

PETRONAS TECHNICAL STANDARDS

MANUAL

FISCAL FLOW MEASUREMENT OF NATURAL GAS

PTS 32.32.00.12

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This revision of PTS **32.32.00.12- Fiscal Flow Measurement of Natural Gas** has been updated incorporating PETRONAS Lessons Learnt, Best Practice and new information issued by relevant industry code and standards.

The previous version of this PTS **December 1999** will be removed from PTS binder/ e-repository from herein onwards.

Document Approval

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PREFACE

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They are based on the experience acquired during the involvement with the design, construction, operation and maintenance of processing units and facilities. Where appropriate they are based on, or reference is made to, national and international standards and codes of practice.

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1. INTRODUCTION

1.1 SCOPE

This PTS specifies requirements and gives recommendations for measuring, with the highest accuracy class, volume flow, mass flow and energy flow of natural gas. The typical field of application of this PTS concerns Custody Transfer and Sales measurements for onshore and offshore applications, requiring uncertainties of not more than 1% for custody transfer and 2% for ownership allocation.

The PTS specifies the requirements of flow measurement stations and gives recommendations for their selection, design, installation, validation and maintenance, with the purpose of achieving a consistent and cost-effective approach and realising contractually agreed availability and uncertainty levels.

The word "fiscal" in context of this PTS has been expanded from its original meaning of "pertaining to government finance" to "pertaining to income and revenues of parties concerned, including government taxation". However, as an example wet gas measurements and gas allocation measurements, which both could have fiscal duties, are excluded because they usually fall in different accuracy classes, if only due to their inability to comply with the strict conditions specified in this PTS.

NOTE: Allocation measurement via wet gas or multi-phase flow measurement demands an approach that takes specific account of flow conditions, as discussed in separate documents or standards.

This PTS covers four types of meter: multi-path ultrasonic, orifice, turbine and Coriolis meters. The legal status of each type is different and this may affect the choice of the meter.

This is a revision of the PTS of the same number dated December 1999; see (1.6) regarding the changes.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by PETRONAS, the distribution of this PTS is confined to companies forming part of PETRONAS or managed by a Group company, and where necessary, to Contractors and Manufacturers/Suppliers nominated by them.

This PTS is intended for use in natural gas facilities.

If national and/or local regulations exist in which some of the requirements may be more stringent than in this PTS, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this PTS which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this PTS as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party, which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party, which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party, which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

- Black and white list** A contract document providing:
- measurement and analysis methods and standards, data transfer, etc. generally agreed by contract parties for use in fiscal flow measurement (white list);
 - measurement and analysis methods and standards, data transfer, etc. to be agreed by contract parties for application in fiscal flow measurement on a case-by-case basis (black list).

1.4 GLOSSARY OF TERMS AND THEIR ABBREVIATIONS

1.4.1 General terms

Automatic Gain Control	AGC	A mechanism in the electronic control unit of an ultrasonic flow meter that automatically adjusts the amplification of the received transducer signals to a specific level.
Autonomy Time		The specified time of a UPS that the battery shall be capable of supplying rated current to the load within the specified voltage limits.
Availability		The relative time that a system performs its assigned duty. Unavailability is complementary to availability.
Coriolis meter		Device consisting of a flow sensor (primary device) and a transmitter (secondary device) which primarily measures the mass flow by means of the interaction between a flowing fluid and the oscillation of a tube or tubes; it may also provide measurements of the density of the fluid (ISO 10790).
Data Acquisition and Control Architecture	DACA	The standard architecture used to enable process control, monitoring and optimisation of assets, through secure and reliable networks, systems and applications
Fiscal		Concerned with income and revenues of parties concerned including government taxation. NOTES: 1. This is an expansion of definition by others, e.g. DTI definition: "Concerned with government finance" and is inclusive of aspects concerning Custody Transfer and Sales and as well as ownership allocation.. 2. Analytical and availability performance of the various categories of measurements covered by this PTS are not necessarily identical. Requirements follow from project specifications.
Fiscal (...) measurement		A measurement yielding fiscal data (of specified parameter). E.g.: fiscal flow measurement NOTE: This is an expansion of the definition by others, e.g. DTI definition: "A system, or element of that system, that is used to determine production rates that will ultimately generate revenue for the Government".
Fiscal data		Data relating to income and revenues of parties concerned including government taxation.
Fiscal Measurement Network		A data network that interconnects various components of the fiscal measurement system. (without reference) NOTE: The fiscal measurement network is typically a TCP/ IP Ethernet and is often a vendor proprietary system.

Fiscalisation		The process of producing and accruing fiscal data from fiscal measurement(s).
Flow computer		Element of the flow measurement that performs the flow computation and flow integration. NOTE: A flow computer is a secondary instrument and is usually a fiscal element in the measurement system.
(...) Measurement station		The station or plant that performs measurement (of specified property or properties). (without reference) E.g.: Fiscal flow measurement station
(...) Measurement system		A complete set of measuring instruments and other equipment assembled to carry out a (specified measurement task) (BS 5233). E.g.: Flow measurement system
Metrological tapping		Process connection used for measurement.
Multipath		Method of flow rate measurement in which the average fluid velocity over a number of different paths is determined (ISO/17089).
On-line Process Gas Chromatograph	PGC	Usually a liquid-gas chromatograph that has been designed to operate continuously without human intervention. Its principal task is to split a subjected sample into its constituents and to measure and report them as a fraction of mass or volume. (without reference) NOTE: Human intervention should only be required for maintenance and performance retention of the equipment.
Orifice meter		Method of flow rate measurement based on the pressure difference over an orifice plate, which is generated by the flowing fluid.
Pressure reference tap	Pr point	A metrological tapping on the body of turbine or ultrasonic meters for the measurement of the pressure relevant for the determination of the operating density (also Pm point). (without reference)
Primary device		Device, which generates a signal enabling the determination of the flow-rate. (ISO 4006) NOTE: A primary device is an instrument.
Process Control Network	PCN	A data network system that interconnects various instrumentation systems for the purpose of process control and process automation. (DACA) NOTES: 1. It is also connected to the Process Control Access Domain, which enables communication with the Office Domain. 2. The process control network is an element of the data acquisition and control architecture.
Recording device		A printer or electronic device that logs one or more outputs from the flow computer and / or from the supervisory computer. NOTES: 1. The data typically concerns fiscal amounts but also data that is legally required. 2. A (fiscal) recording device is typically the non-volatile memory of the flow computer including its display or an equivalent electronic device or a conventional (ticket) printer.
Redundancy		Duplication of functionality.

Secondary instrument		Any other instrument than a primary device that is required for obtaining volume flow or mass flow or energy flow under specified conditions. NOTE: ISO 4006 defines a secondary device as: "Device, which receives from the primary device a signal and displays, records, transforms and/or transmits it in order to obtain the value of the flow rate ". This definition is too limited to be of use in this PTS.
Supervisory computer		A digital computer that processes the data from one or more flow computers for producing reports and executing the connection with the process control network. (without reference) NOTE: A supervisory computer is a secondary instrument and is usually not a fiscal element in the measurement system.
Transit time (time-of-flight) difference method (in short: "transit time")		Method of flow rate measurement in which the average fluid velocity along the acoustic path is determined from the transit-time difference of two ultrasonic signals, one travelling upstream and one downstream, over the same distance in the flowing fluid (ISO/17089).
Turbine meter		A fluid measuring device in which the dynamic forces of the flowing fluid cause the turbine wheel to rotate with a speed approximately proportional to the rate of volume flow (ISO 9951).
Turndown ratio (...)		The quotient of the maximum and minimum result (of a specified property) that can be achieved with retention of specified characteristics. NOTE: For example, the turndown ratio in <i>flow</i> should obey the specified uncertainty of the measurement station.
Ultrasonic flow meter		Flow meter which generates ultrasonic signals and receives them again after they have been influenced by the flow in such a way that the observed result can be used as a measure of the flow rate (ISO/17089).
Uninterruptible Power Supply	UPS	Secure source of power for vital systems.

1.4.2 Terms concerning accuracy performance

Adjustment		The operation intended to bring a measuring instrument or a measurement system into a state of performance and freedom from bias suitable for its use.
Average Run Length	ARL	The average number of times that a process will have been sampled and evaluated before a shift in process level is signalled. (ISO 3534-2) NOTE: The ARL is a Control Chart property and is a function of the significance level of testing and the magnitude of the error.
Calibration		The set of operations which establishes, under specified conditions, the relationship between values indicated by a measuring instrument or measuring system, or values represented by a material measure, and the corresponding known values of a measured quantity (measurand) (BS 5233). NOTE: In various PTS the term validation is often used with the same meaning as the above definition whilst calibration is often used with the same meaning as Adjustment as defined above. This PTS will use the terms Calibration and Adjustment in strict compliance with the definitions herein, i.e. in compliance with BS 5233.

Chance Causes	The causes of variability, which are common to the natural variations of the process ("Fundamentals of Quality Control and Improvement", A. Mitra).
Control Chart	A chart, with upper and/or lower control limits, on which values of some statistical measure for a series of samples or sub-groups are plotted, usually in time or sample number order. The chart frequently shows a central line to assist detection of a trend of plotted values toward either control limit (ISO 3534-2). NOTE: A control chart is used to investigate if a process can be considered to be under control.
Control Limit CL	The error limit which, if exceeded, justifies immediate action in order to regain Statistical Control. NOTES: 1. The limit relates usually to the 99.7 % confidence level. 2. At the control limits or beyond, i.e. outside the interval between the upper and lower control limits, immediate corrective action is required in order to recover from out-of-control conditions and to limit their effects.
Error	The result of a measurement minus the (conventional) true value of the measurand (BS 5233).
Measurand	A quantity subjected to measurement (BS 5233).
Measurement result	The value of a measured quantity (BS 5233).
Measurement Standard	A material measure, measuring instrument, reference material or measuring system intended to define, realize, conserve or reproduce a unit or one or more values of a quantity in order to transmit them to other measuring instruments by comparison (to serve as a reference) (BS 5233). NOTE: In the context of this PTS, Measurement Standards refer to calibration equipment and reference material.
Overall uncertainty (of a measurement)	The combined uncertainty of measurement when that result is obtained from the values of a number of other quantities. NOTE: This definition is a modified version of that in ISO 5168: "The combined standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities". Standard uncertainty in ISO 5168 is the "Uncertainty of the result of a measurement expressed as a standard deviation". Standard deviation in the context of this PTS has been taken as the experimental standard deviation as applied in BS 5233.
Permissible error	The extreme values of an error permitted by specifications, regulations etc. for a given measuring instrument (BS 5233). NOTES: 1. In the context of this DEP, it should include: An error which relevant parties have agreed to be without consequences for any of the parties concerned. 2. The permissible error shall not exceed the specified uncertainty of measurement or, in the case of an entire measurement system, the specified overall uncertainty of measurement.
Primary standard (reference material)	A standard that is designated or widely acknowledged as having the highest metrological qualities and whose value is accepted without reference to other standards of the same quantity (ISO 14111).

Reference material		A material or substance one or more of whose property values are sufficiently homogeneous and well established to be used for the calibration of an apparatus, the assessment of a measurement method or for assigning values to materials (ISO 14111).
Secondary standard (reference material)		A standard whose value is assigned by comparison with a primary standard of the same quantity (ISO 14111).
Statistical Process Control		The condition of stable chance causes under which the process operates ("Fundamentals of Quality Control and Improvement", A. Mitra).
Traceability		The property of a result of a measurement whereby it can be related to appropriate standards, generally international or national standards, through an unbroken chain of comparisons (BS 5233).
True value		The value which characterizes a quantity perfectly defined, in the conditions that exist when that quantity is considered. The true value of a quantity is an ideal concept and, in general, cannot be known exactly (BS 5233). NOTE: True value is estimated by repeated or single measurements.
Uncertainty (of measurement)		An estimate characterizing the range of values within which the true value of a measurand lies (BS 5233). NOTE: In the context of this DEP, the uncertainty of a measurement shall be estimated on basis of two times the experimental standard deviation as permitted by BS 5233.
Validation		The process that ensures the trueness of the measurement. NOTE: During normal operation, validation is conducted to ensure that the equipment item continues to operate according to its performance specification.
Verification		A demonstration that an equipment item operates as expected. NOTE: It is usually assumed that no calibration or corrective action is required in case the subject has passed verification.
Warning Limit	WL	The error limit which, if exceeded, justifies immediate action in order to secure Statistical Control. NOTES: 1. The limit relates usually to the confidence level of 95 %. 2. At the warning limits or beyond, i.e. outside the interval between the upper and lower warning limits but without either the upper or lower control limit being exceeded, attention is called to the possibility of out-of-control conditions. It is good practice to check immediately any overshooting of the warning limit. Confirmation indicates that the process is not under control and that intervention is therefore justified.

1.4.3 Terms concerning fluid properties

Compression factor	Z	The quotient of the actual (real) volume of an arbitrary mass of gas, at a specified pressure and temperature, and the volume of the same gas, under the same conditions, as calculated from the ideal gas law.
Compression factor	Z₀	The compression factor at specified conditions.
Density		The mass of a gas sample divided by its volume at specified conditions of pressure and temperature (ISO 6976).

Gross Heating Value (industry) or Superior Calorific Value (ISO 6976)	GHV	The amount of heat which would be released by the complete combustion in air of a specified quantity of gas (<i>on a molar, mass or volume basis</i>), in such a way that the pressure at which the reaction takes place remains constant, and all the products of combustion are returned to the same specified temperature as that of the reactants, all of these products being in the gaseous state except for the water formed by combustion, which is condensed to the liquid state at the same specified temperature (ISO 6976) . NOTE: Superior Calorific Value is based on the real gas conditions and can be expressed per unit volume under specified conditions or per unit mass. Specified conditions are by default as defined in ISO 13443 and should therefore be taken as 288.15 K for the temperature and 101.325 kPa for the pressure, which values also hold for the enthalpic correction of the superior calorific value as mentioned in the above definition.
Limit properties		The constraints of composition or properties of the gas as stipulated in the gas supply contract.
Relative density	RD	The density of a gas divided by the density of dry air of standard composition (both) at the same specified conditions of the density (ISO 6976). NOTE: Specified conditions are by default as defined in ISO 13443 and should therefore be taken as 288.15 K for the temperature and 101.325 kPa for the pressure.
Wobbe Index	WI	The superior calorific value on a volumetric basis divided by the square root of the relative density (ISO 6976).

1.5 CROSS-REFERENCES

Where cross-references to other parts of this PTS are made, the referenced section number is shown in curly brackets {}. Other documents referenced in this PTS are listed in {8} and {9}.

1.6 SUMMARY OF MAIN CHANGES

This PTS is a revision of the PTS of the same number dated December 1999. This has been a major revision and it is impractical to list the changes herein.

2. GAS SALES CONTRACTS AND APPROVAL AUTHORITIES

2.1 PHILOSOPHY

The fiscal flow measurement system shall be fair and impartial to all parties concerned.

The design of new installations or revision of existing installations shall be subject to agreement between contract parties and legal/metrology authorities concerned.

There should be a single party responsible for design, construction and commissioning.

Relevant parties shall retain the right to duly witness commissioning and validation and to audit the measurement station on compliance with the contract.

2.2 CONTRACT CONDITIONS

The contract should refer to the main commercial and fiscal issues.

Measurement details should be covered as an addendum to the contract thus avoiding undue revision of the contract if only technical details change. Any deviations or changes concerning the addenda should be justified and agreed at working level {7.1}.

The overall uncertainty and availability data of the metering station should initially be estimated from operational experience with other facilities of similar design and purpose, and may be quoted as target values in the contract.

The “Black and White List” in Appendix A should be considered when designing the contract.

3. FLOW MEASUREMENT METHODS

3.1 COMMON REQUIREMENTS

Fiscal flow measurement shall be performed using generally accepted and field-proven methods and international standards.

The total life cycle costs of ownership of the measurement station shall be optimised against the requirements stated below. Due attention shall be given to safety, environment and legal aspects.

The design should aim for a single measurement station.

The gas to be measured shall be homogeneous and single-phase fluid and be free of solids and liquid contaminants in the measuring section. The gas flow shall therefore not reach its water or hydrocarbon dew point anywhere in the measuring section.

NOTE: In the EP environment, gas is not always dry and clean. The measurement location should be chosen with caution, e.g. avoiding outlets of separators where liquid carry over can occur whilst gas composition varies with operating conditions of the separator. Under such conditions additional measures are likely needed such as periodic or even continuous automatic sampling for verifying composition and inferring fluid properties from composition. Even in treated gas, liquid contamination remains a risk, e.g. due to carry over of glycol (or by-products thereof) from glycol treatment plants or seal oil originating from compressor systems. Such contamination, together with the remains of solids like iron oxides, will inevitably collect at the bottom of the piping system.

The gas flow in the meter inlet of primary elements other than Coriolis meters shall show a fully developed, turbulent velocity profile without pulsations and be consistent with the requirements of the measurement standard applicable to the device selected.

The number of meter runs shall be based on the design capacity, the allowable maximum and minimum gas velocity, the required minimum flow rate and the designated flow range of the primary device and the availability requirements of the flow measuring station.

NOTE: A large size of meter (apart from a Coriolis meter) will inevitably result in longer meter runs, which may be a reason for reducing the meter size and installing additional meters instead. Such a configuration will result in better turndown of the metering station and may reduce uncertainty (provided the error relative to the maximum flow remains constant over the range of alternative meter sizes).

The design capacity of the flow measuring station is the maximum, continuous flow rate that can be measured within the specified uncertainty. In a station with multiple meter runs, the design capacity is the sum of the flow rates of the non-spare meter runs with no single meter run exceeding its maximum continuous flow rate at which its uncertainty is just within design specifications.

The minimum flow of the measurement station is the minimum, continuous flow rate of the smallest meter run at which its uncertainty is just within design specifications and beyond which flow integration should be stopped. An alarm shall be initiated if an individual flow meter indicates a flow rate below its minimum flow rate at which its uncertainty is just within design specification.

The minimum flow shall be set for positive and, if present, negative flows and shall be determined for each individual meter run. Non-equal distribution of flow between parallel meter runs shall be taken into account. This is particularly critical with low differential pressure across the meter runs.

Redundancy shall meet the requirements of {5}. Any unavailability of the flow measuring station shall only make a small contribution towards the specified unavailability of the production facility, as defined in the field development plan. The policy with respect to spare meter runs or redundant equipment shall be in line with the plant design and also to PTS on Gas Measurement Guidelines.

Depending on the availability requirements of the measurement station, a spare primary device may be considered as either “not installed” (and properly stored) or as “installed” in a spare meter run. Spare meters shall not be operated during normal operation and shall only be brought into service in case of failure of other meter run(s).

