MAR 05 1997 (20) Sta. 37

ENGINEERING DATA TRANSMITTAL

1. EDT 601041

2. To: (Receiving Organization)	3. From: (Originating Organization)	4. Related EDT No.:
Distribution	Engineering Testing Laboratory - 8C921	N/A
5. Proj./Prog./Dept./Div.:	**6. Design Authority/ Design Agent/Cog. Engr.:**	**7. Purchase Order No.:**
8C921	K. S. Witwer	N/A
8. Originator Remarks:		**9. Equip./Component No.:**
For Review and Release		N/A
		10. System/Bldg./Facility:
		200 General
11. Receiver Remarks: **11A. Design Baseline Document?** [ ] Yes [X] No		**12. Major Assm. Dwg. No.:**
		N/A
		13. Permit/Permit Application No.:
		N/A
		14. Required Response Date:
		ASAP

15. DATA TRANSMITTED

(A) Item No.	(B) Document/Drawing No.	(C) Sheet No.	(D) Rev. No.	(E) Title or Description of Data Transmitted	(F) Approval Designator	(G) Reason for Transmittal	(H) Originator Disposition	(I) Receiver Disposition
1	HNF-SD-WM-TRP-269	N/A	0	Report on Ignitability Testing of Flammable Gasses in a Core Sampling Drill String	QS	2	1	

16. KEY

Approval Designator (F)	Reason for Transmittal (G)	Disposition (H) & (I)
E, S, Q, D or N/A (see WHC-CM-3-5, Sec.12.7)	1. Approval 4. Review 2. Release 5. Post-Review 3. Information 6. Dist. (Receipt Acknow. Required)	1. Approved 4. Reviewed no/comment 2. Approved w/comment 5. Reviewed w/comment 3. Disapproved w/comment 6. Receipt acknowledged

17. SIGNATURE/DISTRIBUTION
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(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN	(G) Reason	(H) Disp.	(J) Name	(K) Signature	(L) Date	(M) MSIN
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18.	19.	20.	21. DOE APPROVAL (if required) Ctrl. No.
K.S. Witwer Signature of EDT Originator — Date 1/9/97	John Schofield Authorized Representative for Receiving Organization — Date 3/3/97	M.J. Schliebe Cognizant Manager — Date See Blk. 17K 3/5/97	[ ] Approved [ ] Approved w/comments [ ] Disapproved w/comments

Report on Ignitability Testing of Flammable Gasses in a Core Sampling Drill String

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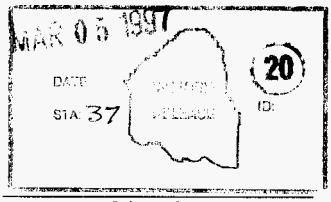
EDT/ECN: 601041 UC: 2070
Org Code: 8C921 Charge Code: N4H3B
B&R Code: EW3120074 Total Pages: ~~34~~ 35

Key Words: Pittsburgh Research Center, Ignitability, Core Sampling

Abstract: This document describes the results from testing performed at the Pittsburgh Research Center to determine the effects of an ignition of flammable gasses contained in a core sampling drill string. Testing showed that 1) An ignition of stoichiometric hydrogen and air in a vented 30 or 55 ft length of drill string will not force 28" or more of water out the bottom of the drill string, and 2) An ignition of this same gas mixture will not rupture a vented or completely sealed drill string.



Release Approval Date

Release Stamp

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REPORT ON IGNITABILITY TESTING OF FLAMMABLE GASSES IN A CORE SAMPLING DRILL STRING

HNF-SD-WM-TRP-269
REV. 0

December, 1996

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

IGNITABILITY TESTING OF FLAMMABLE GASES IN A CORE SAMPLING DRILL STRING

1.0 INTRODUCTION

The Numatec Hanford-Engineering Testing Laboratory (ETL) received funding from the Characterization Equipment Design Group to test the explosive energy resulting from an ignition of flammable gases within a core sampling drill-string. Specifically, the goal was to observe if such an ignition and resulting explosion would cause hot combustion gases to be expelled through a column of water at the bottom of a length of drill string. This column of water would simulate liquid waste - in which a core sampling drill string might be placed during normal sampling operations. An escape of these hot combustion gases from the drill string could theoretically lead to an ignition of the flammable gases contained within the waste tank - a serious safety concern. The ETL enlisted the services of the Fires, Explosions, and Explosives Group at the Pittsburgh Research Center (PRC) of the National Institute of Occupational Safety and Health (NIOSH) to provide necessary facilities, equipment and manpower to support this research effort. (The PRC was formerly part of the U.S. Bureau of Mines and is now part of its successor - NIOSH.) This testing followed Test Plan WHC-SD-WM-TP-512[1] and was performed during October 1996. The test site was the U.S. Government Pittsburgh Research Center near Pittsburgh, PA. Aldo Furno, Gregory M. Green, Richard A. Thomas, and Tracy L. Goldbach of PRC provided direct support during set-up and testing. The authors also thank Robert F. Chaiken of PRC for his input to the interpretation of the data.

2.0 TEST METHOD AND TEST EQUIPMENT

2.1 TEST METHOD

Per the test plan, a length of either thirty or fifty-five feet of standard 2.25" (OD) drill string was suspended vertically, with the bottom one to three feet placed in a container of water. The submerged end of the drill string was capped with a rotary drill bit to simulate actual field sampling conditions. A rotary bit was chosen over a push mode bit because its purge hole geometry allowed an easier gas release path than the "non purge hole" push-mode bit. (This being the "more bounding" or "conservative" scenario because it provided the easiest path for gas to escape out the bottom of the drill string.)

The top of the drill string was fitted with a remotely controlled ball valve with a ½" diameter opening. Testing was done with the ball valve both open and closed. The container of water, which was a 55 gallon (22½" diameter) metal drum for some testing and a 30 gallon (16" diameter) drum for later

tests, contained a one to three foot column of water. (The change from the 22½" diameter to the 16" diameter was intended to produce a larger water level change in the drum for a given a gas release.)

