APPENDIX U-5

EXECUTIVE SUMMARY OF INVESTIGATION OF PORTABLE METHANE AND MULTI-GAS DETECTORS

U.S. Department of Labor

Mine Safety and Health Administration
Approval and Certification Center
765 Technology Drive
Triadelphia, West Virginia 26059

November 17, 2011

MEMORANDUM FOR NORMAN G. PAGE
Accident Investigation Team Leader

FROM: JOHN P. FAINI
Chief, Approval and Certification Center

SUBJECT: Executive Summary of Investigation of Portable Methane and Multi-Gas Detectors Recovered from Performance Coal Company's Upper Big Branch – South Mine

The Approval and Certification Center (A&CC), as requested by Upper Big Branch Mine Accident Investigation Team Leader, Norman Page, conducted a laboratory investigation of portable methane and multi-gas detectors recovered from a fatal mine explosion at the Upper Big Branch Mine-South on April 5, 2010.

The investigation began with a preliminary inspection of all the exhibits. The preliminary inspection included decontamination of items that were considered potentially biohazardous, documenting visual observations, and photographing as-received conditions of the detectors. These inspections were followed by performance checks ('bump tests') and thermal ignition tests.

Data was downloaded from the detectors that featured datalogging capabilities. This data was provided to all interested parties as it became available.

Where feasible, performance tests were conducted on operational detectors to determine the accuracy of the instruments when tested in the methane-air mixtures specified in 30 CFR Part 22.7. For the datalogging detectors, the time and date displayed by the detectors was observed over a period of up to approximately seven months and compared to time clocks from external time verification sources. The rate of change was calculated from this data; where possible, this rate of change was used to extrapolate the instruments' time on April 5, 2010.

A detailed inspection of all exhibits except Exhibit Number B15B was deemed unnecessary by the Accident Investigation Team since they determined that these exhibits were not located near the origin of the explosion. Therefore, only Exhibit Number B15B was subjected to a detailed inspection.

The results of the inspections, tests, and evaluations are summarized below.

INSPECTIONS, TESTS, AND EVALUATIONS ON EXHIBITS

Performance Checks ('Bump Tests')

The performance of each functional instrument was checked at least once; some were checked contemporaneously with receipt but all were checked immediately prior to a complete methane performance test. These performance checks were performed with the respective manufacturer's calibration gas and equipment, and are commonly referred to as 'bump tests'. The following tables summarize the results of these checks, and, where available, give the last calibration date as stored in the detector's memory.

Industrial Scientific Corporation M40•M

Exhibit No.	Serial No.	Last Calibration Date	Fresh Air Readings			Bump Test Readings			Date of Test
			Methane	CO	Oxygen	2.5% Methane	100 ppm CO	19 % Oxygen	
A-20	0701048-573	2010-03-03	0.0	0	20.7	2.4	107	18.8	Jul 8, 2010

CSE 102/102LD Detectors

Exhibit No.	Serial No.	Fresh Air Reading	Reading in 2.5% Methane	Date of Test
A7A	5277	0.0	0.4	Jul 8, 2010
		0.1	2.4	Nov 3, 2010
B18-c	88486	0.1	0.3	Jul 8, 2010
		0.1	1.6	Nov 4, 2010
		0.1	1.1	Nov 8, 2010
B26-d	7328	(erratic)	(erratic)	Jul 8, 2010
		0.1	2.2	Nov 4, 2010
		0.1	2.2	Nov 8, 2010
PE-0290	84403	0.0	2.2	Nov 4,2010
		0.1	2.2	Nov 8, 2010
PE-0292	4898	N/A	N/A	NO TESTING[1]
PE-0298	7811	N/A	N/A	NO TESTING[2]
PE-0314	79905	0.0	2.3	Nov 4, 2010
		0.0	2.3	Nov 8, 2010

1 Exhibit Number PE-0292 was damaged as-received and no performance testing was possible.
2 Exhibit Number PE-0298 was damaged as-received and no performance testing was possible.

