# Vastar Resources, Inc.
## Deepwater Horizon
## BOP Stack Design
## Technical Position Paper

5094

Exhibit No. ______
Worldwide Court Reporters, Inc.

**Issue:** BOP Stack Design

**Date:** September 1, 2000

**Discipline:** Engineering, Subsea, and Drilling Systems

**Responsible:** Dick Metcalf & Dan M. Welch – Vastar

**Issue:**
Overall design of the BOP Stack for the Deepwater Horizon.

**Decision:**
The BOP Stack most suited for this application is a Cameron TL Guidelineless, 18-3/4" 15K stack rated for 10,000 ft water depth.

1) Stack configuration:

**BOP Capabilities for Deepwater Horizon**

| Well Control Capabilities | Capability |
|---|---|
| 1. Close on open hole | Yes |
| 2. Close annular and circulate out kick: | Yes |
| a. Bleed, bullhead or lubricate wellbore | Yes |
| b. Circulate out both choke and kill line simultaneously | Yes |
| c. Flush or circulate out trapped gas below upper annular | No |
| d. Flush or circulate out trapped gas below lower annular | Yes |
| 3. Strip pipe: | Yes |
| a. Annular stripping | Yes |
| b. Annular to annular | No |
| c. Annular to ram (not recommended with VBRs) | Yes |
| d. Ram to ram (not recommended with VBRs) | Yes |
| 4. Hang-off drill pipe and circulate out kick | Yes |
| a. Bleed or bullhead wellbore | Yes |
| b. Lubricate wellbore | Yes |
| c. Circulate out both choke and kill lines simultaneously * | Yes |
| 5. Shear drill pipe or disconnect drill pipe if severe weather situation | Yes |
| a. Circulate well after shear or drill pipe disconnect | Yes |
| b. Circulate across stack between shear and hang-off rams | Yes |
| c. Bleed or bullhead wellbore below hang-off rams | Yes |
| d. Circulate stack or lubricate wellbore below hang-off ram | Yes |
| 6. Outlet between annulars to expedite removal of trapped gas | No |
| 7. Deepwater: Hung-off | |
| Circulate across stack to remove possible gas | Yes |
| a. Above hang-off | Yes |

| | |
|---|---|
| b. Below hang-off | Yes |
| 8. Outlet below bottom preventer to expedite pressure test of bottom ram | Yes |
| 9. Hang off on upper VBR and shear drill pipe on tube | Yes |
| 10. Accessibility to change out primary annular | Fair |
| 11. Measurement from top hang off ram to bottom of SBR | 93" |

- In hang off position, it is not recommended to routinely circulate up kill line due to possible erosion in #1 Master Ram outlet

**Lower Stack Configuration (Bottom to Top) :**

**Vetco SHD H-4 Connector 18-3/4" 15,000 psi WP ( See TPP for WH Connector)**

Operating pressure: 1,500 – 3,000 psi
Latch volume: 7.37 gal.
Unlatch volume: 9.9 gal.
Secondary volume: 14.18 gal.
Wellhead gasket release to ROV Panel
Wellhead connector unlatch to ROV Panel
Pilot operated check valve to ROV Panel

**TL BOP, Double, 18-3/4" 15,000 psi WP with ST-Locks and sequence valves**

Operating pressure: 1,500 – 3,000 psi
Close volume: 24.3 gal. Per cavity
Open volume: 22.4 gal. Per cavity
ST- lock volume: 3.4 gal. Per lock
Lower ram cavity: 5 – 1/2" pipe rams
Upper ram cavity: 3-1/2" - 6-5/8" Variable Rams
Lower kill outlet: **MCS Marine Choke and Kill Target Valve, 3-1/16" 15,000 psi WP**
Open volume: .90 gal.
Close volume: .94 gal (failsafe assist)
Lower inner and outer kill valve
Failsafe close panel 1
Lower choke outlet: Blank
Upper kill outlet: P/T Sensor
To Riser Control Box
Upper choke outlet: **MCS Marine Choke and Kill Target Valve 3-1/16" 15,000 psi WP**
Open volume: .90 gal.
Close volume: .94 gal. (failsafe assist)
Lower inner and outer choke valve
Failsafe close panel 2