Gas mixing and flow system instrumentation and test procedures were similar to those used for previous joint projects by the PRC and WHC[2,3,4]. The flammable gasses were mixed in a 120-L chamber and then flowed to the drill string. Flammable gas flowed via a copper tube up through the drill bit in the bottom of the drill string to a spot just above the water level. When the water level was varied for different tests, the position of the gas inlet tube was also adjusted to keep it just above the water level. The gas flowed up the drill string and exited out the ½" diameter vent opening at the top. One pressure transducer was placed just above the 36" water line and another was placed approximately 2" below the ball valve at the top of the drill string. These transducers provided a record of pressures generated during an explosion . One ignitor port was placed just above the 36" water line, another was placed near the center of the length of drill string, and a third was placed just below the top ball valve. This configuration provided three possible locations for placing the electric match or hot wire ignitor.

A six-foot section of ½" schedule 40 pipe was placed above the ball valve at the top of the drill string for the tests incorporating 55 feet of drill string. This extra length of pipe added some possible additional flow restriction to the combustion gases. It was added to more closely simulate hardware used on the Core Sampling Trucks.

A stoichiometric mixture of hydrogen and air (30% H_2 and 70% air) was chosen as the final test gas. This mixture was also used in previous ignitability testing[3] where it was determined to be bounding over any flammable waste tank gas mixture in terms of ignitability. The mixture was fed at 0.028 m^3/min (1ft^3/min) for either four or five minutes, respectively, depending on whether a 30 or 55-ft length of drill string was being used. Gas flow was shut off after this initial purge and the mixture was immediately ignited using either an electric match or a hot wire. The 55 or 30-gallon drum was observed for both a change in water level and the presence of gas bubbles rising to the surface. These were recorded using a high speed video camera. The pressure transducer outputs obtained during each test were recorded on a PC-based data acquisition system.

These purge times were verified during previous[4] ignitability testing and were verified again using Gas Chromatography (GC) during the current test series. In the previous testing, nitrogen was flowed through the system and an oxygen analyzer was used at the top of the drill string to determine the time necessary to purge. In the current tests, gas mixtures of either 20% or 30% H_2 in nitrogen were flowed from the 120-L mixing chamber to and through the drill string. Hydrogen-nitrogen mixtures were used to avoid the danger in handling flammable gas samples, but they would have the same flow characteristics as hydrogen-air mixtures. The samples for GC analyses were collected through a fitting in the wall of the pipe at about 20 ft above the gas inlet. The GC analyses confirmed that the hydrogen concentration was as predicted and that the purge times were sufficient. These results can be seen in Appendix B.

An additional set of four tests involved igniting the flammable mixture in a completely closed drill string. One of these used a 20% hydrogen and 80% air mixture and the other three used the

stoichiometric mixture. A plug was placed in the bottom of the fifty-five foot long drill string and gas was fed through a fitting approximately three feet from the bottom. The gas flow was shut off after five minutes, the upper ball valve was immediately closed, and gas mixture was ignited.

The hydrostatic pressures corresponding to 1 and 3 ft of water are 2.96 and 8.96 kPa (0.43 and 1.30 psi), respectively. The expected explosion pressure[2] resulting from an ignition of stoichiometric H_2-air is much larger than these hydrostatic pressures. The question that these tests is expected to answer is whether the pressure pulse lasts long enough to expel the water and allow gas bubbles to escape. These tests are conservative because the gas bubbles that might escape would be cooled as they pass through the liquid before they could reach the potential flammable gases above the liquid waste. In reality, a relatively large escape of gases would be necessary in order for the gases to remain hot enough (after passing through the liquid waste) to still ignite flammable gases above the waste.

2.2 TEST EQUIPMENT

The test equipment used is outlined in the test plan, however, some minor changes/additions to the plan were made as follows. An extra hole was burned into the face of the rotary mode sampling bit to allow a copper gas inlet tube to pass through without restricting the flow of the combustion exhaust gases. Also, part of a 55-gallon drum was welded onto the top of another 55-gallon drum to increase the total height to four feet for the 22½" diameter drum. This drum was used for the first tests. A 30-gallon drum, with a 16" diameter, was similarly modified and used for the remainder of the tests.

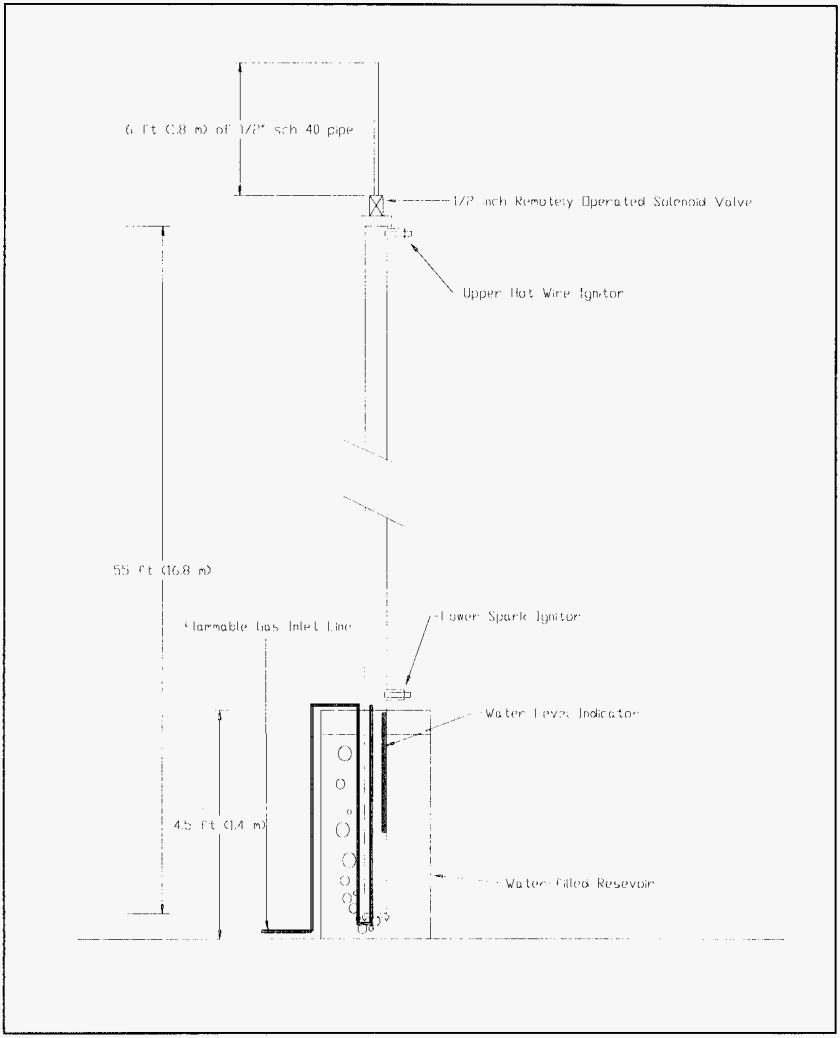
Some equipment information was not available when the test plan was written and is given below in Table 1 by item name, manufacturer, and part number.

