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The Total Control of Well Integrity Management

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Abstract

This paper describes a web-based program which provides a comprehensive approach to well integrity management covering all potential integrity threats to the whole well. This “cradle-to-grave” software, the Intetech Well Integrity Toolkit (iWIT), provides well information and data analysis for timely, informed, decision-making. Using its own or existing client databases, this software carries out quantitative data analysis in real-time and provides feedback to the operator about the condition of individual wells and also overviews of the whole field integrity status.

The iWIT software has been used in fields with less than 50 up to over 1600 wells. Installations have been made in primary recovery fields to tertiary recovery fields, both onshore and offshore. The software has been installed in new and mature fields; some fields with no automation in place and some which have been automated for over a decade.

All the operators that have installed the software to date have decided to expand its use, either to incorporate more assets (e.g. the integrity management of the flowlines up to the manifold) and/or to install the system throughout their group operations internationally. Current installations include two Gulf operators in Abu Dhabi and Qatar.

The management of well integrity is a vital element in the successful, economic and safe operation of all assets. Data relevant to well integrity is widespread, including the safety critical elements test results; monitoring of annulus pressures; evaluation of tubing and casing integrity; inspection results from well logs; evaluation of scaling risks etc. The management of, and continuous evaluation

of, this vast range of data presents a huge challenge. The system described in this paper has met that challenge comprehensively.

Introduction

The essential function of an oil and gas producing/injecting well is to transport hydrocarbons/fluids in a cost effective and safe manner. The importance of well integrity total control has been recognized and accepted as a key part of safe operations for a long time. Significant improvements concerning both well design and operating procedures have been made. Nevertheless, the integrity of all well barrier components is continuously threatened and requires great vigilance to ensure continuous active control without the risk of unintentional leakage of well’s fluid to the environment.

A well has the potential to create hazardous events, and hence well risk must be acceptable. The release of inflammable/explosive fluids (hydrocarbons) to the surroundings is by far the most significant risk factor.

The extended lifetime of wells, and recent regulations and standards demand that there is a need for a systematic control during the entire life cycle of a well. Typical scenarios exist where, for different reasons, total control of well integrity is paramount for the continued safe and economic operation:

1. The field operation with a large number of wells which is unmanageable for engineers to track actual changes in individual well status, identify developing problems and deal with ongoing routine and non-routine monitoring.
2. The field operation with few wells, each well with high productivity and critical supply value, where any time lost to well barrier failure implies high lost revenue cost.
3. The field operation with old assets, already nearing or beyond the original design life. All well barrier elements will have experienced degradation: corrosion of tubulars; degradation of fluids; wear of seals. The reduction in integrity of well barriers is a huge challenge to estimate the impact on risk and to safely continue operation.

4. The field operation with limited annual workover capability based on availability of rigs. Each workover has to be carefully prioritised to address the root cause of significant well barrier integrity problems on the most productive-critical wells. Pro-active planning of activities is critical rather than reacting to problems as they develop in order to reduce uneconomic shut-in of valuable wells.
5. New fields where best practice is to be enshrined from start-up. Real-time tracking of production conditions enables an established safe-operating-envelope condition for the wells to be actively maintained in an auditable manner.
6. Challenging fields with high pressure, or sour products, or in highly environmentally sensitive areas, where a breach of well integrity leading to leakage of well's fluid to the environment is not tolerable.

Our experience indicates that almost all operations have a lot to gain from implementing an active control system for well integrity. Whilst well integrity management system documentation provides the framework for decision-making and the organisational structure, total control of well integrity requires a *system* to be implemented with a sophisticated datahandling, analysis and communication capability. Such a system, the Intetech Well Integrity Toolkit (iWIT), has been in operation since 2006 with various operators internationally and is especially developed to meet the enormous challenge of providing total well integrity control. This paper discusses some of the challenges and some learning steps from a number of case histories.