Meter runs other than those using Coriolis meters shall be thermally insulated in order to eliminate heat transfer from the piping or instrument well attachments and to meet any limiting value for the accuracy of the flow measurement concerned. The length of the insulated section shall at least satisfy the straight length requirements and shall include the temperature element and the primary device. For temperate countries where the change in temperature is not significant, the requirement for thermal insulation is on a case to case basis.

The contractual availability of gas flow may require a station by-pass, which shall be normally closed and controlled by permits or locks.

The energy flow shall be determined from real time integration of the volume or mass flow and the Gross Heating Value, all expressed in consistent units and, if applicable, referenced to the same reference conditions. Meter runs shall not be located at a low point in the piping location. The configuration shall be such that the primary device shall be in a self-draining position. Refer to Appendix F.

Each meter run shall be equipped with isolation valves of the cylindrical full-bore type conveniently located in order to allow any leakage to be detected.

Layout of the meter run shall provide adequate access for maintenance and for the replacement or removal of the meter and adjacent upstream and downstream piping.

NOTE: Factory recalibration of ultrasonic meter may require the inclusion of upstream and downstream piping, i.e. the complete meter run.

The internal diameter of the pipework shall be selected so that gas velocities do not exceed 20m/s thus avoiding vibration-induced fatigue of components such as thermowells and sample probes.

NOTE: Coriolis meters are capable of handling velocities up to 0.4 times the critical gas velocity. In this case the dynamic pressure drop across the meter is usually the limiting factor for the gas velocity.

Structural and pipe vibrations and pulsating flow can cause systematic errors and should be avoided.

NOTE: Pulsations (e.g. from compressor stations) could be reduced by pulsation dampeners or by providing buffer capacity in the system.

3.2 SELECTION, DESIGN AND INSTALLATION OF PRIMARY FLOW ELEMENTS

The selection of the primary flow element shall be subjected to approval by the contract parties and/or the host country authorities for each individual application.

The selection of the primary element depends on the fluid properties, performance requirements, (life cycle) costs, and legal and safety requirements.

Primary elements should be selected from the following options and shall be suitable for the intended purpose:

- a) Multi-path transit-time ultrasonic flow meter {3.2.1}
 - 1) Design should be full line-size and multi-path time-of-flight.
 - 2) Ultrasonic flow meters may not be approved as fiscal elements in some countries, unless exempted by local authorities (e.g. Weights and Measures).
- b) Orifice flow meter {3.2.2}
 - 1) Where trouble-free operation of ultrasonic flow meters cannot be ensured, square-edge flange-tapped orifice flow meters should be considered. Orifice flow meters are widely accepted as fiscal elements.

c) Turbine flow meter {3.2.3}

- 1) In view of their vulnerability to wear and tear, the permanent operational use of turbine flow meters should be avoided especially in the EP environment.

d) Coriolis meter {3.2.4}

Coriolis meters are primarily mass flow meters, which means they are practically independent from flow distribution patterns no flow conditioning is required. They yield excellent calibration stability and require minimum secondary instrumentation as compared to other meters discussed in this PTS.

3.2.1 Multi-path transit-time ultrasonic flow meter

3.2.1.1 General considerations

Fiscal gas flow measurements by means of ultrasonic flow meters shall be in accordance with ISO 17089 and AGA 9 and with field-proven installation practices.

The ultrasonic flow meter shall have a locally approved certificate of calibration in accordance with the Manufacturer's procedures. A certificate of the calibration of the ultrasonic flow meter at operating pressure shall only be produced if required by the parties involved. The calibration data provided in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter according to ISO 9951. The monitoring facilities available in modern ultrasonic meters shall be used for health checking (transducer performance/malfunctioning, meter pollution), to enable early detection of imminent malfunction of the meter.

Ultrasonic flow meters can be susceptible to ultrasonic noise (control valves) and distortions of the flow profile, which shall be fully considered during the design stage.

3.2.1.2 Design

Depending on the availability requirements {5} and in order to provide maintenance access to the transducers without the need to shut down the metering run, the metrological tappings holding the transducers may be equipped with double-block-and-bleed valves.

At least one set (2 pcs) of spare transducers of each transducer type (if applicable) shall be procured and properly stored.

3.2.1.3 Installation

Multi-path transit-time ultrasonic flow meters shall be installed and operated in accordance with ISO 17089, AGA 9 and the Manufacturer's recommended installation practices and applicable regulations.

The ultrasonic flow meter shall be operated within the specified operating envelope to satisfy its uncertainty constraints. Swirl and non-uniform velocity profile effects should be reduced to an insignificant level by piping design. Swirl-free conditions can be taken to exist when the swirl angle at all points across the pipe cross-section is less than 2°. Straight length requirements, inlet and outlet connections and/or the type and location of a low pressure-loss flow conditioner should be in accordance with Manufacturer's specifications. The upstream and downstream straight length piping should be included in the scope of delivery of the metering station, thereby allowing for calibration of the meter including the associated straight pipe lengths.

The straight length downstream of a concentric piping reducer shall be at least 40 pipe diameters. The straight length downstream for all other all cases shall be 3 pipe diameters. If no concentric reducer is installed, the straight length upstream for one-directional flow measurement shall be at least 25 pipe diameters. For bi-directional measurement the upstream and downstream straight length shall be at least 25 pipe diameters in each direction and 40 pipe diameters between the meter and a concentric reducer, if installed.

It shall be verified that the ultrasonic meter is not influenced by the layout of the upstream or downstream piping in such a way that overall uncertainty specifications are exceeded. If necessary, flow straighteners of standardised design (ISO 5167) or of agreed proven

design might be installed. The flow straightener may form part of the 10-pipe diameters upstream length.

NOTE: Mechanical strain on the meter, provided it remains below the values set by the Manufacturer, should not affect the meter's accuracy.

The centre line of the ultrasonic flow meter shall be aligned with the pipe centre line within 1 % of the internal pipe diameter

The upstream and downstream straight lengths shall be straight and their cross-section circular over their entire length.

The root pass of any circumferential weld in the upstream pipe section shall be ground flush with the inside pipe wall. Inspection of the inside of the pipe shall be possible. Seam-welded pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the entire required straight length. The seam shall not be within any sector of $\pm 30^\circ$ centred on any pressure tapping used in conjunction with the primary element. Any weld bead shall be restricted in height to the permitted step in diameter.

Gaskets shall not protrude at any point inside the meter tube assembly.

The bores of the upstream straight length section and the downstream straight length section shall equal the inlet and outlet bores of the meter, respectively.

The operating pressure shall be measured at the location of the pressure tapping, which shall be within an angle of 30° from top orientation of the pipe (often the Pr point on the body of the meter).

The operating temperature shall be measured at the following point. The temperature sensor(s) for uni-directional flow measurement shall be located between 3 pipe diameters and 5 pipe diameters downstream of the meter. For bi-directional flow measurement this location shall be between 3 pipe diameters and 5 pipe diameters upstream or downstream of the meter.

The densitometer pocket should be located between 2 pipe diameters and 5 pipe diameters downstream of the meter.

The meter shall not be installed in the immediate vicinity of devices that may affect the ultrasonic signals; e.g. pressure reduction valves. Tees or short-radius bends could accomplish some in-line noise reduction.

3.2.1.4 On-line computation of the flow rate

The flow rate (both negative and positive) shall be calculated according to ISO 17089.

3.2.1.5 Health monitoring

Health monitoring facilities based on the built-in diagnostic features of path comparison (velocity of sound and path differences), AGC levels, pulse rejection check, noise etc. should be applied to their full extent.

3.2.2 Orifice flow meter

3.2.2.1 General considerations

Fiscal gas flow measurements by means of orifice meter runs shall be in accordance with ISO 5167-2. Square edge/flange taps orifice meter types should be used.

3.2.2.1 Design

In view of the constraints described below and of the general uncertainty requirements for fiscal gas measurements based on orifice flow meters, which could typically be 1 % overall uncertainty, the turndown ratio of a single orifice meter run should not exceed 5 : 1.

The maximum flow reading taken from a differential pressure device (dP-cell) shall not be clipped by the maximum output of the transmitter. Hence, the maximum flow maximum flow rate shall be reached when reading 90 % to 95 % of the calibrated range.

The diameter ratio ($\beta = d/D$) should not exceed 0.6 in order to achieve minimum uncertainty according to ISO 5167-2. The overall uncertainty in the volume flow rate measurement shall be calculated according to ISO 5168 and the "ISO Guide to the expression of uncertainty in measurement".

The differential pressure at maximum flow across the highest range differential pressure transmitter should not exceed 700 mbar and shall not exceed 1000 mbar. In the latter case the bending of the orifice plate shall be verified to ensure that it does not exceed the minimum requirements as stated in ISO 5167-2 and ISO/TR 9464.

The minimum permissible calibrated range for a differential pressure transmitter is 60 mbar.

The number of differential pressure transmitters per meter run and their ranges are determined by the required rangeability of the measurement station under operating conditions and by the uncertainty specifications of the installed differential pressure transmitters, which should be not more than three, defined as "High", "Medium" and "Low".

Smart transmitters should be used on account of their built-in temperature compensation and diagnostic features, and because they enable an all-digital circuit to be created using the Hart protocol thus further reducing uncertainty. Multi-variable smart transmitters shall not be used unless they are used for single-variable measurement and are legally accepted (e.g. Weight and Measures approved).

Fieldbus concepts do not necessarily improve performance as compared to analogue devices with Hart capability.

3.2.2.3 Installation

The operating pressure shall be measured at the plane of the upstream pressure tapping of the differential pressure transmitters. Though the static pressure of the gas shall in general be measured by means of an individual pipe wall pressure tapping, it is preferable to use the same upstream tapping as the differential pressure transmitter(s).

The operating temperature of the gas shall be measured downstream of the primary element, to avoid flow profile distortion. The thermowell shall be situated between 5 and 15 pipe diameters downstream of the primary element or in accordance with the values given in ISO 5167-2 if it is located upstream.

The thermowell well shall be positioned in close proximity with the densitometer, if the latter is installed.

It may generally be assumed that the downstream and upstream temperatures of the fluid at the differential pressure tapings are the same within the limits of application of ISO 5167-2. However, if the highest accuracy is required and there is a large pressure loss between the upstream pressure tapping and the temperature location downstream of the primary device, then it is necessary to calculate the upstream temperature from the downstream temperature (measured at the above distance from the primary device), assuming an isenthalpic expansion between the two points.

3.2.2.4 On-line computation of the flow rate

The flow rate shall be calculated according to ISO 5167-2, using equipment approved by all contractual, operational and legal/regulatory (e.g. Weights and Measures) parties concerned.

For the on-line computation of the flow rate, fixed values may be used for the kinematic viscosity (ν) and the isentropic exponent (κ), based on the average operating conditions.

The calculation of the Reynolds number (Re) shall be based on the actual flow rate.

3.2.3 Turbine flow meter

3.2.3.1 General considerations

Fiscal gas flow measurement by means of turbine meters shall be in accordance with ISO 9951. Turbine meters should not be used where frequently interrupted and/or strongly fluctuating flow or pressure pulsations are present. The turbine meter shall be in

accordance with contractual and/or legal obligations (e.g. Weights and Measures authorisation).

For each turbine meter a (Weights and Measures) certificate of calibration at a high (line) pressure shall be available. The calibration data stated in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter according to ISO 9951.

The risk of incurring damage from extreme operating conditions shall be minimised by carefully selecting the location of the measurement station and by providing adequate, additional protection if required. Typical risks are: dirt or liquid pollution during start-up, shock waves when opening valves.

3.2.3.2 Design

Depending on the availability requirements {5} of the flow measuring station one spare turbine meter shall be available either as a 'not installed' (and properly stored) or as an 'installed' (in a spare meter run) spare meter. The policy with respect to spare meter runs or redundant equipment shall be in line with the plant design.

3.2.3.3 Installation

The turbine meter shall operate within the specified operating conditions. Swirl and non-uniform velocity profile effects shall be reduced to an insignificant level by proper installation of the meter. Straight length requirements and/or the type and location of a flow conditioner shall be in accordance with ISO 9951 and Manufacturer's specifications.

The turbine meter centre line shall be within ± 1 % of the pipe centre line.

The upstream pipe section adjacent to the turbine meter shall be cylindrical over a length of at least 2 pipe diameters according to ISO 5167. The root pass of any circumferential weld in the upstream pipe section shall be ground flush with the inside pipe wall. Inspection of the inside of the pipe shall be possible. Seam-welded pipe may be used provided that the internal weld bead is parallel to the pipe axis throughout the entire required straight length. The seam shall not be within any sector of $\pm 30^\circ$ centred on any pressure tapping used in conjunction with the primary element. Any weld bead shall be restricted in height to the permitted step in diameter.

Upstream filters shall be installed. The filter elements shall be of such a type that 98 % of particles measuring $1\ \mu\text{m}$ or larger will be intercepted, or the turbine Manufacturer's requirements shall be followed if more stringent.

The pressure tapping marked 'Pm' (or old mark: 'Pr') on the meter body shall be used as the pressure sensing point for the operating pressure measurement.

The operating temperature shall be measured at the following point. The recommended location of the thermowell is as close as possible downstream of the turbine wheel but within 5 pipe diameters from the wheel.

Turbine meters shall be provided with vane failure detection.

3.2.3.4 On-line computation of the flow rate

The flow rate shall be calculated according to ISO 9951 using equipment approved by the contract parties and by the local authorities (e.g. Weights and Measures).

Refer to {5} for the relationship between availability and flow computation.

3.2.4 Coriolis meter

3.2.4.1 General considerations

Fiscal gas flow measurements by means of Coriolis meters shall be in accordance with ISO 10790 and AGA 11 and with field-proven installation practices.

The Coriolis meter shall be in accordance with contractual and/or legal obligations (e.g. Weights and Measures authorisation).

The Coriolis meter shall have a locally approved certificate of calibration in accordance with the Manufacturer's procedures. The calibration data stated in the certificate shall include the error of the meter for at least 6 points over the whole range of the meter.

3.2.4.2 Design

Due to economics, Coriolis meters larger than typically DN 150, which could be typically installed in a DN 200 manifold, should not be selected.

The design should take into consideration the lower density limit, which is constrained by the accuracy limitation of the meter. The lower density limit should be typically set to 4 kg/m³.

NOTE: The following is a type specific case.
Maximum meter capacity in kg/h of a DN 100 meter is limited to the numerical value of 3150 * density in kg/m³ and a lower capacity limit of 9000 kg/h, which typically results in a rangeability of 1:25 for a 100 bar gas application.

Coriolis meters are primarily mass flow meters. The density signal from a Coriolis meter shall not be used for fiscal purposes due to the wide ranging uncertainty of typically 0.5 kg/m³ absolute, in relation to the actual range of densities that apply to gas measurements. If required, the volumetric flow under specified conditions shall be calculated from the prime mass flow signal and either of the following options:

- On-line measurement of relative density {4.5.3.2}
- Relative density inferred from composition {4.4.c, 4.5.3.3}

The density signal from the Coriolis meter may be used as an indicative measurement, e.g. for the detection of entrained liquid, which may show up as a transient.

Mass flow accuracy is not affected by meter pollution e.g. by coating. However, since this type of pollution will change the added mass to the vibrating tubes it will consequently cause offset of the density calibration. Facilities should be made available to allow cleaning, e.g. by rinsing if the density output is used and in cases where such conditions could be expected.

Materials shall be selected so as to minimise erosion and corrosion and thereby limit the risk of calibration shifts.

Depending on its design characteristics, the meter may be immune to swirling fluid or non-uniform velocity profiles. However, the Manufacturer shall be consulted regarding upstream and downstream piping requirements and the use of flow conditioners.

Monitoring facilities available in modern design Coriolis meters shall be used for health checking enabling early detection of imminent malfunction of the meter.

NOTE: Modern design includes on-line validation whereby a forced response of the meter is validated against a known value. Such a test is usually operator induced and can be performed on-line under flowing conditions or during a limited period of instrument outage or under no-flow conditions.

In view of their inherent geometry, Coriolis meters are likely to cause a noticeable pressure drop, which should be taken into account when designing the measurement system.

The meter shall be checked for noise conditions in accordance with the Manufacturer's recommendation. Harmonics of the exciting frequency and other frequencies that have a simple relation to the exciting frequency of the vibrating tubes will interfere with the meter operation. These harmonics may also be flow induced; e.g. due to pulsation. High gas velocities, valves, choked flows, shock waves, critical nozzles, liquid and solid particles present in the fluid, etc., may generate noise.

If a Coriolis master meter is used for validation {6.9}, care should be taken to avoid cross talk, which could be achieved by separating the sensors over a distance of three times the lay-length of the meter (so as to achieve sufficient signal attenuation). Cross talk can also be avoided when applying meters that operate at different vibrating frequencies.

The design shall take into account the effects of varying operating pressure on the calibration of the meter. The Manufacturer should advise on the dynamic pressure

compensation that may be required depending on the variability of the operating pressure and the targeted uncertainty of the meter.

3.2.4.3 Installation

The meter orientation shall be highest point up.

The flow sensor will be subjected to axial, bending and torsional forces during operation. Changes in these forces, resulting from variations in process temperature and/or pressure, can affect the performance of the Coriolis meter. Care should be taken to ensure that no forces are exerted on the meter from clamping arrangements.

Measures should also be taken to prevent excessive stresses from being exerted on the Coriolis meter by connecting pipes. Under no circumstances should the Coriolis meter be used to align the pipe work. Alignment of the instrument shall be in accordance with the Manufacturer's specification, i.e. typically within 1 % of the internal pipe diameter.

Common piping practice for the supporting of adjacent piping should be sufficient to suspend the meter and no additional supports are generally required. Arrangements shall be in accordance with the Manufacturer's recommendations.

3.2.4.4 On-line computation of the flow rate

Mass flow is the prime output of the meter, which does not require any further scaling than dynamic pressure compensation if deemed necessary.

3.3 DESIGN AND INSTALLATION OF SECONDARY INSTRUMENTS

Selection of secondary instruments shall be in accordance with:

- PTS 32.31.00.32
- Refer to {4.5} for on-line analyser systems.

Redundancy shall be in accordance with {5}.

Refer to {6.3} for calibration ports and testing manifolds.

Metrological tapings shall not be used for other purposes unless specified otherwise in this PTS.

The mounting of the instruments shall facilitate proper readability of their gauges or indicators.

Where applicable, the Hart protocol should be considered for signal transfer so as to reduce the sources of uncertainty in the measurement chain and to improve the diagnosing capabilities of the measurement systems.

