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Test Report for Core Drilling Ignitability Testing

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Abstract: Testing was carried out with the cooperation of Westinghouse Hanford Company and the United States Bureau of Mines at the Pittsburgh Research Center in Pennsylvania under the Memorandum of Agreement 14-09-0050-3666. Several core drillng equipment items, specifically those which can come in contact with flammable gasses while drilling into some waste tanks, were tested under conditions similar to actual field sampling conditions. Rotary drilling against steel and rock as well as drop testing of several different pieces of equipment in a flammable gas environment were the specific items addressed. The test items completed either caused no ignition of the gas mixture, or, after having hardware changes or drilling parameters modified, produced no ignition in repeat testing.

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TEST REPORT

FOR

CORE DRILLING
IGNITABILITY TESTING

WHC-SD-WM-TRP-257
REV. 0

July 23, 1996

Keith S. Witwer

Engineering Testing Laboratory
Westinghouse Hanford Company
Richland, Washington

Testing was carried out with the cooperation of Westinghouse Hanford Company (WHC) and the United States Bureau of Mines (USBM) at the Pittsburgh Research Center in Pennsylvania to determine specific ignition hazards involved with core sampling of Hanford flammable waste tanks. This effort, which followed Westinghouse Supporting Document Test Plan WHC-SD-WM-TP-411, Rev 1, and Memorandum of Agreement 14-09-0050-3666 between WHC and the USBM, was carried out between February and May, 1996. Kenneth L. Cashdollar, Aldo Furno, Gregory M. Green, Carrie E. Lucci, Tracy L. Goldbach, and Richard A. Thomas of the USBM provided direct support during testing. Kenneth L. Cashdollar and Carrie Lucci co-authored section 3.1.4 and provided appendices F & G of this report.

Several core drilling equipment items, specifically those which can come in contact with flammable gasses while drilling in some waste tanks, were tested under conditions similar to actual field sampling conditions. Rotary drilling against steel and rock as well as drop testing of several core drilling equipment items in a flammable gas environment were the specific issues addressed. Testing of these items showed either no ignition of the flammable gasses, or if an ignition occurred, a modification of the equipment or a change in a drilling parameter (such as maximum allowable down force) prevented an ignition in subsequent tests.

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CORE DRILLING IGNITABILITY TESTING

1.0 INTRODUCTION

To determine specific ignition hazards involved with Core Sampling of Hanford flammable waste tanks, testing was carried out with the cooperation of Westinghouse Hanford Company (WHC) and the Pittsburgh Research Center (PRC) of the United States Bureau of Mines (USBM). Personnel from the Westinghouse Engineering Testing Laboratory (ETL) and the USBM Fires, Explosions and Explosives (FE&E) group were directly responsible for the testing.

Due to the explosion hazard involved, the USBM Pittsburgh Research Center near Pittsburgh, PA was chosen as a test site. The USBM has qualified personnel and equipment on location which were uniquely suited for the hazards involved.

The Westinghouse Characterization Equipment Engineering Group (CEE) provided funding and direction for the test, while personnel from the Los Alamos National Laboratories (LANL) provided consultatory input. Testing was initiated to resolve issues raised by LANL during preparation of a Safety Assessment (SA) of the Core Sampling System[1] and Appendix T of the SA gives the functional requirements and acceptance criteria for this testing.

The cooperative contract between WHC and USBM is covered by Memorandum of Agreement (MOA) 14-09-0050-3666, and the Supporting Document Test Plan for this effort is WHC-SD-WM-TP-411, Rev. 1. The test plan contains specific test methodology and equipment description and are not included in this report. Testing occurred between February 1 to May 3, 1996.

It should be noted that both the English and Metric system of units are employed in this report. Much of the core drilling equipment and subsequent drilling parameters are described in English units in other WHC documentation, and for convenience, these parameters are repeated here in English as appropriate.

2.0 TEST DESCRIPTION

The purpose of this testing was to determine if an ignition of flammable gasses would occur under credible core sampling conditions. Many different dynamic processes occur while sampling but only a limited number of these which have a direct bearing on the flammable gas ignition issue required testing. The dynamic processes of interest can be generally categorized as follows:

- What ignition hazard of the sampling bit/waste interface exists while rotary drilling?
- What ignition hazard of the drill string/riser tube interface exists while rotary drilling?
- What ignition hazard of the sampler and associated ancillary equipment within the drill string exists before, during, and after a sample is obtained?

Note that each of these items involve drilling equipment which can make direct contact with the flammable gas mixtures found in some waste tanks.

2.1 SPECIFIC TEST ISSUES

The above categories are further broken down into the following six ignition questions which this testing was designed to address:

1. Will an ignition of a flammable gas occur while drilling into rock in a waste tank?
2. Will an ignition of a flammable gas occur while drilling into a metal object in a waste tank?
3. Will an ignition of a flammable gas occur after an accidental drop of sampler and the subsequent impact onto the internal surface of a drill bit?
4. Will an ignition of a flammable gas occur after an accidental drop of the Remote Latching Unit and subsequent impact onto a sampler?
5. Will an ignition of a flammable gas occur during an impact caused by a misalignment of the Quill Rod Adapter and drill string?
6. Will an ignition of a flammable gas occur during the frictional rubbing of drill string against a steel riser?

Two additional questions were raised during the course of testing. These are;

1. Will an ignition of a flammable gas occur during an impact of one section of carbon steel drill string onto another section of carbon steel drill string?
2. How long will it take to cause an ignition when the drill bit operates in frictional heating mode on hard objects?

2.2 TEST ITEMS

The above issues involve specific core drilling equipment. Table 1 below lists these according to item description and part number.

TABLE 1 - EQUIPMENT TESTED

ITEM DESCRIPTION	PART NUMBER
Standard Rotary Mode Bit	100IVD/8
TSAP Rotary Mode Bit	9505-15E
Push Mode Bit	H-2-85345 (with ECN 613541)
Core Sampler (Rotary and Push Mode)	Rotary - H-2-85097-72 Push - H-2-85097-8, H-2-690140-3
19" Carbon Steel Drill String	H-2-821457-7
Nickel Plated Fluted Drill String	H-2-821457-13 (Core Barrel)
Stainless Steel Drill String (Representing Quill Rod Adaptor)	304 SS - no part number (QRA P/N - H-2-690051-3)
Remote Latching Unit	H-2-690142

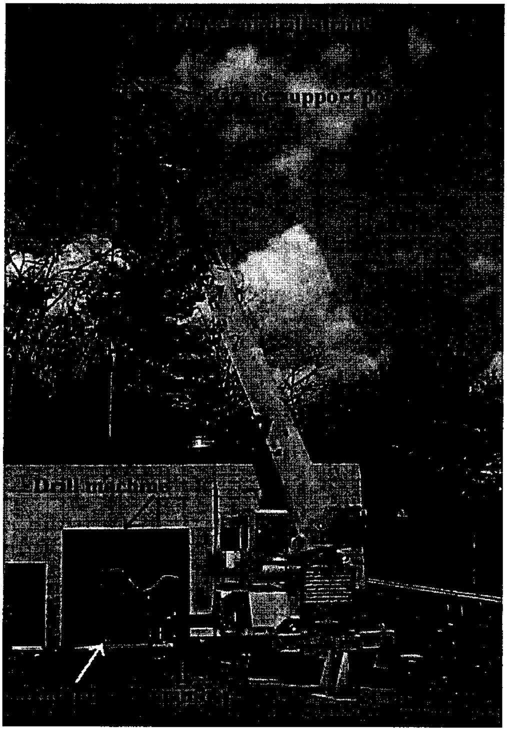
With one exception, each of the above items are identical to warehouse stock of equipment used for normal drilling operations. As is described later, some of these items were modified during testing, but any final modification made to an item became the new standard design used for field sampling operations. The one exception was the Quill Rod Adaptor (QRA). Since the test parameters did not require the entire QRA apparatus to be tested, only the pertinent component (stainless steel pipe section) was tested. This is also described in the following section.

3.0 TEST METHOD AND TEST EQUIPMENT

3.1 TEST EQUIPMENT

3.1.1 CORE DRILLING MACHINE

PHOTO 1 - 60 Foot Drop Test Arrangement



The drilling machine used was a Longyear Model 34[1]. This testing drill, in its basic form, is the same type of drill installed on the core sampling trucks for field operations. The drill provided both rotational and downward motion for bit testing as well as a support fixture for the 60 foot length of drill string used in the drop tests. Photo 1 shows the 60 foot test arrangement. Notice that the pipe is supported near the bottom using the drill rig and near the top using a mobile crane.

The drill was remotely controlled during testing to provide operator safety and to allow instantaneous control of both the downward motion and rotation (for bit and drill string rub testing) of the drill bit.

The sixty feet of drill string was composed of standard five foot sections. The topmost section had a pulley attached to it to allow a cable to be attached to a dropping mechanism inside the pipe. The other end of the cable was held by an operator on the ground. During a typical drop test, the device to be dropped was raised to the top of the sixty feet of drill string and held until the pipe and test chamber were filled with flammable gas. The operator on the ground would then make a sharp pull on the holding cable which would provide the necessary momentum to release the item from dropping mechanism and down through the drill string onto the test specimen.

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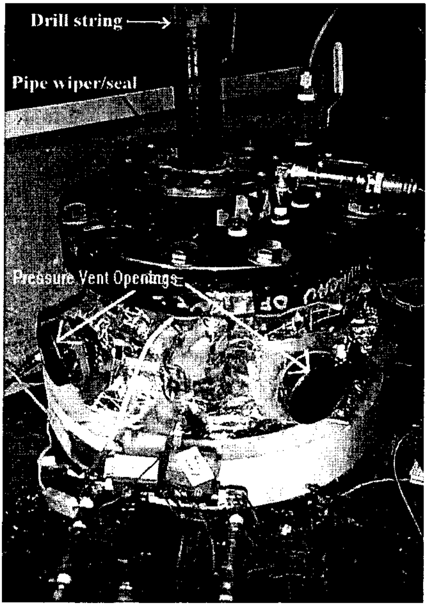
[1] Longyear is a trademark of Longyear Incorporated

3.1.2 IGNITION TEST CHAMBER AND DRILL STRING

A 15 liter steel test chamber (Photo 2 below) was used to contain the flammable gas and objects to be drilled against. The chamber was sealed so that the flammable environment could be closely controlled and it was designed so that if an ignition of the flammable gas were to occur, thin diaphragms located on the ports (vent openings) of the chamber would rupture. The ruptured membranes would allow the sudden pressure to vent, thereby protecting the test chamber and any surrounding test equipment.

PHOTO 2 - Ignition Test Chamber



The item to be drilled into or against, or impacted, was mounted on the bottom plate of the test chamber. A small tube with multiple holes drilled into it formed a circle which was placed on the outer edge of the bottom plate. The flammable gas from a mixing chamber (described below) was routed through this tube providing good distribution of the gasses during purging and testing.

The chamber was fitted with instruments to measure pressure, initial gas temperature and the presence of flame. The pressure and flame sensors provided an indication of the time of ignition while the temperature sensor provided an indication that gas within the chamber was kept at a minimum of 100°C. The pressure sensor also provided an indication of the maximum pressure felt during an ignition which roughly correlated with the energetics involved. The 15-L test chamber is shown here in Photo 2.

