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Discussion on Uncertainty Analyses

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1 INTRODUCTION

Measurement systems are usually specified with a performance target which details the total acceptable measurement uncertainty to be associated with the measured product.

The tool we employ to examine the performance of a measurement system is the uncertainty analysis. The measurement system uncertainty analysis is achieved by the development of an uncertainty budget which identifies, documents and combines the contribution of each device and algorithm proposed for use as in the design of the measurement system.

If the outcome of a measurement uncertainty analysis shows that the system design meets the specified target it is normal practice to accept the system design and move forward with construction.

An uncertainty analysis will also provide an indication of the quality of the measurement equipment employed; however the quality of measurement equipment is rarely analysed or used in support of proposed maintenance programs.

Most, if not all, United Kingdom Continental Shelf (UKCS) based measurement systems are maintained on a calendar basis with the frequency of maintenance reducing with time as the equipment is ‘proven’ in service.

But how closely do we examine the uncertainty analysis; does it tell us everything we need to know and are we using the information gathered to the greatest effect?

Periodically the field operators or field licensees may be required to demonstrate, usually through an audit process, that their respective measurement systems are operated and maintained to standards agreed prior to initial field production.

However the examination of the measurement system design and its ability to meet a measurement uncertainty target may only take place at the design stage.

The intent of this paper is:

1. Describe areas where and the reasons why engineers should increase the level of scrutiny applied to measurement uncertainty calculations.

2. Examine methods to improve our understanding of instrument performance and justify modifications to maintenance plans, whilst preserving target system performance, by the application of observed and recorded evidence. This will seek to introduce and apply reliability and availability concepts to support maintenance strategies.

3. Propose the development of a national database system to capture the results of all United Kingdom Accreditation Service (UKAS) calibration data in a format which can be used to improve the understanding of the long term performance capabilities of instrumentation and flow meters.

2 REGULATORY GUIDANCE ON MEASUREMENT PERFORMANCE

2.1 Regulation and Guidance for Manufacturers

The National Measurement Office (NMO) in the UK is an Executive Agency of the Department for Business, Innovation and Skills (DBIS) and works to ensure that fair and accurate measurement for trade is delivered. Their remit covers transactions regulated by UK trading standards law.

In the case of the Oil and Gas industry the NMO refers to guidance on acceptable standards of measurement performance as a member state of the International Organisation of Legal Metrology (OIML) who provide model recommendations through a series of categorised publications. The OIML model recommendations set out technical specifications and testing requirements which instruments must achieve in order to receive OIML type rating approval. These are recommendations only as the regulation comes under national law.

There also exists the Measuring Instrument Directive [1] (MID) which has been issued by the European Parliament and the Council of the European Union. This directive also seeks to set out minimum standards of instrument performance which manufacturers must meet in order to sell their products on the open market. It would be expected that, if regulated, any instrument would need to be approved under the MID requirements before being accepted for use in a trade application.

The MID refers to the OIML model recommendations to provide the technical specifications to support the results of instrument testing towards the achievement of MID conformance, hence allowing the instrument to be used for trade..

In the UK the NMO has stated that they remain flexible with regards to the application of the MID. Generally UK law only regulates the sale of goods to the public and will therefore only require type approved equipment (through the MID) to be used in these specific applications. Effectively within the UK oil industry the use of the MID will be restricted to only road fuel dispensing and heating oil applications.

This supports the position that end users may wish to apply more stringent quality assurance processes to their acceptance of measuring instruments than those described in the MID if it lies outwith the UK regulated activities.

Both the OIML model recommendations and the MID provide for minimum levels of performance which instruments must meet in order to be sold openly in the market place and provide for assurances around conformity and type rating.

It must be noted however that the minimum levels of performance which these documents direct manufacturers to achieve may not provide the levels of performance required by an end user in industrial or specialist applications.

2.2 Regulation and Guidance for Licensees

The UK's Department for Energy and Climate Change (DECC) have also created and issued a Measurement **Guideline** document [2] which serves the Measurement Model Clause contained within the Petroleum (Production) (Seaward Areas) Regulations 1988. The Petroleum (Production) (Seaward Areas) Regulations 1988 [3] are a Statutory Instrument (SI 1213) and as such ensure that the legal responsibility for meeting the terms of the Measurement Model Clause rest with the Licensee.

