Horizon Incident Recovery

BOP Ram Position
Density and Radiographic Inspection

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Executive Summary

The design of the Cameron BOP as used on the Macondo well is such that when the Blind Shear, Variable, and Test rams are fully closed, there is a locking pin or "wedge lock" that slides into place to ensure that the rams are locked fully closed. When fully engaged, this wedge lock physically moves from one side of the ram body into a bonnet on the other side. Thus the fully deployed presence of the wedge lock within the bonnet is an indication of a fully closed ram.

Density surveys and radiographic images were identified as methods to inspect the bonnets for the presence of the wedge locks. Base line density surveys on the ram bonnets were performed at the Cameron facility to prove the concept and to act as a comparison point. Radiographic images were also obtained on the Blind Shear ram bonnet at the Cameron facility to prove the technology and to act as a comparison if necessary.

The East and West ram bonnets on the Blind Shear, Upper Variable, Lower Variable and Test rams were surveyed with density scans on May 8th through 9th and again on May 15th. The East bonnet on the Blind Shear ram was imaged via radiographs on May 13th and again on May 15th, to serve as an separate data point and to validate the density survey data. Ultrasonic thickness equipment had also been prepared for more data acquisition if needed, but was demobilized based upon the results of the density and radiographic data.

The acquired data set was reviewed by the data acquisition team, which included scientists from Los Alamos, Sandia and Lawrence Livermore National Laboratories, BP technical representatives, Cameron representatives and specialized representatives from critical other companies. Due to the importance of the information, independent processing and validation of the raw radiographic data was performed by both Los Alamos and GE.

The following conclusions have been reached based upon the interpretations supplied by the data acquisition team and independent validation.

- The radiographic data indicates that the wedge lock appears to be present within the East side Bonnet of the Blind Shear Rams. As such the ram is believed to be closed.
- The radiographic data serves as a validation of the data acquired via density surveys of the ram bonnets.
- The density surveys of the ram bonnets are repeatable, and as validated by the radiograph, believed to be valid.

Based upon the separate data points of density scans of the BOP ram bonnets and the radiographic images, the data has been interpreted to indicate the following for ram position:

Blind Shear Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Upper Variable Rams
East Side: May indicate a partially deployed lock, hence a partially closed ram
West Side: Wedge Lock in place

Lower Variable Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Test Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Context

The data acquisition team was assembled at short notice and was comprised of representatives of the three national laboratories, BP staff and consultants and representatives of various companies with expert knowledge. A full listing of the contributing members of the team may be found in Appendix 1.

For all discussion in this document, the BOP rams will be referred to, from the top to the bottom as the Blind Shear Rams, The Casing Shear Rams, the Upper Variable Rams, the Lower Variable Rams and the Test Rams.

The design of the Cameron BOP is such that when the Blind Shear, Variable Pipe, and Test rams are fully closed, there is a locking pin or "wedge lock" that slides into place to ensure that the rams are locked closed. When fully engaged, this wedge lock physically moves from one side of the ram body to the other behind the piston forcing the rams into place. There is a "bonnet" or cylindrical housing designed to allow for this wedge lock to move to the closed and locked position. When fully open and the locks are not engaged, the bonnet is effectively an empty cylindrical housing. When the locks are engaged a portion of the wedge lock and piston fills this cylindrical housing. Detailed engineering diagrams may be found in Appendix 1, while Figure 1 below illustrates the basic design of the wedge lock system.

