



**Health & Safety
Executive**

**OFFSHORE TECHNOLOGY
REPORT - OTO 97 076**

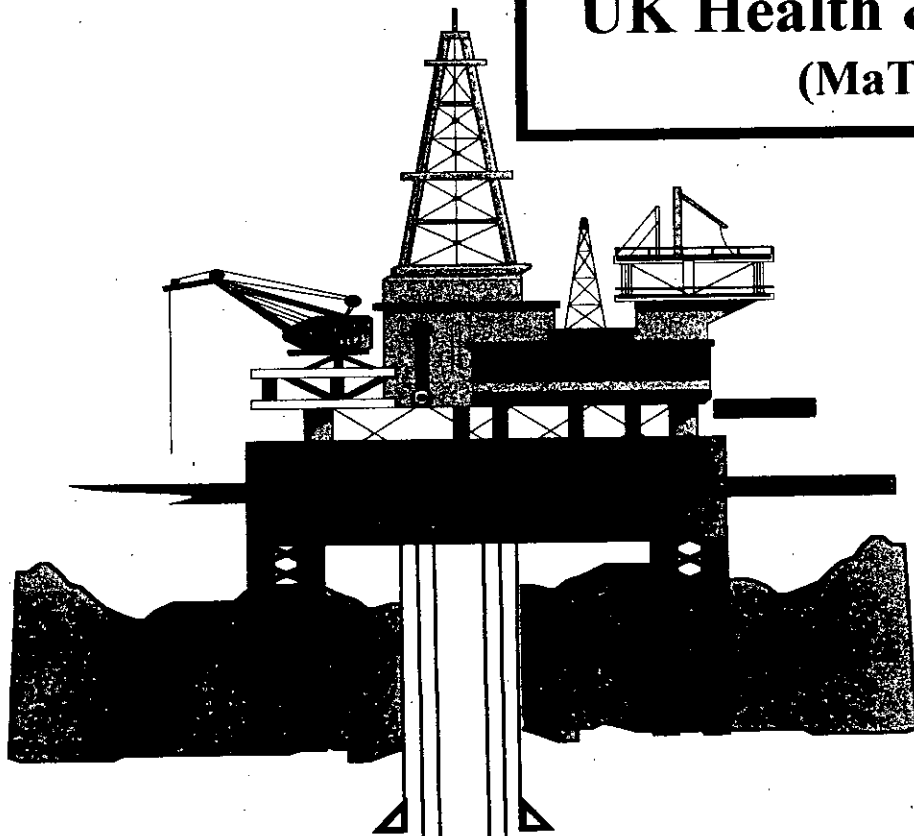
**Well Control Issues in Multi-Lateral Wells
Summary & Guidelines**

This report is made available by the Health and Safety Executive as part of a series of reports of work which has been supported by funds provided by the Executive. Neither the Executive, nor the contractors concerned assume any liability for the reports nor do they necessarily reflect the views or policy of the Executive.