The drill string was fixed in place using the drilling machine chuck. This drill string entered the test chamber and was sealed on its outer surface using a rubber sealing ring (pipe wiper). During the rotational tests, the drill string and a sample tube were sealed at the top. This required a small purge line from the test chamber to allow necessary venting of the flowing gas. During the drop tests, the drill string was open at the top which provided the necessary venting.

Different flammable gas purge times were used, depending on the test to be run. For a rotational test, a shorter four minute purge time at 1 ft^3/min was used to completely clear the chamber of atmospheric gasses. For a drop test, a longer eight minute purge at 1ft^3/min was used to purge the 15-L chamber and 60 ft of drill string. Confirmation that this purge time was sufficient was accomplished prior to actual testing. Nitrogen gas was used as a "test purge" at the 1 ft^3/min flow and an oxygen sensor was placed at either the top of the drill string or at the output of the vent on the test chamber. When the oxygen was reduced to near zero, the purge times were considered sufficient.

A separate pressurized mixing chamber was used to provide the flammable gas to the test chamber. It acted as a reservoir from which premixed gas for both the initial purging of the test chamber at 1ft^3 /min and a continuous 0.2 ft^3/min gas flow during testing could be obtained.

3.1.3 DATA ACQUISITION SYSTEM

A micro computer acquired data from the drill rig. Pertinent input included the following:

- Bit RPM
- Downward Force
- Bit Depth
- Torque
- Elapsed Time
- Test Chamber Temperature

Each input was recorded to a computer file (see Appendix E) at one-half second intervals (typical). Note that these inputs were measured and recorded during the drill bit tests and not during the drop tests. The drop tests required that only the test chamber temperature be controlled and therefore a computer file was not necessary. The temperature was monitored for each test, however, and accordingly noted in a controlled testing logbook[2].

A separate data and control system monitored, recorded, and controlled the flammable gas supply system to the test chamber. This USBM equipment is described below.

3.1.4 FLAMMABLE GAS SUPPLY AND SYSTEM

The instrumentation and test procedures used for this project were similar to those used for a previous joint research project by the USBM and WHC[3]. The flammable gases were mixed in a 120-L chamber (Photo 3 below) and then flowed to the 15-L test chamber (Photo 2 above) during the core drilling ignitability tests. Pressure in the 120-L chamber was monitored using a real-time pressure transducer. At the start of a test, the 120-L chamber was evacuated, and the gases were added at the partial pressures required to give the desired mixture composition at the desired starting pressure. The starting pressure was normally about 3 atm to provide the required flow rates for the expected duration of the drilling test in the 15-L chamber or drop test with the 60 ft of drill string. An internal fan was used to mix the gases for at least 3 minutes before flowing the gas to the 15-L test chamber.

The gas mixtures used were:

1a. 66% H_2, 34% O_2
1b. 30% H_2, 70% air.
2. 30% H_2, 40% O_2, 30% NH_3.
3. 20% H_2, 60% N_2O, 20% NH_3.

The flammable gas mixture flowed through ¼-in tubing from the 120-L chamber to the bottom of the 15-L chamber. An in-line flowmeter monitored the flammable gas flow rate, which was varied remotely by adjusting an electrically actuated needle valve. Flame arrestors were installed in the gas feed line to prevent the flame from traveling from the 15-L test chamber back to the 120-L mixing chamber.

The time required to purge the 15-L chamber of atmospheric gases was measured during preliminary testing by flowing nitrogen through the lines from the 120-L chamber to the 15-L chamber. The oxygen concentration was monitored at the exhaust of the 15-L chamber. At a flow rate of 1 ft^3/min, the feed lines and 15-L chamber were purged within 3 min. For the core drilling tests, the flammable gas flowed for at least 4 min before the start of drilling to insure that the test chamber was purged of atmospheric gases. During the actual drilling, the flammable gas was flowed at a lower rate of 0.2 ft^3/min in order to prevent any air from re-entering the test chamber. For the drop tests, the system was purged for 8 min to insure that the test chamber and 60 ft of drill string were purged of atmospheric gases. A gas dispersion ring placed in the bottom of the chamber was designed by the USBM such that the purge gas would fill and purge the test chamber sufficiently in the time allotted.

Instrumentation for the 15-L chamber included two pressure transducers, one flame sensor, and a type K thermocouple. The pressure transducers were of the strain gauge type and had a response time of 1 msec. The flame sensor was a silicon photo diode. The 320-µm (12.5-mil) type K thermocouple measured the initial gas temperature. The data from the instruments were recorded with a personal computer (PC) equipped with a high speed analog-to-digital (A/D) board. A USBM designed computer software program converted the sensor data to engineering units and plotted the results versus time. These plots were used to obtain the maximum explosion pressure if the gas would ignite. The calibrations of the mixing pressure transducer in the 120-L chamber and the two pressure transducers in the 15-L test chamber were checked daily using the internal calibration resistors provided by the manufacturers. The data from the tests were permanently stored on both the PC hard disk and on floppy disks.

For some of the drilling tests, an infrared video camera was used to measure the temperature of the drill bit and target interface, as described in Appendix G.

PHOTO 3 - 120 Liter Flammable Gas Mixing Chamber

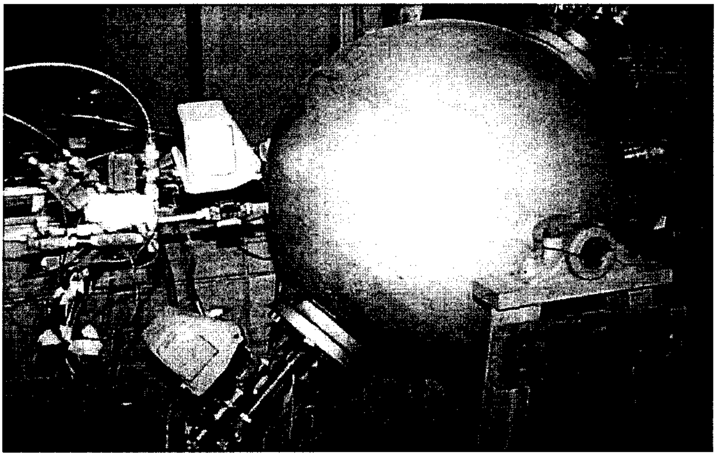


PHOTO 4 - Standard Rotary Bit

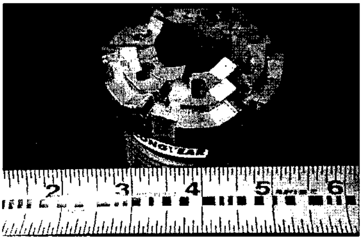
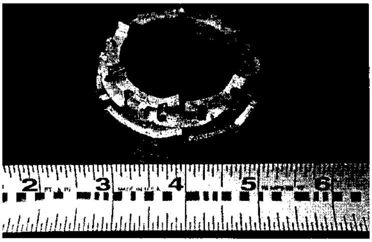


PHOTO 5 - TSAP Rotary Bit



3.2 TEST METHOD

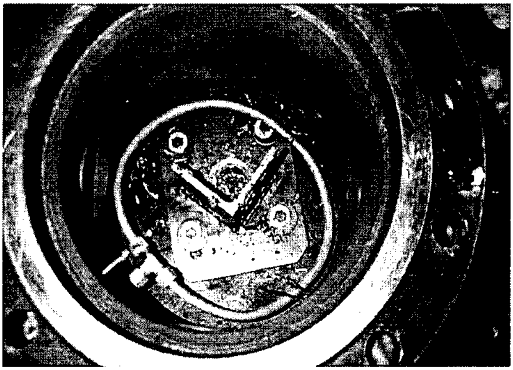
From section 2.1, the specific test issues are addressed using three different test methods. These different methods are described in the following sections.

3.2.1 TEST METHOD 1 - DRILLING INTO A HARD MATERIAL

This section covers the core drilling bit / hard material interaction. The purpose of this test was to simulate the action of a drill bit striking a hard object laying inside a waste tank, such as a piece of structural steel or a rock. Two different rotary bits were tested by drilling against two different hard materials - steel and rock. As outlined in the Test Plan[4], a stoichiometric hydrogen and oxygen mixture (Mix 1a) was to be used first. If an ignition occurred with this mixture then the normal procedure was to then use a stoichiometric hydrogen and air mixture (Mix 1b) for a repeat test. This method had the advantage of quantifying the relative hazard if in fact an ignition occurred with the first mixture but did not occur with the second mixture. Often, however, the actual procedure used was to attempt equipment modifications first, and then substitute with this alternate gas mixture if a fairly simple modification was not successful at preventing an ignition.

A new drill bit was used for each test (except for the ten multiple repeat case noted later) at the initial values of 1350 pounds down force, 65 RPM, and 0.0 ft^3/min (no) purge gas. The downward force was reduced for one of the drill bits and is described later in the results section. The flammable gas mixture was applied at a fixed flow rate of 0.2 ft^3/min during a test. The flammable gas mixture was also used to purge both the drill string and the test chamber (which held the hard material) at a higher flow rate of 1.0 ft^3/min before the actual test began. This insured that no other atmospheric gasses were present to dilute the flammable mixture. A typical test was run for a minimum of three minutes. If no ignition of the gas mixture occurred, an electric match located inside the test chamber was ignited, after the test, to insure that a flammable mix had been present.

PHOTO 6 - Structural Steel Specimen



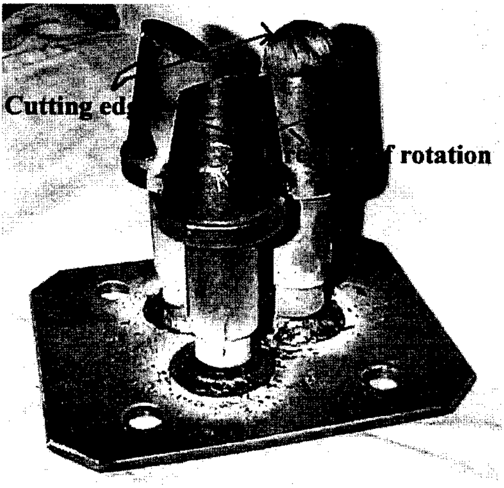
The drill bits used are shown in Photos 4 and 5 above. In addition to flammable gas mixes 1a and 1b, two additional gas mixtures were used for the drilling tests. One mix (called Mix 2) was a hydrogen, oxygen and ammonia (30/40/30 molar ratio respectively) combination. The other (called Mix 3) was a hydrogen, ammonia, and nitrous oxide (20/20/60 ratio) mix. The catalytic effect of ammonia in contact with the copper component in the drill teeth was proposed as a possible ignition "enhancer". The nitrous oxide, as an oxidant, was thought to further promote an ignition in the presence of the hydrogen and ammonia.

3.2.1.1 DRILLING INTO STEEL

Two different steel specimens were used for this series. Steel was selected because it is considered to bound all other possible materials that exist in a waste tank in terms of ability to generate sparks. The first material drilled into was piece of three inch by three inch carbon steel angle iron. Photo 6 above shows this specimen in the 15-L chamber, as viewed from above. The specimen was set "on end" so that the drill bit teeth would abruptly strike against it while descending and rotating. This violent impact was considered to be the most probable way to initiate a spark - thus being bounding over other impact geometries.