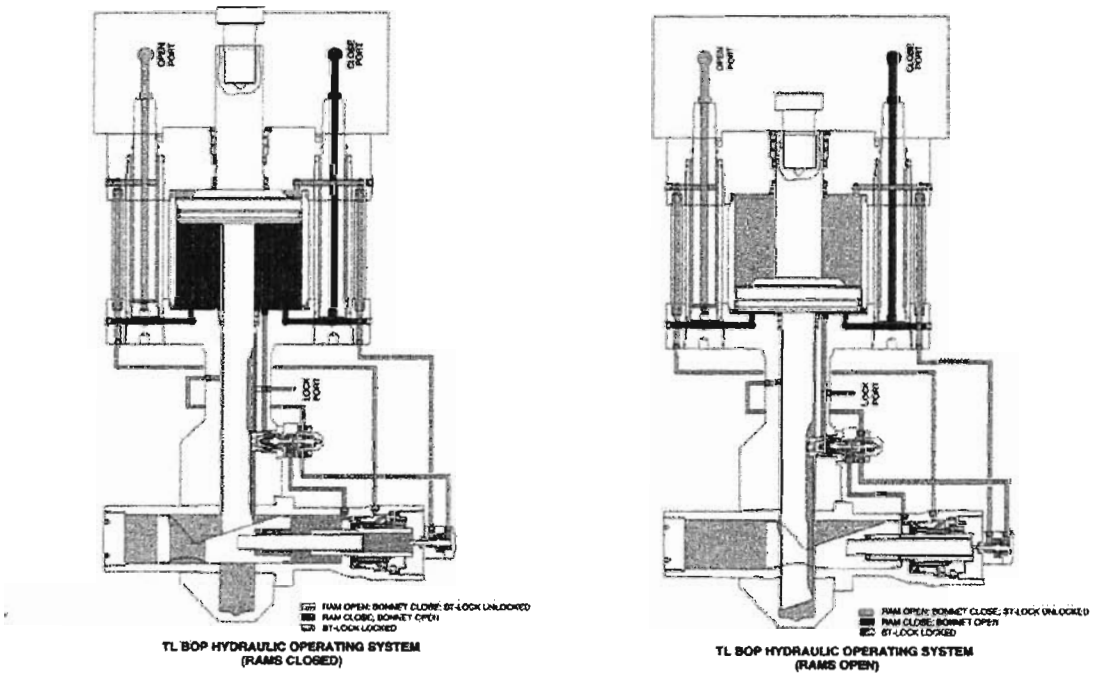

Figure 1: Drawing Depicting the Position of the Wedge Locks

Based upon the mechanical design of the wedge lock system it was theorized that the presence of the wedge lock in the cylindrical bonnet could be detected via a density measurement across the bonnet or via radiographic means.

Density Measurements

Nucleonic or radiometric density measurements, also known as Gamma Ray density measurements, are in use in a variety of industries, including some subsea applications. The measurement is based upon gamma rays that are emitted from a radioactive source and travel through the media in question and enter the detector. The amount of gamma rays absorbed by the material between the source and the detector is proportional to the density of the material. As the density of the material between the source and the detector increases, the counts received at the detector decrease. For the case of the BOP, if a source and detector are placed across the bonnet and the bonnets are empty, as in the case of fully open rams, more counts at the detector would be expected than if the wedge locks were in place and the rams closed.

Baseline Survey & Proof of Concept

In order to prove the technology could work across the thicknesses of metal in the BOP bonnets, a surface test was conducted in the Cameron facility in Morgan City, La on May 5th, 2010 using a BOP similar to that installed on the Macondo well. Measurements were taken using a Cesium 137 source with strength of 7 milliCuries (note that the 16.5 milliCurie source was already deployed offshore) The ram mechanism was cycled from the open to closed position in order to provide a baseline for comparison with field data. The results as shown below in Figure 2 indicated that the presence of the wedge locks within the bonnet could be detected.

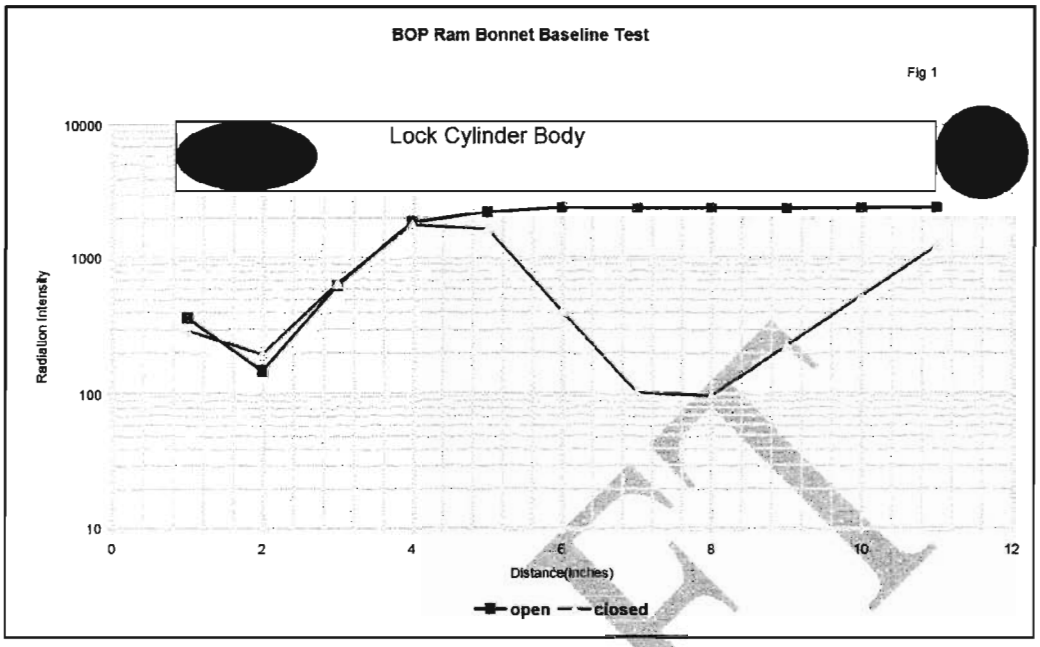

Figure 2: Baseline Data Acquired at Cameron Facility May 5th, 2010.

Field Data Acquisition

Following the yard test at Cameron, the TRACERCO Diagnostics ™ FMI system was deployed. The system can be interfaced and operated via ROV and incorporates a collimated gamma radiation source and detector unit mounted on opposite forks of a variable yoke system. These forks are positioned across the diameter of the item under inspection. The transmitted radiation intensity is measured and compared to the intensity expected for the same item on surface, based upon the item's diameter, wall thickness and system calibration. Pictures of the field deployment may be found in Appendix 2.

The BOP ram bonnets were surveyed on both East and West sides of the BOP, and on the Blind Shear Rams (1), the Upper Variable Rams (2), the Lower Variable Rams (3) and on the Test Rams (4). Data was not acquired on the Casing Shear Rams as there are no wedge locks on these rams.