Table 1 - Test Equipment

Item	Manufacturer	Part Number
5' Drill String Section	Longyear	200182
½" Ball Valve (Remotely Operated)	Whitey Valve	SS-63TF8-42AC
Rotary Mode Core Sampling Bit	Longyear	100IVD/8

The test arrangement is shown in Figure 1 below.

Figure 1 - Test Arrangement



3.0 TEST RESULTS

A detailed table listing data for each test (#8001-8052) is provided in Appendix A. The measured explosion pressures (gauge) from the two transducers are listed in the two columns identified as "P1-b" for the bottom transducer and "P2-t" for the transducer at the top of the drill string. In the last column of the table it is noted whether any gas bubbles were observed during a test.

To focus in on the instances when gas was not released out the bottom of the drill string as well as reduce the hazards involved with the potentially energetic hydrogen and oxygen gas mixture, a graded approach to testing was used. The percentage of hydrogen in the flammable gas mixture was initially set at 10% for the first few tests and was gradually increased until a stoichiometric mixture of 30% hydrogen and 70% air was used. As long as the results showed that either no personnel hazard existed, and/or combustion gases were not being expelled out the bottom of the drill string, the percent quantity of hydrogen was gradually increased. In addition, the drill string length, the height of the water column, and whether the ball valve vent (at the top of the drill string) was open or closed were each adjusted using the same logic. The drill string was only twenty feet long for the first few scoping tests (#8001-8012). This gave a lower volume of available gas and potentially less available energy upon ignition to force gas out the bottom of the drill string. The water level was set to thirty-six inches above the bottom of the drill bit for the first tests and was gradually reduced to twelve inches for subsequent tests. Since the 36" column of water provided a higher hydrostatic head than 12" of water, the first tests had to overcome more hydrostatic pressure for the gas to escape than the following tests. If gas escaped with the level at 12" of water, the level was adjusted higher in subsequent tests until a level was reached where no gas escaped.

The first two tests (out of 52 total) were run with the top ball valve closed at the time of ignition. Combustion gases were violently expelled out the bottom of the drill string with a thirty six-inch hydrostatic head. Because of this violent release, the remaining tests were done with the valve open. This allowed some combustion gases to escape, thereby reducing the explosion pressure pulse.

The gas mixture was ignited using either an electric match or a hot nichrome wire. For simplicity, the electric match was used for tests where the mixture was ignited at the bottom of the drill string. Because of the difficulty of replacing a "one-time use" match placed thirty to fifty-five feet in the air, the hot wire ignitor was developed for use with two of the tests involving ignitions at the center of the drill string and all of the tests involving ignitions at the top of the drill string. All other things being equal, the explosions initiated at the top of the drill string caused combustion gases to be forced out the bottom more readily than explosions initiated near the bottom or near the middle. Because of this, the final tests were done with the ignitions at the top of the drill string.

Notes were kept in a controlled logbook (WHC-N-984 1) during testing. Results from the testing are given below.

3.1 THIRTY FOOT LENGTH OF DRILL STRING

Twenty-seven different tests (#8013-8032 and #8046-8052) were run using the thirty-foot length of drill string. The first of these used a 20% hydrogen and 80% air flammable gas mixture. Since the ignition of this gas mixture did not cause release of gases out the bottom of the drill string, the gas mixture was changed to the stoichiometric hydrogen-air mixture for the remaining tests.

Because ignition at the top of the drill string was the most conservative case (allowing gases to most readily escape), this test condition was used for the final determination of the water height that would just allow bubbles to escape and the water height that would not allow bubbles to escape. A stoichiometric hydrogen-air mixture was used and the top ball valve vent was open for these determinations. Under these test conditions, when the water level was set at 24" or less, gas bubbles escaped out the bottom. When the level was set at 28" or greater, no bubbles were observed. This latter test was repeated six times for verification and the same result (no bubbles) was obtained each time. (For tests with the ignitor at the bottom, 18" of water was sufficient to prevent gas bubbles from escaping.)

The pressures recorded for these tests showed a wide range even for the same test conditions. For ignition at the top, the lowest measured pressure values were ~8 psi at the bottom transducer and ~7 psi at the top pressure transducer (test #8022). The highest values were 198 psi at the bottom pressure transducer (test #8047) and 64 psi at the top pressure transducer (test #8049) for ignition at the top. For ignition at the top, the pressure observed at the bottom pressure transducer was generally higher than that measured at the top transducer. This is because the pressure is generally higher after all the gases have been combusted, at the time the flame reaches the opposite end of the drill string from the ignition point. (For ignition at the bottom, in test #8019 for example, the higher pressure is observed at the top transducer.) The question of whether or not gas bubbles were expelled from the drill string was unrelated to these differences in peak explosion pressure from test to test. The explanation for this effect is probably that the pressure pulse (pressure-time integral) is what determines whether or not gases escape. This is understandable when you consider that the pressure must act on the water for a long enough period of time to overcome the inertia of the water. A high pressure for a short time and a low pressure for a longer time could move the same amount of water.