This first material, made of A36 structural steel, was used for only one test since it was decided that the more incendive 4140 steel should be used. USBM studies[5] have shown that the 4140 steel has a higher probability of generating a spark in an impact than common steel. This 4140 steel was obtained in the form of commercially available coal cutting bits and arranged such that a sharp edged, self-centering geometry was present for the bit to strike against while descending and rotating. All of the remaining tests against steel used 4140 steel. The coal cutter test specimen is shown here in photo 7, as viewed from the side. A description of the material composition of this bit is found in Appendix A.

PHOTO 7 - 4140 Steel Specimen



3.2.1.2 DRILLING INTO ROCK

The next material used was a basalt rock readily found on the Hanford Nuclear Site. This rock was chosen out of a random assortment of rocks because of its convenient size and geometry and because it provided a sharp edged section for the bit to strike against. Another rock out of this assortment was also considered, but it crumbled shortly after impact with the drill bit. Appendix B gives an analysis of four randomly selected Hanford rocks and verifies the relative hardness of the basalt rock. The basalt rock specimen is shown here in Photo 8, as it looked after a series of drilling tests.

Both the Rotary bit and TSAP bit were tested with the rock using the three gas mixtures. An additional, separate test sequence, with one each Rotary

PHOTO 8 - Basalt Rock Specimen

and TSAP bit was also run. During this sequence, a new bit was run for three minutes, allowed to cool to ambient temperatures, and then run again. This process was repeated ten times all with the same bit. This test was designed to show the potential for ignition while drilling with a dull bit.

3.2.2 TEST METHOD 2 - DRILL STRING RUBBING AGAINST STEEL

This test simulated a section of drill string rubbing against a tank riser during a drilling operation. A section of either smooth carbon steel or nickel plated and fluted drill pipe rotated within the test chamber while a piece of the 4140 steel pressed against its side. As the drill string descended into the test chamber and onto the specimen, the down and inward sloping geometry of the test specimen displaced the drill string to one side. The needed amount of displacement was measured prior to the test by applying a side load with a spring scale attached to one side. A side load of two hundred pounds was previously calculated to be the maximum bounding value seen during drilling (from an analysis of actual field sampling conditions - see Appendix C).

PHOTO 9 - Pipe Rub Specimen

Since it was determined that both a fluted and non-fluted section of drill string, and one that did and did not have pipe lubricant, could rub against a tank riser, four different scenarios were run - as follows:

1) A standard uncoated steel drill string rubbing against 4140 (rusted) steel
2) A standard steel drill string with pipe joint compound on it rubbing against 4140 steel
3) A nickel plated and fluted drill string rubbing against 4140 steel
4) A fluted drill string with the nickel coating ground off rubbing against 4140 steel

Since preliminary Infrared camera measurements of this test scenario showed that maximum temperatures of under 200°C were reached at four to five minutes after start of the test, each test was run for 8 minutes to sufficiently bound this time requirement.

The test specimen is shown here in photo 9. This specimen also incorporated the hardened 4140 steel coal cutting bits. The bits were welded and cut such that a flat surface was provided after the drill bit had traveled far enough down and inward on the coal cutting bits. Once this vertical position was obtained, the downward travel was stopped and the drill bit was rotated at the same location for the duration of the test.

3.2.3 TEST METHOD 3 - DROP TESTING OF COMPONENTS

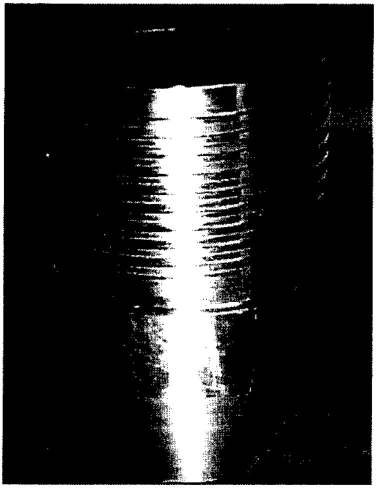
This section describes the simulation of an accidental drop of drilling equipment. Four different pieces of drilling equipment were to be dropped within a flammable gas environment.

Different heights were employed and are described in the following sections.

3.2.3.1 SIXTY FOOT DROP OF SAMPLER ONTO DRILL BIT

This test simulated the accidental dropping of a Westinghouse Universal Sampler onto the inner surface of a sampling bit. Both a standard rotary bit (Photo 3) and a push mode bit (Photo 10 below) were used. The drop height was sixty feet - the maximum height a sampler could fall during actual field operations. No ignition was expected because of the stainless steel composition of the sampler. Therefore, LANL calculations specified that only ten repetitions of this drop were required. Due to the destructive forces involved with this drop, samplers were able to survive only one drop. A modified sampler with a thicker wall near the impact end was fabricated. This sampler geometry was identical to the regular samplers in the impact zone (between sampler and drill bit). Solid metal replaced the ball valve mechanism, but was not part of the impact area.

PHOTO 10 - Push Mode Bit



The rotary version of the Universal Sampler differs from the push mode version in the type of rubber seal insert used near the head. For these tests, the seal was not used to allow the same reinforced sampler to be used with both drill bits. Not using a seal created less drop resistance in the drill string, which allowed the sampler to fall faster, gaining more kinetic energy prior to impact. This made the test slightly more bounding (in terms of ignition potential) than if a unit with a seal had been dropped.

Note that this sampler end piece was constructed of 304 Stainless Steel which was a change from the 410 Stainless Steel used on previous sampler end pieces. This 304 steel was implemented on all field samplers for future sampling efforts.

3.2.3.2 SIXTY FOOT DROP OF RLU ONTO SAMPLER

This test simulated the accidental dropping of a Remote Latching Unit (with attached counterweights) from sixty feet onto a quadralatch mechanism (the top section of a rotary or push mode sampler) during field sampling operations. Like the sampler described earlier, the RLU could conceivably drop a maximum of 60 feet. An ignition was not expected because of the stainless steel construction of the RLU. Therefore, as with the sampler drop, only 10 repetitions of this test were planned. However, as is described in the results section, this testing was deemed unnecessary and subsequently discontinued prior to completion.

PHOTO 11 - Short Drop Test Setup

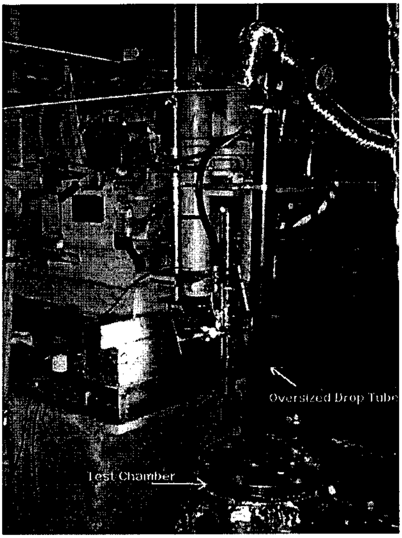
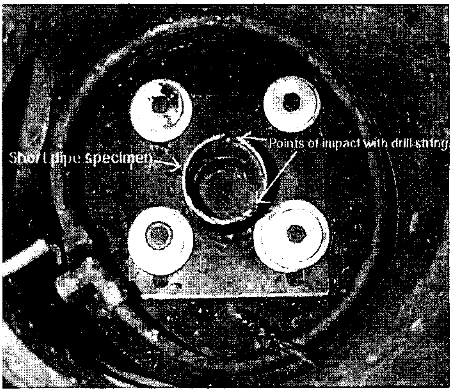


PHOTO 12 - Three Foot Drop Target



3.2.3.3 THREE FOOT DROP OF DRILL STRING

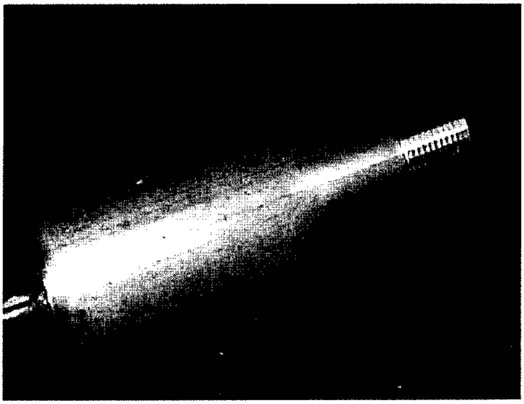
This test simulated the accidental dropping of an 19" carbon steel drill string section during assembly/disassembly while field sampling. The maximum predicted height of an accidental drop is three feet and was the drop height used for this testing. The drill string section was allowed to drop through a tube into the test chamber onto the end of another piece of carbon steel drill string.

Since a carbon steel on carbon steel impact was involved in this test (rather than stainless on carbon steel, or stainless steel onto copper alloy as in other tests), a greater probability of ignition was expected. Thus, for the results to predict a sufficiently low probability of ignition, LANL statistical calculations showed a minimum of thirty repetitions of the drop were required. Photo 11 above shows the drilling rig and test arrangement. Photo 12 above shows the target in the 15-L test chamber - as viewed from above.

3.2.3.4 THREE & ONE HALF FT DROP OF STAINLESS DRILL STRING

This test involved the simulation of a drill string and Quill Rod Adaptor (QRA) impact. During disassembly of the drill string, a misalignment between the riser hole and the drilling rig drill chuck can occur. The QRA attaches to the carbon steel drill string near the drill chuck. A misalignment between the QRA and drill string at this attachment point has been shown to cause a sudden frictional abrasion or impact when the two pieces are unscrewed and separated from each other - raising the concern of ignition of flammable gasses present. Calculations (see Appendix D) show that a maximum kinetic energy of 115 in*lbs could be generated in such an event. A safety factor of two was applied, for conservatism, bringing the kinetic energy involved to 230 in*lbs. A controlled drop of forty four inches, using a 5.22 lb section of stainless steel drill string dropped end to end onto a carbon steel drill string, was chosen to simulate this impact. Due to the relatively low impact energies and the use of stainless steel, no ignition was expected and only ten drops were required. Photos 11 and 12 above also illustrate the test arrangement and target used for these tests. The section of stainless pipe dropped is shown here in photo 13.

PHOTO 13 - QRA Impact Specimen



4.0 TEST RESULTS

Of the test items described in the Test Method section, all but one were completed. This one item was the sixty foot drop of an RLU onto a sampler. It was determined, after the release of the test plan, by WHC and LANL, that the design of the RLU cable and cable spooling mechanism sufficiently eliminated the possibility of an RLU drop. This removed the need to continue RLU drop testing. All other tests scenarios were completed and either caused no ignition or a subsequent modification of the particular hardware item and/or drilling parameters prevented an ignition in further testing. Specific details of different test scenarios are given in the following paragraphs. Appendix F lists each test completed in a spreadsheet tabular form.