The data acquired May 8th through 9th, was acquired using a Cs 137 source with strength of 16.5 milliCuries. The count rates seen at the detector were lower than optimal and as a result, there was significant statistical variation on the data. In addition the ability to exactly control the starting position of the surveys subsea is difficult, so an exact match of position linearly along the bonnet could not be expected, although measurements were attempted at a 2" spacing.

The data acquired shows a good correlation to the baseline data, in terms of lower than expected count rates due to the presence of additional metal. Figures 3 and 4 below illustrate the data acquired from the East and West sides across the bonnets (as numbered above) plotted against the baseline reference from the yard test.

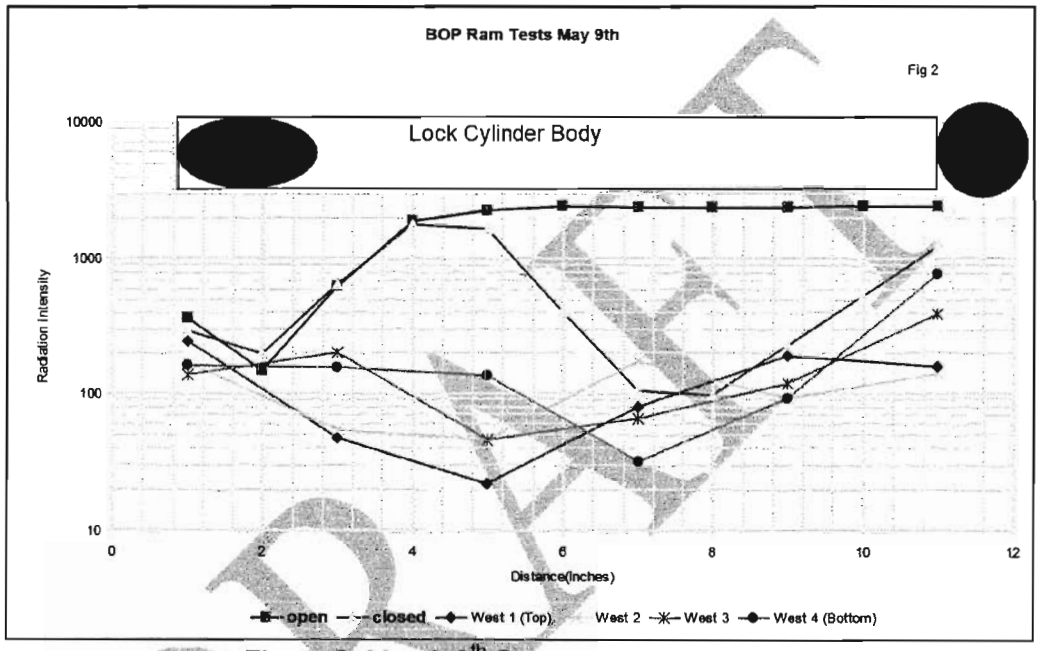

Figure 3: May 8-9th Survey of East Bonnets

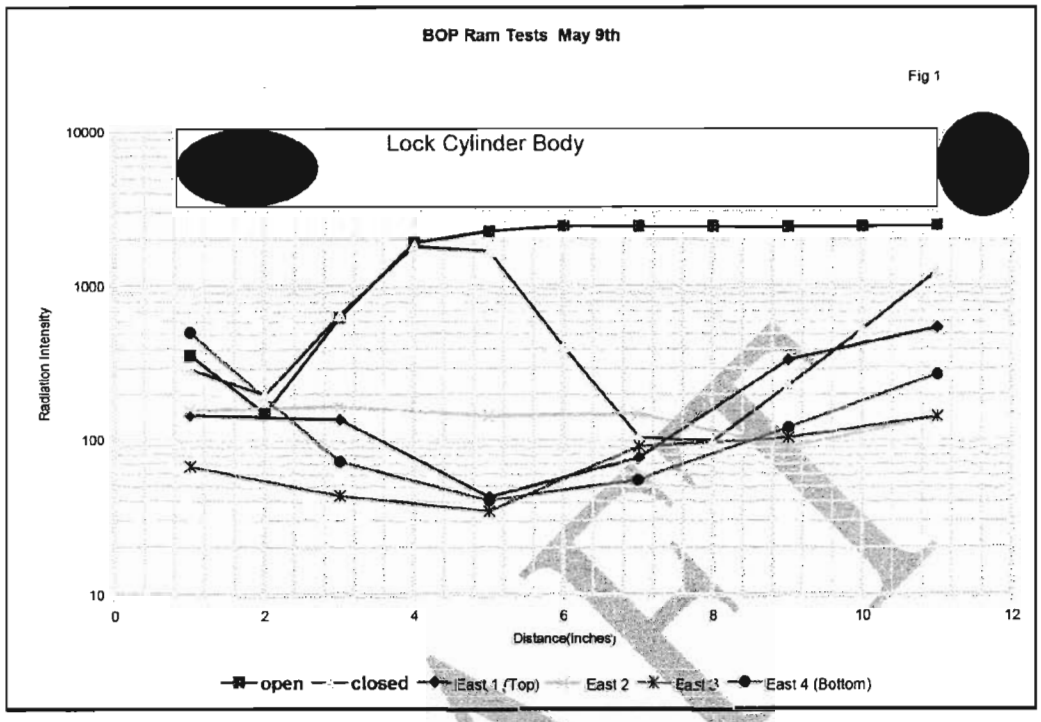

Figure 4: May 8-9th Survey of West Bonnets

Due to the statistical variation and the importance of the information, a decision was reached to repeat the surveys using a stronger source. On May 12th, the surveys were repeated and the data is displayed below in Figures 5 and 6. Figures 5 and 6 also display a calculated count rate threshold for an empty bonnet and a bonnet with an additional 2" of steel material (to mimic the wedge lock) contained within.

