type, an increase in spacing from 2.54 to 5.08 cm increased the cutting force and specific energy significantly, except for the 90° bit, which showed a decrease in specific energy. The difference in the magnitude of cutting force and specific energy between plumb bob and radial bits was reduced with increased spacing.

The higher forces associated with the 90° plumb bob caused the salt in mine 5 to break into randomly larger pieces, but required proportionately less specific energy than the other bits. The random fragmentation of large pieces appeared to be the primary cause of scatter in the test results for mine 5.

In mine 5, even though the bits required 5 to 10 times more cutting force, only trace amounts of RD were generated. The salt in this mine seemed to be substantially stronger than the bituminous coal at mine 1. The salt has definite crystalline structure without loose dust particles in it as opposed to coal. Therefore, it is hypothesized that fewer dust particles are liberated while making cuts in the salt. Because salt is twice as dense as coal, there is less likelihood of the salt particles staying airborne, which affects the collection efficiency of the cyclone.

The data for mine 5 in table 1 show that doubling the space-to-depth (S-D) ratio results in independent cutting, which increases the cutting forces. The specific energy, however, was nearly the same for both S-D ratios, suggesting that it is controlled by the breakout angle of the material being fragmented. Despite higher cutting forces and an increased volume of fragmented material with the increased S-D ratio, no measurable increase in RD occurred. It should be noted that the RAM-1 was not adjusted from the setting for coal to accommodate the increased density or change in reflectance of the salt particles.

Past research has compared the performance of radial bits, including the V-shaped radial bit used in this investigation against the 60°, 75°, and 90° plumb bobs and 80° cigar bits (*9*). These earlier efforts were limited to comparing the cutting force required to make the same types of cuts. Conclusions from the present investigation are very similar to the prior conclusions; i.e., the radial bits require less tangential force and much less normal force over the point attack bits to make the same types of cuts.

The round-nose radial bit and the 90° plumb bob bit have a larger contact area on the clearance side of each tool, which results in a wide streak of crushed and compacted material in the path of each test cut. This appears to be the reason for the greater cutting forces required by these two bit types in salt. This same effect can be seen for the 90° plumb bob in the other mines.

SUMMARY OF TEST RESULTS

Figure 6 is a histogram of the specific energy observed at 1.27-cm DOC for all the mines. In table 1, all bits exhibit lower specific energies for 2.54-cm DOC. The radial bit requires roughly half the energy of its nearest competitor. These results are consistent with past experience (*5-7*).

Figure 7 is a histogram of the RDI for mines 1 through 4 with five bits at 1.27-cm DOC. RDI values at 1.27-cm DOC for mines 1 and 2 are essentially identical for all bits. However, the values for mines 3 and 4 are inconsistent and show no trend. This makes it impossible to compare or correlate bit type to RDI for these mines. The 2.54-cm DOC data of table 1 illustrate the efficiency of the radial design; the radial bit produced significantly lower RD levels than the conical bits, except at mine 4. The large performance difference between radial and plumb bob bits at 2.54-cm DOC, however, may be a result of variations in the physical properties (i.e., cleat orientation, calcite and pyrite fracture filling, parting thickness and composition) of the coal encountered by the two bit types. Without substantial additional in situ testing, this cannot be confirmed.

Specific dust, i.e., dust per unit volume of coal cut, is obtained by dividing the airborne respirable dust reading by the total weight of coal produced from each cut. A comparison of the specific dust generated at the various test sites in all four mines was observed to differ erratically for each bit type except the radial bit. The differences in the specific dust values are quite unexpected and not related to any test parameter.

Test results from the Springfield-Harrison No. 5 Seam, mine 1, using 2.54-cm DOC show that when compared with the 90° plumb bob, the radial bit, 75° plumb bob, and 80° cigar bits required 20.8, 33.9, and 45.9 pct more cutting force, respectively, and used 40, 45, and 65 pct of specific energy.

Cutting tests at mines 1 and 2 required approximately the same amount of cutting force and specific energy, while tests at mines 3, 4, and 5 required much higher cutting forces and specific energy. The test results for cutting force, specific energy, or RDI do not correlate with the grindability index of coal seams. Monitoring of RD in mine 4, even under a shroud, appeared to be significantly affected by the higher intake mine air velocity.