4.1 DRILLING INTO STEEL

4.1.1 TSAP BIT (9505-15 Series)

As mentioned in section 3.2.1, the three flammable gas mixtures were used. All three gas mixtures were tested without an ignition during the required three minutes. The required five tests using Mix 1 and three tests each with Mix 2 and 3 were completed at 1350 pounds down force and sixty five RPM. Photo 14 below shows the bit after a typical test against the steel test specimen.

4.1.2 ROTARY BIT (100IVD Series)

The three flammable gas mixtures were also used with this bit. No ignitions occurred while drilling at the standard 1350 lbs down force and 65 RPM. Five tests with Mix 1 and three tests each with Mix 2 and 3 for three minutes were completed, as required. Photo 15 below shows the bit after a typical test on the steel specimen.

PHOTO 14 - Worn TSAP Bit (Against steel)

PHOTO 15 - Worn Rotary Bit (Against Steel)

4.2 DRILLING INTO ROCK

4.2.1 TSAP BIT

The three flammable gas mixtures used with steel were also used with the rock. An ignition occurred using Mix 1a within two minutes using the TSAP bit drilling against a rock. Three steel pins used in the manufacture of the bit, located in the side of the teeth, were removed. It was thought that these pins might have been a source of sparking. However, in subsequent runs with this bit, under the same previous conditions except without the pins, an ignition still occurred. Several changes were proposed to prevent an ignition in subsequent tests.

The bit construction consists of two pieces; the threaded shank section and the toothed section, made of dissimilar metals which are fused together. Originally the threaded shank section and three pins (used to align the two sections during assembly) were constructed of 1018 carbon steel and the toothed end was constructed of a 70 weight % tungsten, 14% copper, 13% zinc and 3% nickel material. The carbon steel shank was changed to a 304 stainless steel by the manufacturer, per WHC request, in hopes of eliminating a potential spark source. However, an ignition occurred within the minimum three minute test period on subsequent tests using either Mix 1a or Mix 1b.

After several trials at reduced down force values, an acceptable value of 860 lbs was found to repeatedly provide drilling with no ignition, for the three minute period, using a hydrogen and air stoichiometric gas mixture (Mix 1b). Five tests were run with no ignitions at this value. Thus, the new drilling limits with this bit (final part number 9505-15E) are changed to 860 lbs down force at 65 RPM.

The other two gas mixtures, Mix 2 and Mix 3, which were tested at 1000 lbs down force (higher than the 860 lbs with Mix 1 because these were done first) and 65 RPM, had no ignitions. A required three tests was run for each gas mixture.

The testing involving one bit repeatedly tested ten separate times experienced ignitions early on. Downward force had to be reduced to 1000 lbs using gas mixture 1b to eliminate an ignition. This test was actually run before the above mentioned testing (which further reduced the force limit to 860 lbs). It is interesting that the bit successfully passed at 1000 lbs here even though it didn't with the later testing. A possible explanation exists. First of all, the ignition at 1000 lbs (which required the reduction to 860 lbs) occurred at two minutes and forty five seconds after the start of the test. Some small variation in the time required to heat up the bit/rock interface should be expected between different bits/tests. Fifteen seconds, the time left before three minutes had transpired, could be within this heat up time variation. Thus, this earlier test at 1000 lbs that did not ignite within three minutes is quite probable. Secondly, the other nine (out of ten total) were using a bit that had worn teeth. A worn bit has been shown[6] to transfer less energy to the bit/simulant interface than a new bit - thus the interface would take longer to heat up with a worn bit than with a new, sharp bit - allowing increasingly longer drilling periods without autoignition. This repeat testing with one bit was only performed against the rock specimen since the rock had been shown during earlier testing to generate the highest temperatures and incidents of ignition.

4.2.2 STANDARD ROTARY BIT (100IVD Series)

No ignitions occurred with this bit within the required three minute test period at 1365 pounds down force and 65 RPM. Note however that subsequent tests which were run for up to seven minutes did experience ignitions. High temperature ignition (autoignition) created at the drill bit/specimen interface was suspected to have caused the ignition. This suspicion was confirmed in additional tests with the use of an infrared camera mounted where the drill bit/rock interface could be viewed. The details of the infrared measurements are found in Appendix G.

The test involving one drill bit used ten times for three minutes each was also completed without an ignition using Mix 1a. This test, like the one with the TSAP bit was only performed against the rock specimen. The steel supporting pins, like those used in the TSAP bit, were later replaced with stainless steel pins as a precautionary measure. This change may have been unnecessary for this bit since none of the used bits showed wearing down to the pin depth. As a result of this testing, the final part number for this bit is 100IVD/8.

4.3 THREE FOOT DRILL STRING DROP

Thirty drop tests of the 19" carbon steel drill string end to end onto another piece of carbon steel drill string in a stoichiometric hydrogen/oxygen atmosphere were run. None of the drops caused an ignition of the gas mixture.

4.4 QUILL ROD IMPACT

Ten drop tests of the stainless steel pipe section (simulating the attaching end of the Quill Rod Adaptor) onto a carbon steel drill string section in a stoichiometric hydrogen/oxygen atmosphere were run. None of the drops caused an ignition of the gas mixture.

4.5 SIXTY FOOT SAMPLER DROP ONTO STANDARD ROTARY BIT (100IVD/8)

Preliminary scoping tests showed that a likely ignition source during a drop could be the quadralatch fingers rubbing against the serrated edges, or grooves, which are machined on the inside of the sample tube. Other than the inner bearing surface in the drill bit, these grooves are the only other spot where metal to metal contact is made between the sampler and drill string. These grooves are machined such that the quadralatch fingers can easily slide over them in one direction (towards the drill bit) but cannot normally slide past in the opposite direction (away from the drill bit). However, given enough force, either a portion of the fingers or the groove tips could shear off allowing the sampler to slide past. Since both the quadralatch and the inside of the core sample tube are made of carbon steel, this shearing action could be a potential ignition source.

The quadralatch fingers and the section of the sample tube containing the serrated edges were changed to the less incendive 304 stainless steel to address this issue. No ignition occurred for any of the ten drops with this new stainless steel composition. Mix 1a was used for all of these tests.

4.6 SIXTY FOOT SAMPLER DROP ONTO PUSH MODE BIT

Ignitions during preliminary scoping tests showed that the inner geometry of the push bit could be a possible ignition source during impact with a sampler. The bit was modified so that the inner bearing surface was machined to a 10° down and inward slope towards the center with three 1/8" diameter pins (made of 304 SS) silver soldered 120° apart in the surface.

Ten drops were successfully completed with this design using gas mixture 1a.

4.7 DRILL STRING RUBBING AGAINST STEEL

All twelve tests of the fluted and smooth drill strings rubbing against steel in a stoichiometric hydrogen/oxygen atmosphere were run. No ignitions occurred during testing. Additional scoping tests using an Infrared camera showed temperatures values well below the required autoignition temperature -

even after drilling for twenty six minutes continuously with the same bit. This is also discussed briefly in Appendix G.

5.0 CONCLUSIONS AND RECOMMENDATIONS

All the test issues as outlined in the supporting test plan, and some additional items identified in this test report, were addressed. Each test item passed without ignition of the flammable gas. Some items passed "as is" - without any modification to the hardware or any change to drilling parameters. Other items required a change to the hardware or a modification to the drilling parameters (such as reduction in allowable down force) before they would pass without an ignition. Items of note include the push-mode bit which needed a change in the sampler/bit contact surface and the TSAP bit which required a reduction of maximum allowable downward force from 1350 lbs to 860 lbs. In addition, the quadralatch fingers, sample tube end section, and rotating bearing on the sampler were changed to a less incendive stainless steel composition. These particular items should be addressed before their associated hardware is used for actual field sampling operations.

6.0 DISPOSITION OF TEST ITEM

All WHC equipment and test items used for this testing have been shipped back to the Engineering Testing Laboratory. This testing is complete.

7.0 REFERENCES

1. Unal, C., "Safety Assessment for Rotary Mode Core Sampling in Flammable Gas Tanks", WHC-SD-WM-SAD-035, Rev. 0, Westinghouse Hanford Company, Richland, WA.

2. Witwer, K.S., Laboratory Testing Logbook WHC-N-984-1, "Ignitability Testing For Core Drilling System".

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

4. Witwer, K.S., WHC-SD-WM-TP-411, Rev 1, Core Drilling Ignitability Testing, 4/96.

5. Blickensderfer, R. et al. , US Bureau of Mines Publication 7713, "Testing of Coal-Cutter Materials for Incendivity and Radiance of Sparks", 1972.

6. Ralston, G.L., Witwer, K.S., WHC-SD-WM-TRP-252, Rev. 0, "Standard Rotary Bit Temperature Testing Supporting the Safety Assessment for Rotary Mode Core Sampling in Flammable Gas Tanks", 6/96.

APPENDIX A - MATERIAL COMPOSITION OF 4140 STEEL TEST SPECIMEN

SANDVIK
Rock Tools

DATE: May 21, 1996 cc: Keith Witwer

TO: Greg Ralston - Westinghouse Hanford Company

FROM: Greg Mercier

RE: Mat'l. Specs for #308435BF Miner Bit

Listed below are the material specs for AISI4140H steel:

ELEMENT	RANGE WEIGHT %
C	0.37-0.44
Cr	0.75-1.20
Mo	0.15-0.25
Mn	0.65-1.10
P	0.035 Max
Si	0.15-0.30
S	0.040 Max

The carbide grade is a 3-5 micron / 9-11% Cobalt type material, which is very common in the industry. The bit is assembled brazed and heat treated to a hardness of about 45Rc.

Also, enclosed is a 3.5" floppy with a catalog drawing of the 308435BF bit. Good luck in your research and please forward a copy of the report to me when you complete the study.

Best Regards,

Greg Mercier

Sandvik Rock Tools, Inc.

May 21, 1996 10:20 AM WESTHOUS.DOC

Postal Address
P.O. Box 639
Bristol, VA 24203

Shipping Address
15020 Industrial Pk. Rd.
Bristol, VA 24202

Phone
540-669-8311

Fax
540-669-3175

APPENDIX B - HARDNESS ANALYSIS OF ROCK SPECIMENS

Department of Energy
Pittsburgh Research Center
P.O. Box 18070
Pittsburgh, Pennsylvania 15236-0070

May 31, 1996

MEMORANDUM TO: K. L. Cashdollar, Supervisory Research Physicist, FE&E

THROUGH:
M. J. Sapko, Research Supervisor, FE&E cPd, for
G. L. Finfinger, Research Supervisor, GMC GLF
M. A. Trevits, Supervisory Geologist, GMC GLF for

FROM: J. P. Ulery, Geologist, GMC

SUBJECT: Petrographic and Hardness Analyses - Hanford Rock Samples

The testing of the four rock samples you provided is complete. Results of the petrographic analyses and discussion are presented in the following memo. Results of the hardness testing are attached.

In overview, rock samples 1-3 are igneous in origin. Samples 1 & 3 are coarse-grained intrusive or "plutonic" igneous rocks. Sample 2, on the other hand, is a fine-grained extrusive or "volcanic" igneous rock.