The wide range of pressures observed for the same test conditions is probably due to two modes of flame propagation. In one case, the propagation may be nearly laminar and the flame speed is slower. In the other case, the propagation is more turbulent and the flame travels much faster. The shift to turbulent propagation could be caused by small differences in the initial stages of the flame, leading to a rapid acceleration and increased turbulence. For the slower flame, the combustion gases would cool behind the flame front before the flame reached the opposite end of the pipe. This would result in a lower peak pressure but a longer pressure pulse time. For the fast turbulent flame, the combustion gases would not have time to cool before the flame reached the opposite end of the pipe, resulting in a higher peak pressure along with the shorter pressure pulse time.

To compare the pressure pulses, pressure-time integrals were calculated for the bottom transducer for two tests under the same initial conditions. Test #8021 had a peak pressure of 149 psi and a pressure pulse of ~0.8 psi-sec. Test #8022 had a peak pressure of only ~8 psi but still had a pressure pulse of ~0.8 psi-sec. A few pressure-time integrals were also calculated for additional tests with stoichiometric H_2-air, ignition at either the top or bottom, and either 30 or 55 ft of drill string. The values ranged from 0.7 to 1.1 psi-sec.

An additional test (#8032) was run which involved venting through a ½" ball valve mounted in the side of the drill string placed approximately 20 ft from the bottom. For this test, the top ball valve vent was closed (after an initial purge) and the mixture was ignited at the top. As with the previous test, the water level was set at 30" and the mixture was stoichiometric. Gas did not escape out the bottom with this test. This test showed that the positioning of the purge vent was not critical.

3.2 FIFTY-FIVE FOOT LENGTH OF DRILL STRING

Much of the exploratory testing was done with the thirty-foot length of drill string. This answered several questions (e.g.; whether a stoichiometric mixture could be used without danger to equipment or personnel; in what position should the ignitor be placed to cause the gas to be pushed out most readily, etc.) and reduced the number of tests needed with the 55 ft of drill string. There were a total of nine tests (#8033-8041) at 55 ft. For these tests, a six-foot length of ½" schedule 40 pipe was installed above the ball valve at the top of the drill string. This hardware modification, which was requested by Characterization Group personnel, provided a possible additional restriction to the escaping combustion gases, thus making the gas more prone to vent out the bottom of the drill string. The additional restriction with this extra length of pipe more closely resembles the restriction from the vent lines on the core sampling trucks and will simplify any engineering changes resulting from this testing.

All of the 55 ft tests were run with the ignitor at the top since this was the most conservative condition for the 30 ft tests. For the 55 ft tests, a few gas bubbles were observed escaping out the bottom when the water level was set at 24". When the level was increased to 28", no gas was observed escaping out the bottom. This latter test was run six more times for verification with the same results. Peak pressures ranged from 9 to 136 psi at the bottom transducer and from 9 to 50 psi at the top transducer for these tests. However, the pressure pulses (pressure-time integrals) were in much closer agreement. For example, test #8037 had a peak pressure of 136 psi and a pressure pulse of ~1.1 psi-sec. Test #8038 had a peak pressure of only ~16 psi and a pressure pulse of ~0.8 psi-sec. The final conclusion from the data at 55 ft was that explosions in the longer drill string were no more likely to expel gas bubbles than those in the 33 ft drill string.

3.3 COMPLETELY CLOSED DRILL STRING

Four tests (#8042-8045) were run with both the top vent closed and the bottom of the 55' drill string sealed off. These tests displayed the ability of the drill string to withstand an unvented explosion without rupturing. Although the bottom cap leaked during one of the tests, the drill string did not rupture on any of the tests. In fact, the pressures observed in these tests were comparable to those from the other vented tests. Pressures ranged from 8 to 75 psi at the bottom transducer and from 8 to 15 psi at the top transducer.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The results show that combustion gases generated from the ignition of a stoichiometric hydrogen and air gas mixture can be contained within a vented thirty to fifty five-foot length of drill string. A minimum hydrostatic back pressure of 28" of water is needed to prevent the gases from escaping through a rotary mode core sampling bit when a ½" diameter vent line is used for escape of the combustion gases. In addition, the results show that a stoichiometric H_2-air explosion within a completely closed drill string will not cause a rupture of the drill string.

5.0 DISPOSITION OF TEST ITEM

Testing is complete and the test items are available for further testing as needed.

6.0 REFERENCES

1. Witwer, K.S., "Testing the Propagation of Flammable Gasses in a Core Sampling Drill String", WHC-SD-WM-TP-512, Rev. 0, 9/96.

2. Cashdollar, K. L., M. Hertzberg, I. A. Zlochower, C. E. Lucci, G. M. Green, and R. A. Thomas, "Laboratory Flammability Studies of Mixtures of Hydrogen, Nitrous Oxide, and Air," WHC-SD-WM-ES-219, Rev. 0, 9/92.

3. Cashdollar, K. L., K. S. Witwer, A. Furno, G. M. Green, and R. A. Thomas, "Ignitability Testing for Core Drilling System," WHC-SD-WM-TRP-224, Rev. 0, 6/95.