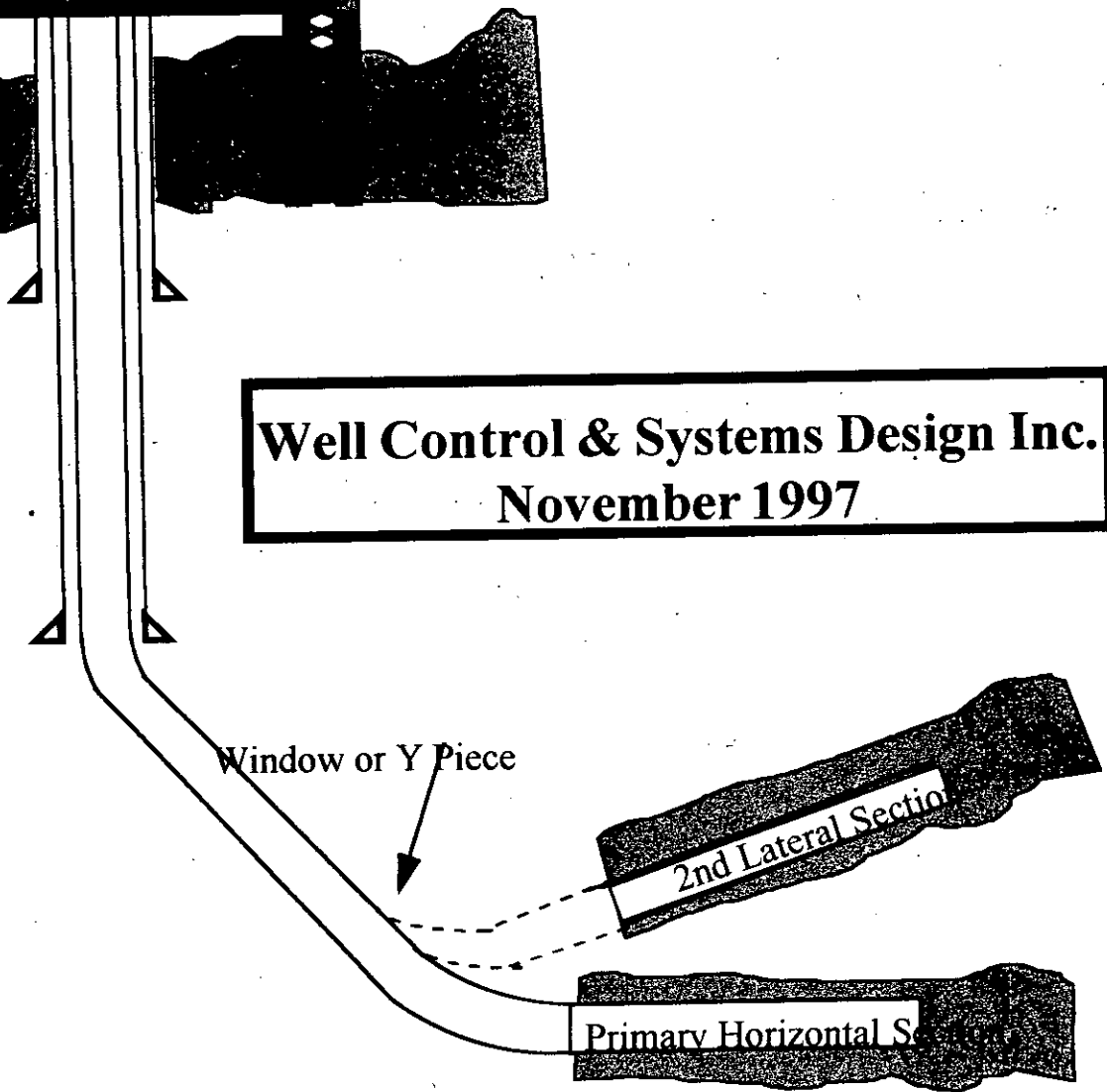
Reports in the OTO series can be obtained from HSE Information Services, Information Centre, Broad Lane, Sheffield S3 7HQ
Tel: 0541 545500.

Well Control Issues in Multi-Lateral Wells Summary & Guidelines

UK Health & Safety Executive
(MaTSU/8845/3518)



Well Control & Systems Design Inc.
November 1997



UKHSE MaTSU/8845/3518

Well Control Issues in Multi-lateral Wells

by

Well Control & Systems Design Inc.

1. Summary and Conclusions
 - 1.1. Overall Summary and Conclusions
 - 1.2. General Conclusions
 - 1.3. Current Operator's/Contractor's Focus on Well Control
 - 1.4. Timeline for Development of Multilateral Technology
 - 1.5. Formula for a Successful Multi-lateral Well

2. Assessing Operators/Contractors Strategy, Competence and Approach to Multilaterals
 - 2.1. Attitudes
 - 2.2. The training/experience issue
 - 2.3. Skill testing questions/Guidelines

3. Introduction
 - 3.1. Purpose
 - 3.2. Tasks
 - Literature search
 - Preliminary modeling
 - Interviews
 - Reservoir/drilling system characterization
 - Detailed modeling
 - Out-of-control well

4. Literature Survey and Interviews
 - 4.1. Methodology
 - 4.2. What the literature said
 - 4.3. What the interviewees said