Chemically, samples 1 & 2 are basic igneous rocks or those that are rich in iron and magnesium minerals and depleted in free silica (i.e., no quartz). Sample 1 would be petrologically classified as a gabbro, originally composed primarily of plagioclase feldspar and pyroxene. Sample 2 would be classified as a basalt, originally composed of plagioclase and pyroxene, and additionally, volcanic glass, an opaque iron mineral, and minor olivine.

Sample 3 is an acidic igneous rock or one in which iron and magnesium minerals are subordinate and quartz is common. The rock is composed of primarily potassic feldspar, quartz, and mica and would be classified as granite.

Sample 4 is sedimentary in origin as evidenced by texture and mineralogy. The rock is predominantly quartz and would be classified as a quartzite.

All samples show some degree of mineralogical alteration that suggest metamorphic processes. Sample 1 shows the most significant alteration, the original minerals are severely to completely altered. The mineralogy and degree of alteration of the original minerals suggest regional metamorphism at the level of greenschist facies.

Although quartz does not alter to other minerals during metamorphism, sample 4 could also be construed as being metamorphosed regionally at the greenschist facies. This is based on the presence of micas, strain shadows in the larger quartz grains, and evidence of comminution and recrystallization of the finer grained quartz ground mass.

Mineralogic alteration is also apparent in samples 2 and 3 although not nearly to the degree of sample 1. Likewise, the degree of physical alteration of samples 2 & 3 is distinctly less severe than sample 4. Therefore, it is not entirely clear whether the mineralogic transformation in these samples resulted from true regional metamorphism or simply burial metamorphism. Assuming that all samples came from the same area, I would be inclined to suggest that samples 2 and 3 were also subject to regional metamorphism at the greenschist grade. Certainly for all samples, implying the low grade metamorphism by attaching the prefix " meta-" to the original rock type would be appropriate.

Results of petrographic analyses:

<u>Sample 1: Metagabbro</u>

Tremolite/Actinolite (green pleochroic sheaves, high birefringence)	27%
Plagioclase feldspar (severely altered, twinned crystals)	24%
Muscovite/Sericite (replacing feldspar)	26%
Pyroxene (Hypersthene?) (severely altered, brown pleochroic, low birefringence)	19%
Epidote (small grains assoc. with sericite, moderate birefringence)	4%

<u>Sample 2: Metabasalt</u>

Plagioclase feldspar (small laths, Carlsbad twinned, occ. phenocryst)	29%
Pyroxene (Augite?) (pale green, low birefringence, altering to amphibole(?))	33%

Opague ground mass (opaque minerals and glass(?))	33%
Gray glass (feldspathoidal(?), rare phenocryst)	4%
Olivine (rare subhedral grains, moderate birefringence)	1%

<u>Sample 3: Metagranite</u>

Potassic feldspar (exsolution, Carlsbad twinning, weak birefringence)	40%
Quartz	35%
Plagioclase feldspar (albite twinning)	14%
Muscovite/Sericite (alteration of feldspar, some original)	5%
Biotite/Chlorite (original biotite altering to green pleochroic chlorite, chlorite w/ "steel blue" birefringence)	5%
Hornblende (brown, cleavage traces)	1%
Epidote	1%

<u>Sample 4: Metaquartzite</u>

Quartz (large grained) (strain shadows)	59%
Quartz (fine grained) (recrystallized cement, comminuted)	27%
Mica (some biotite (primary?), some muscovite/sericite)	11%
Accessory minerals (zircon?)	2%
Opague minerals (magnetite?)	1%
Epidote	trace

James P. Ulery

Attachment

Shore Scleroscope Hardness Test

Laboratory: PRC Rock Mechanics

Date: 5/23/96

Testers: DiMartino and Dolinar Contact: Dolinar, GMC,PRC (892-6549)

The Shore scleroscope hardness test was performed on four rock specimens (boulders). Specimens #1 and #2 were prepared by cutting a section of rock with parallel surfaces about 1 in thick from each boulder. Specimens #3 and #4 were tested on the cut flat surface of the boulders. Ten tests were then run on each specimen with the results averaged. The results are given in the following table along with the equivalent Rockwell C and Brinell values.

Specimen	#1	#2	#3	#4
		Hardness		
Shore	65	90	39	52
Rockwell C	48	64	29	40
Brinell	475	670	270	375

Shore Scleroscope Hardness Test

Laboratory: PRC Rock Mecahnics

Date: 5/23/96 Testers: DiMartino and Dolinar

Sample	#1	#2	#3	#4
Test	Shore Hardness			
1	74	88	43	52
2	65	95	51	57
3	65	92	29	50
4	67	90	32	54
5	60	88	38	50
6	63	94	33	48
7	70	88	42	55
8	65	85	35	50
9	60	91	44	55
10	62		42	48
Average	65	90	39	52
Stdev	4	3	7	3

APPENDIX C - MAXIMUM SIDE LOAD CALCULATION

CC-Mail Message from Hassan Ziada to Jeff Smalley, Dated 2/16/96

```
Author:  Jeff L Smalley at ~WHC128
Date:    7/2/96  7:09
Priority: Normal
TO: Keith S Witwer at ~WHC159
Subject: LATERAL LOAD ON DRILL STRING FOR TESTING
--------------------------------------- Forwarded ----------------------------------------
Author:  Hassan H Ziada at ~WHC321   2/16/96  14:52
TO: Jeffory L Smalley at ~WHC128
CC: Keith V Scott at ~WHC53
CC: Hassan H Ziada
Subject: LATERAL LOAD ON DRILL STRING FOR TESTING
------------------------------------ Message Contents ------------------------------------
```

Jeff;

You requested me to do a scoping evaluation to determine the potential lateral load (friction load) that may develope between the drill string and the 15-ft sleeve if buckling occurs. This load is to be applied in friction tests, for safety concerns. As you know, when buckling starts, you can't control the deflection. However, a reasonable range of loads is provided from early stages of buckling to close to buckling failure. These loads are based on best estimate of hand calculations and finite-element analysis. There is no exact formula or solution that can be used.

Load early in buckling stages = 200 lbf

Load close to buckling failure= 800 lbf

These loads are for drill string lengths between 40-ft and 60-ft. If the operations are monitoring the controlling loads during sampling, I believe the 200 lbf load is appropriate to apply in the test. Otherwise you can go as high as 800 lbf before failure.

If you have any questions, please call me.

Hassan

APPENDIX D - QUILL ROD ADAPTOR / DRILL STRING MISALIGNMENT CALCULATIONS

DON'T SAY IT --- *Write It!*

DATE: January 4, 1996

TO: Keith S. Witwer L6-13

FROM: H. H. Ziada H5-56
Telephone: 6-0910

cc: Roy J. Blanchard S7-12

SUBJECT: DRILL STRING MISALIGNMENT

I made a quick scoping evaluation to estimate the kinetic energy that will result from drill string misalignment. The top of the drill string has a 3/4-in. misalignment with the bottom of the drill rod quill adapter. This misalignment may introduce spark during the disassembly of the tubes. It is required to perform a dynamic test to produce a kinetic energy equivalent to the kinetic energy of the disassembly to simulate the potential spark conditions. Attached is a copy of the informal evaluation.

The results show that the friction energy resulted from the 3/4-in. misalignment is equivalent to 115 in-lbf kinetic energy. For conservatism, a factor of safety of 2 can be applied to the energy. Therefore, a dynamic drop test to generate a kinetic energy in the order of 230 in-lbf, can be performed to simulate the amount of energy released from the misalignment condition. For example, a weight of 5 lbf dropped from a height of 46-in. will produce this amount of energy.

ANALYTICAL CALCULATIONS

Page 1 of 8

Subject Drill string Friction Energy to Develope spark.
Originator Hassan H. Ziada Date 4-18
Checker Date

DRILL ROD MISALIGNMENT LOAD

The bottom of the drill rod quill adapter has a 3/4-in. misalignment with the top of the drill string. This misalignment may introduce spark during disassembly of the tubes

It is required to estimate the striking force between the two pipes.

The quill rod is 81-in. long, and is assumed fixed at the top end. The distance from the foot clamp to the bottom thread is 19-in. The bottom end can be considered pinned at one instance and fixed in other cases.

This Condition of misalignment can be treated as two beams initially deformed but free of stress and then joined and forced to conform to the end conditions.

ANALYTICAL CALCULATIONS

Page 7 of 8

Subject

Originator Hassan H. Zirk Date 4-18

Checker Date

The moments and forces can be calculated from the formulas provided in Roark 1975, Table 3, Cases 5c and 5d.

$D_o = 2.25$ in

$D_i = 1.906$ in.

$A = \frac{\pi}{4}\left[(2.25)^2 - (1.906)^2\right] = 1.12$ in^2

$I = \frac{\pi}{64}\left[(2.25)^4 - (1.906)^4\right] = 0.61$ in^4

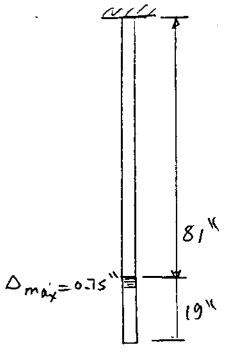
$\Delta_{max} = 0.75$ in.

$E = 29 \times 10^6$ lb_f / in^2

$\sigma_y = 76{,}000$ lb_f / in^2

$\sigma_u = 90{,}000$ lb_f / in^2

static coefficient of friction "μ" $= 0.2$



The fixed-fixed condition produces larger loads.

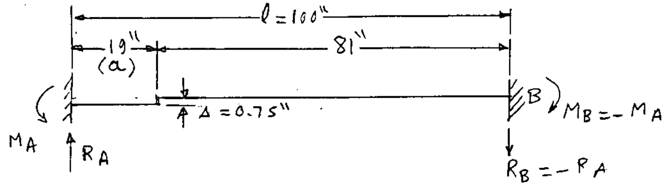
ANALYTICAL CALCULATIONS

Page 3 of 8

Subject

Originator Hasan H. [illegible] Date 4-19

Checker Date



Roark 1975, Table 3, case 5d.

$$R_A = \frac{12EI\Delta}{l^3} = \frac{12 \times 29 \times 10^6 \times 0.61 \times 0.75}{(100)^3}$$

$= 159$ lbf or 300 for 81"

$$M_A = \frac{6EI\Delta}{l^2} = \frac{6 \times 29 \times 10^6 \times 0.61 \times 0.75}{(100)^2}$$

$= 7,960$ in-lbf

$$\text{Energy} = \tfrac{1}{2} P\Delta = \frac{1}{2}\, 159 \times 0.75 = 59.6 \text{ in-lbf}$$

Assume the lower pipe is fixed, i.e. the misalignment occurs with a fixed end at the bottom end of the 81-in. tube

ANALYTICAL CALCULATIONS

Page 4 of 8

Subject
Originator Hassan H. Zeid Date 4-19
Checker Date

$$R_A = \frac{12 E I \Delta}{\ell^3} = \frac{12 \times 29 \times 10^6 \times 0.61 \times 0.75}{(81)^3}$$

$$= 300 \ \text{lb}_f$$

$$M_A = \frac{6 E I \Delta}{\ell^2} = \frac{6 \times 29 \times 10^6 \times 0.61 \times 0.75}{(81)^2}$$

$$= 12{,}133 \ \text{in-lb}_f$$

$$\text{Bending stress} = \frac{MC}{I} = \frac{12{,}133 \times 1.125}{0.61} = 22{,}376 \ \text{lb}_f/\text{in}^2$$

σ_b is Below yield. $< \sigma_y$

$$\text{strain energy} = \frac{1}{2} P \Delta = \frac{1}{2} \times 300 \times 0.75 = 112.5 \ \text{in-lb}_f$$

Friction LOAD

The Calculated 300 lbf is a lateral load, which will Cause a frictional load between the two tube ends when they are unscrewed.