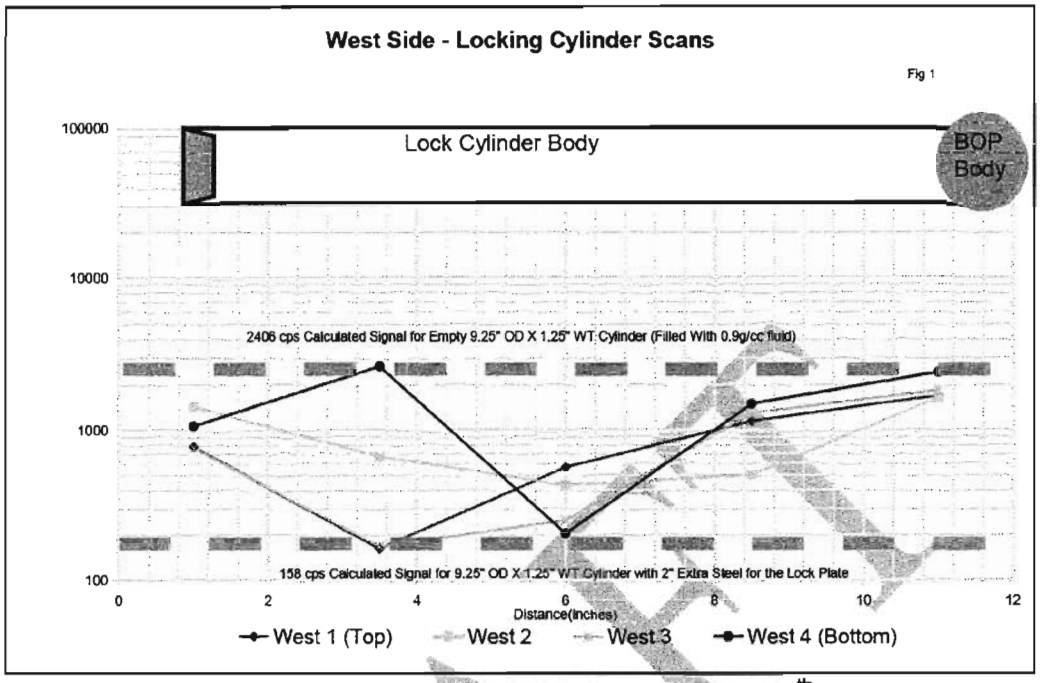

Figure 5: Survey West Side Bonnets May 12th

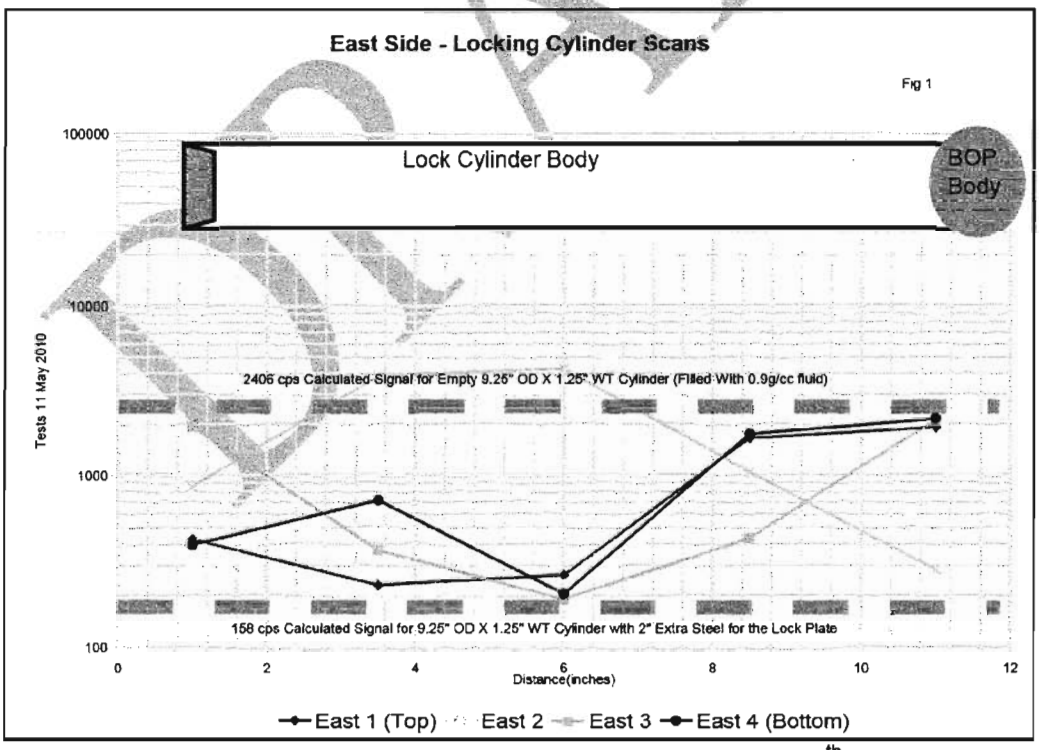

Figure 6: Survey East Side Ram Bonnets May 12th

The data sets were reviewed by scientists from Sandia, Los Alamos and Lawrence Livermore National Laboratories, as well as by the data acquisition team. Oris Hernandez with BP also gave an additional interpretation (independent and separately from the interpretation of the data acquisition team) based upon her knowledge and past use of Tracerco services. Cameron representatives were part of the data acquisition team and the results were reviewed by Melvyn Whitby, Director of Engineering Technology, with Cameron.