Meeting the WIMS Challenges

Increasingly, managers are demanding to see evidence of the active management of their assets. Most operators have established an Asset Integrity Management programme, but many of these are focussed on "visible" surface assets. More rarely, operators have a Well Integrity Management System, WIMS, at least as a documented set of principles. Typically a WIMS document outlines the underlying company philosophy associated with well integrity management, defines roles and responsibilities, defines the safe operating envelope for all well barrier components and puts in place the controls regarding the requirements for monitoring frequency and data collection.

Whilst a WIMS document provides the essential framework, it is only when the words on the page are translated into an active day-to-day system of well integrity management that its goal can be achieved. This is where the use of software becomes the essential vehicle of the WIMS implementation. One element of a WIMS document is a description of roles and responsibilities for

different aspects of well integrity within a company structure. The impact of introducing new software also has an impact upon these roles and responsibilities.

The first step we make with an operator is to study their WIMS or (where there is no WIMS documentation) assist in defining the key elements needed to monitor and control the specific threats experienced under their unique conditions. We also investigate who is responsible for all the separate data which the well integrity engineer needs to pull into the integrated data system and how they are currently working. The challenge we find is that not only has each operator had a different well integrity emphasis, but even individual fields within one operator's control may need a special aspect to be dealt with in a different way. As a consequence, our software allows the customisation of test acceptance criteria and the safe operating envelope to be made on a per field basis; and for some parameters, per well type or per well.

Meeting the Well Integrity Challenges

The range of well integrity problems experienced internationally is widespread and different issues are more prevalent in different parts of the world. The most frequently reported well integrity problems are:

- Sustained annulus pressure,
- Completion string leaks,
- Wear/corrosion/erosion within the completion string,
- Casing corrosion,
- Scaling,
- Wellhead movement,
- Xmas tree and wellhead safety critical element (SCE) leaks.

Individual operators may be fortunate to face only some of these problems, but for many operators the range of problems to be managed is very widespread, either across the whole field of wells, or within individual wells. Any one of these issues is governed by many parameters: well design, well construction practice and the daily changes in operating conditions.

Hydrocarbon producing reservoirs contain acid gases (carbon dioxide and hydrogen sulfide) and high salinity formation water that are generally associated with increasing the severity of tubular material degradation. A great strength of the software, and a valuable feature for operations, is its capability to evaluate quantitatively the material degradation (corrosion & erosion) threats to the well integrity. The corrosion model used has been field-proven for over 10 years and is individually calibrated to match each oilfield. The tubular material degradation model takes into account the mass transport of the corrosive species to the surface and therefore has a flow dependency on the corrosion rate. This is a significant influence on the calculated corrosion rates compared to

models which do not take flow effects into account. A sand erosion model, is also incorporated and safe operating envelopes for 13Cr and other alloy tubing. The output gives, on a per well basis, the wall thickness loss of individual well tubulars and a cross-field review of the installed tubing identifying the percentage of wells having wall thickness loss in various fractions, indicating the future workover demand.

Annulus pressure records integrate automated readings with manually entered data giving a total overview in tabulated and graphical format. The data is automatically trended and communication of adjacent annuli is identified. Thermally imposed and sustained annulus pressure (SAP) cases are distinguished. All pressures are monitored relative to individual maximum allowed annulus surface pressure (MAASP) values per annulus and per well, derating with time dependent on well component degradation and operating conditions (Fig.1). This allows the field to be operated safely but with minimum annuli bleed-off frequency. The transport of fluids within the annulus may result in accelerated corrosion of the casing strings and the resulting wall thickness loss impacts the load carrying capability of the tubulars. Reducing bleed-off frequency reduces the risks of annulus degradation resulting from replenishment of an aggressive annulus fluid.