5. Definitions and Characterization of Multilateral Reservoir and Drilling Systems
 - 5.1. Development of a Multi-lateral well classification matrix

6. Modeling
 - 6.1. Introduction & Summary
 - 6.2. Results Summary
 - 6.3. Results from Modeling a Multi-lateral
 - 6.4. Details of Assumptions and Results (Single Lateral)

7. Out of Control Wells
 - 7.1. Overall Summary
 - 7.2. Summary of Report by The John Wright Company

8. Attachments
 - 8.1. Relevant Papers/Literature Survey
 - 8.2. Modeling Details
 - 8.3. Report on Out-of-Control Wells by The John Wright Company
 - 8.4. TAML Classification of Multi-lateral wells

This work was performed at Well Control & Systems Design Inc. by Colin Leach and David Schwartz and at The John Wright Company by Bill Abel. Any questions should be directed initially to Colin Leach at WC&SD Inc. (phone 281 497 - 5563).

Well Control Issues in Multi-Lateral Wells

1. Summary and Conclusions

1.1. Overall Summary and Conclusions

The primary purpose of this study was to identify well control issues associated with Multi-lateral wells.

In summary:

- The overall approach to drilling Multi-lateral wells should be avoidance of well control problems. This approach should be maintained throughout the "life-cycle" of the well.
- If a well control problem escalated and control of the well was lost the consequences of such an event (for an offshore well) are very severe. This is the primary reason that such events must be avoided (the more so than comparable vertical wells).
- Well control incidents are unlikely, provided Multi-lateral wells are drilled into reservoir sectors of known type and pressure, where the pressures of the different branches of the Multi-lateral are close and where there is no lost circulation. This type of drilling carries a low risk of a well control event.
- Oil reservoirs are generally considered to be low risk with respect to well control. This is because no gas migration takes place and a steady pressure can be applied throughout a conventional kill.
- Multi-lateral wells are best suited to low risk situations, like those noted above. It is probably not appropriate to drill Multi-lateral wells when the risk of well control events is medium to high - in this case, the risked consequence of a well control event is potentially unacceptably high. Note that for land wells, the consequences of an out-of-control Multi-lateral well are relatively low - this is not the case for an offshore well and hence the risks that can be taken must be much reduced in comparison.
- Multi-lateral wells involving branches with significantly different pressures have a medium to high risk for a high consequence well control incident. It is suggested that either this type of well not be drilled in the first place, or 2 or more mechanical barriers be in place to isolate the different branches - in effect, the branches would become individual single laterals.

Guidelines are required to determine which reservoir combinations are "safe" and which ones are not. We cannot provide general guidance on this subject at this stage. However, we are sure that any prudent operator should have performed detailed calculations to assess the potential for crossflow etc., if reservoirs of different pressures or depths are to be simultaneously exposed. The potential for this type of event must have been recognized.

- The complete "life cycle" of the well should be examined to decide whether reservoir pressures (for the different laterals) will remain the same or diverge as production occurs. This examination must take into account the various reservoir parameters,

production philosophy and the impact of reservoir pressure maintenance (e.g. waterflooding) which may be very different for each lateral of the Multi-lateral .

- A classification system for Multi-lateral wells has been proposed by a group of companies that form the forum on Technical-Advancement-Multi-Laterals (TAML). The implication of the work here is:
 - ⇒ laterals drilled into reservoirs of the same pressure may be completed as Level 1-4 wells
 - ⇒ laterals drilled into reservoirs that are at the same pressure, but where the pressures within the individual reservoirs may diverge during the life of the well should be completed as a Level 5 or 6 well
 - ⇒ laterals drilled into reservoirs of significantly different pressures must be drilled and completed as a Level 6 well.

Further discussion of this classification can be found in Section 5.

- For “normal” well control incidents, the W & W and Driller’s methods can be used, but there must be a large margin such that an appropriately high safety factor can be added to kill pressures without inducing lost circulation. Bullheading may be considered as a primary means of well control if it has been shown that the exposed formations are forgiving of this type of procedure.
- Completion procedures relying on a single mechanical barrier should be very carefully reviewed (and probably avoided). If a significant pressure is relieved from a Multi-lateral well, the flow from the well will be instantaneous, perhaps not allowing any time for appropriate action and putting personnel in danger.