For Fixed pinned condition the load is one-fourth of the fixed-fixed condition

$P = \frac{300}{4} = 75 \ \text{lb}_f$, and energy $= 28.125 \ \text{in-lb}_f$

ANALYTICAL CALCULATIONS

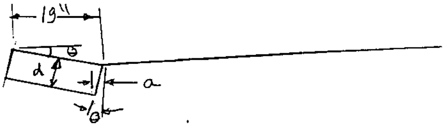
Page 5 of 8

Subject

Originator Date 4-19

Checker Date

Kinematics



Assume Fixed-hinged condition

$$\theta_{max} = \frac{3\ \Delta}{2\ l} = \frac{3 \times 0.75}{2 \times 100} = 0.01125 \text{ rad.}$$

$$\theta = 0.01125 \times \frac{180}{\pi} = 0.644^\circ$$

$$\sin\theta = \frac{a}{d}$$

$$a = 2.25 \sin 0.644 = 0.0253 \quad \text{in.}$$

The screw has a pitch of 0.25-in.

The two tubes will be in contact for an axial distance a of 0.0253-in before the ends loose contact.

$$\text{The travel distance} = \frac{a}{\text{Pitch}} \times \pi D$$

$$= \frac{0.0253}{0.25} \times \pi \times 2.25$$

$$= 0.715 \quad \text{in.}$$

ANALYTICAL CALCULATIONS

Page 6 of 8

Subject
Originator Hassan H. Zida Date 4-15
Checker Date

Assume it takes 0.1 seconds for this travel.

$$\text{Travel velocity} = \frac{s}{t} = \frac{0.715}{0.1} = 7.15 \text{ in/sec}$$

Conservation of Energy:

$$Ft = mv$$

$$\text{Equivalent mass} = \frac{Ft}{v} = \frac{300 \times 0.1}{7.15}$$

$$m = 4.196 \text{ lb}_f \text{ sec}^2/\text{in}$$

$$\text{Energy} = \tfrac{1}{2} m v^2 = \tfrac{1}{2}\, 4.196 \times (7.15)^2$$

$$= 107.25 \text{ in-lb}_f$$

Close to the strain energy of 112.5 in-lb$_f$

$$\text{Equivalent weight} = mg = 4.196 \times 386 = 1{,}620 \text{ lb}_f$$

$$\text{Axial force} = \frac{\text{Friction Force}}{\mu} = \frac{300}{0.2} = 1{,}500 \text{ lb}_f$$

Axial force is close to the equivalent weight.

ANALYTICAL CALCULATIONS

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Subject

Originator   Date 4-17

Checker   Date

The frictional energy can be simulated by a drop load to result in a kinetic energy of 107.25 in-lb$_f$.

Having the same weight of the drop test with a 55 lb$_f$ weight core sampler, the drop height can be determined as follows:

$$\text{Energy} = wh$$

$$h = \frac{107.25}{55} = 1.95 \quad \text{in}$$

$$v = \sqrt{2gh} = \sqrt{2 \times 386 \times 1.95} = 38.8 \ \text{in/sec}$$

Conclusion

The friction energy resulted from the 3/4-in. misalignment is equivalent to 115 in-lb$_f$ kinetic energy.

ANALYTICAL CALCULATIONS

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Subject
Originator Hosam H. [illegible]
Date 4-19
Checker
Date

Test simulation

To be on the conservative side, apply a factor of safety of 2 to the kinetic energy.

A dynamic drop test to generate a kinetic energy in the order of 230 in-lbf, can be performed to simulate the amount of energy released from the misalignment condition.

For example, a 5 lbf weight dropped from a 46-in. height will produce this amount of energy.

APPENDIX E - RAW DATA FILES

Due to the large number and size of data files associated with this testing, this information is stored in and can be retrieved from the Characterization project files.

APPENDIX F - SUMMARY LISTING OF TESTS

Westinghouse Hanford Ignitability Testing - February through May 1996

Date	USBM run	WHC test	H2 %	O2 %	air %	Bit	Test piece	Notes
2/1/96	7022	001	66	34	-	TSAP 9505-15B-19	angle iron	no ignition
"	7023		"	"	-		match ignition	
2/2/96	7024	002	66	34	-	TSAP 9505-15B-20	three coal cutter bits	no ignition
"	7025		"	"	-		match ignition	
2/5/96	7026		66	34	-		match ignition after purging	
2/5/96	7027	003	66	34	-	rotary 100IVD/8, L13	three coal cutter bits	no ignition
"	7028		"	"	-		match ignition	
2/5/96	7029	004	66	34	-	rotary 100IVD/8, L2	three coal cutter bits	no ignition
"	7030		"	"	-		match ignition	
2/5/96	7031	005	66	34	-	rotary 100IVD/8, L7	three coal cutter bits	no ignition
"	7032		"	"	-		match ignition	
2/5/96	7033	006	66	34	-	TSAP 9505-15B-25	three coal cutter bits	no ignition
"	7034		"	"	-		match ignition	
2/5/96	7035	007	66	34	-	TSAP 9505-15B-7	three coal cutter bits	no ignition
"	7036		"	"	-		match ignition	
2/5/96	7037	008	66	34	-	bit with carbide inserts	three coal cutter bits	no ignition
"	7038		"	"	-		match ignition	
2/6/96	7039	009	66	34	-	TSAP 9505-15B-24	rock #1, diorite	no ignition
	7040		"	"	-		match ignition	
2/6/96	7041	010	66	34	-	rotary 100IVD/8, L14	rock #1, diorite	no ignition
"	7042		"	"	-		match ignition	
2/7/96	7043	011	66	34	-	rotary 100IVD/8, L8	rock #2, basalt	no ignition
"	7044		"	"	-		match ignition	
2/7/96	7045	012	66	34	-	TSAP 9505-15B-23	rock #2, cracked	gas ignited at ~3 min during core drilling
2/7/96	7046	013	66	34	-	TSAP 9505-15B-30	rock #2, cracked	no ignition, 5 min drilling test
"	7047		"	"	-	with pins removed	match ignition	
2/7/96	7048	014	66	34	-	TSAP 9505-15B-18	rock #2, cracked	no ignition, 5 min drilling test
"	7049		"	"	-	with pins removed	match ignition	
2/8/96	7050	015	66	34	-	TSAP 9505-15B-13	rock #2, cracked	gas ignited at ~5 min during core drilling
2/8/96	7051	016	66	34	-	TSAP 9505-15B-2	rock #2, cracked	gas ignited at ~2 min during core drilling
						with pins removed		
2/8/96	7052	017	66	34	-	TSAP 9505-15B-4	rock #2, cracked	gas ignited at ~2 min during core drilling
2/20/96	7053	018	66	34	-	Rotary 100IVD/8 L3	rock #2, cracked	no ignition, 5 min drilling test
	7054						match ignition	
2/20/96	7055	019	66	34	-	Rotary 100IVD/8 L12	rock #2, cracked	no ignition, 5 min drilling test
	7056						match ignition	
2/20/96	7057	020	66	34	-	Rotary 100IVD/8 L8	rock #2, cracked	gas ignited at ~6 min during drilling (7 min test)
2/20/96	7058	021	66	34	-	Rotary 100IVD/8 L6	rock #2, cracked	gas ignited at ~5½ min during drilling (7 min test)
2/21/96	7059	022	66	34	-	Rotary 100IVD/8 L11	rock #2, cracked, with TC	gas ignited at ~5 min, (16½ min test)
2/22/96	7060	023	66	34	-	Rotary 100IVD/8 L15	rock #2, cracked, with TC	gas ignited at ~4½ min, (8 min test)
2/23/96	7061	024	0			Used rotary bit L11	rock #2 , cracked	no H2, IR video camera, T ~ 710 C at 4 min
"	7062	025	0			Rotary Bit L9	rock #2, cracked	no H2, IR video camera, T ~ 820 C at 7 min
"	7063	026	0			Smooth Drill String	200 lb side load in steel	no H2, IR video camera, T ~ 125 C at 5 min
"	7064	027	0			Fluted Drill String with	200 lb side load in steel	no H2, IR video camera, T ~ 125 C at 4 min
						flutes ground off		
2/23/96	7065	028	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7066						match ignition	
2/26/96	7067	029	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7068						match ignition	

2/26/96	7069		66	34	-		Match ignition after 5 min purge	
2/26/96	7070	030	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7071						match ignition	
2/26/96	7072	031	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7073						match ignition	
2/26/96	7074	032	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7075						match ignition	
2/26/96	7076	033	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7077						match ignition	
2/26/96	7078	034	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7079					w/ lubricant	match ignition	
2/26/96	7080	035	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7081					w/ lubricant	match ignition	
2/26/96	7082	036	66	34	-	Fluted Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7083					w/ lubricant	match ignition	
2/26/96	7084	037	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7085					w/ lubricant	match ignition	
2/27/96	7086	038	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7087					w/ lubricant	match ignition	
2/27/96	7088	039	66	34	-	Smooth Drill String	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7089					w/ lubricant	match ignition	
2/27/96	7090	040	66	34	-	Fluted Drill String,	/w 200 lb side load in 4140 steel	no ignition, 8 min drilling test
	7091					Ni coated, lubricant	match ignition	
2/27/96	7092	041	66	34	-	Rotary Bit 100IVD/8 L4	Against three rusted coal cutter bits	no ignition, 8 min drilling test
	7093						match ignition	
2/27/96	7094	042	0	-	-	Used Rotary Bit 100IVD/8 L4	Against 4140 rusted coalcutter	no H2, IR video camera, Tmax = 500 C at 7 min
"	7095	043	0	-	-	Rotary Bit 100IVD/8 L1	rock #2 - 860 lb force	no H2, IR video camera, Tmax = 408 C at 9 min
"	7096	044	0	-	-	"	rock #2 - 1000 lb force	no H2, IR video camera, Tmax = 742 C at 7 min
2/28/96	7097	045	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7098	046	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7099	047	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7100	048	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7101	049	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7102	050	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7103	051	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7104	052	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7105	053	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7106	054	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7107		66	34	-		match ignition	
2/28/96	7108	055	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7109	056	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7110	057	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7111	058	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7112	059	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7113	060	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7114	061	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7115	062	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7116		66	34	-		match ignition	
2/28/96	7117	063	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7118	064	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7119	065	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7120	066	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7121	067	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7122	068	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7123	069	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7124	070	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7125	071	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7126	072	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7127	073	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7128	074	66	34	-	3 ft drill string drop test	drilling string against drill string	no ignition
	7129		66	34	-		match ignition	
2/29/96	7130	075	0	-	-	smooth drill string	200 lb side load	no H2, IR video camera, Tmax ~ 183 C at 26 min
3/5/96	7136		66	34	-	60' drop against used bit		no ignition

