Appendix Q
Possible Ignition Sources

Transocean

The size of the flammable gas cloud that enveloped the *Deepwater Horizon* made an explosion almost inevitable. While the investigation team cannot specify what source or sources caused the gas to ignite, the investigation team has identified and analyzed possible ignition sources.

Engine Spaces (Likely)

Scope and Method of Investigation

Identification of potential ignition sources located in the engine room(s) by:

- Review of gas dispersion analysis and the extent of gas cloud
- Assessments of witness statements
- Review of technical drawings and rig schematics
- Review of engine operating procedures and instruction manuals

Summary of Investigation

No crew members were reported as working in the engine rooms at the time of the incident; however, crew members were present in the adjacent engine control room and electronic technician's workshop. The engine rooms were not classified as hazardous areas. The gas dispersion analysis (*See Appendix P*) shows that hydrocarbons had entered engine rooms 3 and 4 within 60 seconds after the initial release. Of the six engine rooms, engine rooms 3 and 4 are the most likely to have presented an ignition source.

During normal operation, an engine exhaust temperature is likely to exceed 420°C.[1] Hence, it is possible for hydrocarbons to self ignite when in contact with the exhaust covers. Should an engine start over-speeding, the exhaust temperature is very likely to spike to even higher levels, thus increasing the likelihood of self-ignition on the exhaust system.

Another potential scenario for ignition arises from an engine being started. When starting an engine, the air pressure in the start-air system will drop from 30 bar, therefore initiating the start-air compressor. The compressor is electrically driven and not explosion-proof and could be a potential source for sparks. Additionally, the effects of compressing hydrocarbons to such a high degree could lead to an ignition.

Two scenarios are most likely for initiation of an engine start sequence:

- Investigation indicates it is likely that an engine fueled by an uncontrolled source will take on all load and therefore trip the other running engine to prevent reverse power. After an engine has tripped, the Power Management System (PMS) will initialize start-up of an additional engine to maintain dynamic position (DP) status.
- Additionally, after a blackout, the PMS will start all generators on standby to recover power.

A witness stated that he saw an engine "changeover" and witnessed the blackout before the first explosion.[2]

Every time an engine is connected to the electrical bus or disconnected from it breakers will cause electrical sparks. Since this occurs in the switchboard rooms adjacent to each engine room these have been reviewed as a possible ignition sources; however, indications are that the hydrocarbon gas did not reach its low flammable limit in these rooms before the first explosion and are therefore considered as an unlikely ignition source.

The investigation team has identified a number of ignition sources within an engine room and that ignition was likely from one or more engine rooms. The team believes that an ignition and subsequent explosion would most likely be from within the engine room space rather than an actual engine.

Main Deck (possible)

Scope and Method of Investigation

Identification of potential ignition sources on the main deck by:

- Review of gas dispersion analysis and the extent of gas cloud on main deck, excluding areas in which hydrocarbon gas was not present
- Assessments of witness statements
- Review of technical and hazardous area drawings

Summary of Investigation

The main deck of the *Deepwater Horizon* was divided into four quadrants to refine the areas containing a potential ignition source. None of these areas were classified as a hazardous area.

An ignition of the hydrocarbons on the Main Deck was possible, but a specific location could not be identified.

(1) Port Forward (unlikely)

No crew members were reported working in this area at the time of the incident. The gas dispersion analysis shows hydrocarbon gas migrating into the port forward area after the initial release. The overall coverage of gas was low compared to other parts of the main deck (*See Appendix P*), therefore reducing the likelihood of providing an ignition source. The port forward area was mostly covered by pipe storage and the bridge; these areas were unlikely to provide an ignition source. The ventilation fans for lower decks, columns, and pontoons normally would have been running, but the gas cloud was unlikely to have reached its LFL at these vents before the first explosion occurred.

No viable ignition source was identified within this area.

(2) Port Aft (inconclusive)

It was determined that crew members were working with a bucking machine port aft, and their crane operator was in the gantry crane.[3] The gas dispersion shows gas migrating into the port aft quadrant after the initial release. *See Appendix P*. This indicates only a short period of time when ignition could have been possible. There are contradicting witness statements from those working in this area about presence of gas in port aft area;[4] however, the dispersion analysis indicates the gas cloud did not reach them within its flammable range before the first explosion.

Ventilation fans, the bucking machine, and the gantry crane were all possible ignition sources.

(3) Starboard Forward (possible)

Crew members were reported working in this area at the time of the incident.[5] Some crew members were working on the starboard side of the rig with the starboard main deck crane. As the incident started, the crane operator was in the process of trying to lay the crane boom into the boom rest. From pictures taken after the incident, this task was not completed, so it can be assumed that the starboard crane engine was running.[6] Other crew members were in this area but not performing any work that could create a viable ignition source. The gas dispersion analysis shows limited gas migrating into the starboard forward quadrant after the initial release, which allows for a short period in which ignition would be possible. *See Appendix P*. The ventilation fans for lower decks, columns, and pontoons would normally have been running, but the gas cloud was unlikely to have reached its LFL at these vents before the first explosion occurred.