1.2. General Conclusions

The study has identified the two key characteristics that Multi-lateral wells have and which are:

1. Multi-lateral wells are generally low risk because they are drilled into reservoirs and formations of known pressures and it is generally very possible to maintain a positive overbalance with respect to the formation pressure at all times
2. Multi-lateral wells (drilled offshore) should also be classified as having very high out-of-control consequences, because of the high potential pollution damage and cost of an out-of-control well, should such a well get out of control. For the medium depth well chosen as an example for the out-of-control well calculation, it was estimated that up to 25,000,000 barrels of oil could be produced to the sea while relief well operations were carried out to stop the flow.

[note that a Multi-lateral well drilled onshore has a relatively low consequence - this may lead to a much higher risk being taken, which is not insensible]

Even if this relatively low risk is attained, these wells deserve a higher level of attention than normal, simply because of the high consequences of an out of control

well. Safe and effective multilateral wells can be drilled if the proper level of attention is paid during planning and drilling operations. It is the task of management to see that this required level is attained.

Two issues stand out as potentially providing opportunities for blow-outs, which are (somewhat) unique to multilateral drilling. These potential scenarios must either be avoided or be properly addressed during the planning and implementation stages. These scenarios are:

- A. DRILLING MULTILATERALS WHERE THE LATERAL BRANCHES HAVE SIGNIFICANTLY DIFFERENT PRESSURES - note: even drilling different pressured potential producing zones in a vertical wellbore [offshore] is not considered prudent
- B. RELIANCE ON MECHANICAL BARRIERS - if a well becomes underbalanced with a full column of liquid in place which provides a near balance, then there is likely to be a time delay (during which remedial actions can take place) before an out of control situation occurs (typical drilling situation). However, if a mechanical barrier is holding back a significant pressure differential, then the flow from the reservoir would be very sudden, giving very little or no time for remedial action.

The study has also identified some other keys (guidelines) to successful drilling of these wells which will minimize the exposure of the operator/industry. These keys are:

1. The only prudent approach to drilling Multi-laterals is to maintain a safe level of overbalance at all times.
2. This safe level of overbalance cannot be easily maintained if reservoirs with widely differing pressures are exposed to the same wellbore - this must be avoided, or the zones effectively isolated.
3. The mud weight should not be lowered to drill a second or subsequent lateral, unless it can be shown that it is still sufficient to overbalance the existing laterals.
4. If a branch of a multilateral is drilled into a different reservoir segment or compartment, the pressure of the segment or compartment should be established as soon as possible and before any significant reservoir section is exposed.
5. As with single lateral wells, the hydrostatic head of drilling mud in the annulus will not be reduced when the influx first enters the well and is in the lateral portion. However, when the influx "turns the corner" a significant amount of hydrostatic head may be lost and a very rapid flow can occur. It is therefore essential that the volume of fluids in the wellbore be very accurately tracked at all times such that any influx is readily identified, i.e. tight pit discipline must be utilized during drilling operations. In addition, procedures must be designed to eliminate problems such as swabbing.
6. Multi-lateral wells should not be considered if there is a significant potential for lost circulation. If lost circulation occurs, then operations must be suspended until the lost circulation is cured.
7. The W&W and Driller's methods of well control should only be used if an adequate safety overkill can be applied. Without such a margin, there would be a risk of underbalance and rapid unloading.

8. Realistic well control modeling that takes into account both the probable influx composition and the worst case composition (gas) can be used to assess the potential well control methods and the potential for crossflow. Both Rogalands and Anadrill/Schlumberger have models that can handle oil and gas influxes.
9. Bullheading may be an effective method of well control when more than one long reservoir section is exposed and if the exposed formations are known to be forgiving to bullheading operations. The consequences of using bullheading in a specific formation should be assessed.
10. Wherever possible, inactive branches of a multi-lateral should be isolated from any drilling operations on the active lateral. If the pressures/depths of the different branches are very close, a single barrier may be considered.
11. During completion operations, there must not be reliance on a purely mechanical single barrier.
12. It should be remembered that if long reservoir sections are isolated by a bridge plug there is every chance that there will be pressure and hydrocarbon underneath the bridge plug after a short time period. This will then be a mechanical single barrier.