Based upon these interpretations, the following observations have been made:

- The profile of the surveys taken on May 8-9th and May 12th repeat, within expected variation of source strength and statistical variation.
- The surveys exhibit the same patterns of lowered count rates, as the data acquired during the surface test at the Cameron yard, with the exception of the East side of the upper Variable Bore Rams.
- The field surveys exhibit count rates comparable to the theoretical count rates for the wedge locks being in place, with the exception of the East side of the Upper Variable Rams.
- The field survey of the East side of the Upper Variable Ram indicates a mixed response between that of a fully deployed wedge lock and an empty bonnet.

Based upon density scans of the BOP ram bonnets, the data has been interpreted to **infer** the following for ram position:

Blind Shear Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Upper Variable Rams
East Side: May indicate a partially deployed lock, hence a partially closed ram
West Side: Wedge Lock in place

Lower Variable Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Test Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Radiographic

Radiographic images were obtained using specially adapted (pressure and water tight at 5000' depth), Storage Phosphor Imaging plates supplied by GE Inspection Technologies, armored aluminum plate holders supplied by Los Alamos National Laboratory and a Cobalt radioactive source (290 milliCuries) supplied by Tracerco. Not all bonnets could be accessed with the radiographic equipment and the decision was made to take radiographic images across one of the Blind Shear Ram bonnets. The position of the Blind Shear Rams was deemed to be of higher importance than any of the other rams. The radiographic image could then provide a separate data point to validate the results of the density scans of the bonnets.

3 images were taken, one on May 13th, and 2 on May 15th. The first image taken across the East side bonnet of the Blind Shear Ram proved to be too blurred to interpret and refinements to the technique were made. In order to prove that the improved setup would be adequate, radiographs were taken of a similar BOP bonnet at the Cameron facility using the same settings as would be deployed in the field. This proved to be successful. These images were not discussed or interpreted with the field team until after the field data had been processed in order to avoid biasing the field interpretation.

Two subsequent field images were taken on May 15th, with two different settings in order to maximize the chance of success of obtaining a useful image. An interpretation in the field was made by a BP Inspection Technology Specialist, Danny Keck.

The raw data was sent to Los Alamos National Laboratory and to GE for independent processing and validation.

The field processed image and equipment setup are shown below in Figure 7. Figure 8 depicts the processing done by Los Alamos of the raw data and a theoretical image modeled using independent algorithms from the source strength, and engineering drawings supplied by Cameron. These images are **positive** images meaning that the darker areas correspond to more material between the source and the exposure plate.

Figure 9 depicts the independent processing performed by GE with their filters applied. This image is displayed in a **negative** format meaning that the lighter areas correspond to more material being present between the source and the plate.

The field report from Danny Keck (BP), the modeling and images from Los Alamos and the processing from GE may all be found in Appendix 3.