3.3.1 Differential transmitters

Selection shall be in accordance with ISO 5167 and PTS 32.31.00.32

3.3.2 Pressure

The selection and installation of pressure transmitters shall be in accordance with PTS 32.31.00.32

Gauge pressure transmitters are preferred to absolute pressure transmitters because of their better accuracy performance. Operating pressure should be inferred from gauge pressure transmitters in conjunction with the atmospheric pressure measured at the location {4.1.2.1}. Alternatively, the operating pressure should be read as the gauge pressure increased by the average atmospheric pressure of 1.01325 bar.

3.3.3 Temperature

Thermometers for continuous measurement shall be of the platinum resistance insertion type and comply with IEC 60751 tolerance class A. Surface-mounted types should not be used.

The temperature measurement shall accurately present the gas temperature in the line. The effects of heat transfer from the piping or thermowell attachment to ambient shall be limited and the temperature misreading for this reason should be limited to 0.5 K under steady state conditions. Refer to Appendix G for construction details.

The thermowell shall be designed to withstand vortex-induced vibrations in accordance with PTS 32.31.00.32

Clustered thermowells should not be installed in a straight line but should have different orientations (straddled fashion) instead in order to prevent vibration-induced fatigue.

Selection of the temperature elements and their installation shall be in accordance with PTS 32.31.00.32-Gen. If redundancy is required {5} both measurement elements may be comprised in a single assembly thus avoiding the need for an additional thermowell.

The temperature elements should be directly connected as 4-wire resistance thermometers to the flow computer.

NOTE: Dual resistance element thermometers as described above are three-wired systems. The fourth wire of each resistance element may be connected under the screw terminal of one of the three wires that are terminated on the termination block of the thermometer (field side).

A separate thermowell for a reference thermometer shall be positioned in the same plane at a position that is off set by at least 30° as compared to the position of thermowell of the continuous instrument. It is good practice to fill the well with thermo-conductive oil when in use during validation {6}.

3.3.4 Fiscal computing systems

3.3.4.1 General requirements

Systems design and architecture and the retention of IT security shall be compatible with PETRONAS IT policy and {3.3.5}

The flow computer(s) and the associated counter(s) and /or ticket printer(s) shall comply with local legal requirements (e.g. Weights & Measures) and/or the requirements of the contract parties.

One flow computer should be dedicated to each meter run.

Any flow computer associated with fiscal gas measurement shall have no functions other than those associated with the flow measurement.

One or more digital computers may be required to perform the required tasks; e.g. a hierarchical system of more than one flow computer supervised by a supervisory system. The locations where the different computational tasks are performed shall be clearly defined and agreed by the contract parties.

Signal transmission from the gas flow meter and from secondary instruments shall be free of interference and cause no systematic errors.

The flow computer(s) shall have a dedicated maintenance mode, which is activated when the gas flow meter is taken off normal operational duty, e.g. during validation or when the flow computer is tested. The test mode shall enable functional testing of all or some of the flow computer hardware and software functionality. The flow computer design shall be such that during meter validation the amounts shall be registered separately and independently of the measured amounts.

All fiscal quantities for each meter run shall be stored on non-volatile memory in the flow computer, i.e. non-resettable flow integrators. The flow computer shall switch its registration of fiscal quantities to 'errant' counters if the measurement system malfunctions. Fiscal and errant quantities of each meter run should be accrued and stored in a database of the supervisory computer.

Flow integrators shall have sufficient digits so that rollover does not occur more frequently than every 2000 hours at maximum flow.

Fiscal flow data shall be automatically accumulated and stored for an agreed period of time.

NOTE: The read-out of the flow computer is generally considered the last fiscal element in the fiscal measurement chain. Data accrued from here is not usually subject to scrutiny by the regulatory authorities.

Manually entered parameters shall be displayed without rounding off or truncation of values.

The resolution of values presented on the visual display shall be sufficient to verify the calculation accuracy.

It shall be possible to read the digital signal from the A/D converter as an un-scaled/uncompensated value, presented in a binary, hexadecimal or decimal form.

It shall be possible to read the pulses received from a turbine meter directly or as a turbine meter calibration factor (pulse transmission check).

It shall be possible to read diagnostic information received from an ultrasonic meter for health monitoring and to judge the meter performance.

When a flow computer is in standby mode, all functions, fiscal values and parameters shall at all times be available and equal to those in the main flow computer.

Full documentation of the flow computer software shall be available providing the functional design and the implementation of the package (e.g. for audit purposes).

The total error of the analogue to digital converter of the flow computer, including resolution, linearity, repeatability and other random errors, shall not exceed $\pm 0.020\%$. Algorithm and unintentional rounding-off errors for computations of fiscal quantities in the flow computer shall be less than $\pm 0.001\%$.

The flow computer shall be housed in accordance with the Manufacturer's recommendations with respect to environmental conditions (temperature, vibration etc.).

The flow computer shall automatically stop flow integration at flow rates below a preset value. This value shall be determined for each individual application, depending on permitted uncertainty (low flow cut-off).

3.3.4.2 Data integrity and security

The overall logical and physical security of the computer system shall be demonstrated and ensured. The computer shall be equipped with self-diagnostic functions ensuring that, at any time and at any level, the computer equipment is operating correctly.

The algorithms and fixed parameters important for accurate computation of fiscal quantities shall be organised in a layered security system in such a way that only authorised personnel can access them. Any change in algorithms and/or parameters shall be registered and stored with identification of the initiator and the date, as well as the "as-found" and the "as-left" values of parameters.

The program and parameter settings shall be subject to a regime of version control and be identifiable by a unique version number.

The version number shall be changed and registered whenever permanent program data are altered. The current version number of the program and parameter settings list shall be printed on each page of the respective print-out of listings.

The data transmission links shall be continuously monitored and an alarm generated if faults are detected.

Each flow computer shall be equipped with automatic self-diagnostic functions, which will be executed every computing cycle or every 10 seconds, whichever is less. The results of this diagnostic action will be made available instantaneously to the supervisory computer. The following monitoring facilities should be typically available:

- error in execution of routines;
- error in permanent stored data;
- error in internal voltage reference values;
- flow of mass and volume outside the range;

- input diagnostics from any faulty secondary equipment such as transmitters, gas chromatographs, densitometers etc.;
- deviations between measured values, valve status and parallel metering runs.

The supervisory computer should be equipped with watchdog functionality to monitor the performance of data transfer between flow computer and supervisory computer. The flow computer parameters, e.g. the calibration factors of flow meters and the parameters for calculating fiscal amounts, should be stored in the supervisory computer, compared continuously and alarmed in case of deviation.

3.3.4.3 Administrative functions

The flow computer shall provide ample recording and logging functions through a secure communication facility to other systems (e.g. transmission of hourly or daily reports). The following functions shall be provided by the flow computer system (if applicable):

- storage of accumulated fiscal quantities for each metering run and the total metering system and an option to print these quantities;
- alarm reports;
- change logs
- monthly storage of measured parameters and accumulated quantities for each metering run. An option to print-out such data;
- communication facilities via VDU, printer and terminal.

The fiscal computing system shall have sufficient ports for recording devices and alarm printers where required by legislation.

A common printer for alarms and reports may be used if an acceptable priority routine is established. The fiscal computing system shall have provision for (suppressed) automatic logging, storing and reporting of the following information:

- alarms for any faults detected by the computer;
- manually entered parameters on the computer that can be changed by an operator. Where fixed values are used instead of the live signals this shall be identified on the print-out;
- quantity reports, printed every 24 hours with optional interim reports;
- instantaneous values for flow rate and all signals from the meters and the instrument loops;
- any change of parameters or algorithms;
- calibration reports;
- configuration parameters e.g. calibration constants, meter dimensions, time averaging period, and sampling rate.

The fiscal computing system shall, for each meter run, automatically log and store at intervals of 1 h and 24 h: cumulative quantities of mass, volume and energy, and average values of pressure, temperature and density.

The retention time for storing these data shall comply with local regulations or the contract, whichever is the longer.

3.3.4.5 Power supply

The metering system shall be powered by an uninterruptible power supply (UPS); ref. PTS 33.65.50.31. and PTS 33.65.50.32. Failure of the normal power supply and UPS fault status shall be monitored and alarmed by the flow computer.

Additional back-up facilities in each computer shall ensure that fiscal figures are not lost under any circumstances.

3.3.4.6 Computer routines for fiscal gas measurement

The system response to changes of the metering system's input signals shall not be greater than 1 s. Parameters having longer response time, such as density and temperature, shall not exceed a response time of 5 s.

The flow computer shall be configurable to perform coherent fiscal calculations according to at least the following standards or sections of this PTS:

- Isentropic exponent, according to Appendix E
- Kinematic viscosity, according to Appendix E
- Reynolds number.
- Z_0 at Standard Conditions, according to ISO 6976.
- Z at actual temperature and pressure, according to ISO 12213.
- Relative Density, according to ISO 6976.
- Density at Normal Conditions, according to ISO 6976.
- Operating density at actual temperature and pressure, according to ISO 12213.
- Molecular Weight, according to ISO 6976.
- Gross Heating Value, according to ISO 6976.
- Wobbe Index, according to ISO 6976.
- Orifice meters: Actual flow rate, according to ISO 5167-2
- Turbine meters: Actual flow rate, according to ISO 9951
- Ultrasonic meters: actual flow rate, according to ISO 17089
- Coriolis meter: actual flow rate according to ISO 10790

In order to verify the flow computer software, duly tested and accepted flow and uncertainty calculation programs, independent of and not identical to the programs used in the flow computer, that apply the standards cited above and are run on an off-line computer shall be available to provide the necessary reference information.

3.3.5 Data security

The fiscal measurement system shall be connected to the Process Control Network (PCN) via the supervisory computer. There shall be no other connections between the Fiscal Measurement Network and the Process Control Network.

The Supervisory computer shall include an OPC (OLE for Process Control) server to send the data to and from the data historian. The data historian shall be the only location where users can get access to the fiscal data.

Internal business users and applications shall not be able to directly access the supervisory or fiscal flow computers.

External business users, e.g. contract partners, shall only be able to access metering data as remote users under a Third Party Access (TPA) agreement.

Vendors shall be able to access the Fiscal Measurement Network for diagnostics and repairs only via a thin client in the Process Control Access Domain (PCAD). No modems shall be connected to the metering hardware and instrumentation.

Control and automation (C&A) maintainers shall be allowed access to the Fiscal Measurement Network and hardware. The use of laptops and portable media shall be in strict compliance with PETRONAS IT general requirements.

Furthermore, the fiscal measurement system shall comply with the following requirements:

- The anti-virus software selected by Shell shall be able to be run and it shall be possible to download the latest versions regularly from a dedicated server.
- Operating system patches shall be able to be applied automatically through a dedicated server.
- Regular backups shall be made on a dedicated server.

- Remote User Access shall be allowed for vendors and external business users. Optionally, this access may also be granted to the individual flow computers or transmitters and analysers.

3.4 HOUSING FACILITIES

If required, the housing shall be designed in accordance with PTS 32.31.50.13-Gen. and with contractually agreed requirements, e.g. overpressure protection and climate control of the facility.

Such a facility may be shared with the analyser equipment if it is sheltered {4.5}.

The housing should be provided as a single, prefabricated unit complete with all instrumentation, supporting and auxiliary systems installed.

There should be single-point responsibility for the design, construction, and commissioning of the housing facilities; this should be entrusted to a specialist firm.

4. FLUID PROPERTY DETERMINATION

4.1 GENERAL

Fluid properties other than pressure and temperature are covered below.

The determination of fluid properties shall be traceable to national and international standards through a system of analytical procedures, reference materials and calibration procedures.

Depending on metering requirements, technical feasibility and economic justification fluid properties may be determined either on-line or off-line by a testing laboratory. Only if technically feasible and economically viable may fluid properties be determined on-line by a process stream analyser {4.5}. The method selected should meet local needs and encompass all requirements, e.g. logistics and training of local staff.

4.1.1 Fluid properties characteristics

The characteristics of the fluid properties in conjunction with the capacity of the flow station and the variability of the gas composition should determine the methodology of determining fluid properties {4.6}.

Fluid properties characteristics of natural gas can be divided into two groups:

4.1.1.1 Fluid properties for fiscal gas measurements

Apart from pressure and temperature the following are physical properties required to infer mass, volume and energy flow at standard condition:

- Operating density (ρ)
- Relative density (RD)
- Gross heating value (GHV)

Depending on process dynamics and the financial risk entailed by the uncertainty of the property concerned, the of above properties may be determined either on-line by means of on-line process analyser systems or off-line by a testing laboratory {4.6}.

Operating density, relative density and gross heating value are all properties that can generally be reliably measured on-line, either as direct measurements or inferred from compositional data.

Furthermore, the following are required if orifice meters are used:

- Isentropic exponent;
- Kinematic viscosity.

NOTE: These parameters are usually entered as fixed values in the flow computer and their sources of reference are given in Appendix E, see {4.4}.

4.1.1.2 Limit properties

Limit properties are defined by the constraints on composition or properties of the gas as stipulated in the gas supply contract. Typical limit properties include, but are not necessarily limited to, the following:

- Wobbe Index
- Water content
- Sulphur compounds
- Mercury
- Oxygen

Depending on the complexity of analysis and the operational risk incurred during the period that a property exceeds the limit value, the above properties may be determined either on-line by means of on-line process analyser systems or by the testing laboratory.

Wobbe Index can often be made available in real time as an inferred measurement from process gas chromatography {4.5.3.3}. Less preferred is direct measurement {4.5.4.1}.

Water content, hydrogen sulphide and oxygen can generally be reliably determined by on-line analyser systems provided that contaminants are absent from the fluid matrix. Alternatively, the testing laboratory may make these determinations.

Other properties are less suitable for determination by on-line analysers and should therefore form part of the contractually approved sampling and analysis scheme.

4.1.2 Operating and referenced conditions

4.1.2.1 Operating pressure and temperature

- if an ultrasonic flow meter is used as primary device: refer to {3.2.1.3}
- if an orifice meter is used as primary flow device: refer to {3.2.2.3}
- if a turbine meter is used as primary device: refer to {3.2.3.3}

The measurement of operating pressure and temperature for fiscal purpose, e.g. the conversion to volumetric flow under specified condition, is not a requirement for Coriolis meters.

4.1.2.2 Referenced conditions

Referenced temperature and pressure conditions should be selected in accordance with ISO 13443 for:

- enthalpic correction when determining the enthalpy of transformation between inferior and superior calorific value,
- gas metering condition.

Specified conditions are therefore by default 288.15 K for the temperature and 101.325 kPa for the pressure, which values also hold for the enthalpic correction of the (superior) calorific value as mentioned in the above definition.

4.2 SAMPLING

4.2.1 Modes of sampling

4.2.1.1 Spot sampling

Spot sampling shall be compliant with ISO 10715. The design of permanent sampling facilities like the sample take-off assembly and sample lines shall comply with PTS 32.31.50.10

Spot sampling is typically required for confirmation of values obtained during validation and in all intermediate cases where it is deemed necessary to confirm the properties determined by on-line analyser systems (sample reference value).

Spot sampling is also sufficient for the determination of properties for fiscal gas measurements that are used for the periodical updating of fixed entries into the flow computer for Group 1c (small capacity plants) or Group 2 (gas with constant composition) {4.6}. In that case the samples shall be collected at mutually agreed intervals.

4.2.1.2 Flow proportional sampling for the laboratory analyses of composite sample

Flow proportional sampling shall be compliant with ISO 10715. Refer also to ISO 8943 as an example (dry gas part only). Permanent sampling facilities like the sample take-off assembly and sample lines shall be compliant with PTS 32.31.50.10.

Flow proportional sampling is typically required for the determination of properties for fiscal gas measurements that are used for the periodical updating of fixed entries into the flow computer for Group 1b (medium capacity plants) and Group 2 (gas with constant composition) {4.6}. The sampling interval and/or sample volume shall be such that a filled sample cylinder contains an adequate sample that is representative of the flow-averaged composition.

4.2.1.3 Continuous sampling for on-line analyser systems

Continuous sampling shall comply with PTS 32.31.50.10. and PTS 32.31.50.11

4.2.2 Additional requirement

Sampling frequency shall meet the requirements of the contractually agreed sampling and analysis scheme.

The sample taken shall be free from dirt and liquid components by virtue of the design of the sample system and the adequate selection of sampling components.

The sample shall be withdrawn by means of a sample probe of design compatible with DEP 32.31.50.10. The design shall consider the aspects of vibration-induced fatigue.

The sample take-off probe should be located with due consideration to upstream and downstream straight length piping requirements as if it was a thermowell.

Delay times between sample point and analyser should not exceed 60 s, which for most on-line analyser applications requires a sample by-pass loop.

Disposal of waste samples and/or by-products of the analysis shall be compliant with PTS 32.31.50.11. Where possible, excess sample shall be returned to a low pressure point in the process or, less preferably, to flare. However, creating a shortcut across the flow measurement device is not acceptable; i.e. adhering to the principal that all matter passing the point of fiscal gas measurement shall be measured.

Sampling systems should be kept at a temperature that is at least 5 K above the gas stream hydrocarbon and / or water dew point in order to avoid condensation and liquid particle entrainment in the gas.

Heat tracing if applicable should be self-regulating electrical tape, which shall meet the requirements of electrical codes for the area in which they are used.

Two weeks after start-up of a new production installation or flow measuring station and on three occasions thereafter at fortnightly intervals, samples shall be taken. The composition resulting from the first sample shall replace the artificial start values (GHV, ρ_0 etc.) in the measuring station. The compositions resulting from the three subsequent samples shall be used to calculate the first averaged values to be used in the measuring station.

4.3 ANALYTICAL METHODS

Fluid properties shall be determined either in accordance with or in a manner traceable to the analytical methods in Appendix D.

4.4 DETERMINATION OF INFERRED FLUID PROPERTIES

Fluid properties of natural gas may be inferred from:

- a) compositional data obtained from spot sampling {4.2.1.1}
- b) compositional data obtained from flow proportional sampling {4.2.1.2}
- c) compositional data obtained from on-line analysers {4.2.1.3}
- d) established correlations

The method of inference shall be chosen from Appendix E.

NOTE: Inference from established correlations {4.4.d} mainly concerns GHV. For mixtures of natural gas streams from two or more different sources the GHV may be determined from the correlation between the Gross Heating Value and the Relative Density. If, over the whole operating range, this correlation is within the specified accuracy, the GHV can be derived from the on-line measurement of relative density {4.5.3.2}.