4. Witwer, K.S., "Test Report for Core Drilling Ignitability Testing", WHC-SD-WM-TRP-257, Rev 0, 8/96.

5. Controlled Logbook, "Ignitability Testing for Core Drilling System", WHC-N-984 1, K. Witwer - Custodian

APPENDIX A - DETAILED LISTING OF TESTS

Pittsburgh Flame Propagation Testing - October 1996
NHC Engineering Testing Laboratory Pittsburgh Research Center

Date	Test #	H2 %	air %	P1-b psig	P2-t psig	Pipe Length(ft)	Water Depth(in)	Water drum Diameter	Top Vent	Ignitor/ position	notes
10/10/1996	8001	10%	90%	~9	~11	20'	36"	22.5"	closed	match/bottom	no drill bit, bubbles, 1000 Hz
	8002	10%	90%	~7	~9	20'	36"	"	closed	match/bottom	no drill bit, bubbles
	8003	10%	90%	~22	~23	20'	36"	"	open	match/bottom	no drill bit
	8004	10%	90%	~11	~11	20'	36"	"	open	match/bottom	no drill bit
	8005	15%	85%	~4	~5	20'	36"	"	open	match/bottom	no drill bit
	8006	20%	80%	~9	~10	20'	36"	"	open	match/bottom	no drill bit
	8007	25%	75%		no data	20'	36"	"	open	match/bottom	no drill bit, no PC data
	8008	25%	75%	~18	--	20'	36"	"	open	match/bottom	no drill bit
	8009	30%	70%	56	83	20'	36"	"	open	match/bottom	no drill bit
											cam lock dust plug blew off
10/15/96	8010	30%	70%	96	120-159	20'	36"	"	open	match/bottom	with drill bit, P2 zero off
	8011	30%	70%	113	142-227	20'	36"	"	open	match/bottom	P2 zero off
	8012	30%	70%	~26	~24	20'	36"	"	open	match/top	switched to 1000 psia
											transducers on pipe
	8013	20%	80%	~7	~9	30'	36"	"	open	match/bottom	
	8014	30%	70%	74	214	30'	36"	"	open	match/bottom	

Date	Test #	H2 %	air %	P1-b psig	P2-t psig	Pipe Length(ft)	Water Depth(in)	Water drum Diameter	Top Vent	Ignitor/ position	notes
	8015	30%	70%	58	222	30'	12"	"	open	match/bottom	bubbles
	8016	30%	70%	54	214	30'	24"	"	open	match/bottom	
10/16/96	8017	30%	70%	52	203	30'	18"	"	open	match/bottom	
	8018	30%	70%	46	179	30'	15"	"	open	match/bottom	
								changed water drums			
	8019	30%	70%	51	215	30'	15"	16"	open	match/bottom	
	8020	30%	70%	~8	~8	30'	15"	"	open	match/top	bubbles
	8021	30%	70%	149	48	30'	15"	"	open	match/top	no video
	8022	30%	70%	~8	~7	30'	15"	"	open	match/top	bubbles
	8023	30%	70%	~22	~15	30'	18"	"	open	match/top	bubbles
	8024	30%	70%	~40?	175	30'	18"	"	open	match/bottom	
	8025	30%	70%	~20?	~20	30'	18"	"	open	match/middle	bubbles
	8026	30%	70%	~30	~17	30'	24"	"	open	match/middle	
10/17/96	8027	30%	70%	~30	22	30'	24"	"	open	hot wire/middle	switched to 4000 Hz
	8028	30%	70%	~20	22	30'	18"	"	open	hot wire/middle	bubbles
	8029	30%	70%	~10?	~10	30'	24"	"	open	hot wire/top	bubbles
	8030	30%	70%	--	~9	30'	30"	"	open	hot wire/top	

Date	Test #	H2 %	air %	P1-b psig	P2-t psig	Pipe Length(ft)	Water Depth(in)	Water drum Diameter	Top Vent	Ignitor/ position	notes
	8031	30%	70%	~10	~9	30'	30"	"	open	hot wire/top	
	8032	30%	70%	~9	~9	30'	30"	"	closed	hot wire/top	vent open at middle of pipe
	8033	30%	70%	~12	~9	55'	24"	"	open*	hot wire/top	some bubbles
	8034	30%	70%	~9	~9	55'	24"	"	open*	hot wire/top	some bubbles
	8035	30%	70%	~11	~9	55'	28"	"	open*	hot wire/top	
	8036	30%	70%	~9	~9	55'	28"	"	open*	hot wire/top	
10/18/96	8037	30%	70%	136	~50	55'	28"	"	open*	hot wire/top	new gas mix
	8038	30%	70%	~16	~12	55'	28"	"	open*	hot wire/top	gases added
	8039	30%	70%	123	~25	55'	28"	"	open*	hot wire/top	new gas mix
	8040	30%	70%	~11	~11	55'	28"	"	open*	hot wire/top	gases added
	8041	30%	70%	~11	~14	55'	28"	"	open*	hot wire/top	new gas mix
	8042	20%	80%	~9	~8	55'	--	"	closed	hot wire/top	bottom of pipe plugged off
	8043	30%	70%	~75?	~15	55'	--	"	closed	hot wire/top	bottom of pipe plugged off
	8044	30%	70%	~10	~10	55'	--	"	closed	hot wire/top	bottom of pipe plugged off, leaked
	8045	30%	70%	~8	~10	55'	--	"	closed	hot wire/top	bottom of pipe plugged off
11/12/96	8046	30%	70%	177	50	30'	28"	"	open	hot wire/top	new gas mix
	8047	30%	70%	198	47	30'	28"	"	open	hot wire/top	new gas mix

Date	Test #	H2 %	air %	P1-b psig	P2-t psig	Pipe Length(ft)	Water Depth(in)	Water drum Diameter	Top Vent	Ignitor/ position	notes
	8048	30%	70%	140	48	30'	28"	"	open	hot wire/top	gases added
	8049	30%	70%	134	64	30'	28"	"	open	hot wire/top	
	8050	30%	70%	121	45	30'	28"	"	open	hot wire/top	
	8051	30%	70%	122	46	30'	28"	"	open	hot wire/top	
	8052	30%	70%	125	43	30'	28"	"	open	hot wire/top	

*1/2" diameter vent plus 6 ft of 1/2" pipe

APPENDIX B - GAS CHROMATOGRAPHY MIXTURE ANALYSES

Gas Chromatography analysis was conducted at the Pittsburgh Research Center to determine actual percentages of the component gasses used for this testing. The particulars are as follows:

Test Conditions:
5 sections or 25 ft of drill string, plus ½" ball-valve vent opening & 6 ft section of ½" pipe; top sampling location - 2½ ft below top of drill string, bottom sampling position - 3 ft above (closed off) base of drill string, 2" above gas inlet, gases sampled by Vacutainer, analyzed by gas chromatography.