Contractual agreements made between parties to undertake field developments or for entry into commingled pipe line systems will also contain legally binding measurement clauses, usually designed to protect the interests of individual shippers, the combined interests of all the shippers and the pipe line operator.

With reference to the above we can see that there may be a variety of legal metrological obligations placed upon licensees in the UK to comply with DECC guidelines and contractual agreements to include for International Standards which may be referenced within these.

Unlike some other jurisdictions, UK guidelines are not regulations and hence do not fall within the scope of the MID. This allows DECC to assess measurement systems based on their duty and value and may require instrument specifications more or less stringent than that met by MID or OIML approval.

3 INSTRUMENT PERFORMANCE AND END USER NEEDS

Whilst there are clear legal and contractual obligations for licensees to meet defined metrological requirements, the legislation supporting the performance of measuring instruments may not necessarily drive the development of instruments which can meet the exacting requirements of the end user.

The Oil and Gas industry measurement sector seeks to protect a very high value product however the number of measurement instruments required to achieve this may be very low when compared to the world wide market in other industry sectors where the value of products can be much lower e.g. manufacturing, food production, agriculture, water industry etc.

This could lead to a situation where the investment required in developing, building and testing measurement equipment to the exacting specifications and requirements of the oil and gas industry may not be commercially viable for all manufacturers. In contrast where manufacturers have received approvals and type rating for their equipment, the actual performance could greatly exceed the stated minimum requirements.

The manufacturers understanding of the actual performance capabilities of their instrumentation are typically found within the technical specification document. The technical specification document is the vehicle the manufacturer uses to present the customer with an indication of the typical performance characteristics which could be achieved.

It must be noted that there may be little or no legislation in the UK governing the veracity of the information presented within a manufacturers technical specification; trading standards or trade descriptions policies may give some protection but cases could be difficult to prove particularly in the industrial sector. **Caveat Emtor!**

4 MEASUREMENT UNCERTAINTY AND SOURCE DATA

The international standards and guidelines most often referenced in the development of measurement uncertainty calculations are the Guide to the expression of Uncertainty in Measurement PD6461: Part 3:1995 (GUM) [4] and the Measurement of Fluid Flow – Procedures for the Evaluation of Uncertainties (ISO5168 2005) [5].

Both of the documents referenced in [4] and [5] categorise measurement uncertainty into two distinct areas:

1. Type A – Uncertainty estimates quantified from the statistical analysis of the results of a number of observations.
2. Type B – Uncertainty estimates which are quantified and evaluated by other means.

The evaluation of measurement uncertainty is therefore not entirely prescriptive and presently the Type B estimate permits the use of engineering judgement, and application of some assumptions, where factual information such as the results of measurements and specific testing is not available.

It should be an acceptable position to say that Type A uncertainty estimates will always be more reliable than Type B uncertainty estimates as there will be fewer, if any, assumptions or engineering judgements required when analysing the outcome of the statistical analyses of a set of measurement data.

The first part of this paper will consider what improvements in measurement uncertainty may be gained if the referenced documents [4] and [5] were to explicitly state that engineers should strive to minimise the use of engineering judgement and assumptions and favour Type A uncertainty estimates over Type B.

4.1 Type A Uncertainty Data Sources

According to the GUM and ISO5168:2005, the most reliable data source for use within an uncertainty calculation will be derived from the mean and standard deviation of a set of measurement data results obtained at representative conditions (GUM Ch 4.2.1 page 10).

This means that we should place greater emphasis upon obtaining measurement results at operating conditions, inclusive of installation and environmental effects, in order to gain the best possible insight to equipment performance. The acquisition of type A data will supplement and hopefully reinforce any type B data available for the reference device.

The operators of measurement systems in the UKCS undertake routine maintenance programs where the results of field verifications are captured, analysed and stored. The maintenance programs are designed such that verifications checks performed are traceable, repeatable, robust and auditable.