No well that exhibits sustained annulus pressure is operated without problems. Managing operating risk means not letting small annulus integrity problems become big ones. What is often overlooked is the interaction of all the potential problems. Yet, it is often the case that when a well problem is investigated there are several factors which have contributed. It is really critical to take a holistic view to avoid overlooking combinations of problems which together can present a major threat. Integration of the tubular degradation model with the annulus pressure management, wellhead movement and SCE leak testing provides a uniquely powerful insight into the possible root causes of one of the most critical well integrity challenges.

Proactive well integrity management is the route to the maintenance of well integrity while maximizing field production. The methodology adopted here has proven to be an effective tool for well barrier control and well integrity management.

Meeting the System Challenges

Considering the cost of data collection, maximizing use of the information is a key part of oilfield cost-efficiency. The use of a web-based system makes the information fully available to all persons able to access the company intranet. Control of user rights ensures that access to the system is correctly controlled.

Introducing a new database system first requires an evaluation of what already exists. In a typical long established operation, collection of well design data in various forms may be already established. Database systems may already exist for certain classes of data. Many operators have an established drilling information system which will normally contain some details of the casing design, the well deviation profile, the mud and cementing program and possibly well handover documentation with the completion diagram etc. Other operators keep some or all of this information stored in a document folder system where the usual filing of data is by subject such as "completion diagram", "deviation survey", within which all wells will be found. The data retrieval concept therefore demands that if information is sought for a particular well, several folders have to be opened to pull together data for one well.

In a more logical set-up, all the critical well design data is accessible logically organized by well. This gives immediate access to the necessary information without having to address various independent data sources or open multiple folders. By properly configuring the system, links can be made between different data sources and document repositories so that data which is spread around an existing data system, too long established and widely utilized to be replaced, can be accessed seamlessly.

Similarly, the operational data collected in the context of well integrity has often been captured in a variety of data systems, ranging from the engineers favourite, spreadsheets, to large multi-user relational databases. The variety of situations encountered is very wide. One operator already had over 20 years of production information sitting in a "dumb" database with a typically unfriendly outdated user-interface which kept the data largely inaccessible. By interfacing to the well integrity software on the front end the engineers now get access to the true value of this substantial data resource. Other operators have interfaced as many as five databases, physically located in different offices, to the well integrity system. This provides the capability to integrate multiple data sources which to date could never talk to each other. On the contrary, one operator had no pre-existing initial data other than a folder system of document and spreadsheets files and so a purpose built database was put together for them with complete well design data for 300+ wells pulled from original records etc. and then interfacing to their SCADA data source for the up to date real-time operational data.

Certain well integrity data is of quite specialist interest and is frequently collected in a personal spreadsheet with all of the lack of security which is associated:

- tendency for data entry errors such as typos or autofill and copied mistakes;
- problem of version control as files get updated and overwritten;
- problem of multiple versions as copies of files get made and shared around groups of engineers;

- easily lost data which is not formally backed up;
- no continuity of system when engineers change jobs.

By comparison, with formal data entry error trapping, checks and approval of input data and automated data format and back-up, the well integrity software enshrines best data practice. Essentially, well integrity has to be built on data integrity and system integrity, so easily configurable controls are needed at every step.

The key message is to have a high level of flexibility to allow the software to be configured to compliment the existing operator strengths and to introduce better practice where possible. Several operators have taken the opportunity of implementing the new well integrity approach to carry out an audit of their existing data systems and decide which ones are obsolete and should be replaced, and which ones are necessary to maintain.

Meeting the Task Management Challenges

International guidelines, national regulations and individual company Well Integrity Management Systems documentation will all provide guidance on the requirements for well component testing. The wide-ranging diagnostic well integrity activities can include:

DIAGNOSTIC WELL INTEGRITY ACTIVITIES (examples)	ACTIVITY FREQUENCY (example)
Routine annulus pressure monitoring.	Typically daily, sometimes less frequently.
Annulus pressure bleed-off /build-up test.	Periodically, in accordance with the operator's annulus management policy.
Mechanical integrity test of well barrier.	Pre-rig testing, leak evaluation, underground injection control (UIC) testing,
Routine valve functioning and seal pressure testing of wellhead and Xmas tree components.	Typically annually or biannually.
Routine SSSV testing.	Typically annually or biannually.
Production and annulus fluid sampling.	Periodically.
Scale sampling.	Periodically
Tubing caliper logging.	Periodically
Casing logging.	Periodically
Corrosion coupon monitoring.	Biannually.