MSA Solaris Multi-Gas Detectors

Exhibit No.	Serial No.	Last Calibration Date	Fresh Air Readings			Bump Test Readings			Date of Test
			Methane	CO	Oxygen	2.5% Methane	60 ppm CO	15 % Oxygen	
B15B[3]	A5-86223	3-18-2010	---	0	N/A	0.00	0	N/A	Jul 8, 2010
			---	9	N/A	---	15	N/A	Nov 3, 2011
PE-0074[4]	A5-104696	3-15-2010	---	N/A	19.6	0.00	N/A	14.0	Jul 8, 2010
			0.20	N/A	N/A	2.35	N/A	N/A	Nov 3, 2011
PE-0086	A5-58751	2-14-2010	0.00	Var. 8-11	20.8	2.00	48	14.7	Jul 28, 2010
			0.00	0	20.8	2.30	51	14.9	Nov 3, 2011
PE-0118[5]	A4-26051	3-17-2010	N/A	N/A	N/A	N/A	N/A	N/A	N/A
PE-0323	A5-106631	4-1-2010	0.00	N/A	20.8	2.25	N/A	14.7	Nov 3, 2011

The detectors that passed the 'Bump Test' were considered to be accurate and not subjected to the performance test. Those detectors that gave readings outside the acceptable limits of the pass/fail criteria of the 'Bump Test' were subjected to performance testing (summarized below) both before and after calibration. The criteria for determining if a detector was outside the acceptable limits of the pass/fail criteria of the 'Bump Test' was based on the criteria developed for machine-mounted methane monitors, that describes that, when tested with 2.5% methane-in-air gas mixture, the allowable error is 2.5 ± 0.5.

The following detectors gave readings outside the acceptable limits of the pass/fail criteria of the 'Bump Test' when tested at the A&CC, as applied to methane performance: Exhibit Numbers A-20, A7a, B26-d, PE-0290, PE-0314, PE-0074, PE-0086, and PE-0323.

3 Oxygen cell in Exhibit Number B15B was greater than two years old when tested; it was most likely past the end of its useful life.

4 Oxygen cell in Exhibit Number PE-0074 was apparently bad when the unit was received at A&CC; by the time testing was conducted in November, the CO cell had apparently reached the end of its useful life.

5 No accuracy tests were performed on Exhibit Number PE-0118. Initially, the display was bad, and, before tests could be conducted, the unit stopped working properly.

No determination can be made of calibration accuracy and status of any detector at the time of the explosion.

Data Download

The data stored in all MSA Solaris and Industrial Scientific Corporation M40•M Multi-Gas Detectors was downloaded and provided to the Accident Investigation Team for further analysis. Additionally, the data downloaded from the MSA Solaris Multi-Gas Detectors was used to produce a document describing the contents of the data contained therein because such document was not available from the manufacturer. The downloaded data was also used in the time drift study discussed below.

Performance Testing

The operational detectors were subjected to testing in the methane-air mixtures specified in MSHA's test protocol for approval of portable methane detectors. The tables below summarize the results of the tests. The table entries in ***bold italic*** font were outside the allowable limits of error found in 30 CFR Part 22.7 for approval testing of a new, calibrated, methane detector.

CSE Corporation Methane Detectors

Exhibit No.	Model	Serial No.	Test Gas Mixture (% CH_4 in Air)								Source of Reading
			0.00	0.25	0.50	1.00	2.00	3.00	4.00	5.00	
A7A	102LD	5277	0.2	0.4	0.6	0.9	1.8	2.7	***3.4***	4.3	Detector
			0.00	0.24	0.51	1.02	2.03	3.03	4.02	5.01	IR Analyzer
B18-c[6]	102	88486	0.1	***0.0***	***0.1***	***0.3***	***0.9***	***1.4***	***1.9***	2.5	Detector
			0.00	0.24	0.51	1.02	2.03	3.03	4.02	5.01	IR Analyzer
B26-d	102LD	7328	0.1	0.1	***0.3***	***0.7***	***1.7***	***2.6***	***3.3***	4.2	Detector
			0.00	0.24	0.51	1.02	2.03	3.03	4.02	5.01	IR Analyzer
PE-0290	102	84403	0.0	0.2	0.4	0.8	***1.7***	***2.5***	***3.2***	4.1	Detector
			0.00	0.24	0.51	1.02	2.03	3.03	4.02	5.01	IR Analyzer
PE-0292	102LD	4898	NO TESTING[7]								
PE-0298	102LD	7811	NO TESTING[8]								
PE-0314	102	79905	0.1	0.3	0.5	1.0	1.8	2.7	***3.4***	3.9	Detector
			0.00	0.24	0.51	1.02	2.03	3.03	4.02	5.01	IR Analyzer