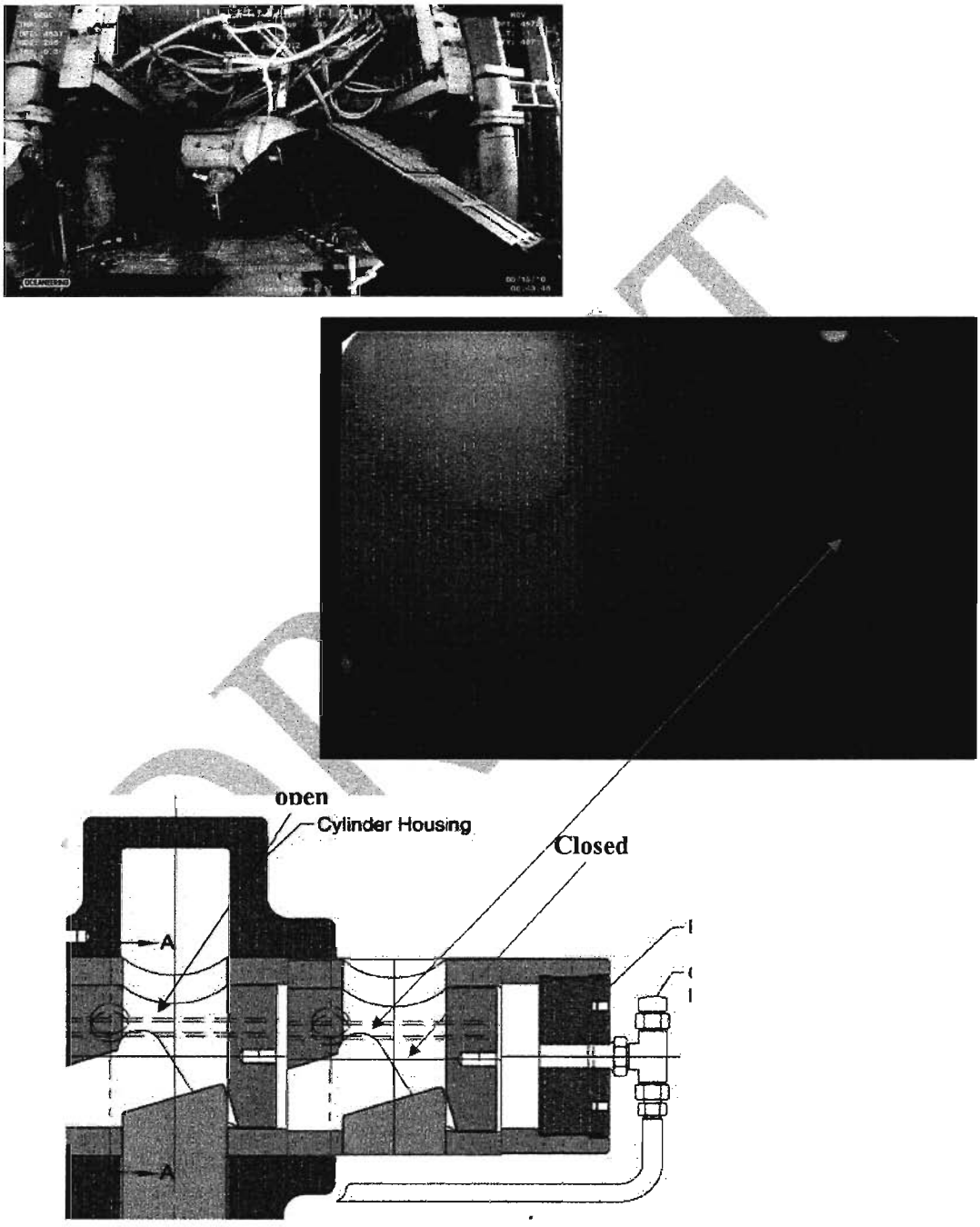

Figure 7: Field Processed Radiograph of East Blind Shear Ram Bonnet

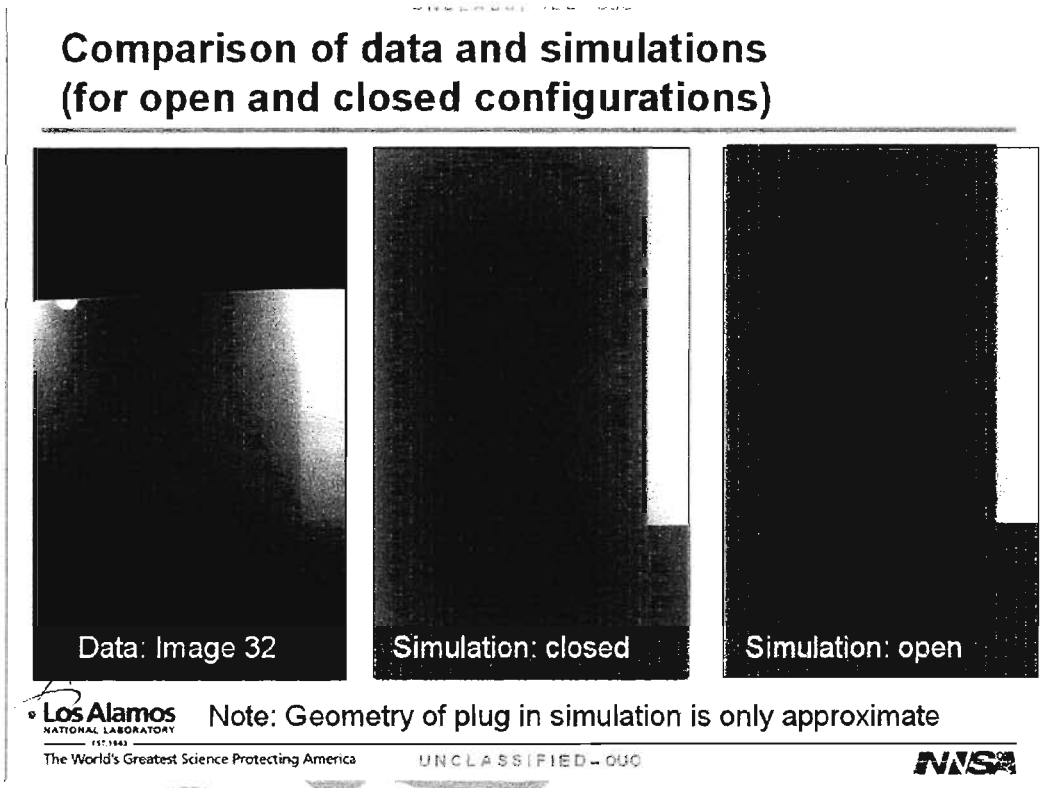

Figure 8: Los Alamos Processed Data and Modeled Results
(Positive Image)