4.5 DETERMINATION OF FLUID PROPERTIES BY ON-LINE MEASUREMENT

4.5.1 Design and construction of on-line analyser systems

Design, selection and construction of on-line analyser systems and analyser house facilities shall be in compliance with:

- PTS 32.31.50.10
- PTS 32.31.50.11
- PTS 32.31.50.12
- PTS 32.31.50.13

There should be single-point responsibility for the design, construction, and commissioning of on-line analyser systems; this should be entrusted to a specialist firm.

On-line analyser systems should be delivered as packaged units complete with sample take off assembly, sample pre-conditioning system, sample transport lines, sample conditioning system and sample disposal system.

Due attention shall be given to any limitations specified by the Manufacturer, e.g. operating and environmental conditions, calibration requirements.

4.5.2 Methodology

Measurement results obtained from on-line analyser systems shall be traceable to the standards kept at the testing laboratory. Traceability should be established by the reference materials used for calibration of the on-line analyser systems being in agreement with the standards that are kept and maintained by the testing laboratory.

If the above scheme is not practicable, traceability may be achieved by manually sampling the process at a suitable location close to the sample take-off of the analyser system and subsequently analysing the sample and comparing it with the concurrent analyser measurement result. A suitable location needs to be investigated but is possibly at the sample handling system of the on-line analyser system, e.g. close to the sample entry port of the analyser.

Spot sampling and subsequent laboratory analyses are subject to increased variability due to the process of sample handling, thus causing increased uncertainty of the measurement.

Control Charts shall be used to control calibration and maintenance intervention in order to curb any undue variance and bias in measurement results {6.4}.

4.5.3 On-line analysers for the determination of fluid properties for fiscal gas measurements {4.1.1.1}

4.5.3.1 Operating density (ρ)

The measured value shall represent the density at the upstream face of the orifice plate or in the throat of a turbine meter or ultrasonic meter (reference point P_m), which should be achieved by maintaining pressure and temperature inside the densitometer as closely as practicable to these locations. If this is not possible the appropriate corrections shall be made to the measured value.

The measurement principle should be based on vibrating mass. However, density should be inferred from gas composition measured by PGC instead {4.5.3.3} if fouling or liquid contamination is inevitable, which has an adverse effect on the uncertainty of the measurement.

- NOTES:
1. Vibration type densitometers are accurate and reliable instruments though extremely sensitive to fouling conditions. The measurement uncertainty of on-line densitometer applications is typically rated as better than 0.15 % whilst that of inferred density from composition in accordance with ISO 12213 is typically 0.3 % to 0.6 % depending on process conditions and the quality of input data.
 2. The density signal from a Coriolis meter shall not be used for fiscal purpose {3.2.4.2}.

Densitometers should be either pocket style with external sample loop connection (like the "Solartron" design) or retractable insertion type (like the "Sarasota" design).

The preferred line-up with an orifice meter is to circulate the flow between the low pressure tapping point and a point downstream of the orifice plate where pressure recovery is complete (ISO 5167-2, paragraph 5.4.1). Refer to Appendix C. The pressure condition of the densitometer should be close to downstream pressure, i.e. an open connection between the densitometer and the low-pressure tapping, whilst the sample flow control element should be located in between the sample tapping at the pressure recovery point and the densitometer. In this case the density shall be corrected for the measured pressure differential across the plate and possibly other effects. The design rules in this DEP should not give rise to any excessive pressure differential warranting additional temperature correction due to isenthalpic expansion effects {3.2.2.3}.

NOTE: Some flow computers provide the algorithms for correcting density measured at downstream pressure.

The temperature of the densitometer shall be kept within 0.5 K from the process temperature, which represents an additional density error of approximately 0.15 %. With a pocket type of densitometer, the line pocket and protruding instrument shall be placed inside a thermally well-insulated box that surrounds the whole pipe section over a length of approximately 1 m and over which length the insulation shall be stripped. Sample take-off and flow controls of the densitometer shall be located inside the same box.

The pressure and temperature conditions shall be checked for retrograde condensation. Pocket type densitometers are not suitable for such conditions whilst the insertion type may be affected by liquid droplets adhering to the moving parts of the analyser, thus causing an undue increase in mass.

Inferred measurements should have preference in this case {4.4.c, 4.5.3.3}.

4.5.3.2 Relative Density (RD)

The measurement principle should be based on vibrating mass. As the analyser is of an extractive type, sample conditioning is likely to be conducted satisfactorily, thereby reducing sensitivity to fouling.

The test gas for calibration purposes shall be representative of the process gas and shall have a Relative Density that is similar to the average Relative Density of the gas that has to be measured.

4.5.3.3 Process Gas Chromatography (PGC)

The composition of the natural gas with regard to nitrogen, carbon dioxide and C₁ to C₅ and C₆₊ shall be determined by a PGC according to ISO 6974-5.

Fluid properties may be inferred from on-line compositional data produced by the PGC as explained in {4.4.c}.

4.5.4 On-line analysers for the determination of fluid properties for limit properties {4.1.1.2}

4.5.4.1 Wobbe Index (WI)

Inferred measurements should have preference {4.4.c, 4.5.3.3}.

The Wobbe Index analyser may operate on the basis of residual oxygen that is present in the flue gas of a sample combusted under over-stoichiometric conditions.

4.5.4.2 Oxygen

The sampling system shall be designed to avoid the inclusion of air locks, e.g. dead spaces where air can be trapped after opening of the sample system. Sampling systems shall be absolutely airtight.

The measurement principle should be based on the use of electro-chemical and paramagnetic cells.

4.5.4.3 H₂S

The sampling system shall be absolutely free of free water, e.g. due to condensation.

The measurement principle should be based on the discolouration of lead acetate paper when exposed to H_2S .

4.5.4.4 Water dew point

The sampling system shall be kept at a constant temperature with sufficient margin above ambient temperature so as to avoid the adsorption or desorption of water by the sampling tube under the influence of varying sample temperature; e.g. avoiding any day/night error cycle.

Water dew point analysers should be chosen from the following types (refer to PTS 32.31.50.12 for instrument characteristics):

- Thin film metal-oxide-type sensor.
- Vibration of hygroscopic crystal.
- Conductivity of a hygroscopic salt.
- Silicon oxide type.
- Fibre-optic type sensors.

Chilled mirror types shall not be used on-line.

Thin film aluminium oxide sensors shall not be exposed to temperatures above 70 °C.

Fibre-optic type sensors shall not be exposed to temperatures above 95 °C.

The above analysers are hygrometers, which respond to change in partial water pressure. Hence, their sensitivity increases with increasing total pressure, for which reason the measurement should be taken at operating pressure if compatible with instrument characteristics.

The above hygrometers provide relative measurements and most of them require regular factory recalibration {6.7.7}.

Water dew point analysers fail if exposed to glycol even at low levels of contamination. Hence, due attention shall be paid to avoiding such exposure, e.g. due to carry over under overload conditions if a glycol-treating unit is positioned upstream of the meter run.

NOTE: Glycol has a low vapour pressure, which makes it likely to penetrate as liquid in low-pressure systems. The water vapour pressure will read low in the presence of glycol due to its hygroscopic effects. Glycol has a shielding effect by absorbing the water that would otherwise have reached the sensor.

In some designs, corrosive gas can attack delicate parts such as soldered connections to the sensor. Glycol treatment plants may produce aggressive agents as by-products when overloaded. Sour gas may form a corrosive environment.

4.6 SELECTING THE METHOD OF DETERMINATION OF FLUID PROPERTIES

For the determination of the fluid properties for fiscal gas measurements the following groups can be distinguished:

Group 1:	gas with a variable composition, subdivided as follows:
1a:	'large' capacity ($> 10^6 \text{ m}^3/\text{d}$ at specified conditions, for at least 3 successive years),
1b:	'medium' capacity (capacities other than as described for Groups 1a and 1c),
1c:	'small' capacity: $\leq 50,000 \text{ m}^3/\text{d}$; or between $50,000 \text{ m}^3/\text{d}$ and $\leq 10^6 \text{ m}^3/\text{d}$ at specified conditions for less than 3 successive years).
Group 2:	gas with a constant composition.

By definition, natural gas has a constant composition (Group 2) if:

- it is produced from one reservoir block; and
- any deviation of both the GHV and ρ_o readings of the last three gas samples is smaller than 0.5 % of the mean values from these three (spot) samples taken in accordance with the required minimum interval time.

NOTE: Possible variations in gas composition should be factored into the deviation of GHV and ρ_o by means of reservoir data or other information.

In all other cases the gas has, by definition, a variable composition (Group 1).

For fluid properties for fiscal gas measurements the following methodology should be made available:

Group 1a:	Determination by on-line measurement {4.5} Inferred from on-line compositional data {4.4.c}
Group 1b:	Inferred from compositional data obtained from flow proportional sampling {4.4.b} Inferred from on-line compositional data {4.4.c}
Groups 1c and 2:	Inferred from compositional data obtained from spot sampling {4.4.a}

5. AVAILABILITY AND REDUNDANCY

The design shall fulfil the contractually agreed availability requirements, which shall include any period of outage and flow reduction as a result of meter run validation, other maintenance or equipment failure.

The projected availability shall be demonstrable to all parties concerned by an agreed failure analysis methodology.

The unavailability of a single component of the fiscal gas measurement system due to failure or maintenance shall result neither in the interruption of ongoing measurements nor in the loss or invalidation of contractually required data.

In multi-meter run stations the redundancy requirements for each meter run are subject to failure analysis and should be agreed upon on the basis of the availability requirements. The redundancy requirements, if applicable, are outlined below.

Redundancy shall be designed to minimise common mode failure. For this purpose, due attention shall be paid to the diversity of measurement principles. Redundant systems shall have segregated power supplies with UPS back up.

NOTE: The autonomy time (the specified time that the battery shall be capable of supplying rated current to the load within the specified voltage limits) of the UPS shall fulfil project requirements. UPS is required for bridging power outages of short duration and for the safe shutdown of the metering station in the event of a total power shut down.

Redundancy at meter run level, if required, should be a system of Pay and Check, each capable of producing independently the contractually required data. Data from Pay and Check systems shall be continuously accrued and recorded thus creating two independent data sets of equal parity.

Discrimination alarms shall be made available for all redundant measurements in the system. The level of discrimination should depend on the uncertainty for each measurement and shall be statistically supported.

Data shall be deemed invalid and be marked as such and not be used for fiscalisation when produced:

- under identified failed conditions;
- as a result of ongoing testing or other maintenance activities.

The Pay system should be used by default for fiscalisation whilst the Check system should be considered for fiscalisation if the Pay system is not available for the above reasons.

Redundancy shall cover the following elements as a minimum:

- The power supply of the measurement system. The means of back up shall be by UPS.
- The pressure and temperature measurements.
- For orifice meters, at least the differential pressure measurement with the highest range.
- The flow computer and its ticket printer, the latter if installed to meet legal requirements.
- In some cases legislation may require a turbine meter to be equipped with a mechanical counter.
- On-line measurements of fluid properties. Redundancy should be diverse; e.g. a direct measurement should be backed up by an inferred measurement.

The following are design considerations:

- The change out of failed equipment with redundancy should not interrupt the continuity of contractual measurements.

- Components designed and installed without redundancy should be sufficiently robust to comply with availability requirements. Installed spares or a multi meter run configuration should be considered if the availability requirements cannot be met by a single meter run.
- Design and spares policy should be optimised to minimise the repair time of failed, non-redundant changed-out equipment.
- Orifice carriers should be considered for mitigating unavailability due to periodic inspection of the orifice plate or its replacement in the event of its failure.

NOTE: Orifice carriers may pose a potential safety risk in that valves or seals may leak or valves may be operated in a wrong sequence. Operating instructions shall be strictly followed when opening orifice carriers.

- Failure of one of the acoustic paths of an ultrasonic flow transmitter should not invalidate its measurement.
- The number of parallel runs should be such that the contractual continuous maximum flow rate can be measured with one meter out of service whilst the rest of the meters are operating within their specifications.

NOTE: As an alternative, if a temporary reduction in maximum flow rate is contractually tolerated, the holding of readily available calibrated spares for ultrasonic meters or turbine meters should be considered. Under no circumstances shall the maximum gas velocity be exceeded when switched to redundancy unless validation can be done under high load conditions without hampering the continuity of supply.

The relationship between the planned unavailability (U) of the production facility and the contribution of the flow measuring station to that unavailability is shown below:

Unavailability of the production facility (U)	Contribution of the flow measuring station
$\leq 3 \%$	1 % (i.e. contributes $\leq 0.03 \%$ of U)
$> 3 \%$	2 % (i.e. contributes $\leq 0.06 \%$ of U)

6. VALIDATION

6.1 GENERAL

Validation comprises calibration and, if necessary, adjustment of the gas flow meters and the secondary instrumentation pertaining to the measurement system. Adjustment should be governed by means of Statistical Process Control using Control Charts {6.4}, but in any case a component shall be adjusted if its calibration shows deviations outside the permissible error limits.

6.2 TRACEABILITY

Measurement results shall be traceable to national and international standards through a documented system of calibration procedures, analytical procedures and measurement standards.

- Calibration procedures describe the processes of confirmation and retention of traceability of measurement results.
- Analytical procedures are documentary procedures that describe the analytical method to establish chemical or physical properties (fluid properties in the context of this PTS) within specified accuracy and repeatability.
- Measurement standards cover all calibration equipment and reference material that is needed to complete the traceability chain.

6.3 CALIBRATION

Calibration should be performed in situ without instruments having to be removed. Hence, sufficient calibration facilities for each instrument shall be provided, e.g. calibration ports and testing manifolds.

If in-situ calibration is not possible the instrument concerned shall be scheduled for regular factory recalibration {6.7}, which may require a spare, calibrated instrument to be available.

Calibration of instruments other than those suitable for single-point calibration should be carried out over the whole operating range of the component.

Calibration at different conditions is only acceptable if this is accounted for in agreed uncertainty calculations.

Calibration shall take due account of the strength of the local gravitational field. Dead weight testers shall be either factory-calibrated or corrected for this condition.

The location of instruments that are subject to calibration shall not frustrate the use of Measurement Standards, which may require a conditioned environment in order to achieve statutory performance.

- NOTES:
1. As an example, dead weight testers (DWT) are usually certified for operating within a limited temperature range, which may require the subjected instrument(s) to be located in the same room where the DWT is located. A way around this is to use a transfer standard, which can be brought outside and is suitable for the environment in which the subjected instrument is located. The transfer standard in turn should be calibrated against the DWT.
 2. For optimum uncertainty, placing instruments like differential pressure transmitters in a conditioned environment may be considered. This reduces any residual uncertainty that is otherwise introduced by variations in environmental conditions.

Calibration equipment shall have a valid calibration certificate issued by a national or accredited laboratory. Such equipment shall have an uncertainty of measurement of up to one-third of the uncertainty of the instruments to be calibrated under the conditions at which the tests take place, with the exception of master meters, which have an uncertainty similar to that of the target instrument {6.9}. Calibration certificates shall specify the systematic error in the measurement result as a function of calibrated range and include a statement on the uncertainty of the calibration results.

Classification and control of reference materials shall comply with ISO 14111. Production of Reference Material shall comply with ISO 6142. Reference Material shall have a valid

certificate stating the relevant quality, including the uncertainty inherited from the fabrication process for each component, and the expiry date. Certification may be performed by either the factory or by a third party laboratory.

The testing laboratory shall maintain a set of primary standard reference materials that cover the range of properties of interest. The range should account for the limited linearity of the relevant analytical procedures.

Maintenance department should maintain a set of secondary standard reference materials for the calibration and checking of on-line analyser systems, which shall be traceable to the highest standards at the testing laboratory. For this purpose, the testing laboratory shall periodically test the secondary standard reference materials.

Measurement standards shall be dedicated to the validation of fiscal gas measurements only. They shall be stored and used at an assigned location under appropriate conditions as stated at the relevant certificates and annexes.

The zero reading of a Coriolis meter may be influenced by piping stress, which may be propagated onto the meter via the mounting facilities and support points {3.2.4.3}. Hence, zero stability is only achieved when the meter is installed and when zeroed at operating conditions. The meter should be re-checked within two to four weeks after installation for zero drift under operating pressure and temperature and adjusted if necessary. Beyond this, zero drift is unlikely to occur under stable operating conditions. A zero check should be done as part of the validation procedure.

6.4 ADJUSTMENT

Control Charts are commonly used in maintenance to control calibration and maintenance intervention so as to reduce any undue variance and bias in measurement results. In this way the variability of measurement systems can also be evaluated and factored into the periodic updating of the uncertainty analysis. The use of control charts limits longstanding errors and may improve the equity of the fiscal gas measurement.

Control charts shall be applied for on-line analyser systems and should be used for other fiscal gas measurements, all in compliance with ISO 7873.

Their purpose is to check the general condition of the equipment. The checking frequency may be higher than the formal validation frequency that has been agreed between the parties. This is often the case with PGCs, which typically require bi-weekly checking whilst formal validation might be done every three months.

A failed equipment condition, including failed calibration, shall immediately result in corrective action and, if necessary, adjustment. The failed condition should be investigated before the instrument concerned is adjusted, and subsequently documented.

NOTE: Failed condition includes all causes and failures that force the equipment outside its performance and / or operating envelope. Systems should be designed so that hardware failures and adverse process conditions will be alarmed automatically with a high probability. Remaining errors may show up during checking or calibration. Calibration can only be checked by comparing the equipment against a measurement standard, which process can be automated and therefore be equipped with alarms as well.

The permissible error should be set to 1.5 times the overall uncertainty, including the calibration uncertainty, i.e. coinciding with the Control Limit. The rules of intervention are aligned with this criterion.

As a minimum rule, a calibration should be considered failed if the calibration error established during validation is outside the Manufacturer's specification.

The following are the minimum rules of intervention.

Rule 1: a single validation score exceeds the Control Limit on either side of the central line

Rule 2: two out of three consecutive validation scores exceed the Warning Limit on the same side of the central line

Rule 3: four out of five consecutive validation scores exceed the $\frac{1}{2} \times$ Warning Limit on the same side of the central line

Rule 4: eight or more validation scores fall on one side of the central line

Intervention is justified if at least one of the above rules is satisfied. Each of the rules yields a significance level of 0.27 %. The rules should be applied simultaneously, which reduces the confidence interval of the decision to approximately 99 %.

At the warning limits or beyond, i.e. outside the interval between the upper and lower warning limits but without either the upper or lower control limit being exceeded, attention is called to the possibility of out-of-control conditions. It is good practice to check immediately any overshooting of the warning limit. Confirmation indicates that the process is not under control and that intervention is therefore justified (duplicate reading). This basically complies with Rule 2.