3/5/96	7137		66	34	-		match ignition	
3/5/96	7138	076	66	34	-	60' drop, sampler against rotary bit		no ignition
3/5/96	7139		66	34	-		match ignition	
3/5/96	7140	077	66	34	-	60' drop, sampler against rotary bit		regular steel quadralatch, ignited at drop
3/5/96	7141	078	66	34	-	60' drop, sampler against rotary bit		stainless steel quadralatch, no ignition
3/5/96	7142		66	34	-		match ignition	
3/6/96	7143		66	34	-		sampler did not drop match ignition	
3/7/96	7144	079	66	34	-	60' drop of RLU with 36 lb weight against steel quadralatch		mixture ignited on drop
3/11/96	7145	080	66	34	-	60' drop, sampler against rotary bit		no ignition
	7146	081	66	34	-	60' drop, sampler against rotary bit		no ignition
	7147	082	66	34	-	60' drop, sampler against rotary bit		no ignition
	7148		66	34	-		match ignition	
3/11/96	7149	083	66	34	-	60' drop, sampler against rotary bit		no ignition
	7150	084	66	34	-	60' drop, sampler against rotary bit		no ignition
	7151	085	66	34	-	60' drop, sampler against rotary bit		no ignition
	7152		66	34	-		match ignition	
3/11/96	7153	086	66	34	-	60' drop, sampler against rotary bit		no ignition
	7154	087	66	34	-	60' drop, sampler against rotary bit		no ignition
	7155	088	66	34	-	60' drop, sampler against rotary bit		no ignition
	7156		66	34	-		match ignition	
3/11/96	7157	089	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7158	090	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7159	091	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7160	092	66	34	-	60' drop, sampler against pushmode bit		no ignition
	*						after test, ignition at top by RLU & pulley	
3/11/96	7161		66	34	-	7 min purge test	match ignition	
3/11/96	7162	093	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7163		66	34	-		match ignition	
3/11/96	7164	094	66	34	-	push mode bit sitting on top of stainless steel object and rubber mat		ignition occured on drop
3/12/96	7165	095	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7166		66	34	-		match ignition	
3/12/96	7167	096	66	34	-	60' drop, sampler against pushmode bit		no ignition
	7168		66	34	-		match ignition	
3/12/96	7169	097	66	34	-	60' drop, sampler against pushmode bit		no ignition, bit broke
	7170		66	34	-		match ignition	
3/12/96	7171	098	66	34	-	60' drop, sampler against pushmode bit		ignited on drop
3/13/96	7173	099	66	34	-	60' drop, sampler against pushmode bit		no ignition, TCs in bit
	7174		66	34	-		match ignition	
3/14/96	7175	100	66	34	-	60' drop of sampler on pushmode bit		ignited on drop, bit broke
3/14/96	7176	101	66	34	-	60' drop of sampler on pushmode bit		ignited on drop, bit did not break
3/14/96	7177	102	66	34	-	60' drop of sampler on pushmode bit		ignited on drop, bit did not break
3/14/96	7178	103	66	34	-	60' drop of sampler on pushmode bit		ignited on drop, bit did not break
3/14/96	7179	104	66	34	-	60' drop of sampler on rotary bit		no ignition, bit did not break
3/14/96	7180		66	34	-		match ignition	
3/15/96	7181	105	66	34	-	60' drop sampler on push bit	quadralatch fingers removed	ignited on drop, bit did not break
3/15/96	7182	106	66	34	-	60' drop sampler on push bit	teflon disc with s.s. quadralatch	ignited on drop
3/19/96	7183		66	34	-	5 min purge, top of chamber sealed	match ignition	
3/19/96	7184		66	34	-	5 min purge, top of chamber sealed	match ignition	
3/19/96	7185		30	40	30 NH3	5 min purge, top of chamber sealed	match ignition	
3/19/96	7186		30	40	30 NH3	5 min purge, top of chamber sealed	match ignition	
3/19/96	7187		20	60 N20	20 NH3	5 min purge, top of chamber sealed	match ignition	

3/20/96	7188	107	66	34	-	60' sampler onto modified push bit	3 SS pins welded on contact surface	no ignition
3/20/96	7189		66	34	-		match ignition	
3/20/96	7190	108	66	34	-	60' sampler onto modified push bit	3 SS pins welded on contact surface	no ignition
3/20/96	7191		66	34	-		match ignition	
3/20/96	7192	109	66	34	-	60' sampler onto modified push bit	3 carbon steel pins on contact surface	ignited on drop
3/21/96	7193	110	66	34	-	60' drop of 40 lb RLU	onto stainless steel quadralatch	ignited on drop
3/22/96	7194	111	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7195		"	"	"		match ignition	
3/22/96	7196	112	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7197	113	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7198		"	"	"		match ignition	
3/22/96	7199	114	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7200	115	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7201		"	"	"		match ignition	
3/22/96	7202	116	66	34	-	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7203	117	"	"	"		match ignition	
3/22/96	7204	118	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7205		"	"	"		match ignition	
3/22/96	7206	119	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7207	120	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7208	121	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7209	122	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7210		"	"	"		match ignition	
3/22/96	7211	123	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7212		"	"	"		match ignition	
3/22/96	7213	124	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7214	125	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7215	126	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7216	127	30	-	70	60' drop of sampler	modified push bit and sampler tube	SS upper, no ignition
	7217		"	"	"		match ignition	
3/25/96	7218	128	30	-	70	60' drop of RLU and counter weight	SS quadralatch	ignited on drop
3/25/96	7219	129	30	-	70	60' drop of RLU + counter weight	SS quadralatch, SS sample tube	ignited on drop
3/26/96	7220	130	30	-	70	60' drop of RLU + counter weight	SS plate	no ignition
	7221		"	"	"		match ignition	
3/26/96	7222	131	66	34	-	60' drop of RLU + counter weight	SS plate	no ignition
	7223		"	"	"		match ignition	
3/27/96	7224	132	66	34	-	TSAP w/ s.s. Shank, 9505-15E-11	rock #2 cracked	3 min run, ignited during drilling
3/27/96	7225	133	30	-	70	TSAP w/ s.s. Shank, 9505-15E-10	rock #2 cracked	3 min run, ignited during drilling
3/28/96	7226	134	66	34	-	Modified TSAP Bit 9505-15E-7	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7227		"	"	"		match ignition	
3/28/96	7228	135	66	34	-	Modified TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7229		"	"	"		match ignition	test 1 of 10
3/28/96	7230	136	66	34	-	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7231		"	"	"		match ignition	test 2 of 10
3/28/96	7232	137	66	34	-	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7233		"	"	"		match ignition	test 3 of 10
3/28/96	7234	138	66	34	-	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7235		"	"	"		match ignition	test 4 of 10
3/28/96	7236	139	66	34	-	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, ignited during drilling
								test 5 of 10
3/28/96	7237	140	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7238		"	"	"		match ignition	test 5 of 10
3/28/96	7239	141	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7240		"	"	"		match ignition	test 6 of 10
3/29/96	7241	142	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7242		"	"	"		match ignition	test 7 of 10
3/29/96	7243	143	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7244		"	"	"		match ignition	test 8 of 10
3/29/96	7245	144	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7246		"	"	"		match ignition	test 9 of 10
3/29/96	7247	145	30	-	70	worn TSAP Bit 9505-15E-9	rock #2 cracked, 1000 lbs of force	3 min run, no ignition
	7248		"	"	"		match ignition	test 10 of 10

3/29/96	7249	146	66	34	"	New rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7250		"	"	"		match ignition	test 1 of 10
3/29/96	7251	147	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7252		"	"	"		match ignition	test 2 of 10
3/29/96	7253	148	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7254		"	"	"		match ignition	test 3 of 10
3/29/96	7255	149	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7256		"	"	"		match ignition, gas flow off	test 4 of 10
3/29/96	7257	150	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7258		"	"	"		match ignition	test 5 of 10
3/29/96	7259	151	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7260		"	"	"		match ignition	test 6 of 10
3/29/96	7261	152	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7262		"	"	"		match ignition, gas flow off	test 7 of 10
3/29/96	7263	153	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7264		"	"	"		match ignition	test 8 of 10
4/1/96	7265	154	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7266		"	"	"		match ignition	test 9 of 10
4/1/96	7267	155	66	34	-	worn rotary bit 100IVD/8, L1	rock #2 cracked, 1350 lbs of force	3 min run, no ignition
	7268		"	"	"		match ignition	test 10 of 10
4/1/96	7269	156	30	40	30 NH3	TSAP 9505-15E, S/N 6	3 coal cutter bits, 1350 lb, 65 RPM	new gas mixture, no ignition
	7270		"	"	"		match ignition	
4/1/96	7271	157	30	40	30 NH3	TSAP 9505-15E, S/N 8	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7272		"	"	"		match ignition	
4/1/96	7273	158	30	40	30 NH3	TSAP 9505-15E, S/N 14	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7274		"	"	"		match ignition	
4/1/96	7275	159	30	40	30 NH3	Rotary Bit 100IVD/8, S/N 10	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7276		"	"	"		match ignition	
4/1/96	7277	160	30	40	30 NH3	Rotary Bit 100IVD/8, S/N 8	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7278		"	"	"		match ignition	
4/1/96	7279	161	30	40	30 NH3	Rotary Bit 100IVD/8, S/N 3	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7280		"	"	"		match ignition	
4/1/96	7281	162	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N 5	3 coal cutter bits, 1350 lb, 65 RPM	new gas mixture, no ignition
	7282		"	"	"		match ignition	
4/1/96	7283	163	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N 9	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7284		"	"	"		match ignition	
4/1/96	7285	164	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N 6	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7286		"	"	"		match ignition	
4/1/96	7287	165	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N 15	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7288		"	"	"		match ignition	
4/1/96	7289	166	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N 12	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7290		"	"	"		match ignition	
4/1/96	7291	167	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N 13	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7292		"	"	"		match ignition	
4/1/96	7293	168	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N 17	3 coal cutter bits, 1350 lb, 65 RPM	no ignition
	7294		"	"	"		match ignition	
4/2/96	7295	169	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N A	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7296						match ignition	
4/2/96	7297	170	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N B	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7298						match ignition	
4/2/96	7299	171	20	60 N2O	20 NH3	TSAP Bit 9505-15E, S/N C	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7300						match ignition	
4/2/96	7301	172	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N L7	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7302						match ignition	
4/2/96	7303	173	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N L3	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7304						match ignition	
4/2/96	7305	174	20	60 N2O	20 NH3	Rotary Bit 100IVD/8, S/N ??	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7306						match ignition	
4/2/96	7307	175	30	40	30 NH3	Rotary Bit 100IVD/8, S/N L4	rock #2 cracked, 1000 lbs 65 RPM	new gas mixture, no ignition