This stored information forms the basis for an excellent source of Type A uncertainty data for a number of the components within the measurement system. Due to the fact that all verification check data is retained, including failures to meet required performance levels, it is possible to reflect on historical performance.

Components of measurement systems for which Type A uncertainty data, and the type of data may be available are given below in Table 1 for illustration purposes. This list is not exhaustive.

Table 1 – Type A Uncertainty Data

Equipment	Verification Check	Output
Turbine/Coriolis/USM Meter Prove Data	Meter Proving	K-Factor Data Variation
Orifice Plate Inspections	Visual (sharp edge / flatness) Inspections	Pass / Fail Indication
Orifice Carrier Inspections	Visual Damage and Operation	Pass / Fail Indication
Differential Pressure Tx	Rising and Falling Errors Across Operating Range	Range Performance Data
Static Pressure Tx	Rising and Falling Errors Across Operating Range	Range Performance Data
Temperature Transmitter	Rising and Falling Errors Across Operating Range	Range Performance Data
Temperature Element (PRT)	Spot Check Errors	Performance Data
Flow Computer Calculations	Programming, Algorithms, Input/Output	Performance Data
Liquid Density Transducers	Spot Check Errors	Performance Data
Gas Density Transducers	Spot Check Errors	Performance Data
Gas Chromatograph	Spot Check Errors	Performance Data

Whilst it may not be possible to obtain representative Type A data for all components within the measurement system at operating conditions; the list above demonstrates that a large amount of data is available to support an analysis of individual instruments and overall system performance.

Statistical analysis of the results of verification checks and calibrations will establish the experimental standard deviation of the mean for each instrument and provide an insight as to the distribution of the data around the mean so that an appropriate coverage factor may also be established.

Typically this information is presented in support of modifications to the calendar based frequency of maintenance activities however it may not be called upon to support the actual in service performance of a measurement system.

4.2 Type B Uncertainty Data Sources

It is recognised that it may be difficult to obtain reliable uncertainty estimates in the absence of a set of representative test data. The GUM [4] and ISO5168 [5] provide some guidance as to the application of scientific and engineering judgement in this case.

Specifically the GUM, Section 4.3.1 page 11 [4] states for Type B uncertainty data that “the standard uncertainty is evaluated by scientific judgement based on all of the available information on the possible variability of the measurand” and the pool of information may include:

1) Previous measurement data
2) Experience with or general knowledge of the behaviour and properties of relevant materials and instruments
3) Manufacturers specifications
4) Data provided in calibration and other certificates
5) Uncertainties assigned to reference data taken from handbooks

There are many sources of data available which will be of use in providing a Type B uncertainty estimate. However it must be stressed that it is in this area where the greatest care must be exercised to reduce or remove the use of assumptions if we are to obtain reliable uncertainty estimates.

It may be however that the use of manufacturer’s technical specifications as a source of uncertainty information is the area where most improvements in the reliability of data could be achieved.

Manufacturer’s technical specifications contain a wide amount of information regarding the performance of equipment which can be presented in different ways. This means that the end user does not always have an opportunity to directly compare the performance of equipment and the technical specification may not contain all of the relevant information required to construct a reliable uncertainty estimate.

This may be most notable where a confidence level or coverage factor is not presented on the technical specification.

4.3 Coverage Factors

The coverage factor provides an indication of the confidence that the manufacturer can place on the accuracy figures presented in the technical specification and is usually obtained from a statistical analysis of test results (as per type A uncertainty data).

The confidence level, or coverage factor, also describes the frequency distribution of the supplied accuracy data and shows if this is distributed according to a normal, rectangular, triangular or some other form of distribution.

Where there is no coverage factor presented then the user can know nothing of the frequency distribution and therefore which coverage factor should be applied.

Technical specification accuracy values which do not contain details of coverage factor are generally treated as though they have a rectangular frequency distribution in accordance with the guidance provided by the GUM [4] and ISO5168 [5].

In addition to the situation where no coverage factor is supplied some manufacturers may supply coverage factors which do not necessarily conform to those recommended by the GUM [4] or ISO5168 [5].

