Recommended Practice for the Design, Testing, and Operation of Subsea Multiphase Flow Meters

API RECOMMENDED PRACTICE 17S
SECOND EDITION, XXXX 202X

Ballot Draft September, 2021

AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

Users of this standard assume all responsibility for ensuring safe handling and compliance with all applicable laws regarding radioactive materials.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Classified areas may vary depending on the location, conditions, equipment, and substances involved in any given situation. Users of this Recommended Practice should consult with the appropriate authorities having jurisdiction.

Users of this standard assume all responsibility for ensuring safe handling and compliance with all applicable laws regarding radioactive materials.

Foreword

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 200 Massachusetts Ave, NW, Washington, DC 20001. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 200 Massachusetts Ave, NW, Washington, DC 20001.

Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Ave, NW, Washington, DC 20001, standards@api.org.

Contents

Page

To be developed prior to publication

Introduction

Multiphase flow is a complex fluid phenomenon presenting many observable and distinctly different spatial patterns. These flow regimes are a function of fluid composition, velocity, flow orientation, geometry, and operating conditions. This creates a greater number of variables requiring measurement than single phase flow. Multiphase flow meters (MPFMs) use a combination of measurement principles and software models to delineate component parameters of the specific flow condition being measured. These elements are further combined to simultaneously resolve the total flow state and inform the user of the flow rate of each phase.

This document is intended for use by persons familiar with the principles of multiphase flow and the technologies used to measure its constituent parts. This Recommended Practice (RP) outlines a strategy for the correct sizing, specification, integration, and testing of MPFMs to maximize their performance for a specific application. Measurement techniques used in MPFMs are complex and only brief descriptions are included herein. It is recommended that the reader be acquainted with API *MPMS* Ch. 20.3 which describes in detail the technologies of multiphase metering, calibration, measurement uncertainty, and operation. API *MPMS* Ch. 20.3 referred to in this document wherein the reader should seek further information or best practice. API *MPMS* Ch. 20.3 is not specific to subsea applications.

Various expertise is required throughout the life cycle of the MPFM to achieve optimal performance. Due to the number of interfaces and design parameters a strategy is required to ensure the meter is appropriate for its specific application. This RP acts as a guide outlining key parameters of the strategy that quantifies meter performance based on application, sizing data, technology constraints, and performance checks through supplier, independent facilities, and in situ tests.

There is a distinct separation in ownership between MPFM specification, testing, and installation versus commissioning and operation. This RP addresses equipment design in Section 4 to Section 8 and commissioning/ operational issues in Section 9 and Section 10. To ensure accuracy and functionality of the MPFM, a coherent handover between equipment design and long-term operations is required. Several operational issues are addressed in this RP, as well as metering methodologies, but these are only intended as suggested interfaces to be addressed. This RP should be used in combination with appropriate measurement and operational standards to develop a comprehensive strategy for the design, installation, and long-term operation of an MPFM.

Recommended Practice for the Design, Testing, and Operation of Subsea Multiphase Flow Meters

1 Scope

This document provides recommendations for the sizing, specification, system integration, testing and operation of in-line subsea multiphase flow meters (MPFMs) for measurement of full stream, multiphase flow for well testing, allocation measurement, fiscal measurement, well management, and/or in flow assurance applications. This Recommended Practice (RP) includes wet gas flow meters as a subset of MPFMs.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards* (*MPMS*), Chapter 20.3, *Measurement of Multiphase Flow*

API Specification 6A, *Specification for Wellhead and Tree Equipment*

API Specification 17D, Design *and Operation of Subsea Production Systems—Subsea Wellhead and Tree Equipment*

API Standard 17F, *Standard for Subsea Production Control Systems*

API Recommended Practice 17N, *Recommended Practice for Subsea Production System Reliability and Technical Risk Management*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purpose of this document the following terms and definitions apply. For consistency, these are identical to those used in API *MPMS* Ch. 20.3.

3.1.1
accuracy
The degree of conformity of a measurement to a known standard for the unit of measurement.

3.1.2
actual conditions
measurement conditions
line conditions
flowing conditions
Conditions of pressure and temperature of the fluid at the point where fluid properties or flows are measured.

3.1.3
allocation
The mathematical process of determining the proportion of produced fluids from individual entities (zones, wells, fields, leases, or producing units) when compared to the total production from the entire system (reservoir, production system, and gathering systems) in order to determine value or ownership to attribute to each entity.

3.1.4
availability
The ability of an item to be in a state to perform a required function under given conditions at a given instant of time, or in average over a given time interval, assuming that the required external resources are provided. High availability can be achieved through high reliability (equipment rarely breaks down) or maintainability (when equipment breaks down it is repaired quickly) or a combination of both.

3.1.5
calibration
The process or procedure of adjusting an instrument, such as a meter, so that its indication or registration is in satisfactorily close agreement with a reference standard.

3.1.6
fiscal
Of or relating to financial matters. With respect to measurement, those that have a financial impact on custody transfer, allocation, royalty, or taxation.

3.1.7
fiscal measurement
Measurement systems and procedures required to determine a quantity that may be expected to have a direct financial impact to affected parties. Contrast with custody transfer measurement (as defined in API Manual of Petroleum Measurement Standards [MPMS] Ch. 1, Second Edition).