	7308						match ignition	
4/2/96	7309	176	30	40	30 NH3	Rotary Bit 100IVD/8, S/N L1	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7310						match ignition	
4/2/96	7311	177	30	40	30 NH3	Rotary Bit 100IVD/8, S/N L6	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7312						match ignition	
4/2/96	7313	178	30	40	30 NH3	New TSAP Bit 9505-15E, S/N 23	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7314						match ignition	
4/2/96	7315	179	30	40	30 NH3	New TSAP Bit 9505-15E, S/N 24	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7316						match ignition	
4/2/96	7317	180	30	40	30 NH3	New TSAP Bit 9505-15E, S/N 1	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7318						match ignition	
4/3/96	7319	181	66	34	-	New TSAP Bit 9505-15E, S/N 22	rock #2 cracked, 1000 lbs 65 RPM	H2-O2, ignited during drilling
4/3/96	7320	182	66	34	-	New Rotary Bit 100IVD/8, S/N L5	rock #2 cracked, 1000 lbs 65 RPM	no ignition
	7321		"	"			match ignition	
4/3/96	7322	183	30	-	70	New TSAP Bit 9505-15E, S/N 21	rock #2 cracked, 1000 lbs 65 RPM	H2-air, ignited during drilling
4/3/96	7323	184	30	-	70	New TSAP Bit 9505-15E, S/N 18	rock #2 cracked, 860 lbs 65 RPM	no ignition
	7324						match ignition	
4/3/96	7325	185	30	-	70	New TSAP Bit 9505-15E, S/N 20	rock #2 cracked, 860 lbs 65 RPM	no ignition
	7326						match ignition	
4/3/96	7327	186	30		70	New TSAP Bit 9505-15E, S/N 16	rock #2 cracked, 860 lbs 65 RPM	no ignition
	7328						match ignition	
4/3/96	7329	187	30		70	New TSAP Bit 9505-15E, S/N 25	rock #2 cracked, 860 lbs 65 RPM	no ignition
	7330						match ignition	
4/3/96	7331	188	30		70	New TSAP Bit 9505-15E, S/N 19	rock #2 cracked, 860 lbs 65 RPM	no ignition
	7332						match ignition	
4/4/96	7333	189	66	34	-	New TSAP Bit 9505-15E, S/N 16	3 coal cutter bits, 1350 lbs, 65 rpm	no ignition
	7334						match ignition	
4/4/96	7335	190	66	34	-	rotary bit 100IVD/8, s/n 9	rock #3, 1350 lbs, 65 rpm	no ignition
	7336						match ignition	
4/4/96	7337	191	66	34	-	rotary bit 100IVD/8, s/n 8	rock #3, 1350 lbs, 65 rpm	no ignition
	7338						match ignition	
4/30/96	7339	192	30	-	70	60' drop, HD sampler	onto rotary bit	no ignition
	7340		"	-	"		match ignition	
4/30/96	7341	193	30	-	70	60' drop, HD sampler	onto rotary bit	
		gas mixture ignited outside chamber by heating tape, before sampler hit bit						
5/2/96	7342	194	30	-	70	60' drop, new RLU + counterweight	onto quadralatch & sampler	no ignition
	7343		"	-	"		match ignition	
5/2/96	7344	195	30	-	70	60' drop, new RLU + counterweight	onto quadralatch & sampler	no ignition
	7345		"	-	"		match ignition	
	7346	196	30	-	70	60' drop, new RLU + counterweight	onto quadralatch & sampler	ignited at drop
5/3/96	7347	197	66	-	34	44" drop of 5 lb SS pipe onto drill st	1 of 10	no ignition
	7348	198	66	-	34	44" drop of 5 lb SS pipe onto drill st	2 of 10	no ignition
	7349	199	66	-	34	44" drop of 5 lb SS pipe onto drill st	3 of 10	no ignition
	7350		66	-	34		match ignition	
	7351	200	66	-	34	44" drop of 5 lb SS pipe onto drill st	4 of 10	no ignition
	7352	201	66	-	34	44" drop of 5 lb SS pipe onto drill st	5 of 10	no ignition
	7353	202	66	-	34	44" drop of 5 lb SS pipe onto drill st	6 of 10	no ignition
	7354	203	66	-	34	44" drop of 5 lb SS pipe onto drill st	7 of 10	no ignition
	7355	204	66	-	34	44" drop of 5 lb SS pipe onto drill st	8 of 10	no ignition
	7356	205	66	-	34	44" drop of 5 lb SS pipe onto drill st	9 of 10	no ignition
	7357	206	66	-	34	44" drop of 5 lb SS pipe onto drill st	10 of 10	no ignition
	7358		66	-	34		match ignition	

APPENDIX G - INFRARED TEMPERATURE MEASUREMENTS

TEMPERATURE MEASUREMENTS

InfrareCamerara System

An infrared (IR) video camera observed some of the core drilling tests in the 15-L test chamber. The IR video system (Hughes/FLIR Probeye model 7300) was used to record the temperature changes of the drill bit and target during the drilling process. For these observations, there was no flammable gas in the test chamber. The IR camera observed through the port (vent opening), which was not covered with plastic as it had been for the ignitability tests. The spatial resolution of the IR camera was about 2 mm at the observation distance of 0.6 m (2 ft).

The IR video measures radiation at wavelengths of about 2 to 5 μm. This radiation is then converted to a false-color temperature display on the video monitor, at 30 frames per second. The IR video, therefore, provides a false-color image of the drill and target during each test, with the colors being related to temperature. At the right side of the video image, a temperature-color key correlates the temperature range with the display colors. The IR system provides a more accurate reading if the measured temperature is in the upper half of the selected temperature range. Therefore, the temperature range was varied during the test in order keep the observed temperature within the upper half of the range. The wider the temperature range, the greater the error in the measured temperature, so the smallest usable range was selected. During a test, the maximum temperature within the field of view was listed on the monitor. For the drilling tests, the maximum temperature was observed at the interface between the drill bit and target, as expected. This maximum temperature was constantly updated as the temperature changed. The IR temperature data for each test were recorded on standard video tape, giving a record of the maximum observed temperature as a function of time.

The emissivity (ϵ) of the object viewed can be entered into the IR video system and is used in the calculation of temperature from the measured IR radiation. During the videotaping of the tests, the emissivity used by the IR video system was set at 1.0. After testing was complete, calibration tests using a hot plate were performed to determine the actual emissivity of the drill bit. A typical rotary bit was placed on a hot plate and heated. The surface temperature of the bit (~120°C) was measured with a type K thermocouple. Then the emissivity setting for the IR video camera was varied until the temperature measurement from the IR camera agreed with that measured by the thermocouple. This was repeated at several locations on the bit surface. The best-fit emissivity of the cutting surface of the bit was 0.3 to 0.5. Therefore, the previously recorded IR temperature data for the core drilling tests were corrected to an emissivity of ~0.4, as described in the following paragraph.

First, a standard infrared radiation source (Land black body furnace model MT) was used to confirm the IR camera's temperature calibration over the range of 150 to 650°C. Then, the black body was used to determine the equations to convert the temperatures measured using an emissivity of 1.0 to the actual temperature of a bit with emissivity of ~0.4. To do this, the black body furnace was set to six temperatures over the range of 150 to 650°C. At each temperature, the IR camera emissivity was set to

1.0, 0.8, 0.6, and 0.4 and the apparent IR camera temperature was recorded. These data were then used for the emissivity correction to the recorded IR temperatures. Below is a brief table illustrating the conversions.

Recorded Temperature at $\epsilon = 1.0$	Corrected Temperature at $\epsilon = 0.4\pm0.1$
200°C	215±10°C
400°C	530±40°C
600°C	840±65°C

Interpretation of Temperature Measurements

The autoignition temperature[1] (AIT) of H_2-air is 520°C and the AIT of H_2-O_2 is ~400°C. The AIT is relatively independent of gas concentration near the stoichiometric value. These AIT values were measured in a closed volume chamber with all walls uniformly heated so that there was a large area of contact with the gas, allowing the entire gas volume to be heated to the test temperature. The minimum ignition temperatures are significantly higher if the heated area is much smaller and only part of the gas volume is heated. For example, the ignition temperature of H_2-air was 750°C when it was heated by a 1-mm diameter nichrome wire[1]. Using an interpolation based on data for other gases in a heated chamber and with 1-cm and 1-mm heated wires[1], the ignition temperatures of H_2-air and H_2-O_2 were estimated for other sizes of heated surfaces. For a heated surface of about 1-cm size, the estimated ignition temperature of H_2-air is about 650 to 700°C and that for H_2-O_2 is about 550 to 600°C. The observed hot spots during core drilling were also of the order of 1 cm, based on the IR camera data.

In general, the IR camera temperature measurements confirmed that the ignitions that did occur during drilling were due to hot spots at the drill bit/target interface. When the temperature was reduced by decreasing the downward force of the drill, the ignitions no longer occurred. For the test scenarios that never produced ignitions (test method 1a - drilling into steel, and test method 2 - drill string rubbing against steel), the measured IR camera temperatures were well below that required for autoignition.

In tests with a rotary bit drilling into rock at 1350 pounds force and 65 RPM, the measured IR camera temperatures (corrected to an emissivity of ~0.4) were ~365°C after 2 min, ~440°C after 3 min, ~550°C after 4 min, and ~670°C after 5 min of drilling. This showed that the frictional force heating caused the localized temperature to increase in time because the heat could not be conducted away from the interface fast enough. In several tests of drilling under this scenario (see section 4.2) in the presence of stoichiometric H_2-O_2, the gas mixture ignited at 4½ to 6 min, consistent with the estimated ignition temperature of this mixture with a 1-cm hot spot. In tests with a rotary bit drilling into rock at 860 pounds force, the measured IR camera temperatures (corrected to an emissivity of ~0.4) were ~170°C after 3 min, ~240°C after 4 min, and ~290°C after 5 min of drilling. As expected, the reduced downward force decreased the observed temperature. Although IR camera temperatures were not measured for the TSAP bits, it is expected that their temperatures would also be lower for a reduced downward force. However, based on the ignitability data, the temperature of the TSAP bit during drilling was probably higher than that of the rotary bit. This could be explained by the smaller mass of the TSAP bits, which would provide less of a heat sink.

In tests with a rotary bit drilling into steel at 1350 pounds force, the measured IR camera temperatures (corrected to an emissivity of ~0.4) were ~200°C after 3 min, ~225°C after 4 min, and ~350°C after 5 min of drilling. These temperatures were significantly lower that when drilling into the rock at the same downward force. Ignitability tests (see section 4.1) showed no ignitions for this test scenario.

Temperature measurements were also made for the case of the drill string rubbing against steel (side force of 200 pounds). In this case, the observed hot spot was on the drill string. The emissivity of the steel drill string was measured by comparing the IR camera temperature with a thermocouple measurement on the surface after the rotation was stopped. The emissivity of the drill string was 0.9 to 1.0. The measured IR temperatures were less than 150°C during 4 to 10 min tests. For a longer test up to 26 min, the maximum observed IR temperature was ~180°C. No ignitions would be expected at these temperatures. This was confirmed by the ignitability tests in the presence of flammable gas.

Appendix G Endnote

1. Kuchta, J.M., USBM Bulletin 680, "Investigation of Fire and Explosion Accidents in the Chemical, Mining, and Fuel Related Industries - A Manual, 1985".

DISTRIBUTION SHEET

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