It is noted that some multiphase flow meter (MPFM) manufacturers have in the past issued specification sheets where the coverage factor on the stated uncertainty value was appropriate to the 90% confidence level rather than the more usual 95%. As this will show the performance of the flow meters in a better light than if a 95% coverage factor were used, any claim made on the technical specification must be closely examined. More recent literature from MPFM manufacturers show that a 95% confidence level is being adopted for use.

There are also some manufacturers, possibly those with instruments used in more critical applications, who quote their confidence level at the 99% (coverage factor of 3) value which will be a much more stringent value to prove achievable.

A normally distributed data set gives rise to the use of a coverage factor of 2 to describe a confidence level of 95% derived from measurement data and a rigorous uncertainty budget. A rectangular distribution gives rise to the use of a coverage factor of 1.732 to achieve the same outcome. Other given confidence levels such as 90% must be closely scrutinised to ensure that the coverage factor is determined and applied correctly at a 95% confidence level.

It is usual for a supplied coverage factor to be adopted and used as a divisor in the uncertainty budget to manipulate the supplied accuracy data from an expanded uncertainty value to a standard uncertainty value. Table 2 below gives an indication of the most commonly used coverage factors; the use of coverage factors are more fully described in the GUM [4] and ISO5168 [5].

Table 2 – Confidence Levels and Coverage Factors

Coverage Factor from Technical Specification	Confidence Level	Distribution	Divisor to Obtain Standard Uncertainty
3	99%	Normal	3
2	95%	Normal	2
None Given	95%	Assume Rectangular	$\sqrt{3}$ (1.732)
None Given	95%	Assume Triangular	$\sqrt{6}$ (2.45)

If we examine the fundamental source of confidence levels, or coverage factors, we can readily understand that they rely on a data set for their generation. If we consider the determination of coverage factors in the context of equipment performance we can see that the data set used must encompass and contain the results of equipment testing.

Where no coverage factor is supplied by the manufacturer there may be genuine reasons for assigning universal or generalised accuracy values as an indication of performance. This may be in consideration of situations where end users may wish to deploy equipment in process conditions or systems which are less than ideally suited for the equipment.

In general users developing an uncertainty budget will apply a rectangular distribution to manufacturer's uncertainty or tolerance claims in the absence of a confidence level. However as there is no evidence to support the existence of a rectangular distribution this is a wholly assumed position.

The GUM and ISO5168 make reference to C F Dietrich, Uncertainty, Calibration and Probability, The Statistics of Scientific and Industrial Measurement, 2nd edition 1991 [6] in support of the use of the rectangular distribution in the absence of a confidence level. However it must be noted that Dietrich goes on to say that the "vast majority" of distributions will be normal or Gaussian.

In reality if we hope to verify the 'type' of meter or instrument in the actual operating environment then only by monitoring and analysing the performance of many devices in many different locations will we be able to verify the manufacturers estimate.

4.4 Scrutiny of Data

Personnel employed in the development of uncertainty estimates must ask what should be done in the advent that the manufacturer's technical specification does not provide a coverage factor or if the supplied confidence level is not consistent with those given in the GUM [4] or ISO5168 [5].

There may be a number of factors upon which a decision could be made:

1. Adopt the guidance of the GUM [4] and ISO5168 [5] and apply a rectangular distribution to the given accuracy values if you already have experience of the equipment in service and have confidence in its performance.
2. Contact the manufacturer to determine if there is any test data available which could be used to obtain a frequency distribution and an appropriate coverage factor which may not be in the public domain.
3. Consider undertaking independent testing of the equipment at conditions which match your needs to develop your own data set.
4. If there is no supporting data available from the manufacturer or the cost of independent testing is not viable then consideration may need to be given to the selection of alternate equipment.

Any concerns over equipment performance must be highlighted at the earliest possible opportunity in order to prevent the purchase and installation of unsuitable equipment.

It is recommended that where no coverage factor is available within a manufacturer's technical specification that the personnel performing the uncertainty analysis must alert the responsible project or design engineers to a potential concern with the equipment specified.

Failures to identify or tackle concerns with the technical specifications of equipment could lead to the undertaking of Joint Industry Projects (JIP's) to examine performance. The JIP's can be time consuming and expensive to conduct and could ultimately lead to the abandonment and replacement of poorly specified equipment.