If the starboard crane engine was running it could have provided a spark or hot surfaces for ignition.

(4) Starboard Aft (inconclusive)

No crew members were reported working in this area at the time of the incident. The gas dispersion analysis shows gas migrating into the starboard aft quadrant in the area of the riser skate (probably from the mud-gas separator and shale shaker ventilation) from very early on after the initial release (*See Appendix P*), which allows for a short period in which ignition would be possible. Electrical motors for various ventilation systems were covered in gas early after the initial release, and those motors could have ignited the hydrocarbons before they reached the engine rooms. However, witness statements show indication of gas entering some engine rooms (i.e., engines in engine rooms 3 and possibly 6 revving up); therefore, an ignition source from these electrical motors does not fit in with the sequence of events and are considered to be an unlikely source of ignition.[7] The ventilation fans for lower decks, columns, and pontoons normally would have been running, and the gas cloud was likely to have reached its LFL at these vents before the first explosion occurred. However, for the same reason as with the electrical motors, these ventilation fans have been disconnected as an ignition source.

Non-explosion proof lights and junction boxes were a possible ignition source. The transformer room and its ventilation system are not believed to have provided an ignition source. The equipment located in the transformer room is very unlikely to have created an exposed spark or a significant hot surface.

Drilling Areas (Possible)

Scope and Method of Investigation

Identification of potential ignition sources located in the drilling areas by:

- Review of gas dispersion analysis and the extent of the gas cloud
- Assessments of witness statements
- Review of technical and hazardous area drawings and rig schematics
- Review of equipment lists

Summary of Investigation

Most of the drilling areas on the *Deepwater Horizon* were classified as Zone 2 Hazardous Areas and, therefore, all equipment had to be in compliance with American Bureau of Shipping (ABS) rules for that area; no evidence has been found that this was not the case.[8] Though rated (classified) to only contain explosion-proof equipment, it is possible that an ignition point could exist in the area due to the presence of foreign objects or damage from well debris. The drilling area was divided into five parts for investigation purposes as follows:

- Shale Shaker Area (classified as a Zone 1 Hazardous Area)
- Mud Pump Room (not classified as a Hazardous Area)
- Mud Pit Area (classified as a Zone 2 Hazardous Area)
- Drilling Floor Area (classified as a Zone 2 Hazardous Area)
- Mud-Gas Separator (within a classified Zone 2 Hazardous Area)

Possible ignition points existed in various locations within the drilling area, but the investigation team has been unable to determine an exact ignition point

(1) Shale Shaker Area (unlikely)

Crew members reported working in this room prior to the incident. The shale shaker area was classified as a Zone 1 hazardous area, and all equipment had to be in compliance with ABS rules for this room; no evidence has been found that this was not the case.[9] The drill crew had emptied the sand traps prior to the incident, but at the time of the incident, neither they nor any third party were believed to be working in (cleaning) the sand traps.[10] Therefore, it is very unlikely that zoned equipment was exposed or unzoned equipment was present in the area. Gas entered this room shortly after it was released onto the rig (back feeding from the gumbo box into the shaker room) and activated the gas detection system.[11] It should be noted that the gas concentration quickly rose above its upper flammable limit (UFL), certainly before the first explosion. *See Appendix P*. An ignition source due to damage to equipment within the area is possible, but the possibility of flying debris is considered unlikely.

Ignition within this area is considered unlikely.

(2) Mud Pump Room (possible)

Crew members were working in this room prior to the incident. The mud pump room was not classified as a hazardous area. Leading up to the time of the incident, three of four pumps were operational, and a witness reports that repair work on the fourth pump had been completed prior to the explosions; [12] therefore, this work is not deemed to be a likely cause of ignition. Gas entered this room shortly after it was released onto the rig and was in the region of its LFL at the time of the first explosion. *See Appendix P*. After one of the explosions, a witness opened a door and looked into the room, but did not enter due to the damage he observed.[13] It is unknown if the explosion in this room originated from within it or initiated in another space such as an engine room.

Ignition within this area is considered possible.

(3) Mud Pit Room (unlikely)

No crew members were reported working in this area at the time of the incident. The mud pit room was classified as a Zone 2 hazardous area, and all equipment had to be in compliance with ABS rules for this room; no evidence has been found that this was not the case.[14] As far as can be established, no maintenance work was being undertaken in this room at the time of the incident. Gas entered this room less than 90 seconds after it was released onto the rig and was near its LFL at the time of the first explosion. *See Appendix P*.

Ignition within this room is considered unlikely.