Microbial analysis.	Periodically
Casing cathodic protection potential.	Annual.
Remote operated vehicle survey.	Typically three yearly.
Corrosion/scale inhibition treatment.	Continuous/ periodically
Wellhead movement monitoring.	Typically daily, sometimes less frequently.
Tracking of safety critical element component change-out.	Periodically
Tracking of other wellwork activities.	Periodically

The requirement for, frequency of, and acceptance criteria for different diagnostic well integrity activities can be dependent upon well type, well age and well location. The result is a vast matrix of daily and periodical tasks which can be managed down to an individual well-level with the individual test results being checked against each wells' own safe-operating-envelope and unique acceptance criteria.

The software needs to identify what work is required to be done on any day; giving warning of upcoming work demand and identifying tasks which are overdue. This broad task-scheduling capability ensures that no critical well barrier component inspections get overlooked and so there is no risk that a required monitoring check is forgotten. There is a capability also to ask for a "reminder" of an upcoming ad hoc task with the email warning of that task being sent to the responsible party. All these aspects are critical to bring to life a "planned" well integrity management approach as defined in a typical company WIMS document, particularly in fields with large numbers of wells.

Meeting The Data Communication Challenges

A key challenge of management is being able to monitor in detail whilst not losing sight of the high-level overview. Well integrity data is gathered with a per-well focus, with immediate access to all the relevant well design information. However, the bigger picture is how the integrity status of the whole field of wells is changing on a continuous basis as data is entered into the system. This can really provide improved business efficiency by gathering together key information from each well across the field and presenting it in a way which helps to identify possible integrity improvement steps.

One North Sea-based well integrity engineer was faced with a new set of Xmas tree pressure test results which was indicating a leak. He was sure that the problem was not isolated, but to investigate that question required manually sifting through a lever-arch file of previous

sheets of test results. Once the new system was in place he could not only review historical test data for an individual well, but could retrieve from the software a reliability report for all tested safety critical components for every well across the whole field. This allowed rapid identification of individual wells with consistent leaks, specific components which were consistently failing and requiring maintenance or replacement, and comparative reliability performance of SCE from different manufacturers.

The field manager has little time to devote to detailed well integrity concerns, but they still have the ultimate responsibility for the safety of their staff working within company installations and for the protection of the surrounding environment. Having this software in place provides a map of the field with the well locations colour coded according to their overall well integrity status (Fig.2). It is easy and quick to identify problem wells and seeing them located within the field helps to establish the potential risk that they may pose. Similarly, a field status overview shows in a single table how many wells of different types are in operation or closed-in or other company-defined well status codes. It tells the manager how available his well-stock is and of the available wells, what their integrity status is (Fig.3). This particular report was considered to be the critical daily summary required by one field manager of a giant onshore field in Kazakhstan.

One major North American operator with more than 1000 wells wished to make forward planning of workover requirements for future years not just based on historical demand, but also taking into account the gradual transition of tubing from L80 to 13Cr in his producers over time. The software provided a complete statistical breakdown of tubing metallurgy by well type and well location in the field, with an estimated failure date of the remaining life of the L80 tubing to assist in the estimation of future failure rate.

Many of these reports have been specifically developed to respond to the particular reporting demands of the individual operator, whereas others pull together best practice from our deployments. Communication of the results of multiple well integrity evaluations in a succinct way makes well integrity issues much more visible to senior management which ensures better support for the workover budget related to well integrity work.