By the time any performance issues have been identified and a JIP is convened to examine these and provide corrective recommendations there is a possibility that mismeasurements have been ongoing.

5 MAINTENANCE OF METERING SYSTEMS

Whilst there are many industry guidelines, standards and documents which discuss the methods required to achieve reliable measurements there are few, if any, documents which describe a basis for the maintenance activities required to ensure that measurement systems continually perform within their design uncertainty parameters.

5.1 Industry Guidance on Maintenance Program Design

Measurement systems in the UKCS are typically maintained on a basis where the results of verification checks and calibrations are used to reduce or increase the frequency of maintenance activities dependent upon the observed results.

In addition to the performance of routine verification checks, DECC and UKCS pipe line operators may recognise that some system designs may provide a greater level of assurance than others and be prepared to accept a more relaxed maintenance regime where there is:

1. Monitoring of diagnostic data
2. The use of duplicated instrumentation
3. The implementation of online uncertainty modelling
4. The availability of dedicated metering technicians on site

Whilst the design of new measurement systems may be in a position to take advantage of improved diagnostic capabilities or duplicate instrumentation our more mature systems may require significant investment to recognise these.

It must be noted that all of the above approaches are entirely depend upon the detectibility of equipment faults in the interim period between verification checks in order to prevent mismeasurement.

Faults identified by any of the above methods should be classified as detectable failures. Detectable failures will alert personnel to potential faults within the measurement system through alarms and allow these to be corrected in a timely manner.

Faults which cannot be identified by any of the above methods should be classified as undetectable failures. Undetectable failures will exist until a verification check of performance is conducted and a problem is identified.

The period between verification checks, maintenance frequency, then becomes crucial in identifying undetected faults to minimise the period in which these could go uncorrected.

The most typical approach used in the UKCS as the frequency of maintenance verification checks is:

1. Perform verification checks on all installed equipment monthly for a period of 12 months.
2. Use the results of these 12 verifications to apply for a reduction in the frequency of maintenance, normally to quarterly checks, for a further 12 months.
3. This approach then normally iterates annually upon the success of the verification checks to a position where maintenance could be performed at a maximum frequency of annually depending upon the continued good performance of equipment.
4. Where equipment is found to fail the verification checks then this process may be restarted and monthly checks resumed.

The process described above has been arrived at through the experience of users and regulatory authorities over time. Whilst this approach may provide a level of confidence and apparent rigour, an analysis of equipment performance prior to the system going into service will yield a scientific basis for maintenance frequency.

5.2 Data Supporting Availability Analysis

In order to establish the most appropriate maintenance frequency for a metering stream or station we can undertake an analysis of the availability of installed equipment to ensure continued performance within target uncertainty parameters is preserved.

Regulatory and contractual obligations ensure that all verification check data relating to measurement systems is retained in a format which can be readily audited. There are routine audits of metering systems carried out which ensure that verification checks are performed using calibrated and traceable test equipment in a systematic manner according to written procedure.

The large number of metering systems in operation and the verification data stored for these provides us with a large volume of reliable information on which to base a reliability analysis.

The information provided from Table 1 – Type A Uncertainty Data provides the information we require to perform a reliability and availability analysis.

The nature of measurement system design gives rise to the repeated use of equipment due to a variety of reasons such as fluid properties, flow ranges or process conditions. A field operator can readily find that the same manufacturer's equipment is in use across a number of assets and that the volumes of associated verification check data available is very large.

The data available for all measurement equipment can then be used to predict the performance of the metering stream and station.

5.3 Industry Guidance to Availability Analysis

There are well understood methods and approaches available to develop an availability analysis of a measurement system.

For the context of this analysis availability is defined as the proportion of time for which a component is not failed and is dependent upon both the failure rate of a component and the period between verification checks.

The result of the availability analysis will yield a percentage value for the period where the metering system is available within target uncertainty parameters.

The most closely aligned international standard for our needs may be IEC 61511 [7] Functional Safety, Safety Instrumented Systems; which provides a framework for identifying safety criteria for instruments and software as well as a process for managing instrumentation to ensure stated requirements are achieved.