In summary, Multilateral Wells can be drilled in a safe manner if a few simple guidelines (those noted above) are followed. In particular, this means that operations must be conducted such that an overbalance is maintained at all times. A thorough review of the complete "life cycle" of the well must be carried out to ensure that benign initial conditions (which will not lead to a well control incident) do not change over the life of the well, such that there is a significant potential for a well control. In addition **and most importantly**, the personnel charged with carrying out such work must carry out this work in a very disciplined manner despite the perceived and real low risk of a well control event. Successfully overcoming this second challenge (motivation) is probably the hardest and key task involved in such operations.

1.3 Current Operator's/Contractor's Focus on Well Control

Obtaining input for this study has been quite difficult because operators and contractors have not to date recognized significant well control concerns with this type of well. This is reasonable, given the fact that (at least up till now) this type of well has been drilled with a maintained overbalance and into zones of known and fairly close pressure. In addition, much of the drilling has been carried out on land where the consequences of an out-of-control well are much less than would be the case for an offshore location (in particular, personnel can run away from location and the well can normally be "capped" in a few days).

Some concern has been voiced by operators with respect to high consequence (offshore) wells and with respect to higher risk wells. The lack of available methodology and resource with respect to an approach to well control for this type of well has been recognized.

1.4 Timeline for development of Multilateral Technology

- | | |
|------|--|
| 1950 | Experiments in multilaterals via sidetracks begin in the 1950's |
| 1979 | Early documentation of sidetracking leading to first multilateral wells in Anadarko Basin. |
| 1988 | Ten multilateral record set in Louisiana |

- 1989 Multilateral drilled in the Neutral Zone
- 1990 Multilateral wells kick off in South Texas
- 1989-93 Shell Canada completes a series of multilaterals in Saskatchewan
- 1992 Multilateral Tie-Back Systems introduced
- 1993 Unocal completes trilateral offshore California
- 1993 An estimated 50% of horizontal wells in South Texas are multilaterals
- 1994 First dual lateral drilled in the Louisiana Austin Chalk
- 1995 Multilateral tieback systems installed in Canada, Alaska, Oman and Qatar
- 1995 First underbalanced, multi-lateral well drilled with coiled tubing in the UK.
- 1996 Isolated trilateral completed offshore Malaysia
- 1996 First dual lateral completed offshore Thailand
- 1996 PanCanadian completes quad-laterals

1.5 Formula for a successful Multi-Lateral well

The formula for a successful Multi-lateral well includes:

- a. knowing the reservoir pressures, avoiding reservoirs of significantly different pressures and being able to control the well with one mud weight
- b. being able to manage the hydraulic pressures in a long step wellbore
- c. no lost circulation
- d. having the ability to handle well control events with simple industry proven techniques - this implies having adequate safety margins
- e. assessing the pressure of new reservoir blocks before exposing much footage
- f. not relying on single mechanical barriers to keep back large differential pressures
- g. assessing the impact of events that may occur during the life of a well, such that changes in conditions that may result in well control incidents are identified and reacted to.

2. Assessing Operators/Contractors Strategy, Competence and Approach to Multilaterals

2.1. Attitudes

The operators and contractors who have been contacted have confirmed the "void" that exists with respect to strategy and approach to well control for multi-lateral wells.

This is largely a function of the perceived (and actual) low risk level of many of these type of wells.

Very recent discussions have indicated a desire on the part of certain operators to fill the "void". However, there is no clear idea as to what to fill the "void" with.

2.2. The training/experience issue

Multi-lateral wells have (to date) been considered to be low risk - as a result, there has been very little attention paid to training specifically aimed at well control for this type of well.

There is very little experience of well control in this type of well.

Given the perceived (and actual) low risk of drilling operations for this type of well (i.e., provided lost circulation is avoided, the risk of a well control incident while drilling is low), the key to training will be in motivating the wellsite team to take the proper precautions and approach to drilling such that everything does remain under control.