Meeting The Working Method Challenges

The success of the total control of well integrity software implementation depends upon the enthusiasm with which it is accepted in the company and this almost always requires some adjustment in the method of working. Success is driven from the top: where the management team acknowledges the reporting and management control benefits of the new software and supports staff training in the new approach, the software gets most readily

incorporated within the normal work flow. Staff who have previously carried out data-entry into a spreadsheet may need support to adapt to the new concept of entering data into a dedicated software package with a new user interface. This is a classic "Management of Change" step where the managers have to ensure there is a combination of support and training to staff regarding the new system, but also a demand that the new method of working is adopted because of the added benefits it brings.

Streamlining data collection often means that data entry into the system is distributed widely across many people and is carried out primarily by those who collect the data. Contracts to 3rd party service companies may need adjusting to incorporate their role in data entry of test results. In a North Sea example, the service company carrying out routine well pressure tests and maintenance was obliged to enter their test results into the well integrity software whilst offshore before departing the installation. They quickly realized the benefits in that results were immediately visible onshore, meaning that follow-up actions and additional test work could be immediately authorized whilst the correct staff were still available. The offshore installation manager requested a particular report format to summarise test status of all his wells which allowed him to keep up to date with regulatory required testing and to have a clear audit trail of proven test work, completely up to date at all times. With his enthusiastic support increasing amounts of well activity work and test results were entered into the system, greatly increasing the visibility of well integrity controls both on- and offshore.

One on-land operator has to cope with the inspection and monitoring of wells spread over wide distances, with some operators travelling for several hours to reach the most remote locations. Daily monitoring data has been slow to be assessed in the past, waiting for the drivers to return to the office. The implementation of the iWIT Notepad system for remote data entry in the field has transformed this situation. The handheld device recognizes the well number through a GPS system and automatically asks for the data to be entered relevant to that well location. Data, once entered, is then automatically downloaded through a variety of communication channels as they become available on the journey through the field. Operators have adopted the new system with enthusiasm. It reduces their time back in the office for transferring results into a computer system and they feel they are positively contributing to the improved working system. The field manager stated that the whole system was a great support to improved efficiency of the business.

In some cases individuals may feel defensive about maintaining their personal spreadsheet or even concerned that the report which used to take half a day a week to produce is now available at the press of a button. Understanding the human impact of new working practices is vital if the system is to be a success. Freeing staff time from some tedious data recording and report preparation is very successful where they feel they have

gained time to devote to more valuable and interesting activities such as problem-well diagnosis or workover planning.

Value-Added Benefits Of Well Integrity Total Control

The fundamental benefit of adopting the total control of well integrity is to bring forward all the analysis of well barrier failing tendency into a pro-active stage, before the critical failure arises. This reduces the frequency of well failures resulting in shut-in for long or short term, and hence productivity is increased. Furthermore, workover planning, a key cost element in a time of limited rig resources, is greatly improved. Every operator who has implemented the software for the total control of well integrity has initially been shocked at the widespread range of problems that are identified. Fortunately this has led to various focused campaigns to address the issues and after a year in operation, the overall well integrity status has been significantly improved with far fewer warning lights. One North Seal Well Integrity Manager explained "I could never get the budget approval for replacing the faulty items identified by the software, but when it was clear how significant and widespread the problem was the money was made available and we've got the problem fixed".

The overwhelming value of the software system identified by one operating company was "**Protecting Baseline Production**" through proper attention to all required well integrity checks and maintenance. There are spin-off benefits in other parameters which can be monitored. For example, one of the features developed for one client is the live monitoring of the wellhead (tubing head) pressure; maintaining it between pre-set values, which are different for each well, to optimize production in a giant onshore field, originally developed without any on-site automation. If the THP goes out of the target range, a clear visible warning is given. One of the data-views is a live continuous output of pressure readings per well. Wells with pressure outside the allowed pressure range are quickly highlighted for correction of the problem as soon as it is noted. The operations department keep this critical data-view continuously set-up on a large video display screen on the wall so that problems are instantly noted by the workers in the office. The previous system used a spreadsheet collection of data which was compared at the end of the day with the allowed THP ranges and then the morning meeting heard about yesterday's "bad players" to be checked up and corrected, after possible a full day of low production. As a consequence of the introduction of the new system production is now continuously closer to target rates, with obvious financial benefits.