The Control Chart should log the results obtained at working point of the instrument, e.g.;

- halfway along the calibrated range of a subjected differential pressure transmitter;
- the sample reference value of the secondary reference material of a PGC.

6.5 VALIDATION INTERVALS

Minimum validation intervals shall be initially established per type of instrument, depending on validation results. With changing instrument performance, validation intervals should be adapted in steps (e.g. increase by 1.5, decrease by 0.5), respecting minimum and maximum intervals per instrument type.

Performance shall be proved by means of Statistical Process Control.

When adjusting the validation interval it should be realised that it can take a number of periods between validations before an error is detected. Detecting that a process is out of control, and the time it takes to come to such a conclusion, is a probabilistic concept as the observations that underpin such a conclusion result from a stochastic process.

NOTE: The average period of detecting an error is a control chart property and a function of validation frequency, the significance level of testing and the shift from the central line in terms of standard error. When 4 rules of intervention {6.4} are applied simultaneously, the significance level of testing will be about 1 %. The average error volume is the product of the average detection period and the error. The volume reaches maximum when the error is about $0.5 \times$ standard deviation or about $0.25 \times$ the Warning Limit.

Refer to Appendix K.

6.6 RECORDS

All data pertaining to calibrations, adjustments (measurement data, calibration factors, events, Control Charts, etc.) and changes in parameters shall be registered and stored for a period of time required by regulation or agreement. This information shall be accessible for inspection by contract parties (witnessing) and shall be part of the station's logbook {7.5.3}. electronic documentation systems should be used. If the plant's Maintenance Management System is used, it should be made accessible to auditors and witnesses of validations.

6.7 FACTORY CALIBRATION AND ITS VALIDITY

All fiscal measurement instruments including receiving electronic equipment like flow computers shall be factory commissioned and provided with the Manufacturer's calibration certificate and relevant testing reports.

The certification shall include embedded secondary sensors if used for fiscalisation purpose or for validation.

NOTE: Some densitometer designs come complete with embedded temperature sensors that may be valuable for better estimating density at line conditions. Such a built in temperature sensor is not accessible on-line for validation.

The specified period of validity of certification shall be complied with, especially if the applicable calibration procedure cannot be repeated in-situ. An adequate sparing and stocking policy shall be in place in order to handle removal of complete units for calibration purposes for the required period of time (where there is no local testing laboratory, this can be a significant period).

NOTE: Parties should agree on the recalibration interval if the Manufacturer has not specified this already (e.g.: factory calibration of a differential pressure transmitter is usually valid for its operational life). Parties, however, may agree on another recalibration interval.

The following measurements systems including their secondary sensors, if installed, require regular factory recalibration:

6.7.1 Ultrasonic flow meters

The initial calibration certificate of an ultrasonic flow meter shall be based on a comparative calibration against an approved and traceable metering standard. At the time of initial calibration a full metrology and geometry check of the meter shall be carried out.

The calibration and checks shall together constitute the “footprint” of the meter, which will be used at future validations. These validations (dry calibration) shall consist of the following:

- Metrology and geometry tests and comparison with footprint (ref. ISO 17089 and AGA 9).
- The difference of the flight of time for each acoustic path measured in both directions with closed in meter, should not result in an error larger than half the specified meter uncertainty.
- The ratio of the speed of sound for the various acoustic paths. The variability of the ratio should be within the Manufacturer's specification.

Failure to meet criteria will void certification and lead to recalibration or rejection.

NOTE: At locations with nearby calibration facilities, periodic factory recalibration may be considered as a better option than the above practice. Because ultrasonic flow meters measure the velocity across the meter section, measurement results depend on the velocity profile at the meter, which is imposed by the flow conditions like surface roughness, Reynolds number, etc. Sensitivity to variations in the velocity profile can be mitigated by a complex sonic path layout. However, conditions like fouling of the meter and the adjacent piping affect the calibration, which may be very noticeable. Hence, if factory recalibration is performed, the following shall apply:

- Include up and downstream piping in the calibration.
- Avoid cleaning (assuming that fouling is an process that halts after a certain period of exposure).

6.7.2 Differential pressure transmitters

Calibration under conditions deviating from operating conditions is permissible under the conditions described in {6.3}. Differential pressure transmitters may therefore be calibrated at atmospheric conditions in situ. Factory (re)-calibration in such a case shall include the specified operating conditions and a deviation table for the instrument response at the various calibration points under atmospheric and operating conditions.

During in-situ calibration the ability of the instrument to repeat the atmospheric calibration characteristics within the stated uncertainty limits shall be sufficiently proven. Failure to meet this requirement will void certification, in which case the instrument concerned shall be replaced.

6.7.3 Turbine meters

Due to their mechanical nature and wear and tear, factory calibration of turbine meters is usually for a limited period of time. The period between recalibration depends on the severity of the service. The initial period between recalibrations could typically be one year, which may be extended if results stay within expectation.

6.7.4 Coriolis meters

The initial calibration certificate of a Coriolis mass flow meter shall be based on a comparative calibration against an approved and traceable metering standard.

Coriolis meters exhibit excellent stability over a prolonged period of time. Calibration should be considered valid for as long as their mechanical integrity is ensured and no obvious errors are reported from common diagnostics or operator induced on-line verification {3.2.4.2}.

Coriolis meters may be only calibrated with an alternative fluid, e.g. water, if the difference in calibration as compared to gas is adequately known. An adjustment to the meter calibration factor may be applied to ensure acceptable meter performance in gas service. Meter uncertainty shall be stated with regard to the intended gas service.

NOTE: Although this seemingly leaves an option for in-situ volumetric calibration using a traditional, transportable meter prover, this is not a practical solution in view of attainable uncertainty of such provers, which may be in the same range as that of the meter, and because of the introduction of other uncertainties such as how well a meter can be made gas free and how well the testing fluid, usually water, can be made free of air. Hence, the master meter concept is preferred as a means of in-situ verification {6.9}.

Coriolis meters may eventually need factory recalibration if in-situ calibration is not possible). Contract parties should agree on the time between factory recalibrations.

6.7.5 On-line densitometers for the determination of operating density

Vibrating type on-line densitometers can only be checked in-situ adequately and repetitively by applying vacuum conditions, which reveals only the natural frequency of the meter within specified uncertainty limits and is insufficient to confirm performance over its entire range.

During in-situ calibration the ability of the instrument to repeat the vacuum calibration characteristics within the stated uncertainty limits shall be proven. Failure to meet this requirement will void certification, in which case the instrument concerned shall be replaced.

In addition, these instruments shall be periodically scheduled for periodic factory recalibration in order to retain valid certification.

Factory calibration should be against a type of gas similar to the process fluid. The calibration shall be corrected for the effects of the speed of sound if the test gas is not similar.

6.7.6 On-line process gas chromatographs (PGC)

The performance of instrumentation parts like detector electronics, or the integration procedure, surpasses the analytical performance. Certification and performance statements shall therefore be based on comprehensive testing of the complete application for the specified conditions and gas composition.

6.7.6.1 Single-point calibration regime

The applications described in ISO 6974-5 have limited linearity. Single-point calibration for PGC is permissible provided the compositional variability complies with that of ISO 6976-2 Table 1. Single-point calibration can be conveniently done in situ using certified reference material without the need for factory recalibration.

6.7.6.2 Multi-point calibration regime

If variability is beyond the above criteria and if the effects of the resulting bias in composition are more than 0.5 % (relative) in terms of Superior Calorific Value (GHV) and Relative Density, the PGC shall be subject to multi-point calibration as explained in ISO 10723 and ISO 6974-2. The initial calibration certificate shall be compatible with this requirement and state the full details of the calibration results.

As multi-point calibration is not easily performed in-situ, the PGC will probably be changed out for a newly calibrated one in the event of calibration failure. Equipment calibration will be void after repair or change out of the following components: column(s), detector and

detector amplifier (-board). The possible requirement of complete change out may affect equipment selection. Dedicated PGCs that are purposely designed for ISO 6974 and ISO 6976 applications are usually more transportable and of a more compact design than a multipurpose PGC.

Once calibrated in this way, a single-point calibration may be adjusted for changing environmental-factors during normal operations; i.e. per component by applying a correction factor to the calibrated range.

Additionally, the instrument concerned shall be periodically scheduled for factory recalibration in order to retain valid certification.

6.7.7 Water dew point analysers

Most types of hygrometers require regular factory recalibration; this does not apply to the vibrating crystal types, which are equipped with an embedded and calibrated permeation tube as a measurement standard for generating a repeatable amount of water in a dry gas stream.

6.7.8 Flow computers

It should be possible to check the A/D converter if signal transmission is not all digital. The flow computer should be scheduled for the recalibration of the A/D converter if it cannot be adequately checked in-situ.

NOTE: Flow computers should be checked as part of the loop. However, an acceptable result obtained this way is not conclusive as regards the performance of the A/D converter, in view of its usually better accuracy than that of the connected analogue elements.

6.7.9 Master meter

In view of its certification function, the master meter shall be re-calibrated promptly when due {6.9}.

6.8 UNCERTAINTY

Uncertainty is inherent to the measuring process and is influenced by the operating conditions and environment. Typical uncertainty specifications from the measuring instrument Manufacturer do not necessarily reflect the operating environment of the instruments concerned. The uncertainty envelope under operating conditions is often stretched beyond what is quoted by the Manufacturer. Instruments shall therefore be selected from a matured and proven type population with favourable inherent properties such as the minimum bias and drift.

Instruments used for fiscal gas measurement that tend to drift persistently in one direction and therefore consistently produce errors of identical signature shall not be selected and shall immediately be repaired or replaced when such a condition is proven in operation, so as to limit long term, standing errors and to secure equity for all parties concerned.

Uncertainty under operating conditions of each instrument in fiscal gas measurement shall be proven and based on calibration results as described in {6.3}. Design of the fiscal measurement and selection of instruments shall cover the complete operating envelope in order to achieve projected performance under operating conditions.

The uncertainty of the gas flow meters and the secondary instrumentation shall at least comply with the legal/contractual requirements.

Permissible errors shall be specified:

- for the elements of the fiscal gas measurement that can be calibrated and adjusted individually and that can be replaced in case of failure;
- for the fiscal gas measurement as a whole. The probabilistic concepts of uncertainty shall be fully covered when engineering the uncertainty budget.

As a minimum the performance of each element as referred to above, shall be proven to the above criteria during validation. If all elements pass it may be concluded that the fiscal gas measurement as a whole is acceptable.

Additionally contract parties may agree on performance validation of the fiscal gas measurement as a whole, e.g. using the master meter concept.

NOTE: It should be borne in mind that the overall error results from the contribution of errors of elements. Because of the probabilistic approach, the overall error could occasionally exceed the permissible error limit whilst each of the elements yields acceptable performance. In this case, this condition should be monitored during subsequent validation sessions to investigate if this behaviour is persistent, which may be indicative of persistent errors in elements. Control Chart methodology may help to resolve such problems.

6.9 MASTER METER CONCEPTS

Master meters may be used to confirm, by comparative testing, the accuracy performance of installed meters (target meters) that cannot be calibrated in situ and/or cannot be easily removed for laboratory or factory recalibration. The aim of using a master meter is to extend the period between laboratory or factory recalibrations of target measurement system(s). Parties should agree on how long current certification may be extended on the basis of comparative testing.

Master meters are no substitute for redundancy and shall be dedicated to verifying the performance of the target meter(s) only.

Hence, the master meter shall not be permanently lined up as “duty” and shall only be used when required for comparative testing. Lining up shall take full account of the straight piping lengths requirements.

The master meter shall be at least as accurate as the target meters and, in order to avoid common mode errors, should be of different operating principles to those of the target meters.

The permissible error between master and target measurement system shall not exceed the overall uncertainty of both measurement systems, which value shall be statistically substantiated. The installed meter shall be declared failed if the permissible error is exceeded. The installed meter shall not be adjusted on the basis of this comparison.

Master flow meters are typically turbine meters or ultrasonic meters but could also be differential pressure transmitters of a high accuracy class.

7. ROLES AND RESPONSIBILITIES

The following describes the minimum roles and responsibilities that should be agreed.

7.1 CONTRACT CUSTODIANS AND SPECIALIST FORUM

Each contract party should assign a contract custodian with the following duties:

- Implementation of the respective party's side of the contract at operational and technical level;
- Contact person for the other contract parties concerning operational and technical matters.

A specialist forum should be established at working level, which should deal routinely with technical, analytical and operational matters.

The assigned representatives should hold a professional and recognised status within the company that they represent and carry sufficient accreditation and authorisation to deal with the day-to-day problems that may arise. The contract custodian of each company should chair the respective specialist forum.

The disciplines represented in the specialist forum should be Operations and Instrument engineering and/or maintenance whilst other specialists may be called in on a need basis. Contract parties should agree on the issues that can be delegated to the specialist forum and how this process should be managed.

7.2 OPERATIONS

The station operator shall assign operational responsibilities covering the development and execution of operating strategy, and the keeping of the plant within its operating and performance envelope according to the agreed design.

The station operator shall prepare and provide auditable procedures for its operation, which comprise:

- nomination of qualified and competent operational staff;
- formulation of a yearly plan for maintenance of process hardware;
- formulation of performance indicators necessary to judge the operational performance;
- plant access procedures including safety aspect;
- management of work order system;
- definition of the communication protocol with contract parties.

NOTE: Where applicable, the operation of meter run and by-pass valves, pressure regulation equipment and associated filters should be checked for correct operation if they have an influence on the performance of the measurement system.

7.3 MAINTENANCE

The station operator shall assign maintenance responsibilities, covering the development and execution of maintenance plans and including:

- retention of plant integrity according to the agreed design. Under this clause changes to the station are not allowed unless managed through a controlled change process;
- validation of the fiscal gas measurement;
- maintenance of parameter settings;
- maintenance of technical documentation.

The station operator shall prepare and provide a system of auditable procedures and governing competences and responsibilities for:

- validation and performance assessment of the measurement system;
- maintenance;
- modification.

The procedures shall be accessible to all parties and ensure that the fiscal gas measurement is validated and maintained so as to retain its design performance during its service life. The procedures shall comprise:

- organisational responsibilities for planning, scheduling and implementation of validation and maintenance activities;
- organisational responsibilities with respect to change control of the fiscal flow measurement systems;
- nomination of a qualified and competent instrumentation technician, responsible for calibration and maintenance of fiscal gas measurement systems;
- formulation of a yearly plan for maintenance and validation of the fiscal flow measurement stations, agreed with Operations and other parties;
- formulation of performance indicators necessary to judge the performance of the fiscal gas measurement system(s) and its components (hardware and software);
- formulation of the criteria concerning the management of parameter settings;

NOTE: The validity of parameters as fixed inputs into the flow computer should be regularly reviewed according to a contractually agreed procedure. Parameters (RD, GHV etc.) emerging from the sampling and analysis scheme of the previous year should be individually reviewed and compared with their respective current reference value. If within the agreed margin, each of the parameters concerned shall be considered not to have changed, and parameters may be adjusted only if justified by relevant statistical inference.

- clear instructions, in line with the gas contract, for informing witnessing parties about future calibrations and about their access to installations and relevant information.

7.4 TESTING LABORATORY

Sampling and analysis schemes associated with fiscal gas measurement processes are subject to strict commercial compliance. Hence, when fiscal gas measurement is commissioned, an independent testing laboratory shall be contracted for the determination of fluid properties as stipulated in the gas supply contract.

Contract parties should agree on third party facilities for executing the contractually approved sample and analysis scheme.

Only laboratories with a proven record of performing the required analyses may qualify for rendering the required services. Such laboratories should have been audited prior to the concluding of any contract with them. The auditor should be a qualified chemist with a status that is recognised by all parties concerned. The following are the minimum requirements:

- compliance with safety standards as set by the Group and furthermore acceptable to all contract parties;
- compliance with ISO 17025;
- compliance with ISO 14001;
- ISO 9001 certification and the embedding of performance of the analytical Laboratory through participation in Group managed interlaboratory exchanges (proficiency testing or “round robin” testing).

NOTE: Exchanges where typical production samples are tested by multiple measurement systems, using a specified test protocol, provide a cost-effective means of assessing measurement system accuracy relative to average Group performance.

The testing laboratory is responsible for:

- keeping the standards and maintaining the path of traceability of analytical methodology to external bodies;
- maintaining traceability of on-line analyser measurement results to the standards kept at the testing laboratory {6.3};
- performing contractually agreed spot sampling and subsequent fluid analyses {4.2.1.1};
- execution of the contractually agreed flow proportional sampling schemes {4.2.1.2}.

7.5 DOCUMENTATION AND RECORDS

The station operator shall establish and maintain an archive containing all documentation, of which the following elements form part, required for the operation and maintenance of the measuring station for a period of time required by regulation or agreement. Documentation shall be auditable and accessible to all contract parties.

The following manuals shall be maintained.

7.5.1 Operations manual

An operations manual should typically document:

- Functional description including operating conditions, design parameters and process engineering flow schemes (PEFS).
- List of alarms that can occur and required responses.
- Planning of validation and the sampling frequency.
- Switching meter runs in or out of service.

NOTE: During switching, the instrumentation should be kept at line pressure by switching meter runs via the upstream isolation valves.

- Preparation and leak testing prior to validation.
- Routine maintenance activities, e.g. lubrication schemes.

7.5.2 Measurement manual

This manual shall give a detailed description of the flow measurement system(s) and methodology followed to achieve the required results. The following information shall be specified in detail:

- Complete description of measurement system including operating principles of instrumentation and the methodology of determining mass, volume and energy flow.
- Change control procedures concerning fiscal measurement systems.
- Methodology and quality assurance of results obtained.
- Uncertainty analysis including the overall uncertainty of fiscal measurement system(s) and the documentation of permissible errors.
- Rules of handling measurement deviations. Maintenance intervention should be as specified in the rules in {6.4}.
- Handling and communication of acknowledged measurement deviations exceeding permissible error limits, with special attention to notification of contract parties and the regulatory authority.

- Methods and criteria for measurement corrections.
- Measurement values inferred instead of directly measured, in the event of failing input.
- Logging of information in support of the qualitative and quantitative operation of the measurement station including date stamped information concerning:
 - calibration results/reports of instruments and calibration equipment;
 - parameter list of flow computer;
 - maintenance activities;
 - operational activities, e.g. when meter run was changed over.
- Detailed instructions for the operation, calibration, adjustment, maintenance and documentation of the fiscal measurement system(s).
- Review of validation intervals.
- Competence of maintenance staff.