6 Exhibit Number B18-c could not be calibrated because the maximum reading with 2.5% cal. gas was 1.9.
7 Exhibit Number PE-0292 was damaged and no performance testing was possible.
8 Exhibit Number PE-0298 was damaged and no performance testing was possible.

MSA Solaris Multi-Gas Detectors

Exhibit No.	Serial No.	Test Gas Mixture (% CH_4 in Air)								Source of Reading
		0.00	0.25	0.50	1.00	2.00	3.00	4.00	5.00	
B15B[9]	A5-86223	NO PERFORMANCE TESTING								
PE-0074	A5-104696	0.10	0.40	0.55	1.00	1.95	2.90	4.05	5.00	Detector
		0.00	0.27	0.50	1.00	2.03	3.03	4.03	5.03	IR Analyzer
PE-0086	A5-58751	0.00	0.25	0.50	0.95	1.90	2.85	3.90	5.00	Detector
		0.00	0.27	0.50	1.00	2.03	3.03	4.03	5.03	IR Analyzer
PE-0118[10]	A4-26051	NO PERFORMANCE TESTING								
PE-0323	A5-106631	0.00	0.25	0.40	***0.75***	***1.70***	***2.60***	***3.40***	4.35	Detector
		0.01	0.27	0.52	1.00	2.04	3.02	4.05	5.00	IR Analyzer

The Solaris readings noted as "5.00" above were accompanied by an alternating message 'OVER' on the display, indicating an over range condition. All visual, audible and vibrating alarms were given as defined in each detector's setup.

Industrial Scientific Corporation M40•M Multi-Gas Detector

Exhibit No.	Serial No.	Test Gas Mixture (% CH_4 in Air)								Source of Reading
		0.00	0.25	0.50	1.00	2.00	3.00	4.00	5.00	
A-20	070148-573	0.0	0.0	0.4	0.9	1.8	2.8	3.7	4.5	Detector
		0.00	0.28	0.54	1.04	2.04	3.04	4.00	4.99	IR Analyzer

The M40•M gave all audible, visual, and vibrating alarms as expected.

9 When attempting to calibrate Exhibit Number B15B, the detector gave a 'span failed' message. No performance testing was conducted.

10 No accuracy tests were performed on Exhibit Number PE-0118. Initially, the display was bad. After replacement of the display, the operatiou of the detector was erratic. The detector stopped working properly before tests could be conducted.

Time Drift Study

The Industrial Scientific Corporation and MSA instruments featured internal clocks. The length of a time period measured by these internal clocks can deviate from the length of the same time period measured by more precise means; one second measured by a gas detector can differ from one second as measured by the National Institute of Standards and Technology (NIST).

In laboratory environmental conditions, it was noted that clocks in each detector did, indeed, differ from that obtained from external time verification sources. Given the tolerances of each time measurement, calculations were made to determine the minimum and maximum rates of drift of the detector's internal clock as compared to the time from external sources.

The downloaded data from the detectors was scrutinized to locate an entry on April 5, 2010 that might signify a significant event (over-range of a specific gas or gases). The minimum and maximum drift rates were then used to correlate the time for that entry to the expected time from external sources.