This will require a lot of discipline and determination on the part of the wellsite team and a great deal of back-up and support from the onshore management team. In particular this will require a tremendous amount of encouragement to perform the operations in a "tight" manner, even though it will be apparent that a certain amount of "sloppiness" on the part of the drilling team will not necessarily result in a well control incident. The rewards (to the operator) for carrying out the work in a proper manner will not be obvious. The downside of having a well control problem will be very significant.

A training program should be pulled together once procedures have been finalized. The program should really be a thorough run through of the procedures, with plenty of time available for discussion (enhancement of procedures?) and for detailing responsibilities.

2.3 Skill testing questions

a. Knowing the reservoir pressures/characteristics

What reservoir sections will each of the branches expose?

What is the likely pressure and other formation properties of each of these sections?

What is the reservoir fluid?

How much confidence is there in this information?

Has each reservoir section been penetrated and tested?

The whole basis of the suggested approach to well control is the avoidance of well control problems. This can only be achieved if the pressures of each lateral are known throughout the life of the well. A major implication is that this type of well should only be used to exploit a well known reservoir. Significant involvement of the reservoir evaluation team is required to ensure that the lateral is drilled in the required formation and that the reservoir encountered is as expected. An oil well is significantly less of a well control issue than a similar gas well.

b. Being able to manage the hydraulic pressures in a long step wellbore

During normal drilling operations, what is the pressure likely to be along the exposed formation? A. With the pump off? B. While pumping at full rate?

Are any of these pressures likely to result in lost circulation or any other problems?

Lateral wells are typically drilled using a hole size of 6" or less. Under these conditions and also with a requirement to move cuttings along a near horizontal bed, mud pump rates are relatively high, and given the long lateral sections, annular friction pressures may be significant. In addition, the annular friction pressure at the toe of the lateral may be significantly higher than the annular friction at the heel of the lateral. These annulus friction effects must be accounted for. In some cases, drilling of an oversize hole (e.g. by using a bi-center bit) may be essential.

c. No lost circulation

Is there any likelihood of lost circulation?

Is crossflow possible?

If so, between which reservoir sections?

Lost circulation and/or crossflow means that effective control of the well has been lost. There must be sufficient margin such that these possibilities are avoided.

d. Having the ability to handle well control events with simple industry proven techniques

If reservoirs of different pressures/depths will be left exposed, what well control method will be applied?

Conventional (W&W/Driller's)?

Bullheading?

Bullheading may be a more effective means for well control rather than the conventional Wait and Weight or Driller's methods. If the latter methods are used, there must be a sufficient margin available to allow for the application of a safety margin of pressure which will ensure that flow does not occur from any exposed formation during a kill.

If bullheading has been selected as a primary means of well control has there been an assessment of how "forgiving" the exposed formations will be to bullheading and the likely consequence of such a procedure?

Some formations are very forgiving to bullheading and primary (hydrostatic) control is very readily regained. By contrast, other formations are not forgiving to bullheading and many operational problems can follow bullheading procedures in this type of formation. Some experience of bullheading in the formation to be encountered is essential.

If a conventional method of well control is to be applied, what will be the maximum overpressure that would be put on a shallow exposed branch?
Will this overpressure result in a flow into the branch?

Conventional kill methods will place an excessive pressure on a shallower (static) lateral branch. This excessive pressure could result in lost circulation and effective control of the well. The pressure that must be placed on the deeper (active) lateral and the resultant pressure on the shallower (static) lateral must be assessed.

Is there any intention to drill a shallow branch subsequent to a deep branch?
If so is there any intention to carry out conventional well control operations in the shallow branch?
Can the operator list the problems of circulating off bottom in a well control situation?
Does the operator know of any UK well control events that were considerably escalated by circulating off bottom?

If a shallow branch is drilled with a deep branch already open and a well control event occurs, then effectively there may be a prolonged circulation off bottom (with respect to the deeper branch). If, for any reason, the deeper branch starts to flow, there is the potential for the well unloading unless the proper attention is paid to the kill circulation. Circulating off bottom has been the cause of escalation of North Sea well control incidents in the past. It is a situation that must be avoided.