7.5.3 Station logbook

The Station logbook shall contain information in support of the qualitative and quantitative operation of the measurement station, which shall include date stamped information concerning:

- calibration results/reports of instruments and calibration equipment;
- parameter list of flow computer;
- maintenance activities;
- operational activities, e.g. when meter run was changed over.

8. REFERENCES

In this DEP, reference is made to the following publications:

- NOTES:
1. Unless specifically designated by date, the latest edition of each publication shall be used, together with any amendments/supplements/revisions thereto.
 2. The DEPs and most referenced external standards are available to Shell staff on the SWW (Shell Wide Web) at <http://sww05.europe.shell.com/standards/>.

PTS STANDARDS

Instruments for measurement and control	PTS 32.31.00.32
On-line process stream analysis - Sample take-off and transportation	PTS 32.31.50.10.
On-line process stream analysis - Sample conditioning	PTS 32.31.50.11.
On-line process stream analysis – Analysers	PTS 32.31.50.12
On-line process stream analysis - Analyser houses	PTS 32.31.50.13
Static DC uninterruptible power supply unit (DC UPS unit)	PTS 33.65.50.31
Static AC uninterruptible power supply unit (static AC UPS unit)	PTS 33.65.50.32
KSLA Report AMER 84.039	

AMERICAN STANDARDS

Measurement of gas by multipath ultrasonic meters	AGA 9
Measurement of natural gas by Coriolis meter	AGA 11

Issued by:
American Gas Association
8501 E. Pleasant Valley Road
30200 Detroit Rd.
Cleveland OH 44145
USA

Standard test method for determination of total volatile sulfur in gaseous hydrocarbons and liquefied petroleum gases by ultraviolet fluorescence	ASTM D 6667
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Issued by:
American Society for Testing and Materials
100 Barr Harbor Drive, West Conshohocken,
PA 19428-2959
USA

BRITISH STANDARDS

Terms used in metrology	BS 5233
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Issued by:
British Standards Institution
389 Chiswick High Road
London W4 4AL
UK

INTERNATIONAL STANDARDS

Industrial platinum resistance thermometer sensors	IEC 60751
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Issued by:
Central Office of the IEC
3, Rue de Varembe
CH 1211 Geneva 20
Switzerland

Copies can also be obtained from national standards organizations.

Measurement of fluid flow in closed conduits – Vocabulary and symbols	ISO 4006
Measurements of fluid flow by means of pressure differential devices – Part 2: Orifice plates, nozzles and venturi tubes inserted in circular cross-section conduits running full.	ISO 5167-2
Measurement of fluid flow – Evaluation of uncertainties	ISO 5168
Gas analysis – Preparation of calibration gas mixtures - Gravimetric method	ISO 6142
Natural gas – Determination of sulphur compounds – Part 1: General introduction	ISO 6326-1
Natural gas – Determination of potential hydrocarbon-liquid content – Part 1: Principles and general requirements	ISO 6570-1
Natural gas – Determination of potential hydrocarbon-liquid content – Part 2: Weighing method	ISO 6570-2
Natural gas - Determination of composition with defined uncertainty by gas chromatography	ISO 6974
Natural gas – Calculation of calorific values, density, relative density and Wobbe index from composition	ISO 6976
Natural gas - Determination of mercury	ISO 6978
Control charts for arithmetic average with warning limits	ISO 7873
Refrigerated light hydrocarbon fluids - Sampling of liquefied natural gas - Continuous method	ISO 8943
Quality management systems – Requirements	ISO 9001
Guide to the use of ISO 5167	ISO/TR 9464
Measurement of gas flow in closed conduits – Turbine meters	ISO 9951
Natural gas – Determination of water by the Karl Fischer method – Part 1: Introduction	ISO 10101-1
Part 2: Titration procedure	ISO 10101-2
Part 3: Coulometric procedure	ISO 10101-3
Natural gas – Sampling guidelines	ISO 10715
Natural gas – Performance evaluation for on-line analytical systems	ISO 10723
Measurement of fluid flow in closed conduits — Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)	ISO 10790
Natural gas – Calculation of compression factor – Part 2: Calculation using molar-composition analysis	ISO 12213-2
Part 3: Calculation using physical properties	ISO 12213-3

Measurement of fluid flow in closed conduits - Ultrasonic meters for gas - Part 1:Meters for custody transfer and allocation measurement	ISO 17089
Natural gas – Standard reference conditions	ISO 13443
Environmental management systems – Requirements with guidance for use	ISO 14001
Natural gas – Guidelines to traceability in analysis	ISO 14111
General requirements for the competence of testing and calibration laboratories	ISO 17025
Natural gas – Correlation between water content and water dew point	ISO 18453
Natural gas – Determination of sulphur compounds	ISO 19739
ISO guide to the expression of uncertainty in measurement	ISBN 92-67-10188-9

Issued by:

International Organisation for Standardisation

Case Postale 56

Geneva 20 Switzerland CH-1211

Copies can also be obtained from national standards organizations.

MISCELLANEOUS

“Fundamentals of Quality Control and Improvement”, A. Mitra	ISBN 0-02-381791-7
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9. BIBLIOGRAPHY

NOTE: The following documents are for information only and do not form an integral part of this DEP.

Standard practice for automatic sampling of petroleum and petroleum products	ASTM D 1477
Standard practice for applying statistical quality assurance techniques to evaluate analytical measurement system performance	ASTM D 6299
Turbine fiscal metering systems for liquid hydrocarbons	PTS 32.32.00.11
“Guidance notes for petroleum measurement under the petroleum (production) regulations” December 2003 issue 7	Department of Trade and Industry Licensing and consents unit
Natural gas – Quality designation.	ISO 13686
Handling calibration gases	ISO 16664
Fluid flow in closed conduits – Connections for pressure signal transmissions between primary and secondary elements.	ISO 2186
Statistics – Vocabulary and symbols – Part 2: Statistical quality control	ISO 3534-2
Gas analysis - Calibration gas mixtures - Certificate of mixture preparation.	ISO 6141
Gas analysis - Determination of composition of calibration gas mixtures – Comparison methods.	ISO 6143
Gas analysis - Determination of the water dew point of natural gas - Cooled surface condensation hygrometers.	ISO 6327
Natural gas – Extended analysis – Gas chromatographic method.	ISO 6975
Natural gas – Terminology.	ISO 14532
Petroleum and liquid petroleum products - Continuous density measurement.	ISO 9857

APPENDIX A BLACK AND WHITE LIST

Below is a black and white list as an **example of a contract appendix** which is in common use for gas sales contracts, updated with the latest international standards and methods. It may be necessary to adapt this list to suit local requirements.

A.1 WHITE LIST

A.1.1 All methods, procedures and international standards, unless stated otherwise, shall be in accordance with the latest editions. In the case of any newly published standard, Seller(s) and Buyer shall mutually agree on adopting such a new standard. Parties may agree on other methods than those stated in this Agreement if such would be more appropriate in view of all the circumstances then prevailing.

A.1.2 The units of quantity shall be in accordance with ISO 13443 Standard reference conditions.

A.1.3 The Gross Heating Value in MJ shall be either measured on-line or by a method mutually agreed between Sellers and Buyer.

In the case of on-line measurement the Superior (Gross) Calorific Value shall be recorded.

A.1.4 The Compression Factor shall be determined in accordance with ISO 12213.

A.1.5 If regular samples or spot samples are taken for determination by laboratory analysis of the composition and physical properties of the natural gas, the following methods will be used:

a) The total sulphur content, the hydrogen sulphide content, the carbonyl sulphide and the alkylthiol content (mercaptans) shall be determined according to ISO 6326.

b) The water dew point shall be determined by measuring the water content according to ISO 10101 and converting this value to water dew point using ISO 18453.

c) The hydrocarbon liquid content shall be determined according to ISO 6570.

d) The oxygen content shall be determined according to ISO standards or by a method mutually agreed between Sellers and Buyer.

e) The natural gas composition, including carbon dioxide, benzene and toluene contents, shall be determined by a gas chromatographic method in accordance with ISO 6974.

NOTE: Composition and physical properties as defined under a, b and c shall be determined by a laboratory mutually agreed upon by Sellers and Buyer.

A.1.6 The system of all measurements, the type of instruments used, the use of derived measurement values instead of direct measurements, the procedures for maintenance and calibration, the methods and criteria by which measurement corrections will be made and other items relevant to the measurement of the natural gas at the Delivery Point shall be mutually agreed upon between Sellers and Buyer and shall be specified in a Measurement Manual.

A.1.7 Within a period of 3 months after start-up of the measuring station at the Delivery Point sellers shall write the text of a "Measurement Manual". This manual shall specify the detailed methods and instruments for measuring and/or calculating the quantity, composition and physical properties of the natural gas delivered, the calibration and maintenance procedures and the inaccuracies of the instruments.

The Measurement Manual is subject to Buyer's approval.

A.1.8 In the laboratory determinations of the composition and physical properties of the natural gas, the Superior (Gross) Calorific Value and the quantity measurements specified in this Article, the appropriate tolerances of the standard methods specified in A.1.5 shall be applied.

If a measurement tolerance is not covered by a standard, Buyer and Sellers shall mutually agree upon such a value, which will be specified in the Measurement Manual. Buyer and Sellers may mutually agree values other than the tolerances specified in the standards.

A.2 AT THE DELIVERY POINT

- A.2.1 Sellers shall at their own expense build, equip, maintain, operate and monitor a measuring station near the Delivery Point or arrange for this to be done.

Such measuring station shall be built, equipped, maintained, operated and monitored according to the appropriate sections of PTS 32.32.00.12

Matters not fully provided for in this PTS shall be dealt with in accordance with the relevant local regulations, as provided for in this Sales Agreement or as mutually agreed upon by the Parties.

- A.2.2 The amount of energy delivered at the Delivery Point shall be calculated on a continuous basis from the delivered flow measured on-line and from the Superior (Gross) Calorific Value determined according to A.1.3. The calculation method shall be specified in the Measurement Manual.

- A.2.3 The delivered quantity of natural gas shall be measured and calculated in accordance with PTS 32.32.00.12.

- A.2.4 Buyer's visits to the measuring station at the Delivery Point, the calibrations and checks of the measuring instruments and the procedures for dealing with improper measurements or incorrect operation of the instrumentation shall all be in accordance with PTS 32.32.00.12

- A.2.5 Buyer is entitled at its sole risk and expense to connect a telemetering system to Seller's measurement system at the Delivery Point. Signals to be transferred shall be mutually agreed.

- A.2.6 At the request of Buyer, Sellers shall make available to Buyer at the Delivery Point the flow, pressure and temperature signals measured at the Delivery Point and, at Buyer's request the Relative Density and Superior (Gross) Calorific Value measurement signals for on-line transfer via Buyer's telemetering system.

The inclusion of any other quality factor(s) of the natural gas than those specified in the contract is subject to mutual agreement between Sellers and Buyer. Buyer is allowed to witness the calibration of any part of the measurement system that affects the measurement signals that have been made available.

- A.2.7 Sellers shall give at least forty-eight (48) hours' notice to Buyer of regular sampling (referred to in A.1.5) of natural gas at the Delivery Point for determination by laboratory analysis of the composition and physical properties of the natural gas. Buyer and Sellers shall mutually agree upon the frequency or change of frequency of regular sampling. Buyer may request, with reasons given, spot samples of the natural gas at the Delivery Point, and Sellers shall inform Buyer of the time of sampling. The regular and spot samples will be collected by the appropriate technique according to ISO 10715. Parties may agree on other methods if more appropriate in view of all prevailing circumstances.

The analysis shall include the composition and physical properties of the natural gas as specified in the contract, unless Buyer and Sellers agree otherwise. Sellers shall inform Buyer of all results of all determinations by Sellers of the composition and physical properties of the regular samples. Buyer shall have the right to be represented to witness the sampling and to verify that the composition and physical properties are determined in accordance with the standards specified in A.1.5. Should Buyer although notified not be represented, the sampling and determination by Sellers shall be considered valid until the following sampling and determination.

A.3 AT THE PRODUCTION LOCATION

- A.3.1 Buyer may request spot samples of the natural gas at the production location, but such request will not be made more frequently than once every sixty months unless such requests are made due to a dispute between Buyer and Sellers concerning the quality of the natural gas. The spot samples shall be taken from untreated natural gas at the production location and downstream of the gas/liquid separator(s).

The production of relevant reservoirs during the sampling will be mutually agreed upon. The spot samples will be collected by the appropriate technique according to ISO 10715. Parties may agree on other methods if more appropriate in view of the prevailing circumstances. The analysis shall include the composition and physical properties of the natural gas as specified in the contract, unless Buyer and Sellers agree otherwise. Buyer shall have the right to witness the sampling and to verify that the composition and physical properties are determined in accordance with the standards specified in A.1.5.

A.4 BLACK LIST

This black list refers to the explicit wish of Buyer to be entitled to receive at the Delivery Point measurement signals *beyond the Delivery Point* at the outlet of Sellers' production location(s).

Under specific circumstances and solely at their discretion, Sellers are prepared to meet some or all of Buyer's requests as listed below under a) to d) inclusive, subject to the following provisos:

1. If requested by Buyer, Sellers are prepared to make available at the Delivery Point without any further conditions the flow measurement signal at the outlet of Sellers' production location(s);
2. If requested by Buyer, Sellers shall make available to Buyer any other already installed measurement signal at the outlet of Sellers' production location(s), including temperature and pressure signals, if Buyer has plausibly demonstrated to the sole judgement of Sellers that such signal(s) are necessary for the proper operation of Buyer's facilities and for Buyer to fulfil its obligations under the Gas Sales Agreement;
3. Under no circumstances shall Sellers agree with Buyer that agreed measurement signals from Sellers' production location(s) will be used for monitoring of contract limits.

Signals of measurements at the outlet of *Sellers' production location(s)*

- a) At the request of Buyer, Sellers shall make available to Buyers at the Delivery Point the flow, temperature and pressure measurement signals at the outlet of Sellers' production location(s) for on-line transfer via Buyer's telemetering system.
- b) At the request of Buyer, Sellers shall make available to Buyer at the Delivery Point the requested signals of installed quality measurements at the production location(s) for on-line transfer via Buyer's telemetering system.
- c) If in Buyer's opinion not yet installed quality measurements at Sellers' production location(s) are necessary for the proper operation of Buyer's facilities and for Buyer to fulfil its obligations under the Agreement, then Buyer and Sellers shall jointly decide on the installation of any such measuring equipment. Before implementing such additional measurements Parties shall agree to what extent each Party shall bear the cost of such additional measurement(s) in view of their respective obligations under the Agreement. Sellers shall not unreasonably withhold their concurrence with Buyer's request unreasonably.
- d) Buyer shall be allowed to witness the calibration of any part of the measurement system at the production location that affects agreed measurement signals to Buyer.

APPENDIX B APPLICATION AND UNCERTAINTY OF COMPRESSION FACTOR CALCULATION

In the following overviews the calculation methods for the compression factor are given together with the relevant operating ranges and corresponding uncertainties in order of priority. If the composition of a gas is not within the specified ranges, special testing is required.

B.1 SGERG-88

The SGERG-88 method as described in ISO 12213-3 covers a wide range of gas compositions, pressures and temperatures for the calculation of the compression factors within an uncertainty of 0.1 %. If for some applications an uncertainty of 0.2 % is acceptable, the pressure range can be increased from 100 bar to 120 bar. The following input parameters shall be used for this method together with the pressure and temperature:

- Gross Heating Value,
- Specific Gravity,
- CO₂ [mol %] and
- H₂ [mol %].

The SGERG-88 method shall be used within the range of applications according to the following table. For detailed information ISO 12213-3 shall be consulted.

Uncertainty		%	0.1	0.2	0.1	0.2
Pressure		[bar]	0-100	100-120	0-70	0-60
Temperature		[K]	263-338			
Specific Gravity		[-]	0.55-0.80			
GHV		[MJ/m ³]	30-45			
Composition		[mol %]				
Methane	CH ₄		70-100			
Ethane	C ₂ H ₆		0-10			
Propane	C ₃ H ₈		0-3.5			
2-Methylpropane	C ₄ H ₁₀		0-1.5(*)			
Butane	C ₄ H ₁₀					
2-Methylbutane	C ₅ H ₁₂		0-0.5(*)			
Pentane	C ₅ H ₁₂					
2,2-Dimethylpropane	C ₅ H ₁₂					
Benzene	C ₆ H ₆					
Hexane	C ₆ H ₁₄		0-0.1(*)			
2-Methylpentane	C ₆ H ₁₄					
3-Methylpentane	C ₆ H ₁₄					
2,2-Dimethylbutane	C ₆ H ₁₄					
2,3-Dimethylbutane	C ₆ H ₁₄					
Cyclohexane	C ₆ H ₁₂					
Cyclopentane	C ₆ H ₁₂					
Heptane	C ₇ H ₁₆		0-0.05(*)			
2-Methylhexane	C ₇ H ₁₆					
3-Methylhexane	C ₇ H ₁₆					
Methylcyclohexane	C ₇ H ₁₄					
Toluene	C ₇ H ₈					
Octane (incl.C8+)	C ₈ H ₁₈		0-0.05			
Hydrogen	H ₂		0-10			
Carbon Monoxide	CO		0-3			
Hydrogen Sulphide	H ₂ S		0-0.02			
Helium	He		0-0.5			
Carbon Dioxide	CO ₂		0-9			9-30
Oxygen	O ₂		0-0.02			
Nitrogen	N ₂		0-20		20-50	0-20
Water vapour	H ₂ O		0-0.015			

(*) Represents the mol % for the total ('+' = sum) of components concerned.

B.2 AGA 8-92DC

The AGA 8-92DC method as described in ISO 12213-2 covers a wide range of gas compositions, pressures and temperatures for the calculation of the compression factors within an uncertainty of 0.1 %. The following input parameters shall be used for this method: absolute pressure, absolute temperature and the complete molar composition of the gas as described in the ISO 12213-2, sub-clause 4.3.