The RDI data were further analyzed with a one-way analysis of variance using the Duncan multiple range test (*11*). The results from the multiple range test are presented in table 2. In this table, the bits are listed in order of increasing RDI from left to right with one row for each DOC at each mine. Based on the Duncan multiple range test, the radial bit produced the lowest RDI at mines 1 and 3, and the highest RDI at mine 4. At mine 2, all bits produced the same amount of RD. Some data may fall in two different groups at the same time because each of the individual mean differences (i.e., radial bit - 90° plumb bob; 90° plumb bob - 75° plumb bob) are within the acceptable error limit, whereas the combined difference (i.e., radial bit - 75° plumb bob) is not. For these field tests, none of the conical bits followed any pattern of RD generation for the experimental design used.

CAUSES OF SCATTER IN RESPIRABLE DUST TEST DATA

There is large scatter in all the test data for both coal and salt cutting. The RDI not only varies from test to test, but the rate of RD generation varies within each test set.

One confirmed cause of RDI variation is the sudden release of energy associated with chip formation when the material fractures. Large bursts of RD have been associated with chip formation by relating peaks in the RD generation to load failure peaks.

Another cause of scatter in the RDI is the distribution of particles within a dust cloud. Because of turbidity, dust clouds do not have any particular shape or form. The density of dust clouds will vary spatially. Shape, size, and density of RD clouds will be altered by the mine airflow and kinetic forces on chip and coal fragments.

These problem areas suggest that the RDI is made up of several different cultures. The total quantity of primary RD generated at the coal face may vary several fold. When the change in RDI due to bit type is much smaller than variability of RDI due to other conditions present at the coal face, the effect of bit type on RD becomes masked.

With the test conditions used, it was not possible to pass the total volume of air in the IST shroud through the cyclone to determine the total amount of RD generated. Results show that there is a considerable difference in the RDI in the coal and salt. Test results also show that there is an erratic variation from bit to bit. The variations within each test series are very similar to a variation found in laboratory conditions where it is possible to sample the total volume of air. It was not possible to find the weight of total RD generated in test cuts, but test results for ARD are considered satisfactory for bit comparison investigations. The present investigation demonstrated that bit selection can not be made on the basis of dust generation alone.

Table 2.-Results of Duncan multiple range test for RDI data

Mine and DOC, cm	*Dust range of bit types*			
Mine 1: 1.27	Radial	90° plumb bob	75° plumb bob	80° cigar
2.54	Radial	75° plumb bob	80° cigar	90° plumb bob
Mine 2:[1] 2.54	Radial	70° plumb bob	75° plumb bob	90° plumb bob
Mine 3: 1.27	Radial	75° plumb bob	90° plumb bob	70° plumb bob
Mine 4: 1.27	70° plumb bob	90° plumb bob	75° plumb bob	Radial

DOC Depth of cut.
RDI Respirable dust index.
[1]Respirable dust production was the same for all bits at 1.27-cm DOC.

NOTE.-Dust measures from left to right: Lower range | Higher range

CONCLUSIONS

The Bureau-designed shroud was found to be satisfactory for comparing RDI generated by different types of bits cutting in coal. Present test results are very similar to laboratory test results reported by other investigators.

V-shaped radial bits have a slight advantage over the round-bottom radial bits. The round-bottom radial bits required 5 to 7 pct more cutting force and leave a streak of compacted salt in each test cut.

When the DOC was increased from 1.27 to 2.54 cm, the cutting force increased; thus the release of greater kinetic energy caused an increase in the RD. In each case, an increase in DOC resulted in an increased cutting force and a decreased specific energy.

Only traces of RD were generated in the salt deposit. Lack of RD generation is attributed to the high density of the salt and its crystalline structure, which causes fragmentation failure along crystal planes.

These test results confirm that it is not possible to recommend a single bit for all coal seams because of wide variance in seam conditions. Therefore, it is recommended that individual tests should be conducted in each mine to select the bit that will minimize respirable airborne dust and cutting forces.

Because of the high degree of scatter in test results, ARD (RDI) cannot be related to bit type. However, despite scatter in test results for ARD, significant difference was found in ARD generated in different coal seams. In general, ARD increased with increasing cutting force in all coal mines. The high degree of scatter encountered in the RDI data is typical of coal data obtained from a variety of face and rib areas. Further field testing in a single mine must be conducted to clarify the relationship among the bit spacing, bit tip angles, and RDI, before correlation may be established between a variety of bit types and coal seams. Such a field testing program would require a larger number of tests than were possible for this report to overcome the inherent variability of results.

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