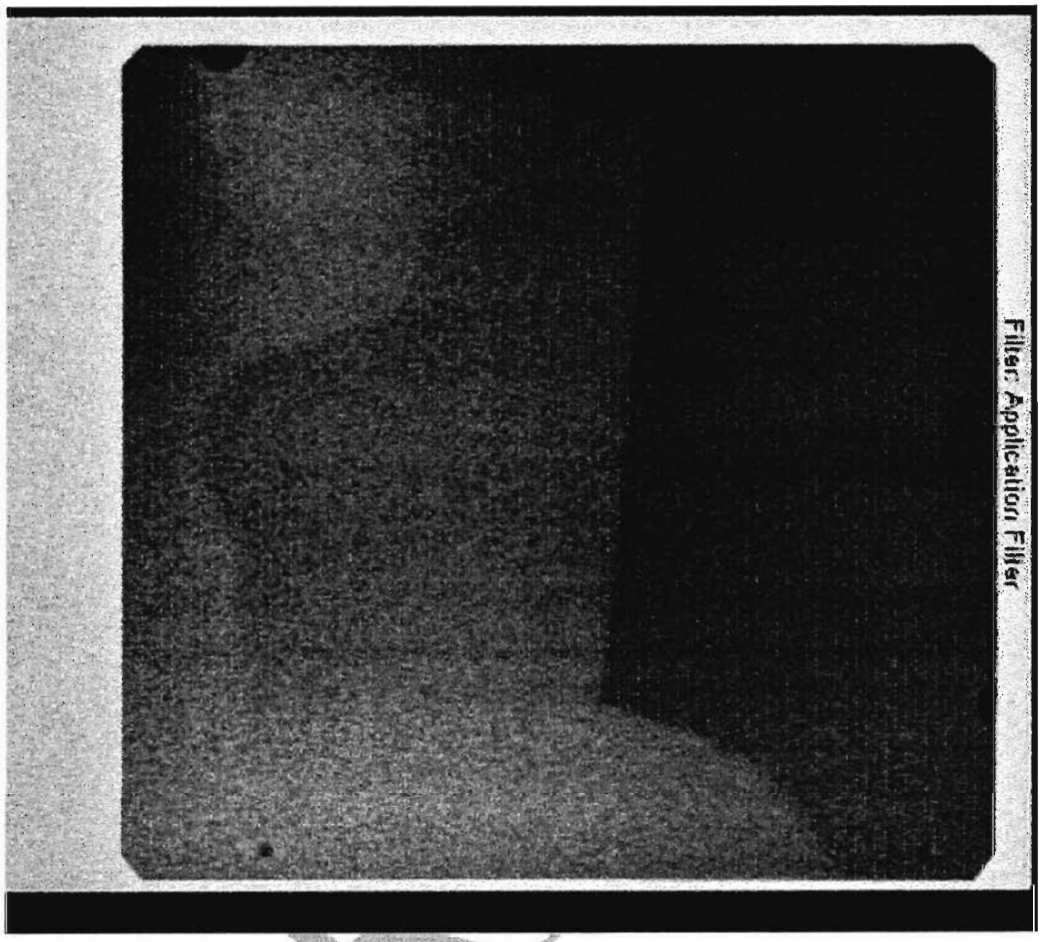

Figure 9: GE Processed Image (Negative Image)

The images were reviewed by scientists from Sandia, Los Alamos and Lawrence Livermore National Laboratories, as well as by the data acquisition team. Cameron representatives were part of the data acquisition team and the results were reviewed by Melvyn Whitby, Director of Engineering Technology, with Cameron.

Based upon these interpretations and in consultation with Cameron, the following observations have been made:

- The wedge lock appears to be present within the East side Bonnet of the Blind Shear Rams. Hence the East side Blind Shear ram is **inferred** to be in the closed position.

Conclusions

The following conclusions have been reached based upon the interpretations supplied by the data acquisition team and independent validation.

- The radiographic data indicates that the wedge lock appears to be present within the East side Bonnet of the Blind Shear Rams. As such the ram is believed to be closed.
- The radiographic data serves as a validation of the data acquired via density surveys of the ram bonnets.
- The density surveys of the ram bonnets are repeatable, and as validated by the radiograph, believed to be valid.

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Test Rams
East Side: Wedge Lock in place
West Side: Wedge Lock in place

Appendix 1: Contacts and BOP Schematics

Team Contact List (needs updated)

DataAcquisitionTeam ContactInfo.xls

Schematics of BOP

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Appendix 2: Tracerco Data and Reports