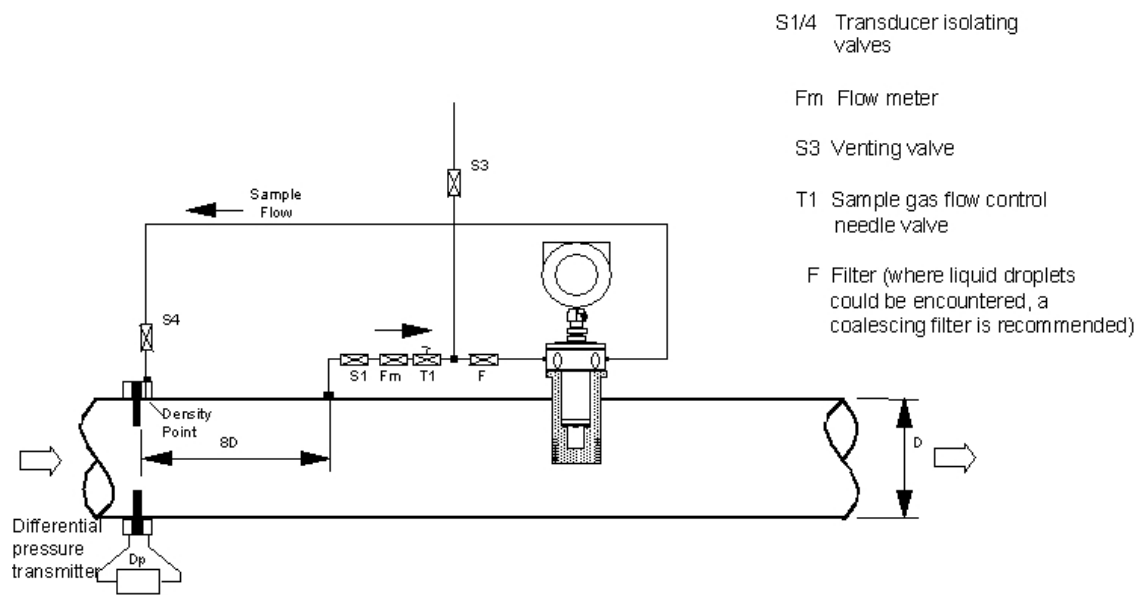
The AGA 8-92DC method should be applied to gases that are not covered by the operating ranges as specified for the SGERG-88 method and within the range of applications according to the following table. For detailed information the ISO 12213, Part 2 shall be consulted.

Uncertainty		0.1				0.2			0.1	0.2	0.1
Pressure	[bar]	0-135	0-185	0-235	0-300	135-300	185-300	235-300	0-120	120-200	0-300
Temperature	[K]	275-350	280-350	285-350	290-350	275-280	280-285	285-290	263-338	263-338	263-338
Specific Gravity	[-]	0.55-0.80									
GHV	[MJ/m ³]	30-45									
Composition	[mol %]										
Methane	CH ₄					70-100					
Ethane	C ₂ H ₆	0-10							0-9		
Propane	C ₃ H ₈					0-3.5					
2-Methylpropane	C ₄ H ₁₀										
Butane	C ₄ H ₁₀					0-1.5(*)					
2-Methylbutane	C ₅ H ₁₂										
Pentane	C ₅ H ₁₂										
2,2-Dimethylpropane	C ₅ H ₁₂					0-0.5(*)					
Benzene (max 0.05)	C ₆ H ₆										
Hexane	C ₆ H ₁₄										
2-Methylpentane	C ₆ H ₁₄										
3-Methylpentane	C ₆ H ₁₄										
2,2-Dimethylbutane	C ₆ H ₁₄					0-0.1(*)					
2,3-Dimethylbutane	C ₆ H ₁₄										
Cyclohexane	C ₆ H ₁₂										
Cyclopentane	C ₆ H ₁₂										
Heptane	C ₇ H ₁₆										
2-Methylhexane	C ₇ H ₁₆										
3-Methylhexane	C ₇ H ₁₆					0-0.05(*)					
Methylcyclohexane	C ₇ H ₁₄										
Toluene (max 0.02)	C ₇ H ₈										
Octane (incl.C8+)	C ₈ H ₁₈					0-0.05					
Hydrogen	H ₂					0-10					
Carbon Monoxide	CO					0-3					
Hydrogen Sulphide	H ₂ S					0-0.02					
Helium	He					0-0.5					
Carbon Dioxide	CO ₂	0-9							0-20		0-8
Oxygen	O ₂					0-0.02					
Nitrogen	N ₂	0-20							0-14		14-50
Water vapour	H ₂ O					0-0.02					

- NOTES:
1. The concentration of Benzene shall not be larger than 0.05 mol %
 2. The concentration of Toluene shall not be larger than 0.02 mol %

(*) Represents the mol % for the total ('+' = sum) of components concerned.

APPENDIX C LINING UP OF DENSITOMETERS IN ORIFICE METER RUNS (POCKET STYLE)



APPENDIX D ANALYTICAL METHODS

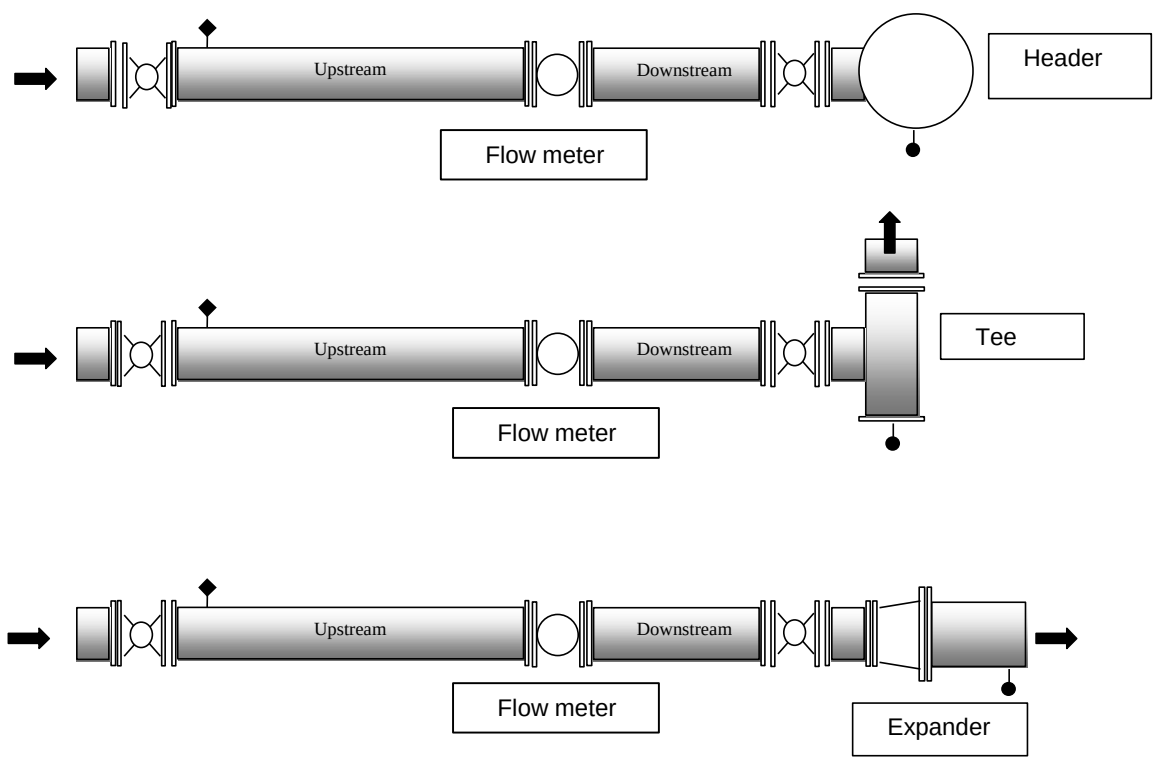
Type of determination	Purpose	Standard	Remarks
Fluid composition	To establish various properties inferred from compositional data.	ISO 6974:2001 part 3	Not to be used if argon is expected in significant amounts. Argon interferes with oxygen.
Water content	• Limit property • To infer water dew point for known gas.	ISO 10101 and pertaining sub sets	
Hydrocarbon condensates	Limit property	ISO 6570 and pertaining sub sets	
Sulphur compounds and total sulphur	Limit property	ISO 19739 ASTM D 6667	H ₂ S is considered to be the only inorganic sulphur compound in natural gas. Method includes H ₂ S, COS and RSH.
Mercury	Limit property	ISO 6978	
Oxygen	Limit property	ISO 6974-3	

APPENDIX E INFERRED PROPERTIES

Property	Symbol	Method	Purpose	Remarks
Molar mass	MM	ISO 6976	Calculate density	
Compressibility	Z_o	ISO 6976	Calculate density and calorific value	
Wobbe Index	WI	ISO 6976	Limit property	
Relative Density	RD	ISO 6976	Calculate volume and WI at specified condition	
Superior Calorific Value	GHV	ISO 6976	Calculate energy (preferred method)	Same as gross heating value GHV.
Superior Calorific Value	GHV	Inferred from WI and RD	Calculate energy (not preferred)	The GHV may be calculated from the Wobbe Index (WI) according to {4.5.4.1} and the Relative Density (RD) of the gas according to {4.5.3.2} if the Wobbe Index and the Relative Density are measured by means of on-line analysers (not preferred)
Superior Calorific Value	GHV	Correlation	Calculate energy (not preferred)	For mixtures of natural gas streams from two or more different sources the GHV can be determined on the basis of the correlation between the Gross Heating Value and the Relative Density. If, over the whole operating range, this correlation is within the specified accuracy, the GHV can be derived from the Relative Density, measured as described in {4.5.3.2}, by means of interpolation.
Water dew point	WDP	ISO 18453	Limit property	

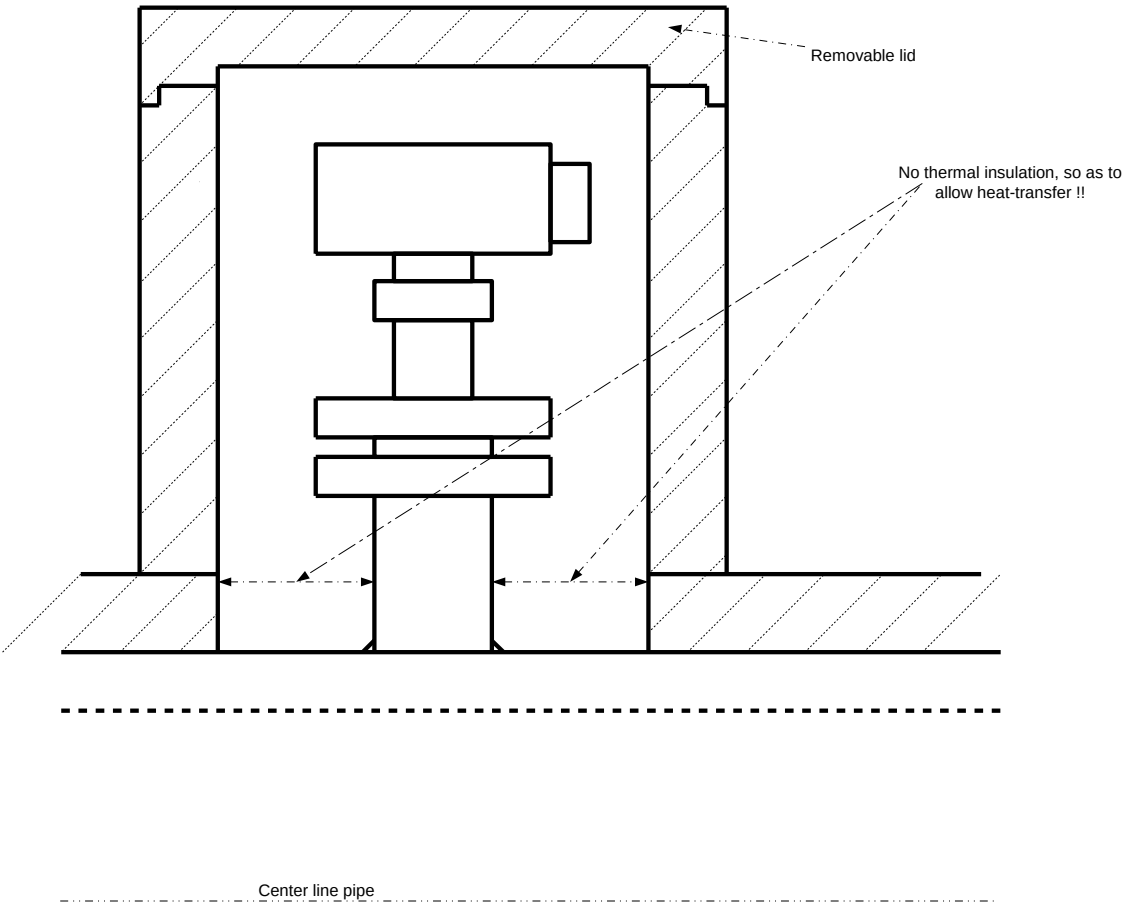
Property	Symbol	Method	Purpose	Remarks
Isentropic exponent	k	KSLA report AMER 84.039	Infer thermodynamic properties	The Cp value should be calculated according to 'The properties of Gases and Liquids' (table 5-10 and 5-11), using the pseudo-reduced pressures and temperatures from KSLA report AMER 84.039. After calculation of the Cp value, the isentropic exponent k shall then be calculated as the average between k and k' according to 'Physical properties of natural gases' (section 2.7.2).
Viscosity	v	- Fluid Flow Service Handbook' (chapter 2A) - NPL report CHEM 53 (method IX-B) - HTFS handbook (paragraph 2.2)	Calculate Reynolds number	The kinematic viscosity of each component should be calculated according to the 'Heat Transfer and Fluid Flow Service Handbook' (chapter 2A). For the gas mixture the viscosity at moderate pressure and operating temperature shall be calculated according to NPL report CHEM 53 (method IX-B). To allow for the effect of pressure a correction shall then be calculated according to the HTFS handbook (paragraph 2.2).
Compression factor	Z	ISO 12213	Infer operating density	The calculation of the compression factor Z of natural shall be based on either of the following methods: - molar composition as per ISO 12213-2; - physical properties as per ISO 12213-3. With reference to pressure and temperature: - Use actual pressure and temperature when on-line composition is available or when spot sample is taken. - Use average temperature and pressure during the period of the flow proportional sampling.

APPENDIX F SELF DRAINING POSITION OF FLOW METERS



APPENDIX G

THERMAL INSULATION FOR DENSITOMETERS
AND TEMPERATURE SENSORS



APPENDIX H TYPICAL EXAMPLES

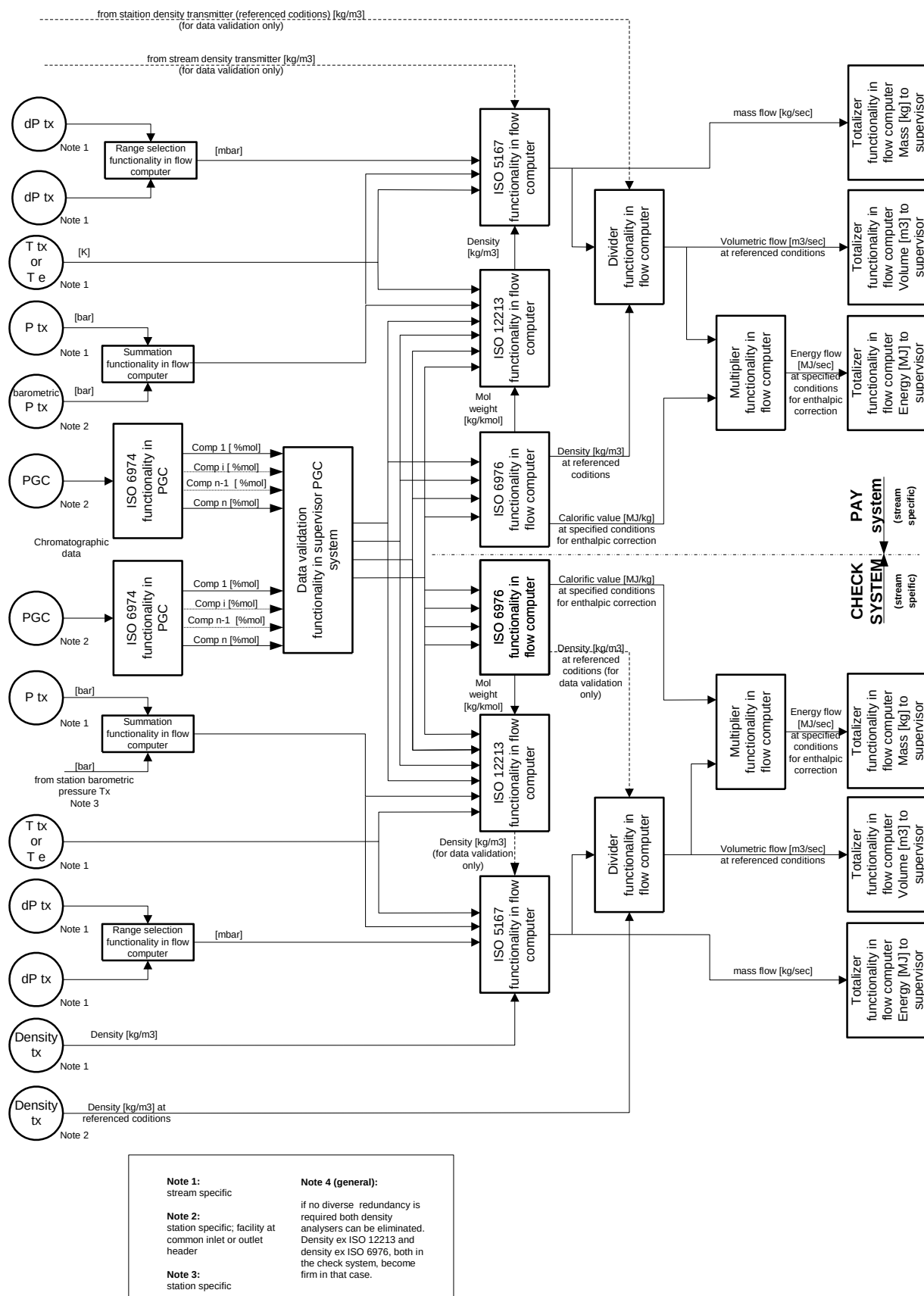
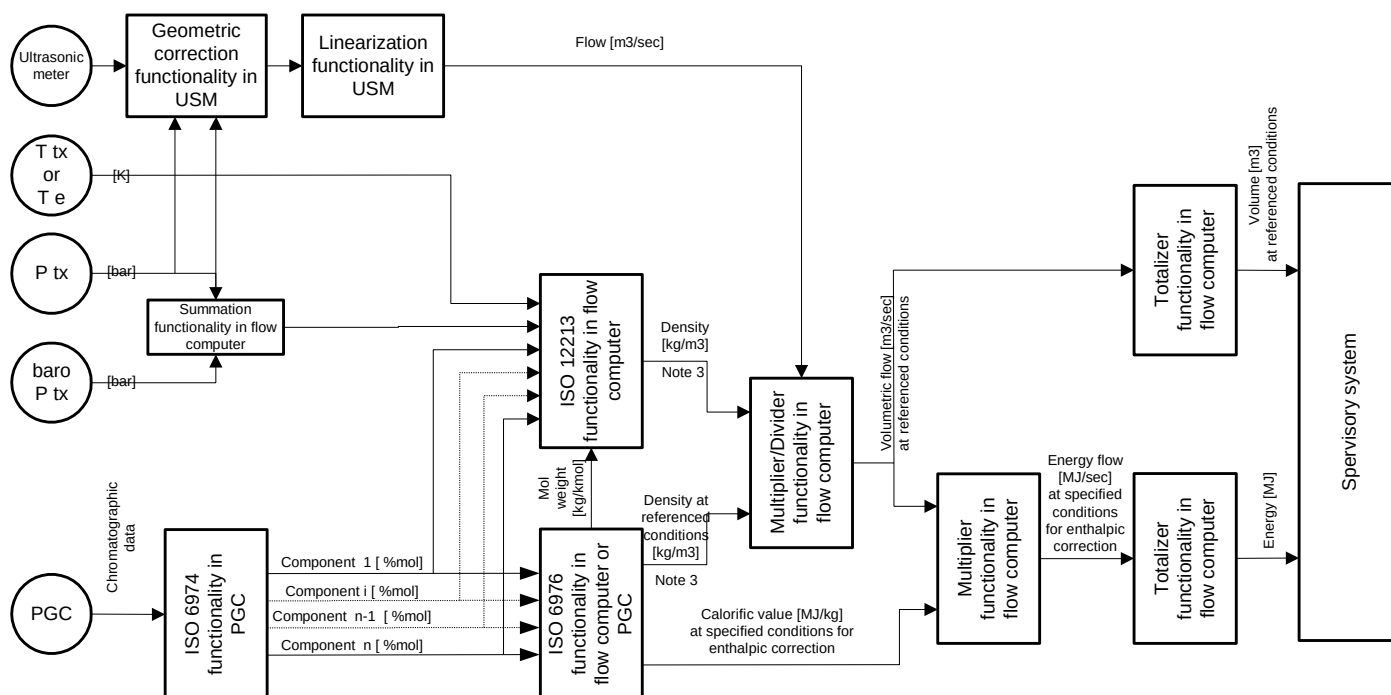