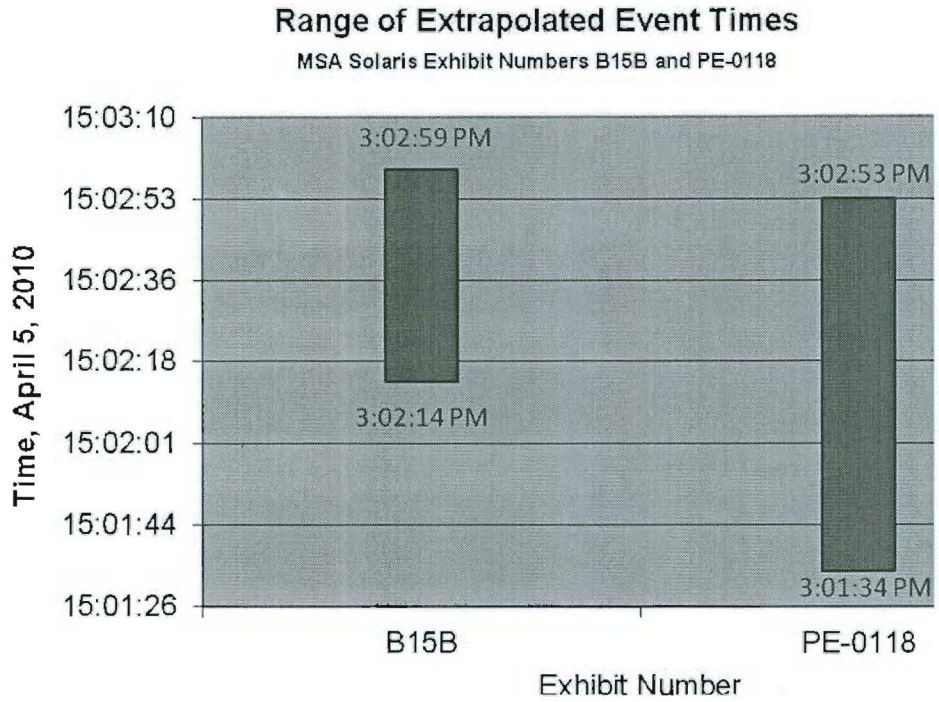
It was determined that the clock in the Industrial Scientific Corporation Model M40•M, Exhibit Number A-20, reset automatically when the battery was depleted. No correlation was possible, although the drift rate was calculated.

It was determined that the MSA Solaris Multi-Gas Detector, Exhibit Number PE-0086 was not energized on April 5, 2010.

When the MSA Solaris Multi-Gas Detector, Exhibit Number PE-0074 was initially reviewed in July 2010, the difference between its internal clock and the external time verification source was approximately 25 hours and 40 minutes. The drift rate was calculated as 6.294 seconds per day; this was insufficient to describe the wide variation noted. Also, the ambient temperature required to cause the drift to describe the difference would necessarily have deviated from normal ambient temperature by unreasonable amount (>496 °C higher or lower than normal room temperature). MSA, the manufacturer of the detector and Maxim, the manufacturer of the integrated circuit were consulted; the only reason that was postulated by either party was "human assistance." However, review of the downloaded data does not support that conclusion. The reason for the clock in Exhibit Number PE-0074 to have deviated from external time by such a wide margin could not be determined in this investigation.

The MSA Solaris Multi-Gas Detector, Exhibit Number B15B recorded an over-range event for combustible gas, oxygen, and carbon monoxide on April 5, 2010. Similarly, on the same date, the MSA Solaris, Exhibit Number PE-0118 recorded an over-range event for oxygen and carbon monoxide, followed by an over-range event for combustible gas at the next recording interval 15 seconds later; it should be noted that these events could have been within as little as 1 second, or as much as 29 seconds. If

the drift was constant from April 5, 2010 until MSHA began taking time measurements, the actual expected time and date for the over-range events is as shown on the graph below.



The difference in the median of these two ranges is most likely due to the differences in the environment of the two detectors. Exhibit Number B15B was received on June 24, 2010, and kept in the climate-controlled MSHA building. Exhibit Number PE-0118 was not received until July 19, 2010. The environment before that date is not known, but has been anecdotally described as non-climate controlled.