Conclusions:
Bottom samples contaminated by air in dead space at bottom of pipe. Top samples agreed to within 1% H_2 of gas mix predicted by partial pressure for new mix and to within 2% H_2 for second gas mixture.

Pertinent detailed information on the samples is given in the table below.

Table Listing Samples Taken

Sample	Position	Time, Gas flow	Hydrogen, %
10/24/96 - 20% hydrogen, 80% nitrogen, new mix in 120-L sphere, fan mixed for 3 min			
A	top	@ 3 min, flow on	20.0
B	"	@ 4 min, flow off	20.2
C	bottom	@ 3 min, flow on	17.4
D	"	@ 4 min, flow off	14.9
10/24/96 - 30% hydrogen, 70% nitrogen, new mix in 120-L sphere, fan mixed for 3 min			
E	top	@ 3 min, flow on	29.7
F	"	@ 4 min, flow off	29.3
G	"	@ 4½ min, flow off	28.5
H	bottom	@ 3 min, flow on	24.4
I	"	@ 4 min, flow off	20.4
J	"	@ 4½ min, flow off	20.6
10/25/96 - 30% hydrogen, 70% nitrogen, new mix in 120-L sphere, fan mixed for 3 min			
1	top	@ 3 min, flow on	28.8
2	"	@ 4 min, flow off	29.1
3	bottom	@ 3 min, flow on	23.2
4	"	@ 4 min, flow off	19.9
10/25/96 - 30% hydrogen, 70% nitrogen, gases added to 120-L sphere, fan mixed for 3 min			
5	top	@ 3 min, flow on	28.8
6	"	@ 4 min, flow off	28.0
7	"	@ 4½ min, flow off	27.8
8	bottom	@ 3 min, flow on	22.1
9	"	@ 4 min, flow off	19.6
10	"	@ 4½ min, flow off	18.2

APPENDIX C - CONTROLLED LOGBOOK (WHC-N-984 1) ENTRIES

 10/10/96

126 The following Tests follow Supporting Document Test Plan WHC-SD-WM-TP-512, Rev. 0 — "Testing The Propagation of Flammable Gasses in a Core Sampling Drill String"

- Initial scoping tests involve using

  * 20 ft length drill string
  * 36" water in ~~barrel~~ drill string (≈ 47" in barrel)
  * Igniter placed just above water level (2") near bottom of drill string
  * 10% H_2 90% Air Flammable gas mixture
  * Vent (½" ball valve) closed at top of drill string
  * Drill string open on the bottom (no drill bit or anything)

These scoping tests are such that they are worst case i.e. a short 20' length of drill string would provide less energy in an explosion than a 30 or 55 ft length (as outlined in test plan). Also, a 10% H_2 mixture is much less energetic than a 30% H_2 concentration which is found in a stoichiometric H_2 & Air mix. So if these tests show gas escaping out the bottom of the drill string then the more aggressive (55 ft at stoichiometric gas, etc) will allow gas to escape.

- Scoping Test USBM8001

  - 20 ft drill string
  - Igniter at bottom of drill string (1" above water level)
  - Vent valve at top of drill string closed (½" Ball Valve)
  - 36 inches water in bottom of drill string
  - 10% H_2 & 90% Air Flammable gas mix
  - Open drill string at bottom

Result: Gas did escape out of drill string and was seen coming up to surface using high speed video camera

- Scoping Test USBM8002
  - Repeat of last test

Result Gas did escape again

10/10/94 Test Book 127

- Scoping Test USBM 8003
  - Repeat of last test except the ½" ball valve at top was opened

Result: No gas seen escaping out of drill string using video camera. Will repeat however to view larger surface area of water in barrel. Note that ball valve was not completely opened at time of ignition.

- Scoping Test USBM 8004
  - Repeat of last test – Wider viewing with high speed camera

Result: No gas seen escaping. Will repeat this test except with H_2 concentration increased to ~~20%~~ KSW 15%

- Scoping Test USBM8005
  - Repeat of last except using ~~20%~~ 15% KSW H_2 ~~80%~~ 85% Air
  - Vent open on Top
  - 36" water
  - Ignited at bottom

Result: No gas seen escaping to water surface.

- Scoping Test USBM8006

Repeat of last test, except using 20% H_2 & 80% Air

Result: No gas seen escaping to water surface

- Scoping Test USBM8007

Repeat of last test - except using 25% H_2 & 75% Air

Result: No gas seen escaping to water surface

- Scoping Test USBM8008
  - Repeat of last test exactly – DAS accidently not started for recording on last Test.

Result: No gas seen escaping to water surface

— Scoping Test USBM8009 10/10/96

1 128 - Repeat of last test except using 30% H_2 & 70% Air.

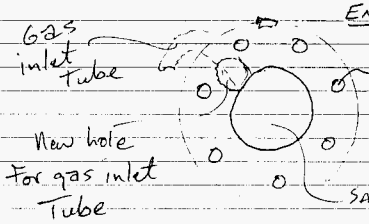
Result: Gas did not escape out at bottom of drill string but the explosion blew the top fitting (plastic camlock) off the end of the pipe. Will repeat test since this event may have provided sudden pressure relief keeping gas from being forced out at bottom of drill string.