(5) Drilling Area (possible)

Crew members were working in this area during the incident. The drilling area was classified as a Zone 2 hazardous area, and all equipment had to be in compliance with ABS rules for this area; no evidence has been found that this was not the case.[15] Gas was present within the drilling area almost immediately after it was released onto the rig and activated the gas detection system. [16] *See Appendix P*. This gas almost certainly was coming from the rotary table and overflowing from the top of the mini trip tank.

The drilling area had several possible ignition sources. The drill floor and derrick were likely subject to damage during the incident due to debris flying from the rotary table under pressure. The possibility of damage to lighting and equipment existed, which could cause an open electrical circuit and exposed spark. Well debris striking against objects on the drill floor or in the derrick could also cause a spark due to contact. The drawworks motors could also provide a source of ignition by drawing hydrocarbons into the blower motors. The driller's work station was a positive pressure environment,[17] but once power was lost, any opening due to open doors or damage from debris could pose a potential spark due to non-zoned equipment located in the space. Any third-party equipment located in the area would require hazardous-area classification and was not determined to be a possible source of ignition.

Ignition within the drilling area is considered possible.

(6) Mud-Gas Separator (unlikely)

The investigation team found that the mud-gas separator (MGS) was overloaded, as evidenced by the design information and Macondo well hydraulic analysis performed by Stress Engineering Services. The MGS was contained within the drill floor Zone 2 hazardous area and had few parts that could have caused an ignition source. Although the MGS was overloaded beyond its design limits, and witnesses describe seeing a flash/explosion in the area of the MGS, the investigation team does not believe that the MGS itself exploded, and it is thought to be an unlikely ignition source.[18]

Ignition from the MGS is considered unlikely.

Moon Pool Area (Possible)

Scope and Method of Investigation

Identification of potential ignition sources located in the moon pool area by:

- Reviewing equipment and maintenance of equipment in the moon pool
- Assessing the potential of mechanical sparks due to well debris
- Review of witness statements and interviews
- Review of gas dispersion analysis

Summary of Investigation

The moon pool was classified as a Zone 2 hazardous area and therefore all equipment had to be in compliance with ABS rules for that area; no evidence has been found that this was not the case.[19] The gas dispersion analysis indicates that a flammable gas cloud was forming within the first 30 seconds after the first release of gas onto the rig. *See Appendix P*. A witness describes "gas pressure" in the moon pool prior to the first explosion;[20] this is believed to be fluid/gas escaping through the slip joint packer, which probably failed due to the pressure of fluid/gas exerted onto it.[21] The chief engineer describes an enormous fire in the moon pool when he went to try and start the standby generator.[22]

Witness statement and review of the slip joint rating indicates that the slip joint packer likely failed and did not maintain a seal of the slip joint. Hence, it is possible that well debris was shooting out of the slip joint, potentially damaging equipment in the moon pool area and causing electrical sparks. Furthermore, debris impacting on the metal structure of the moon pool with such high velocity is capable of creating mechanical sparks and possibly impacting the integrity of equipment that was classified for use in a hazardous area.

The additional equipment, such as equipment provided by a third party, in the moon pool is not believed to be a potential ignition source.

Based on the evidence, the moon pool area has to be considered as a possible ignition source, although an exact location(s) within the area has not been identified.

Off Rig (Unlikely)

Scope and method of investigation Introduction

Identification of potential ignition sources located off rig by:

- Evaluating the likelihood of the sports fishing boat *Endorfin*, the supply vessel *Damon B. Bankston*, and any other vessel in the immediate area of the *Deepwater Horizon*
- Reviewing witness statements, interviews, and information provided by Tidewater Marine

Summary of Investigation

(1) *Endorfin* (unlikely)

Although the *Endorfin* had been under the rig prior to and at the start of the incident, according to the fishermen's statements, "They were about 100 yards from the *Deepwater Horizon* when the lights went out, and the first of a series of massive booms shook the rig."[23] Therefore this fishing boat is unlikely to have been a source of ignition.

(2) *Damon B.Bankston* (unlikely)

The supply vessel *Damon B. Bankston* was about 40 ft. away from the *Deepwater Horizon* on the port side of the rig with oil-based mud (OBM) hose connected and waiting to receive OBM back from the rig when the incident started.[24] The following potential ignition sources on the *Bankston* have been identified:

- Sparks from its exhaust stacks
- Hot work (burning and welding)
- Hot surfaces within its engine room

Information provided by Tidewater Marine indicates that the *Bankston* was equipped with working spark arrestors on its exhaust stacks.[25] From testimony by members of the *Bankston* crew, there is no indication that hot work was being performed on the vessel at the time of the incident. Had hydrocarbon gas entered the engine room of the *Bankston* and ignited, there would have been significant damage to the vessel; there is no evidence this happened. The *Bankston* crew did report to *Deepwater Horizon* survivors that a bridge window was broken, but this is believed to have been as a result of an explosion on the *Deepwater Horizon*.[26] Based on assessment of this information, the *Bankston* is not considered a viable ignition source.