One operator has been using the software at two of their operations for more than 2 years. Their feedback indicates that they are required by regulators to be able to show

actively that their wells are "fit-for-purpose". Use of the dedicated software has provided them with a high level of "**Visibility of Well Integrity**", both within the company and with their external well examiners and government regulators. The comprehensive nature of the integrity assessments has been significantly raised the confidence of the external authorities. At one key meeting the operator was challenged to provide proof that they were in control of the condition of the production tubing in the field. Within seconds they were able to generate a report summarizing all the caliper survey results for every well over time and show the cumulative wall thickness loss related to their production conditions.

Whilst the cost benefit of using the well integrity total control approach are primarily felt in the operational budgets, the benefit of more efficient use of personnel is enormous too. Engineers are pleased to be relieved of tedious data gathering and report preparation tasks, freeing their time for the more in-depth evaluation of solutions to identified well barrier breaches and detailed risk analysis. A shift from the "fire-fighting" mode to "planning" greatly reduces stress and improves work quality for all. In a time of skill shortage, optimum use of skilled personnel is critical to business success.

Conclusions

Response measures to avoid unintentional environmental leakage of well's fluid require an awareness that well barrier elements have failing tendency. The industry can respond to the events when a well is suffering sustained annulus pressure and prevent the increase in operational risk from becoming more widespread across the field. Total control of well integrity is an essential part of achieving long term security of production, cost-effective operation and a zero-leak goal. There are many challenges to be faced:

- The framework of the basic company philosophy and well integrity aims needs to be established.
- The full range of well integrity threats has to be understood and the safe operating envelope for each threat has to be derived.
- The existing data systems needs to be analysed to make optimum use of everything which is good, and replace the parts that are becoming obsolete.
- The scheduling of all the well integrity monitoring activities and tests has to be matched to the requirements, regulations and resources.
- The reporting requirements have to be designed to optimise the communication of the threats to the right personnel in the most succinct way.

- The management of the change in working practice and individual's roles and responsibilities requires support.

The operator must minimize the unintentional environmental leakage risk of well's fluid by effective control of well barrier elements status when in operation and take necessary actions to avoid unacceptable risk. Data relevant to well barrier elements control is widespread, including the results of mechanical integrity tests to safety critical elements; monitoring of elevated annulus pressures; evaluation of tubing and casing actual resistance to fluid containment; inspection results from well logs; evaluation of scaling risks etc. The management of, and continuous evaluation of, this vast range of data presents a huge challenge. The system described in this paper has met that challenge comprehensively.

Author Biographies

Liane Smith, Director of Intetech Ltd, formed the company in 1991 after 10 years working for the Shell Group of Companies in the UK and Netherlands. She has been involved with solving well integrity problems, modelling field corrosion in downhole tubing and selecting materials for production tubing throughout her career. She has a degree in metallurgy and materials science from Cambridge University and a PhD in welding from Sheffield University. She can be contacted at liane@intetech.com.

Dragan Milanovic, Head of Well Integrity in Intetech Ltd., has over 28 years of oil industry experience as a drilling manager, well designer (HPHT sour service), well control specialist, fisherman, engineer, consultant and well integrity expert. He has worked in Middle East, Caspian, Far East, Europe, Caribbean and North America countries including all the oil producing regions. He is the author of numerous technical reports. He is now Head of Well Integrity in Intetech Wells Ltd. Since 1992 he has been working internationally, joining Intetech Ltd in 2003. He has Master in petroleum engineering from the University of Belgrade. He can be contacted at dragan@intetech.com.