In basic terms IEC 61511 provides a framework and a statistical method of determining the frequency of maintenance activities based upon historical instrument performance from a safety performance perspective.

If we were to adapt the perspective of IEC 61511 from safety performance to measurement performance then we may have a useful basis to develop a maintenance strategy targeted to ensure measurement system performance is preserved.

Additional reference material used to construct the availability analysis performed below has been taken from SINTEF, Reliability Data for Safety Instrumented Systems, PDS Data Handbook, 2010 Edition [8] and Dr David J Smith, Reliability Maintainability and Risk, 8th Edition [9].

5.4 Example of an Availability Analysis

The following analysis has been performed in accordance with reference to [7], [8], and [9] and concerns undetectable failures, deliberately excluding detectable failures, to provide a worst case scenario. This example considers a four stream gas orifice metering station on the Judy platform.

The data sets for performing the reliability analysis has been taken directly from the data stored within the J-Block metering maintenance system. Failed equipment is defined as equipment which fails to meet the requirements or tolerances of the verification check, typically recorded as 'As Found' data. It should be noted that the flow computer software is not considered within the analysis.

Performance data was extracted for the following instruments and equipment between 2007 and 2012 in order to determine the failure rate of each component.

Table 3 – Instruments and equipment to be considered

Equipment	Failure Criteria
Differential Pressure Transmitter	Verification check Exceeds +/- 0.25%
Static Pressure Transmitter	Verification check Exceeds +/- 0.25%
Temperature Transmitter	Verification check Exceeds +/- 0.3 Deg C
Gas Chromatograph	Fails Annual health Check
Orifice Plate	Fails Visual Inspection Check
Flow Computer ADC I/O	Verification check Exceeds +/- 0.05%

Failure rates were then calculated for each component in the analysis as follows:

$$\text{Failure\_Rate\_per\_Component} = \frac{\text{Number\_of\_Failures}}{\text{Installed\_Time\_Base}} \qquad \lambda_i = \frac{k_i}{T_i} \qquad (1)$$

Where there were no observed failures of instruments or equipment a failure rate was taken from SINTEF, Reliability Data for Safety Instrumented Systems, PDS Data Handbook, 2010 Edition [8].

Table 4 – Component Failure Rates

Equipment	No of Failures	Time Base (hrs)	Failure Rate (per hr)
Differential Pressure Transmitter	2	395064	5.06E-06
Static Pressure Transmitter	2	288312	6.94E-06
Temperature Transmitter	0	N/A	3.00E-07
Gas Chromatograph	0	N/A	3.00E-07
Orifice Plate	1	179448	5.57E-06
Flow Computer ADC I/O	0	N/A	3.00E-07

5.4.1 Failure Rate of a Single Metering Stream

In order to establish the overall failure rate of a single metering stream we need to sum the failure rates of the individual components. In probability terms this establishes a position where any of the components could fail (A or B or C etc) and provide a worst case failure rate estimate.

$$\text{Total\_Failure\_Rate} := \sum \text{Failure\_Rate\_per\_Component} \qquad \lambda_T = \sum \frac{k_i}{T_i} \qquad (2)$$

$$\text{Total\_Failure\_Rate} = 1.847 \times 10^{-5} \cdot \frac{1}{\text{hr}}$$

5.4.2 Availability of Number (M) out of 4 Metering Streams

Now that we have established the failure rate for a single stream we can consider the situation where we have four identical streams, all with the same failure rate, which we are maintaining in a staggered fashion e.g. Stream 1 is maintained in January, Stream 2 is maintained in February etc.

As previously stated availability is dependent upon both the failure rate and period between verification checks; reference to the definitions of availability can be found in [6].

$$\text{Availability\_Single\_Stream} = 1 - \frac{\text{Failure\_Rate\_per\_Stream} \cdot \text{Verification\_Interval}}{2} \qquad (3)$$

$$A_1 = 1 - \frac{\lambda_1 \cdot V_1}{2}$$

For the case where we have a four stream metering system we can examine the availability of the system, within target uncertainty parameters, under different operating scenarios and maintenance regimes using the following calculation set which is obtained from [9] Ch 8, page 109, Table 8.5 System Unavailability.