(3) Other Vessels in the Area (unlikely)

There were other vessels within the immediate area of the *Deepwater Horizon* at the time of the incident, as confirmed by the response to the distress messages sent by the rig.[27] However, none of these vessels has been identified as being closer than 500 meters to the *Deepwater Horizon* at the start of the incident and, therefore, cannot be considered a viable ignition source.

Based on the information available, the investigation team considers it unlikely that the source of ignition for the hydrocarbon gas cloud on the *Deepwater Horizon* originated from a source "off rig."

1. *Deepwater Horizon* – Exhaust Gas Temperatures, #1 and 2 Main Engines, Aug. 1, 2007.
2. Testimony of William Stoner, Hearing before the *Deepwater Horizon* Joint Investigation Team, May 28, 2010, 340:22−25.
3. Testimony of Micah Sandell, Hearing before the *Deepwater Horizon* Joint Investigation Team, May 29, 2010, 8:7−8, 12:2−4.
4. Transocean Investigation Team Interview of Cole Jones, June 1, 2010.
5. Transocean Investigation Team Interview of Caleb Holloway, May 28, 2010.
6. Picture of unknown source of *Deepwater Horizon*, taken approximately two hours after the start of the incident.
7. William Stoner Witness Statement, April 21, 2010; The United States Coast Guard, Doug Brown Witness Statement, April 21, 2010 *Deepwater Horizon*.
8. *Deepwater Horizon* Operations Manual, Section 9.1, March 2001.
9. *Deepwater Horizon* Operations Manual, Section 9.1, March 2001.
10. Sperry Sun data.
11. Testimony of Andrea Fleytas, Hearing before the *Deepwater Horizon* Joint Investigation Team, Oct. 5, 2010, 13:11−14; Testimony of Yancy Keplinger, Hearing before the *Deepwater Horizon* Joint Investigation Team, Oct. 5, 2010, 150:22−151:7.
12. Testimony of Chad Murray, Hearing before the *Deepwater Horizon* Joint Investigation Team, May 27, 2010, 314:2−9.
13. Testimony of Chad Murray, Hearing before the *Deepwater Horizon* Joint Investigation Team, May 27, 2010, 309:2−10.
14. *Deepwater Horizon* Operations Manual, Section 9.1, March 2001.
15. *Deepwater Horizon* Operations Manual, Section 9.1, March 2001.
16. Testimony of Andrea Fleytas, Hearing before the *Deepwater Horizon* Joint Investigation Team, Oct. 5, 2010, 13:11−14; Testimony of Yancy Keplinger, Hearing before the *Deepwater Horizon* Joint Investigation Team, Oct. 5, 2010, 150:22−151:7
17. HITEC FDS Driller's work station ST3784-FDS-100; R&B Falcon., Safety Systems Design Philosophy, Aug. 23, 2000, TRN-MDL-00402475.
18. Testimony of Micah Sandell, Hearing before the *Deepwater Horizon* Joint Investigation Team, May 29, 2010, 10:5−11:24.
19. *Deepwater Horizon* Operations Manual, Section 9.1, March 2001.
20. Transocean Investigation Team Interview of Cole Jones, June 1, 2010.
21. ABB Vetco Gray, Telescopic Joint with Hydraulic Latch and Fluid Assist Bearing Operating and Service Procedure 6210, June 2000, 2; ABB Vetco Gray, Field Service Manual for Reading & Bates Drilling Co., RBS8D, *Deepwater Horizon*, HMF-H; Marine Riser System and Wellhead Connector, P.O. # MR-87-00023 Co's #C54927.
22. Testimony of Stephen Bertone, Hearing before the *Deepwater Horizon* Joint Investigation Team, July 19, 2010, 41:5−1423 Transocean Investigation Team Interview of Cole Jones, June 1, 2010.
23. Transocean Investigation Team Interview of Cole Jones, June 1, 2010; Huffington Post, May 9, 2010, marine biology student Albert Andry III and three friends had come to the *Deepwater Horizon* to fish.
24. Weekly Leader Episode 68 podcast of Captain Alwin Landry Interview, Oct. 5, 2010; *Damon Bankston* Log, April 20, 2010, TDW-0020.
25. Harold Wilson e-mail message to Billy Brown, Oct. 13, 2010, TWD-06611; Beaird Industries Inc – MSA1 Maxim Spark Arrestor Silencer.
26. Transocean Investigation Team Interview of Kennedy Cola, June 17, 2010; Transocean Investigation Team Interview of Mike Mayfield, June 3, 2010.
27. *Damon Bankston* Log, April 20, 2010, TDW-0020.