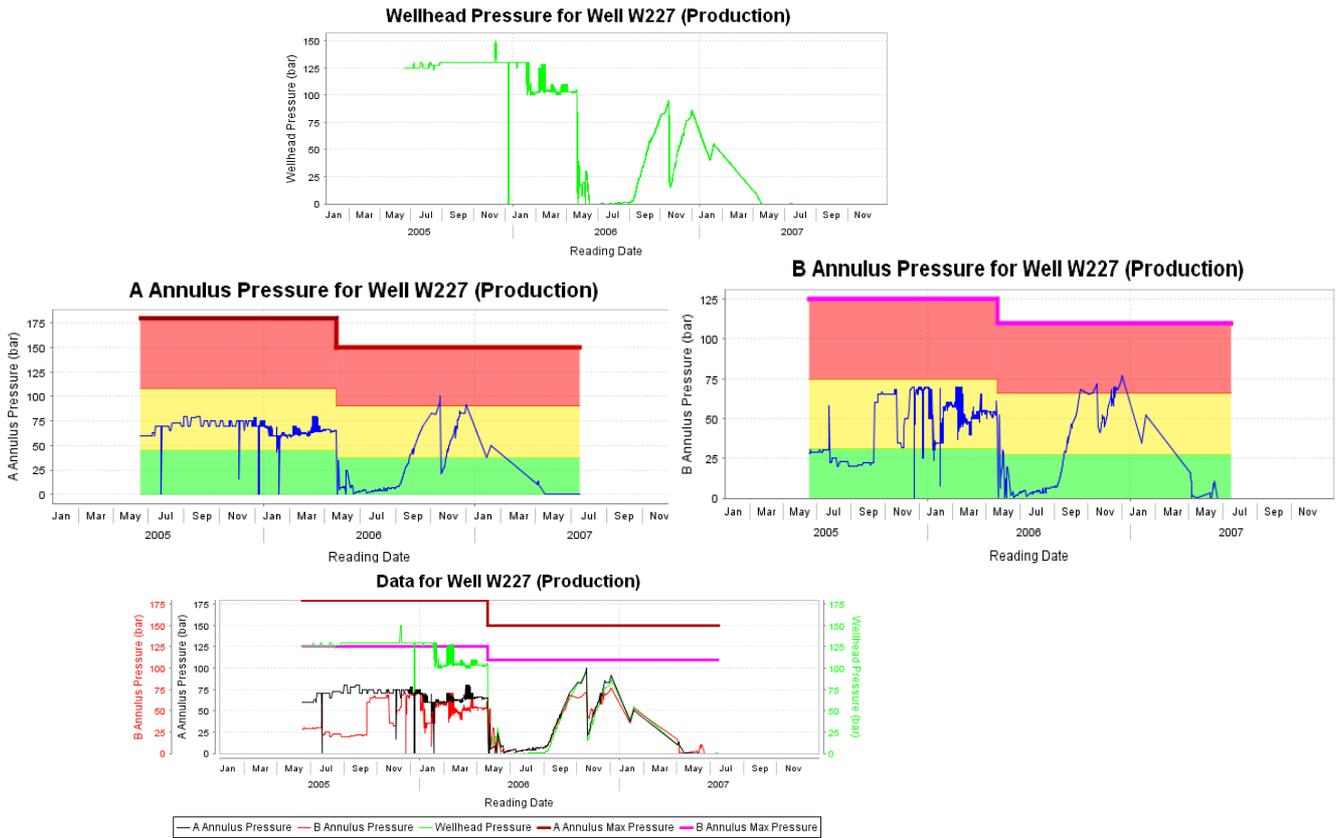


Figure 1 – Example annulus pressure monitoring graphs showing (red line) the annuli MAASP values derated with time.