**TL BOP, Single, 18-3/4" 15,000 psi WP with ST-Locks and sequence valves**

Operating pressure: 1,500-3,000 psi
Close volume: 24.3 gal.
Open volume: 22.4 gal.
Ram cavity: 3-1/2" – 6-5/8" Variable Rams
Kill outlet: Blank
Choke outlet: **MCS Marine Choke and Kill Target Valve 3-1/16" 15,000 psi WP**
Open volume: .90 gal.
Close volume: .94 gal. (failsafe assist)
Upper inner and outer choke valve
Failsafe close panel 3

**TL BOP, Double, 18-3/4" 15,000 psi WP with ST-Locks and sequence valves**

Operating pressure: 1,500 – 3,000 psi
Close volume: Casing shear 69.40 gal.
Close volume: Blind shear 24.30 gal.
Open volume: Casing shear 65.20 gal.

Open volume: Blind shear 22.40 gal.
Lower ram cavity: Casing shear rams ( NO ST-Locks)
To High Pressure Casing Shear Failsafe Close Panel 4
Upper ram cavity: Shearing blind rams
To High Pressure Shear Failsafe Panel 5
To ROV Panel
Lower kill outlet: Blank
Lower choke outlet: Blank
Upper kill outlet: **MCS Marine Choke and Kill Target Valve**
**3-1/16" 15,000 psi WP**
Open volume: .90 gal.
Close volume: .94 gal. (failsafe assist)
Upper inner and outer kill valves
To failsafe close panel 6
Upper choke outlet: Blank
**Reentry Mandrel, 18-3/4" 15,000 psi WP**

**Deadman Panel (See TPP Deadman System)**
Hydraulic accumulator supplied system for closing in well

**ROV Panel (See TPP ROV Panel)**
Provide ROV access to the following:
WH POCV Vent
Accumulator Relief Valve Isolation
Hydrate Remediation Injection – Wellhead Connector
Hotline Bypass (B & Y)
Accumulator Dump (LMRP & Stack)
Riser Connector Unlatch
Riser Connector Gasket Release
Wellhead Connector Unlatch
Wellhead Connector Gasket Release
Ram ST Lock
C/K Connector Unlatch
SBR Close

**Failsafe panels**
Failsafe panels provide relief valves to ensure over-pressure of the accumulator when the BOP- Stack is retrieved from deep water.

**Lower Marine Riser Package Configuration (bottom to top):**

**Cameron HC Collet Connector, 18-3/4" – 15,000 psi WP**
Operating pressure: 1,500 – 3,000 psi
Latch volume: 14.90 gal.
Unlatch volume: 18.50 gal.
Secondary volume: 18.50 gal.
Gasket release to LMRP ROV panel
Primary and Secondary Unlatch to LMRP ROV panel
**DL Annular, Dual, 18-3/4" – 10,000 psi WP**
Operating pressure: 1,500 – 3,000 psi each annular
Close volume: 51.00 gal each annular
Open volume: 45.10 gal each annular
3-1/16" – 15,000 psi outlets below annular packers
Lower outlet: **MCS Marine Choke and Kill Target Valve**
Operating Pressure: 1,500 – 3,000 psi
Close Volume: .90 gal
Open volume: .94 gal (failsafe assist)

Inner and outer bleed valves
Upper outlet: Blank

**MCS Marine Choke and Kill Isolation Valves, 3-1/16" – 15,000 psi WP**
Operating Pressure: 1,500 – 3,000psi
Open volume: .90 gal
Close volume: .94 gal (failsafe assist)

**Choke and Kill Mini Connectors, 3-1/16" – 15,000 psi WP**
Operating pressure: 1,500 – 3,000 psi
Latch volume: 1.50 gal.
Unlatch volume: 2.00 gal.
Secondary volume: 2.00 gal.