Intrinsic Safety

The only tests conducted to determine the intrinsic safety of the detectors were thermal ignition tests. The testing was conducted on Exhibit Numbers A7A, A-20, B15B, B18-c, B26-d, PE-0074, PE-0086, PE-0290, PE-0314, and PE-0323. The damage to Exhibit Numbers PE-0292 and PE-0298 was too extensive to allow for testing. The test was conducted primarily to verify that the catalytic sensor was not reaching temperatures high enough to ignite methane. No ignitions of the test gas mixture were observed.

Additionally, for all the detectors (except those with Exhibit Numbers PE-0292 and PE-0298, because of the extent of damage), the preliminary inspection did not reveal any conditions that would suggest that any exhibit caused the explosion.

OTHER TESTS AND EVALUATIONS

The following are based on tests on exemplar detectors and similar detectors tested in previous investigations, manufacturer's documentation, and other public documentation.

The change in the reading associated with the combustible sensor in the MSA Solaris and Industrial Scientific Corporation M40•M is insignificant due to increases in barometric pressure. However, sudden increases in barometric pressure can cause both of these detectors to experience significant increases in the oxygen reading.

The MSA Solaris Multi-Gas Detector includes a temperature sensor inside the unit. The temperature is recorded every 15 minutes, and the data is contained in the periodic data log. As the temperature at the sensing detector inside the detector increases, the value recorded increases. However, the temperature sensor is somewhat insulated from the ambient temperature due its location; if the temperature outside the unit changes quickly, the temperature recorded by the unit will lag until the temperatures equalize.

The methane (catalytic) sensor used in the detectors is actually a combustible gas sensor. It will respond to other combustible gases. The following tables give the expected cross-sensitivity to other combustible gases, such as hexane, ethane, propane, butane, and pentane.

Expected Response of MSA Solaris to Selected Gases

Combustible Gas	Multiply %LEL Reading by	Column 2 Normalized to methane	Scaling Factor (Reciprocal of Column 3)	Lower Explosive Limit of Gas of Interest	Calculated Reading on Solaris at LEL of Gas of Interest	Displayed Value on Solaris at LEL of Gas of Interest.
n-Hexane	1.3	2.16666667	0.461538462	1.2	0.55	*0.55*
Ethane	0.7	1.16666667	0.857142857	3	2.57	*2.55*
Propane	0.8	1.33333333	0.75	2.1	1.58	*1.60*
Butane	1	1.66666667	0.6	1.8	1.08	*1.10*
Pentane	1	1.66666667	0.6	1.4	0.84	*0.85*
Methane	0.6	1	1	5	5.00	*5.00*

Expected Response of ISC M40•M to Selected Gases

Combustible Gas	Correlation Factor	Scaling Factor (Reciprocal of Column 2)	Lower Explosive Limit of Gas of Interest	Calculated Reading on M40-m at LEL of Gas of Interest	Displayed Value on M40-m at LEL of Gas of Interest.
n-Hexane	2.18	0.458715596	1.2	0.5505	*0.60*
Ethane	1.24	0.806451613	3	2.4194	*2.40*
Propane	1.51	0.662251656	2.1	1.3907	*1.40*
Butane	1.64	0.609756098	1.8	1.0976	*1.10*
Pentane	1.84	0.543478261	1.4	0.7609	*0.80*
Methane	0.6	1	1	5	*5.00*

A document was created that describes the contents of the data downloaded from the MSA Solaris. This is included in an Appendix B to the report. It should be noted that individual data points can become corrupted, and not be reported in the data log.

This report addresses the atmospheres or contaminants that can cause electrochemical oxygen and carbon monoxide sensors and catalytic combustible sensors to fail. For the electrochemical sensors, the most common cause for failure is time; they have a significantly shorter useful life than the catalytic combustible sensor. The most common poisoning agents for the catalytic combustible sensor are those containing silicon.

APPENDIX U-6

EXECUTIVE SUMMARY OF THE INVESTIGATION OF POWER SUPPLY, AMPLIFIER BATTERY, TRACKING TAG, AND TAG READER COMPONENTS ASSOCIATED WITH PYOTT-BOONE TRACKING BOSS TRACKER SYSTEM AND MINECOM UHF LEAKY FEEDER SYSTEM