Table 5 – Availability Calculations M out of 4 Streams

Number of Streams in Operation	Availability
1	$A_{.1} = 1 - \frac{\lambda^4 \cdot V^4}{16}$
2	$A_{.2} = 1 - \frac{3\lambda^3 \cdot V^3}{8}$
3	$A_{.3} = 1 - \frac{6\lambda^2 \cdot V^2}{4}$
4	$A_{.4} = 1 - 2\lambda \cdot V$

5.4.3 Availability Using Different Verification Check Frequencies

Where we use a fixed verification frequency to perform verification checks on installed components we can examine the availability of the metering system arising from this. Tables 6 and 7 below present the results of the availability analysis when determined using monthly verification checks and annual verification checks respectively.

Table 6 – Availability of Metering Station Employing Monthly Verifications

Number of Streams in Operation	Availability (%)
1	99.99999974%
2	99.99989040%
3	99.96933781%
4	97.14052738%

Table 7 – Availability of Metering Station Employing Annual Verifications

Number of Streams in Operation	Availability (%)
1	99.996%
2	99.841%
3	96.072%
4	67.637%

5.5 Analysis of Availability Results

We can see from the above analysis results that the availability of the metering streams is greater when the period between verification checks is lower which confirms the intuitive assertion used to support the typical UKCS calendar based maintenance approach described in section 5.1 above.

We must note that the metering system has been designed to operate with a maximum of three out of four streams in operation at any one time; the fourth stream being utilised to switch streams when maintenance is due.

Given this information we should consider the position where we have three streams in operation as our minimum availability. If production were to decline and we required only two streams out of four to be in operation then our availability would increase as long as we continue to perform verification checks on all four streams.

The data in Table 7 shows that where there are three streams in operation for the Judy gas export system we will have the probability of the metering system operating within target uncertainty parameters with an availability of 96% when performing verification checks annually.

For the same position but with monthly verification checks we have an availability of 99.97%.

We must also remember that the availability analysis only considered undetectable failures which may exist between verification checks. In reality failures will also be identified through diagnostic monitoring and alarm annunciation and will be acted upon in a short time scale by dedicated metering technicians thus further improving availability.

6 PLAN, DO, ASSESS, ADJUST

Most companies have a strategic approach to the work they perform in order to foster continuous improvement and optimise performance. At ConocoPhillips we use the plan, do, assess, adjust approach which provides for the iterative nature of improvements to processes as in figure 1 below:

Figure 1 – Plan, Do, Assess, Adjust Process

It is custom and practice for licensees, regulators and pipe line operators to address the performance of metering systems on an individual basis usually through the audit process. Whilst this permits changes to be applied to individual systems, after review and approval, it does not necessarily permit the industry to learn about performance holistically as there may be legal or contractual issues surrounding the sharing of performance data.

Whilst there are sound commercial reasons for ensuring the integrity and performance of metering systems there are also sound reasons for establishing appropriate maintenance frequencies.

The more typical calendar based approach to metering maintenance requires that we break into hydrocarbon lines frequently in the early life of a metering system and thus increase the cumulative risk of major accident hazards to the platform. The manufacturers of instrument fittings give typical limits of six makes and breaks before the fitting should be discarded but how many operators have a routine program in place to address this.

The removal and replacement of large components such as Coriolis meters and Ultrasonic meters may be incurred too frequently due to a lack of available performance data industry wide. The removal of these components is both time consuming and expensive and experience has shown that the flow meters can be readily damaged through transportation and manual handling.

In failing to share, compile and analyse performance data across the metering industry we are unable to assess and adjust our maintenance strategies or to develop continuous improvement and optimisation programs.

If we apply the plan, do, assess, adjust approach to the way we design, operate and maintain our metering systems we can see that there are opportunities, in line with the recommendations and proposals contained in this paper, to make improvements especially in the assess and adjust areas.

7 RESPONSIBILITIES AND ACCOUNTABILITIES

It is the responsibility of the duty holding company, within the boundaries of the UKCS to ensure that measurement systems meet their required performance standards at the design stage and are then maintained throughout the field life.