What is the potential flowrate from an out of control well?
Is there a blow-out contingency plan?

An out of control multi-lateral well could result in a very large flow of hydrocarbon to the surface. In addition and due to the low pressure drawdown, bridging of the well may not occur. The consequences of an out-of-control well are therefore very serious. Every possible step must be taken to prevent such an occurrence.

Is there the potential for the reservoir to be gas?
Is WBM being used?
If so is the angle through the reservoir section less than 90 deg?

Gas will always migrate upwards and at a rate of up to about 6000 ft/r depending on concentration. This will also be the case in a well that is nearly horizontal (i.e at about 85 degrees). Controlling a well where large quantities of gas may be migrating up the "high side" of the hole may be quite difficult. Anytime that there is gas introduced into the wellbore, it will migrate and dynamic control of surface pressure will be required in order to bring the gas out and maintain control. An angle through the reservoir of greater than 90 degrees ensures that if a gas kick enters the wellbore it will not migrate of its own accord past the lowest point in the wellbore and then up to surface. This type of effect makes well control easier from the perspective that the well can be readily killed down to the lowest point in the well.

If the reservoir is a "dead" oil, then there will effectively be no gas and well control measures will be much easier.

Section 2: Assessing Operator's/Contractor's Competence

Use of SOBM or OBM will effectively produce a situation where if any free gas exits, it will go into solution and then behave like a liquid.

What methods will be used to ensure that even small influxes are detected, even though these will be in a horizontal section on first entry to the well?

What would be seen as a small undetected influx is circulated "round the corner" and into the vertical portion of the well?

What instrumentation is installed to aid in the detection of kicks?

What procedures are in place to avoid swabbing?

Small kicks (including swabbed kicks) have no impact on the bottomhole hydrostatic pressure while the influx is in the horizontal or near horizontal portion of the well. However, as this type of influx is circulated "around the corner" the hydrostatic pressure that is exerted on the bottomhole may be significantly reduced. Given the potential for flow from a lateral section, the flow that may result may be quite sudden and violent. This type of event must be avoided.

Is the well likely to "weep" after circulation is stopped?

If so, how much?

The horizontal portion of the well will provide a long "heat source". Under these conditions, the mud that is in the wellbore will heat up (although mud near surface will cool) and mud will "weep" from the well. It is very prudent to estimate this weeping tendency, such that a real kick can be recognized.

e Assessing the pressure of new reservoir blocks before exposing much footage

What procedures are in place to test the pressure of a newly penetrated reservoir block within a branch?

Will drilling cease while these measurements are made?

Is an RFT run being considered?

Is a "swab" test considered to be sufficient? If so, is the surface equipment set up to perform such a test?

It is important to test the pressure of each newly penetrated reservoir block before a significant section of the new block is exposed. If this is carried out, then the consequences of drilling into a different pressured formation may be minimized.

A "swab" test is simply the operation of inducing a swab to ascertain how close to balance the mud hydrostatic is with respect to the formation pressure. If SOBM is in use it is essential to put bottoms up across a choke. Some addition/modification to the surface equipment is required in order to be able to effectively monitor the "swab" of gas as it comes through the choke manifold system and into the mud gas separator.

f Not relying on single mechanical barriers to keep back large differential pressures

What mechanical barriers will be placed to isolate branches (and sections of branches)?

How many?

How will they be tested?

How will any pressure underneath the barrier be detected/measured?

During completion operations will there be any period when the pressure in the annulus will be reduced significantly below the formation pressure?

How many barriers will be in place at this time?

How will they be tested?

Single mechanical barriers have failed in the past with very serious consequences. Dual barriers offer better protection, especially if there is a means for ascertaining that one of the barriers has failed.

g Assessing the impact of events that may occur during the life of a well

Will the pressures in the different reservoir zones decline at the same rate?

Will production be carried out to equally drain all exposed reservoirs, or simply to generate the maximum instantaneous production rate?

Will waterflooding or any other type of reservoir management operation result in different pressures within one of the penetrated reservoirs?

What will happen if one of the laterals collapses (or bridges) or a mechanical blockage occurs? Will production from the other laterals continue, potentially resulting in a pressure mis-match?