10/15/96

- Scoping Test USBM8010

- Repeat of last test except using new aluminum camlock dust plug fitting.
- Also, a rotary drill bit with the purge holes & center sample hole is mounted on bottom of drill string. The gas inlet tube is routed through drill bit in a cut open portion - see below

END VIEW OF DRILL BIT



Placing the drill bit on the end of the drill string will make it a little harder for the explosion gasses to escape out the bottom. This is similar to field sampling conditions more so than an open ended drill string

8 - 20 ft drill string.
- 30% H_2, 70% Air Gas mixture
- Igniter placed at bottom of drill string (3" above water level)
5 - Water level @ 36' from bottom of drill bit
- 1/2 Ball valve open on top

Result:
- Gas did not appear to escape out bottom of drill string but will repeat this test with camera zoomed in closer for verification

"Scoping Test USBM8011 10/5/90 129

- Repeat of last test exactly with camara zoomed in closer to water surface

Result

No gas escaped during test. A 1mm rise in water level was seen on the camara. Note that an approximate 7mm rise is necessary for all the water in the drill string to be expelled and subsequently allow gas to escape out the bottom.

- Scoping Test USBM8012

- Repeat of last test except that the igniter is now positioned at the TOP of the drill string instead of at bottom.
  - 30% H_2 70% AIR
  - 20 ft drill string
  - 3 ft (36 in) water level

Result — No gas was seen escaping into water. Water level only rose by 1 mm.

- Scoping Test USBM8013

This Test has 30 ft of drill string (Rather than the 20 ft used on previous tests.

- Drill string = 30 ft long
- ~~20% H_2~~ → 20% H_2, 80% Air
- Igniter @ Bottom of drill string
- Water level @ 36" from bottom of drill string
- ½" Ball valve opened at top

Result - No gas escaped out bottom of drill string. Appox 1mm change in water level

- Scoping Test USBM8014
  - Repeat of last test except increasing H_2 to 30%, Air = 70% (stoichiometric)

Result - no gas escaped out bottom of drill string. Slightly larger change in water level ≈ 1.5mm

— Scoping Test USBM8015

130 This test uses a 12" depth of water instead of 36" water level. All other parameters are the same as last test

~~Scoping Test USBM8016~~ KSW

Result: Bubbles (gas) did not escape out of bottom of drill string. Interesting observation — water level seemed to move only 1-2 mm which isn't quite enough to force 12" water out tube. Possibly, however, the water movement is too dynamic, too sudden, to transmit entire surface level change. Thus, with this diameter drum (22.5" Diam) it is difficult to correlate a water level change in drum with change in water level in drill string. However, the presence of gas escaping, is really the goal anyway.

— Scoping Test USBM8016

- This test uses a 24" water level instead of 12" level on last test. All other parameters are the same.

Result No gas escaped out bottom of drill string.

— Scoping Test USBM8017

- This test uses an 18" water level instead of 24" level
Repeat of last test in all other respects

Result: No gas escaped out bottom of drill string

— Scoping Test USBM8018

- Changed to 15" water level.
- All other parameters the same (30% H_2) 30 ft drill string
Igniter at bottom, ½" ball valve open at top

Result: No gas escaped out bottom of drill string

— Scoping Test USBM8019

- Continuation of last tests results (Repeat) - except now using 16" diam drum instead of 22.5" Diam (55.62%) Drum.

Result: No release of gas bubbles out end of drill string. Water level changed 2 to 3 mm

10/16/96 10/16 131

- Scoping Test USBM8020
  - Repeat of last test except ignitor is placed at top of drill string instead of bottom
  - 30 ft drill string
  - 30% H_2 70% Air
  - 1/2" Ball valve opened at top
  - Water level @ 15" from bottom of drill bit.

Result - Air/Gas did escape out bottom of drill string. Will repeat this test to confirm the results (Note: Valve may have accidently been ~~open~~ closed during test)

- Scoping Test USBM8021
  - Repeat of last test exactly.

Result No gas appeared to escape out bottom of drill string but video camara was not recording so this test needs to be repeated.

- Scoping Test USBM0022
  - Repeat of last test exactly

Result: Gas did escape out bottom. Will increase water level to 18" for next test.

- Scoping Test USBM0023
  - Repeat of last test except water level @ 18" instead of 15".

Result Gas did escape out bottom.

- Scoping Test USBM0024
  - Repeat of last test except ignitor is placed at bottom (This will repeat Test USBM8017 for verification)

Result Gas did not escape out bottom of drill string. This confirms previous results from Test USBM8017. Igniting at the bottom has less tendancy to push water out the bottom of drill string. ~~This~~ KSW

- Scoping Test USBM0025
  - Repeat of last test except ignitor placed approximately in center of drill string - 17.5 ft from bottom of drill bit.

Result - Gas did escape out bottom of drill string.

— SCOPING TEST USBM8026 10/16/96

- Repeat of last test except water level
132 now at 24" from bottom of drill bit
- 30 Ft drill string
- Ignitor @ 17.5' from bottom
- Water level @ 24" from bottom
- 30% H_2 70% AIR
- Vent (½" ball valve → C_v = 12) open at top

HNE-SP-WM-TRP-269 Pg. 28/34 Rev. 0

Result No gas escaped out bottom of drill string

— Scoping Test USBM8027

- Testing different Ignitor - Nichrome Hot wire instead of electric match. This will enable ignitor to be placed at top of drill string and not need to be

- Ignitor (@ ~~bottom~~ middle (17.5' from bottom) FSW; 24" water, Vent open, 30% H_2

Result - No gas escaped from drill. Nichrome wire worked. saw ≈6 mm water level rise

— Scoping Test USBM8028

- Repeat of last test except ~~Ignit~~ FSW water level @ 18" instead of 24".

Result Gas, did escape out bottom of drill string

— Scoping Test USBM8029

- 30 Ft drill string
- 30% H_2 70% AIR
- Ignitor at Top
- Water Level @ 24"
- Ball Valve Open

Result Gas did escape from drill string. This test and Test USBM8026 show that igniting at the top of the drill string creates the most energy (pushes out water (with ignitor) at top when it won't if ignitor is in middle or bottom)

10/17/96
133

- Scoping Test USBM8030
  - 30 ft drill string
  - Ignitor at top
  - Water Level @ 30"
  - Valve open on Top
  - Stoichiometric 30% H_2 70% N_2 mix

Result - No bubbles escaped - but will repeat this test because the pressure traces from the pressure transducers ~~was~~ seemed uncharacteristically low.