The responsibility for the provision of suitable measurement systems is incumbent upon the duty holding company.

Accountability for mismeasured production and for making required improvements to poorly performing measurement systems also lie with the duty holding company.

Financial liabilities may be incurred with field development partners or pipe line operators for mismeasured production dependent upon contractual terms, and dependent upon circumstances financial penalties may be applied for by DECC.

In addition, reputational damage may discourage potential development partners or have an adverse affect upon any new field development applications.

8 THE ROLE OF THE ENGINEER

One of the intents of this paper is to encourage engineers to take a position (as have DECC and pipe line operators) which ensures the provision of measurement systems which have a demonstrable level of performance at the design stage and which can be monitored and modified when appropriate during field life.

With regards to the design, operation and maintenance of metering systems there are a number of engineering and management roles involved who all have different responsibilities over the life of a metering system.

1. It is the responsibility of the project engineer to gain approval for the design, test and delivery of suitable metering systems inclusive of adequate spare components to permit the maintenance philosophy to be implemented.
2. It is the responsibility of the maintenance engineer to ensure that the system is operated and maintained in accordance with agreed principles and that corrective action is completed in a timely manner.
3. It is the responsibility of the licensee to ensure that the metering system continues to operate within the target uncertainty parameters.

Such a position demands the availability of traceable evidence to substantiate the performance of the system which will curtail the use of engineering judgement and assumptions.

9 CONCLUSIONS

Any concerns over equipment performance must be highlighted at the earliest possible opportunity in order to prevent the purchase and installation of unsuitable equipment.

To this end the following recommendations concerning the scrutiny of data are made:

1. Uncertainty modelling reports should highlight areas where equipment specified for use may not be suitable. The aim of this recommendation is to ensure the production of a report for others, who may not be skilled in uncertainty modelling, which clearly outlines shortcomings in the availability of data or the use of inappropriate data.
2. It is recommended that where no coverage factor is available within a manufacturer's technical specification that the personnel performing the uncertainty analysis must alert the responsible project or design engineers to a potential concern with the equipment specified.

In order to establish the most appropriate maintenance frequency for a metering stream or station we can undertake an analysis of the availability of installed equipment to ensure continued performance within target uncertainty parameters is preserved.

To this end the following recommendation concerning maintenance activities is made:

3. In order to address the improvements which could be made to the way our metering systems are maintained it is proposed that the utilisation of verification data to determine system availability is adopted and accepted as a viable means of establishing maintenance frequency for metering stations. Evaluation of target availability values based upon system design will be required in order to support this approach.
4. To enhance the development of suitable maintenance activities it is recommended that failure rate data is scrutinised and included within the measurement uncertainty report. It may also be appropriate to conduct an availability analysis within the overall measurement system uncertainty report to support a proposed maintenance regime.

The recording of verification and calibration results can be used to modify maintenance programs on an ongoing basis through statistical analysis of reliability and availability. A national database of all UKAS calibration activities, where results are collated and analysed statistically, would provide a basis for selection of equipment.

To this end the following recommendation concerning the collection of performance data is made:

5. This paper recommends the creation of a national database to capture all UKAS calibration data for instruments and flow meters to provide the information required to monitor and enhance our knowledge and understanding of failure rates and subsequent availability analyses. A database could be structured such that only data relevant to performance is recorded so as to avoid any legal, contractual or regulatory breaches.

10 NOTATION

Notation used within this paper is expanded and described more fully as follows:

Notation	Description
λ_i	Failure rate per component in hours
k_i	Number of failures per component
T_i	Installed time base for all components reviewed in hours
λ_T	Total failure rate of metering stream in hours
A_1	Availability of Metering Station with One Stream in Operation
A_2	Availability of Metering Station with Two Streams in Operation
A_3	Availability of Metering Station with Three Streams in Operation
A_4	Availability of Metering Station with Four Streams in Operation
λ_1 to λ_4	Failure rate of each metering stream in hours (taken as constant where identical metering streams are installed)
V_1 to V_4	Verification interval per stream in hours (The same verification interval has been used for each stream)

11 REFERENCES

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