**Oilstate Flex Joint, 18-3/4" – 5,000 psi WP**
Operating Pressure: 1,500 – 3,000 psi.
Open volume: .90 gal
Close volume: .94 gal (failsafe assist)

**FCS Mud Boost Valve With DF Actuator**
Operating pressure: 1,500 – 3,000 psi
Open Volume: .90 gal
Close volume: .94 gal (failsafe assist)

**Riser Termination Adapter**
Provides Riser Connection interface, and C/K kick-outs.

**Hydraulic Conduit Package**
Controls the flow of hydraulic fluid from the riser mounted conduit or hot line.

2) **BOP Stack Frame:**
The areas of consideration in designing the BOP frame are stack weight, hang off weight during lifting, side loads incurred during stabilization, and side impact loads.
When the BOP is transported from storage to the moonpool it will be supported at its upper and lower frame. This will transmit the weight of the entire BOP stack through the frame which attaches to the BOP at the flanged end of the upper double ram BOP and at the top of the Riser Connector.
When lifting the BOP stack, the load is transmitted through four pad eyes located at the top of the upper frame. The pad eyes will transmit the weight of the entire stack and both frames. The upper frame attaches to the stack at the top of the Riser Connector.
Guide Spears located at two corners of the frame are used as handles to stabilize the BOP stack during lifting. These transmit the side loads into the frame.
Bumper rails are located along the corners on the sides of the frame. The bumper rails are designed to absorb side impacts occurring during transport.

3) **P/T Sensors:**
The BOP stack has two P/T sensors. Upper sensor is located below choke isolation valve.
The lower sensor is located on kill outlet of number 2 BOP cavity.

4) **Tubing Hanger Orientation Pin** (capability):
The BOP control system has two spare hydraulic functions designated for a Tubing Hanger Orientation Pin. For future completion activities, a hydraulically actuated pin can be installed to provide the means for orientation of the tubing hanger and sub-sea tree.

5) **Hydraulic Control system:**
This system has been designed especially for the particular needs of a dynamically positioned vessel. The BOP Control System is an Electro-Hydraulic or Multiplexed (MUX) control system. This means that BOP function commands are transmitted electronically to the subsea pods via armored power and signal cables which run from the main control unit to the subsea pods. Hydraulic supply is provided via a combination of subsea and surface accumulators and a rigid conduit line. The basis of reliability of the system is the redundancy encompassed between the Driller's Panel, Toolpusher's Panel, and the Central Control Unit. Both the Toolpusher's and Driller's control panels are independent of each other. For example, if the Toolpusher's Panel is damaged or inoperative, commands may be issued from the Driller's Panel. The subsea control pods are redundant in that there are two (2) identical pods on the stack, which work independent of each other.

The control system has been designed to applicable API and ABS (CDS) requirements. The system is designed for not only safe and redundant operation during normal drilling and potential well control events, but also incorporates a number of safeguards for significant unplanned events. They are;

Loss of Power/Hydraulics:

This could occur due to massive failure or parting of the drilling riser above the LMRP and below the upper flex joint, which would render control by the subsea pods ineffective. This condition could also be caused by fire and/or explosion which destroys the hydraulic supply and the MUX cables either in control room areas or in the moonpool. In either case, the MUX system contains a "Deadman System" (DMS) which would automatically initiate closure of the blind shear rams and choke/kill isolation valves to seal off the wellbore. It would also initiate a disconnection of the riser connector to allow the rig to move of location. The DMS is powered by stand-by batteries and is not dependent on the system power of operation.

Unplanned Disconnect of the LMRP

There are two safety systems which are incorporated in the control system which are designed to either prevent or control the event of an unplanned disconnect of the LMRP. They are:

1) Physical barriers prevent both the riser disconnect and the wellhead disconnect buttons on the Toolpusher's and Driller's panels to be accidentally activated. Deactivation of these barriers requires direct and deliberate intervention by the operator.

2) Touch screen controls on Operator Interface Panels (OIT's) require two (2) confirmations in order to complete either the riser or wellhead disconnect operation.

3) In the event there were to be an unintentional disconnect of the LMRP from the stack, the control system incorporates an auto-shear circuit which is activated on upward movement of the LMRP. Upward movement of the LMRP activates a circuit, which closes the blind shear rams. Hydraulic supply for this circuit is located in accumulators on the lower stack and does not require the LMRP to be in place.

ROV Intervention

The Deepwater Horizon will have on board, manned for 24hr operation, a work class ROV capable of operating the following BOP stack functions.