Figure H.1 Function diagram for orifice flow meter for gas with variable composition - Diverse redundancy



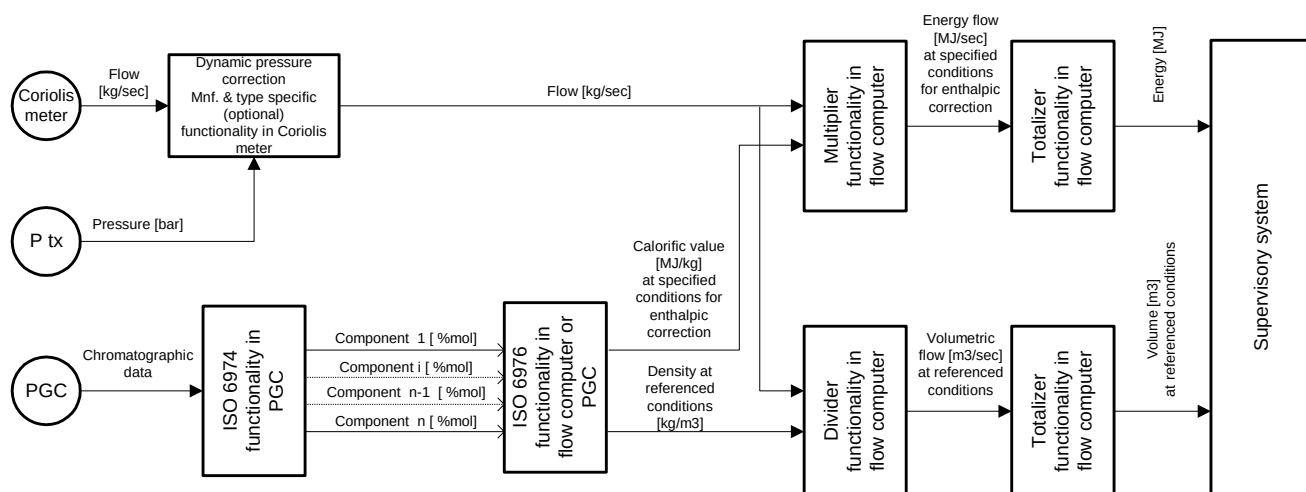
Note 1 (general):
PGC not required in case of constant composition. Calorific value and density at referenced conditions to be calculated from fixed entry for gas composition in flow computer (subject to updating as per para. 4.6, Group 1c.).

Note 2 (general):
PGC not required if only the volumetric flow at referenced conditions is to be reported. A relative density analyzer should be connected instead.

Note 3:
Alternatively density and density at referenced conditions may be replaced by compressibility factor under operating conditions and under referenced conditions and respectively.

Note 4 (general):
No redundancy shown.

Figure H.2 Function diagram for ultrasonic flow meter for gas with variable composition



Note 1 (general):

PGC not required in case of constant composition. Calorific value and density at referenced conditions to be calculated from fixed entry for gas composition in flow computer (subject to updating as per para. 4.6, Group 1c.).

Note 2 (general):

PGC not required in case only the volumetric flow at referenced conditions is to be reported. A relative density analyzer should be connected instead.

Note 3 (general):

Dynamic pressure compensation depends make, style and size and on the variability of the operating pressure. E.g. it is not a requirement in case of regulated station pressure.

Note 4 (general):

Dynamic temperature compensation is usually integral part of the meter

Note 5 (general):

No redundancy shown.

Figure H.3 Function diagram for Coriolis mass flow meter for gas with variable composition

APPENDIX I EXAMPLE OF MEASUREMENT SYSTEM ARCHITECTURE

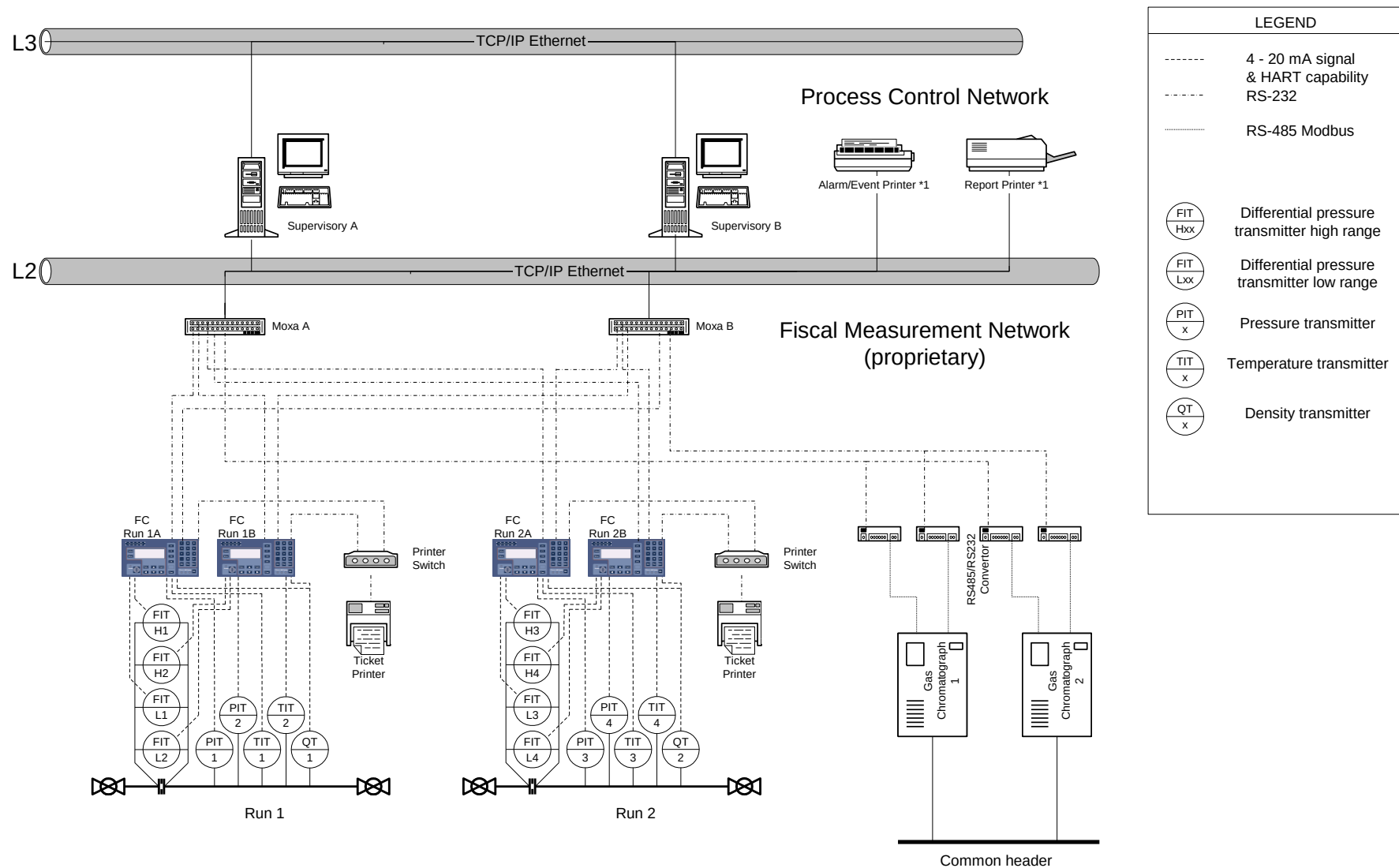
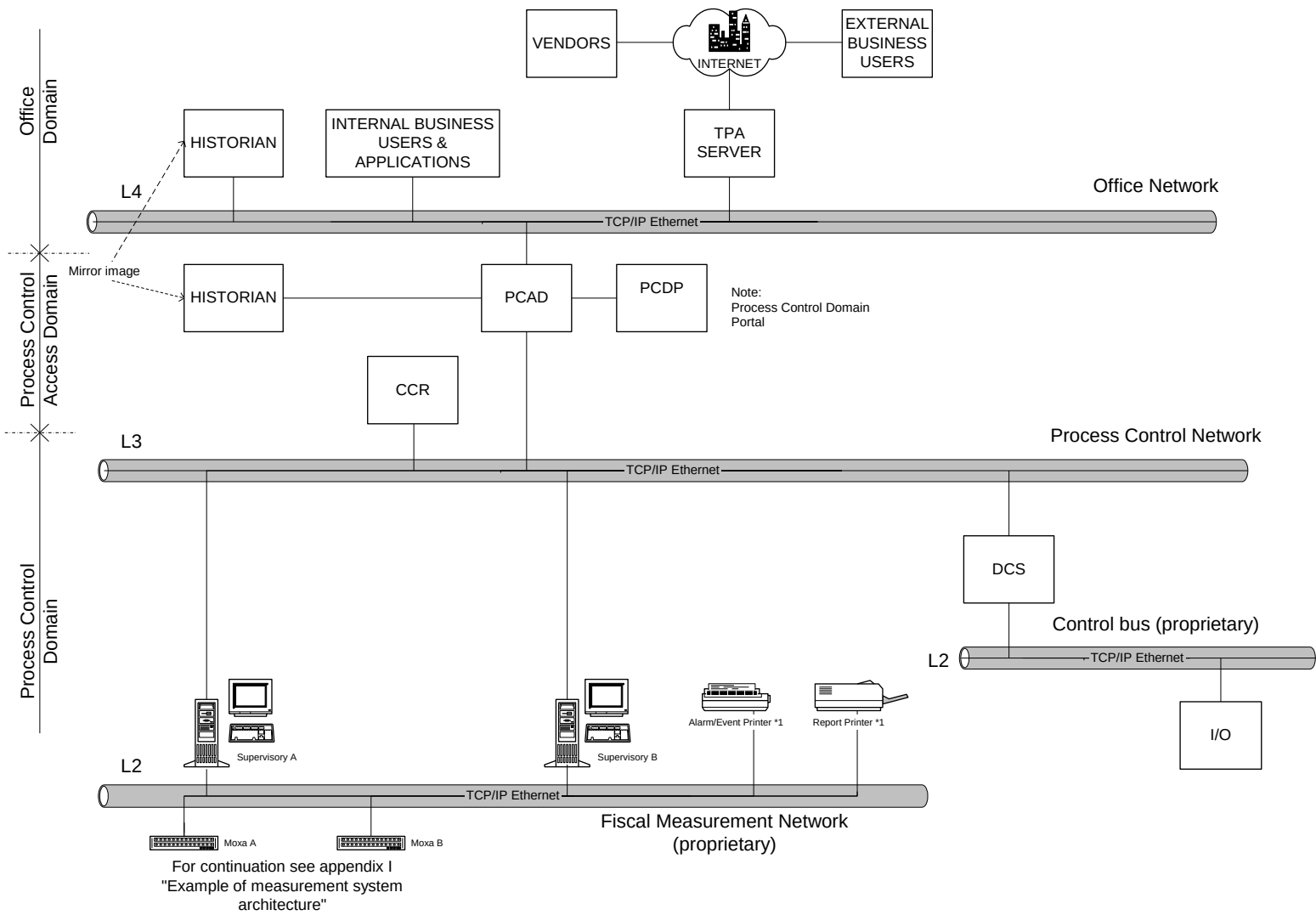
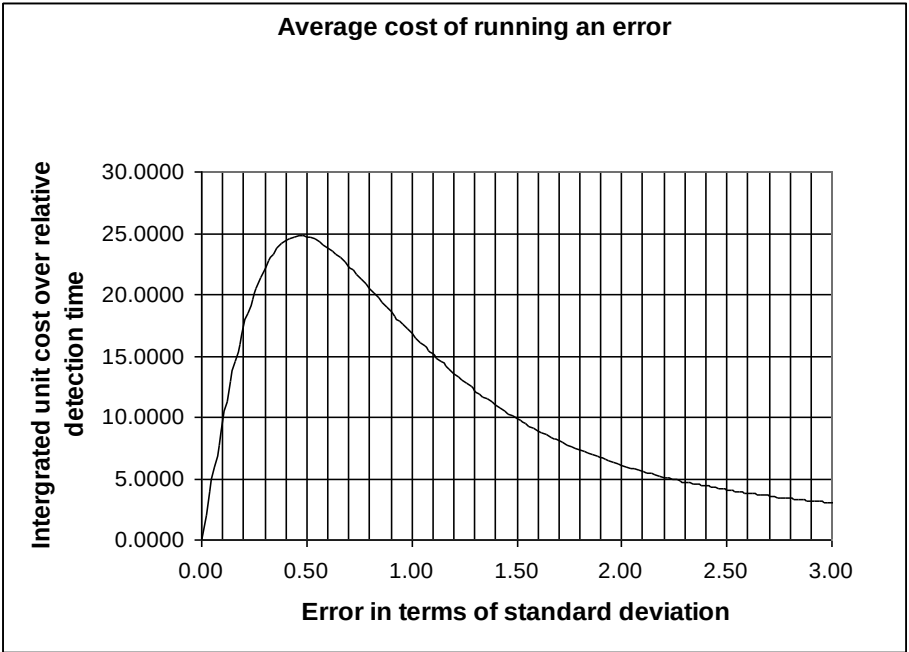
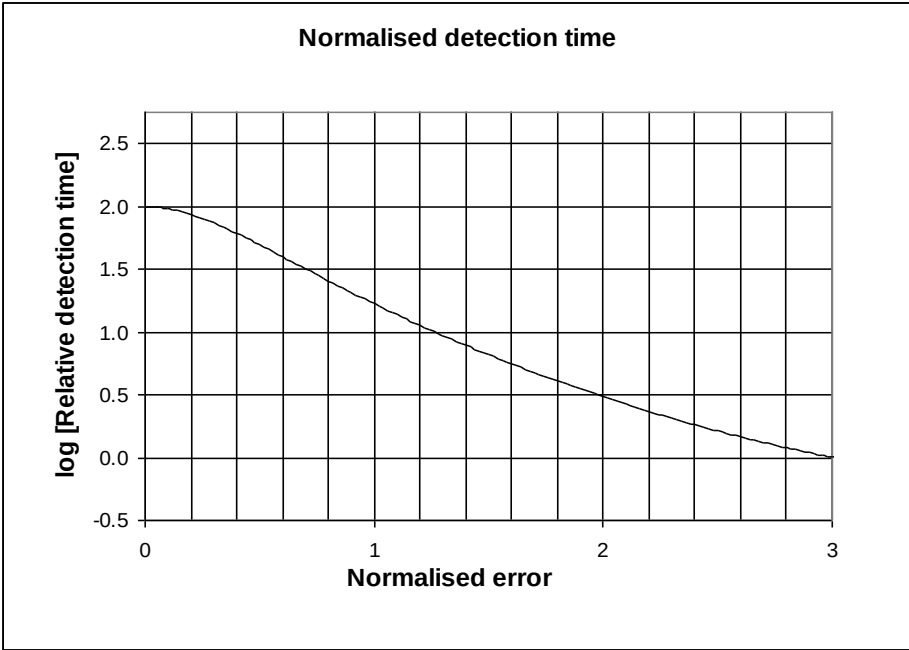


Figure I.1 Dual run orifice metering station with full redundancy

APPENDIX J DACA ARCHITECTURE



**APPENDIX K AVERAGE VALIDATION FREQUENCY BEFORE DETECTING AN ERROR
AND THE RESULTING ERROR VOLUME**



The above applies to sample size = 1 and a significance level of testing of 1 % (when applying simultaneously four rules of intervention each with a significance level of 0.27 %)

Example:

Standardised error [-]	ARL [-]	Error volume [-]
0.5	49.49	24.74
1	16.83	16.83
2	3.04	6.08
3	1.01	3.02

E.g.:

Time between validations	15 days
Average flow rate	10 t/day
Warning Limit	0.6 t/day
Estimated SD	0.3 t/day

Standardised error [-]	Error [t/days]	ARL [days]	Error volume [tons]	Error volume [production days]
0.5	0.15	742.35	111.35	11.14
1	0.3	252.45	75.74	7.57
2	0.6	45.60	27.36	2.74
3	0.9	15.15	13.64	1.36

The Standardised error volume equals standard deviation times period in between validation; for the current case:

$$\text{Standardised error volume} = 0.3 \text{ [t/day]} * 15 \text{ [day]} = 4.5 \text{ [t]}.$$

The average error (or the cost to run an error) can be calculated from the product:

$$\text{Error} = \text{Standardised error volume} * \text{Error volume}$$

e.g. for Standard error = 3:

$$\text{Error} = 4.5 \text{ [t]} * 3.02 = 13.68 \text{ [t]} \text{ (deviation due to truncation of original data)}$$