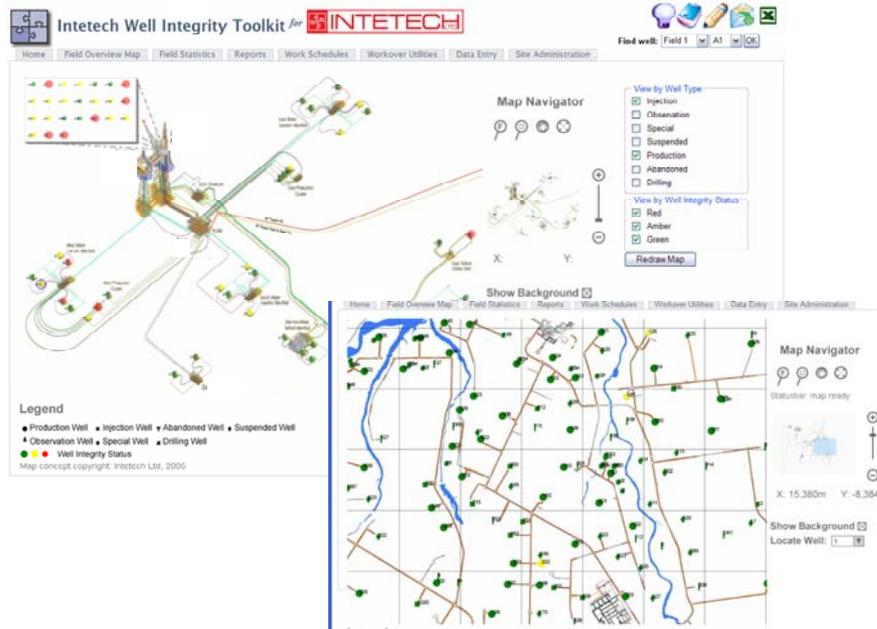


Figure 2 – Example views of offshore and onshore field maps with individual well status distinguished by traffic light colour coding. Clicking on any well links directly to the individual well data.

CATEGORY OF WELLS	Total	WELL NUMBERS						
		Above Reservoir	1	1+2	2	2+3	1+2+3	3
EXPLOITATION WELLS	117							
OPERATING WELL STOCK	117							
PRODUCTION	102							
In Operation	70		118		188, 243, 252, 320, 322, 326, 328, 340, 348, 348, 350, 432, 710, 817			15, 216, 220, 308, 312D, 419, 423, 430, 446, 449, 5488, 5790, 5887, 6384, 713, 718, 818, 905, 910, 912, 915, 918, 920, 933, 9805
Temporarily shut-in	1			106				
Pending flowline hook up after workover	1			804				
Need to be worked over	8		102, 146, 154		145, 827			801
Scheduled for workover	4		109, 215, 23					
Workover in progress (Other well categories)	3		172		811			
INJECTION	15							
In Operation	12				107, 126, 183, 200, 207, 213, 330, 700, 701, 702B, 707, 812, 826, 814			
Temporarily shut-in	2							
Pending flowline hook up after workover	0				221			
Need to be worked over	1							
Scheduled for workover	0							
Workover in progress (Other well categories)	0							
ABANDONED	58							
Permanently abandoned	10	427	100		253			212, 708
Abandoned exploration wells	30							37
Awaiting abandonment	18	112, 427D	105, 108, 208		30, 327			139D
OBSERVATION	1							
Active	1							301
SUSPENDED	48							
Need to be worked over	18	321-1, 806N, 923	103, 166, 170, 238, 433, 7		325, 38			D5
Suspended well	30		1000, 101, 11, 111, 113, 125, 150, 16, 17, 180, 185, 22, 329, 606, 623,		14, 202, 5, 711, 9			425, D1

Figure 3 – Example well status overview report indicating the numbers of types of wells and their status on the requested date. Separate columns identify the reservoir the well is producing from or injecting into and colour coding conveys the well integrity status. Clicking on any well links directly to the individual well data.