- WH POCV Vent
- Accumulator Relief Valve Isolation (LMRP & Stack)
- Hydrate Remediation Injection – Wellhead Connector
- Hotline Bypass (B & Y)
- Accumulator Dump (LMRP & Stack)
- Riser Connector Unlatch
- Riser Connector Gasket Release
- Wellhead Connector Unlatch
- Wellhead Connector Gasket Release
- Ram ST Lock
- C/K Connector Unlatch
- SBR Close

In addition, the ROV system is installed with a "Curser" deployment system which allows launching of the ROV in more severe weather than standard systems.

A complete HAZOP study was completed on the Control system and all issues raised with were resolved.

**Discussion:**

The following is a list of requirements that affect the decision:

- The BOP must comply with:
  - API 6A, Specification for Wellhead and Christmas Tree Equipment
  - API 17D, Specification for Subsea Wellhead and Christmas Tree Equipment
  - DNV Recommended Practice RP B401, Cathodic Protection Design
  - NACE MR-01-75, Standard Material Requirements – Sulfide Stress Cracking Resistant Metallic Material for Oilfield Equipment.
  - NAS 1638, National Aeronautics and Space Administration – Cleanliness Requirements for Parts Used in Hydraulic Systems.

- Vendor Selection (Summary from Well Control System Meeting 12 Feb 99):
  - Price – Cameron is less than Shaffer
  - Vendor Support – Both companies require close monitoring for optimum performance.
  - Delivery – Cameron is 13 months and Shaffer is 10 months.
  - Vendor Confidence – Both companies are capable of producing acceptable systems.
  - Documentation – Cameron data from the RBS8M.
  - Track Record/Fleet Compatibility – Better with Cameron.
- The BOP shall be rated to a minimum working pressure of 15,000 psi.
- The outlet located on the annular was increased from 1-1/2" to 3-1/16" to increase the efficiency of gas bleed down. The decision was made to locate the choke line below the lower annular for ease of service versus below the upper annular for well control reasons.
- There have been a number of reports in the field concerning problems with ST-Locks. Cameron made a presentation to address these problems. The seals on the poppet valves were replaced with metal seals and the automatic sequencing feature was eliminated. Also, the roller bearings are now supplied as matched sets and the thrust bearing material has been upgraded.
- The lower ram is to be the considered the master ram and will contain 5-1/2" fixed rams. This will correspond to the primary pipe size to be used.
- The CSR's are located below the SBR's. The purpose for this arrangement is to protect the sealing capabilities of the SBR. By first shearing with the CSR's and then raising the tail, the SBR's are able to close in the well with less risk of damaging the seal.
- A decision was made to standardize on a manufacturer for the BOP. The Cameron TL-Ram was favored over the Shaffer offering. The Shaffer annular was preferred because of the higher pressure required with the Cameron annular to strip pipe and close on open hole. The choice to go with Cameron was due to system continuity, field performance and fleet compatibility.
- Due to the high loads imposed on the BOP stack and riser, a study was done of the bolting. The results of this study required verifying the hardness value of the bolts to be used. The first set of bolting supplied was determined to be to hard and was subsequently replaced with bolts which had been individually inspected and found acceptable.
- EDS-1 and EDS-2 modes were tested and the times required were verified on shore to be 32 seconds for EDS-1 and 38 seconds for EDS-2.
- Shear test was conducted on both the SBR's and the CSR's. The CSR's were tested on 13-5/8" 88.2# Q125 casing and required 7 seconds to shear and 15 seconds to close at 2,000 psi. The CSR's also were tested on 5-1/2" 1-1/16" wall P110 pipe and required 11 seconds to shear and 27 seconds to close at 2,300 psi. The SBR's were tested on 5-1/2" 21.9# S135 pipe and required 5 seconds to shear and 12 seconds to close at 2,900 psi. Following the shear a successful pressure test was achieved.
- Due to the deep-water capabilities of the stack, the compression medium to be used in the subsea accumulators was investigated. The decision was made to go with Nitrogen instead of Helium. The primary drawbacks to Helium were its smaller atom size, which allow for easier migration through bladders and past seals, industry familiarity, cost and availability.
- Accumulator sizing and selection were based on the most efficient use of space for providing the required hydraulic fluid required to operate the stack. The bottles on the stack valves are required to close the valves under 15,000 psi working pressure. The total subsea accumulator requirements were LMRP: 6 15 gallon bladder bottles, 2 10 gallon bladder bottles, 4 60 gallon piston bottles. STACK: 6 15 gallon bladder bottles, 8 80 gallon piston bottles. All bottles are rated for 10,000 ft depth and 5,000 psi service.
- Coflexip hoses used on the LMRP and Stack are capable of withstanding collapse in 10,000 ft water depth if void.
- Hangoff capabilities of the various pipe rams are as follows:

| **Ram Size** | **Pipe Size** | **Maximum Hang Off Weight** |
|---|---|---|
| 3 ½" x 5 ½" | 3 ½"/ 5"/ 5 ½" | 140,000/ 450,000/ 450,000 |
| 5 ½" | 5 ½" | 600,000 |

- **Stack Weight:**

| | |
|---|---|
| LMRP | 272,000 |
| Stack | 344,800 |
| Total | 617,000 |

| Function name | description | volume gal |
|---|---|---|
| Upper annular preventer | close | 51 |
| Upper annular preventer | open | 45.1 |
| Lower annular preventer | close | 51 |
| Lower annular preventer | open | 45.1 |
| Upper inner choke valve on LMRP | open | 0.9 |
| | close assist | 0.94 |
| Upper outer choke valve on LMRP | open | 0.9 |
| | close assist | 0.94 |
| One pair of fail static choke and kill line isolation valves on LMRP | open | 1.88 |
| | close | 1.8 |
| LMRP connector-primary | latch | 14.9 |
| LMRP connector-primary | primary unlatch | 18.5 |
| LMRP connector-secondary | secondary unlatch | 18.5 |
| Choke and kill connectors | latch | 1.5 |
| Choke and kill connectors | primary unlatch | 2 |
| Choke and kill connectors | secondary unlatch | 2 |
| Ram preventer upper (SBR) | close | 24.3 |
| | open | 22.4 |
| Ram preventer middle upper (casing shear) | close | 69.4 |
| | open | 65.2 |
| Ram preventer middle | close | 24.3 |
| | open | 22.4 |
| Ram preventer middle lower | close | 24.3 |
| | open | 22.4 |
| Ram preventer bottom | close | 24.3 |
| | open | 22.4 |
| Ram preventer lock | lock energize | 3.4 |
| Middle inner choke valve | open | 0.9 |
| | close assist | 0.94 |
| Middler outer choke valve | open | 0.9 |
| | close assist | 0.94 |
| Upper inner kill valve | open | 0.9 |
| | close assist | 0.94 |
| Upper outer kill valve | open | 0.9 |
| | close assist | 0.94 |
| Lower inner choke valve | open | 0.9 |
| | close assist | 0.94 |
| Lower outer choke valve | open | 0.9 |
| | close assist | 0.94 |
| Lower inner kill valve | open | 0.9 |
| | close assist | 0.94 |
| Lower outer kill valve on | open | 0.9 |
| | close assist | 0.94 |
| Wellhead connector-primary | latch | 7.37 |
| Wellhead connector-primary | primary unlatch | 9.9 |
| Wellhead connector-secondary | secondary unlatch | 14.18 |

## RB Falcon Deepwater Horizon
## Technical Position Paper

**Prepared By:**

| Name | Discipline | Signature | Date |
|---|---|---|---|
| Dick Metcalf | Vastar, Subsea Consultant | Dick Metcalf | 9-13-00 |
| Dan M. Welch | Vastar Project Engineer | DMWelch | 9-13-00 |

**Reviewed By:**

| Name | Discipline | Signature | Date |
|---|---|---|---|
| Kevin Wink | Deepwater Horizon, Rig Manager | K. Wink | 9.13.00 |
| Don Weisinger | Vastar, Project Manager | | |

**Prepared By:**

| Name | Discipline | Signature | Date |
| --- | --- | --- | --- |
| Dick Metcalf | Vastar, Subsea Consultant | Dick Metcalf | 9-13-00 |
| Dan M. Welch | Vastar Project Engineer | DMWelch | 9-13-00 |

**Reviewed By:**

| Name | Discipline | Signature | Date |
| --- | --- | --- | --- |
| Kevin Wink | Deepwater Horizon, Rig Manager | K. Wink | 9-13-00 |
| Don Weisinger | Vastar, Project Manager | Don Weisinger | 9/14/00 |