BOP locking cylinder tests cameron baselir

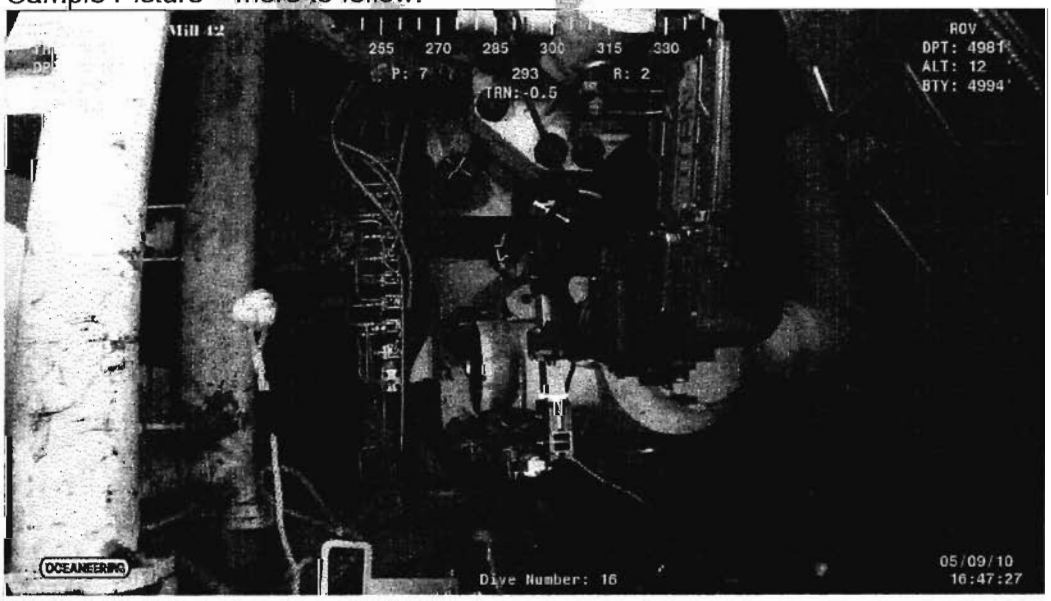
Field Report May 12.doc

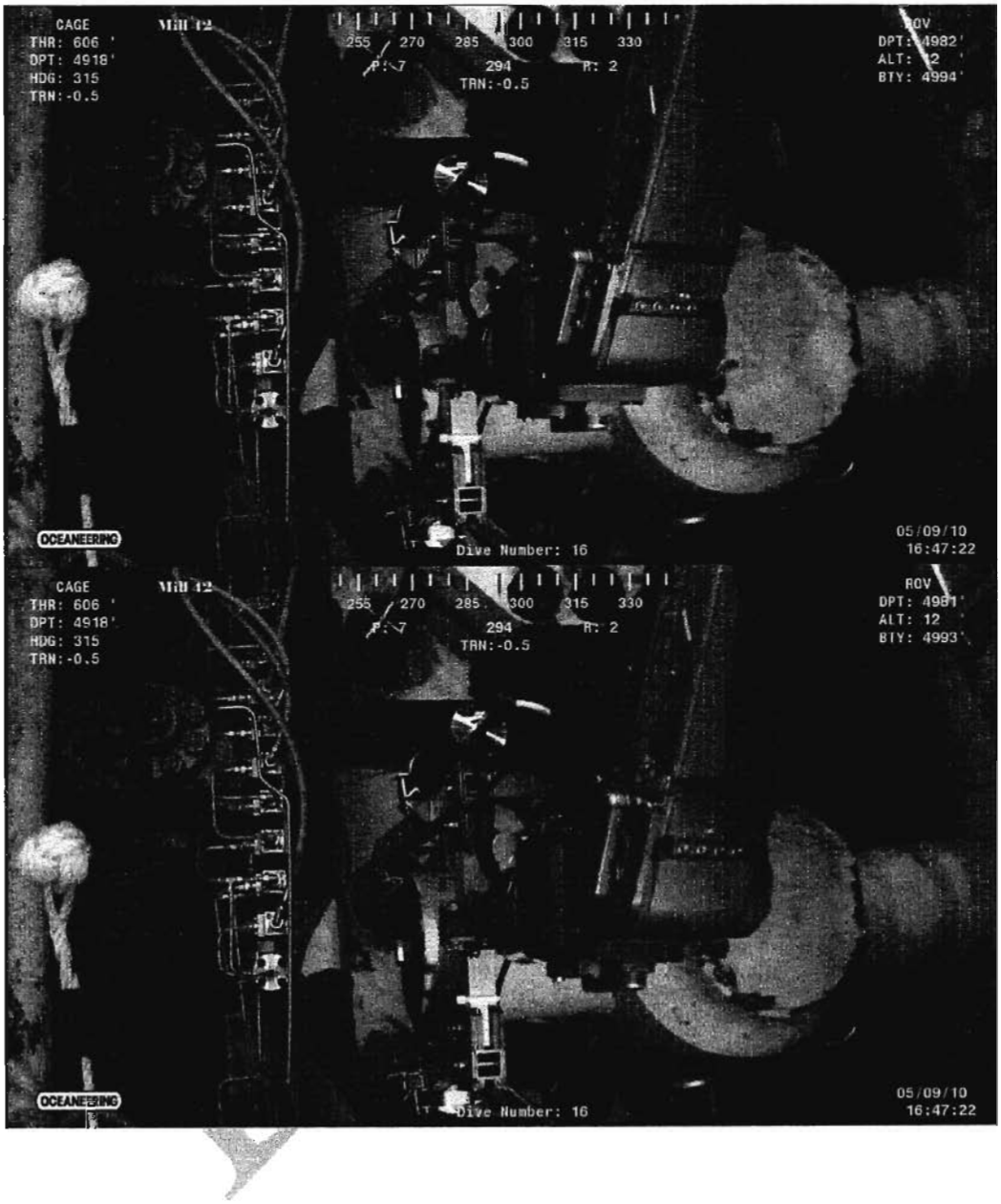
BOP Locking Cylinder Tests 9May2010.xls

BOP locking cylinder Scans West Side 11 M

BOP locking cylinder Scans East Side 11 M

Sample Picture – more to follow:

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Appendix 3: Radiographic Data

Field Report from Danny Keck

5.13.10 Gamma Ray
Imaging Summary Re|

GE Processed Images

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Los Alamos Processed Images and Modeling

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ImageAnalysis_May1!

Radiographs of Bonnet at Cameron Facility

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