- Scoping Test USBM8031
  - Exact Repeat of last test for verification.

Result - No bubbles escaped.

Scoping Test USBM8032

- This test closes Top Ball valve and allows gas to escape out side ½ pipe fitting instead.
  - 30 ft drill string
  - Ignited at top
  - Water level @ 30"
  - Stoichiometric 30% H_2 70% AIR

This will compare against previous test (8031)

Result No gas escaped out bottom of drill string.

- Scoping Test USBM8033
  - changed to 55' drill string with 6 ft of ½" galvanized pipe sticking out end of top of ball valve (Note that ID of pipe is .625" Diameter)
  - Vent (½" Ball valve open) on top
  - Water level @ 24"
  - Stoichiometric 30% H_2 70% AIR
  - Ignited at top

Result: No gas appeared to escape out bottom - however, some small bubbles appeared at the surface several seconds after ignition - so we will repeat test for verification.

- Scoping Test USBM8034 — 10/17/96

134 - Exact repeat of last test

HNF-SD-WM-TRP-269 Rev. 0 p. 30/34

Results / One or two gas bubbles appeared at water surface. Will increase water level to 28" for next test to verify no gas escapes out bottom.

- Scoping Test USBM8035
  - Water level @ 28" from bottom
  - 55 ft drill string + 2 1/2" pipe + 1/2" (ID Ball valve) + 6 ft 1/2" pipe (ID = .625")
  - Ignited at top
  - 30% H_2 + 70% Air

Results / No gas escaped out bottom of drill string. Will repeat for verification.

- Scoping Test USBM8036
  - Exact repeat of last test

Results / No gas escaped out bottom of drill string.

- Scoping Test USBM8037 — 10/18/96
  - Exact repeat of last test

Result / No gas escaped out bottom of drill string.

- Scoping Test USBM8038
  - Exact repeat of last test

Result / No gas escaped out bottom of drill string

- Scoping Test USBM8039
  - Exact repeat of last test

Result / No gas escaped out bottom of drill string

- Scoping Test USBM8040
  - Exact Repeat of last test

Result / No gas escaped out bottom of dr. string

10/3/96 [illegible] 135

- Scoping Test USBM8041

- This Test has a plug on the end of the drill string. This gas can only escape out the top 1/2" vent line. This will simulate having a sampler down in the bottom of the drill string/core barrel.
  - 55 Ft drill string
  - Ignited at top
  - 30% H_2 70% AIR
  - Drill string plugged on bottom
  - Valve open on Top

Result - Ignition appeared to be of the same pressure/energy as the last test which had the bottom open to the water.

- Scoping Test USBM042

- Repeat of last test except top vent is closed and mixture is changed to 20% H_2 & 80% AIR
  - 55 Ft drill string
  - Ignited at top
  - 20% H_2, 80% AIR
  - Bottom plugged
  - Top Plugged

Result - Ignition caused a lower energy pressure pulse than the last test (when the top vent was open) No damage was done to the pipe or any of the fittings.

- Scoping Test USBM043

- Repeat of last test except H_2 = 30%, Air = 70% (Stoichiometric)

Result - ~~Skew~~ Pressure was higher after ignition on this test but did not cause failure of the pipe or any components.

- Scoping Test USBM044

- Repeat of last Test exactly.

Result - Plug on bottom leaked, allowing gas to escape. Will redo test with new plug.

Scoping Test USBM 8045 (HNF-SD-WM-TRP-269 Pg. 53/54 Rev. 0) 10/13/96

Repeat of USBM 8043 exactly (new plug on bottom)

136

Result: Appeared to have the same results as Test 8043 These ignitions produce pressures that are lower than when the pipe is vented.

- Scoping Test USBM 8046

Nov 12 1996
139

- This test confirms results obtained from previous testing-numbers 8030 & 8031. Parameters are identical except the water level is set at 28" instead of 30". This 28" level is what the 55' length of drill string was able to be set at as a minimum.

- 30 Ft. drill string
- Hot wire igniter near top of drill string
- Water level @ 28"
- Valve open on Top
- Igniter at Top

Result - No bubbles ~~ever~~ escaped out bottom of drill string

- Scoping Test USBM 8047
  - Exact repeat of last test

Result - No bubbles escaped out bottom of drill string

- Scoping Test USBM 8048
  - Repeat of last test - except a 6 ft long, 1/2" Diameter Sch 40 galvanized pipe attached to top of ball valve - see tests 8033 through 8041.

Result
- No bubbles escaped out bottom of drill string

- Scoping Test USBM 8049
  - Repeat of last test exactly

Result - No bubbles escaped out bottom of drill string

- Scoping Test USBM 8050
  - Repeat of last test exactly

Result: No bubbles escaped out bottom of drill string.

- Scoping Test USBM 8051 / HNF-SD-WM-TRP-269 Rev. 0 / Pg. 34/39 Rev. 0 / Nov 12, 96

140 - Report of last test exactly

Result: No bubbles escaped out bottom of drill string

- Scoping Test USBM 8052

Result: No bubbles escaped out bottom of drill string

This completes five tests under these conditions ~~of the~~ Raw test Raw

Date	Test #	H2 %	air %	P1-b psig	P2-t psig	Pipe Length(ft)	Water Depth(in)	Water drum Diameter	Top Vent	Ignitor/ position	notes
11/12/96	8046	30%	70%	177	50	30'	28"	"	open	hot wire/top	new gas mix
	8047	30%	70%	198	47	30'	28"	"	open	hot wire/top	new gas mix
	8048	30%	70%	140	48	30'	28"	"	open	hot wire/top	gases added
	8049	30%	70%	134	64	30'	28"	"	open	hot wire/top	
	8050	30%	70%	121	45	30'	28"	"	open	hot wire/top	
	8051	30%	70%	122	46	30'	28"	"	open	hot wire/top	
	8052	30%	70%	125	43	30'	28"	"	open	hot wire/top	

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