3.1.8
flow regime
The physical geometry exhibited by a multiphase flow in a conduit; the geometrical distribution in space and time of the individual phase components, i.e., oil, gas, water, any injected chemicals, etc. For example, liquid occupying the bottom of a horizontal conduit with the gas phase flowing above.

3.1.9
phase
A term used in the sense of one constituent in a mixture of several. In particular, the term refers to oil, gas, water, or any other constituent in a mixture of any number of these.

3.1.10
pressure-volume-temperature
PVT
The phase behaviour and physical properties of hydrocarbon fluids at pressure and temperature.

NOTE Included are relative phase volume, gas-oil ratio (GOR), bubble point and hydrocarbon dew point, density, formation volume factors, compressibility, viscosity, and composition.

3.1.11
redundancy
Existence of more than one means to perform a required function. For example by duplicating items.

3.1.12
reliability
The ability of an item to perform a required function, under given conditions of production, environment, and usage, for a required time interval.

3.1.13
sampling
The collection of production samples which may be taken topside or subsea and at actual or standard conditions.

3.1.14
uncertainty
The parameter, associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand (the value being measured). See ISO/IEC Guide 98-3:2008 for a more complete definition.

3.1.15
validation
The process that substantiates whether technical data and engineering models are within the required range of accuracy, consistent with the intended application.

3.1.16
verification
The process or procedure of comparing an instrument to a reference standard to ensure its indication or registration is in satisfactorily close agreement, without making an adjustment.

3.1.17
virtual meter
Predictive well rate modelling (virtual flow metering system) is a well rate determination method that utilizes computer-based predictive flow modelling techniques in conjunction with real-time well/process sensor and instrumentation data for continuous multiphase well rate estimation.

3.1.18
well test
The execution of a set of planned data acquisition activities to broaden the knowledge and understanding of fluid phase rates and hydrocarbon properties of a producing well from a reservoir.

3.1.19
well trajectory
The trajectory of production parameters displayed by a well over time, sometimes shown in a flow or composition map.

3.1.20
wet gas
A subset of multiphase flow in which the dominant fluid is gas and in which there is a presence of some liquid.

3.2 Acronyms and Abbreviations

For the purposes of this document, the following acronyms and abbreviations apply.

DP	differential pressure
EFAT	extended factory acceptance test
ESS	electrical stress screening
FAT	factory acceptance test
FMECA	failure modes, effects, and criticality analysis
GOR	gas-oil ratio
MPFM	multiphase flow meter
MTBF	mean time between failure
PCU	Power and communications unit
PSL	production specification level
PVT	pressure-volume-temperature
RIT	receive inspection test
ROV	remotely operated vehicle
RSO	Radiation Safety Officer
SCM	subsea control module
SIT	system integration test
STP	standard temperature and pressure

4 Design Criteria

4.1 Operational Philosophy

The operator shall provide an operational philosophy that includes the following:

a. Intended use of the MPFM data and the frequency of data transmission & accumulation
b. Performance requirements for the MPFM including uncertainty, repeatability and reproducibility. ISO/IEC Guide 98-3:2008 (GUM:1995) and ISO/TR 5168:2005 can be used to help understand uncertainty, repeatability, and reproducibility.
c. The number of wells to be measured with each MPFM.
d. Location of the MPFM within the subsea architecture.
   The location of the MPFM is dependent on its intended application and the overall field layout. For continuous measurement from individual wells, the MPFM may be located within a tree as part of a choke bridge/flow module/retrievable module, or as part of a jumper. Subsea MPFMs can typically be configured to measure multiple wells intermittently. In this case, the MPFM can be placed in a manifold with the capability to route the flow from individual wells to the MPFM.

e. Access requirements for retrieving and installing MPFMs and/or MPFM electronic modules.
f. Valve requirements (including operational reliability) for routing different wells through a single MPFM.
g. Reliability requirements for the MPFM.

h. Requirement to verify and/or calibrate the MPFM accounting for the uncertainty of any available in-situ verification methods - e.g. test separator or computational well model and availability of samples.
i. Methods of accounting correctly for gas lift or washwater injection upstream of the MPFM, and the effect on the salinity of produced water.
j. Production profile of the well(s) to be measured.
k. Anticipated operational and flow-assurance concerns as well as PVT characterization.
l. Details of any chemical injection regime (see section 4.8)

The supplier and operator together shall specify

I. Methods of verification of MPFM capability to measure fluid flows within the specified uncertainty range, throughout field life (see Performance Testing, Section 8.5).
II. Methods of determining impact of change in fluid composition on performance.
NOTE - Particular care is required for applications where hydrocarbon composition is expected to change over time, or where salinity of water is expected to change over time.
III. Methods of continuously monitoring MPFM performance and identifying anomalous readings.
IV. Where production profile spans more than one MPFM performance range or size, and consider designing for more than one MPFM to meet the performance and production objective noting that some MPFMs are designed for liquid-dominant or gas-dominant multiphase flow (i.e., not for the full range of GVF).

4.2 MPFM functional Specification and operating envelope

NOTE 1 - MPFMs use various measurement technologies to ascertain different parameters regarding the flow stream, there is no one standard technology. API *MPMS* Ch. 20.3 provides an overview of various principles and measurement technologies.

a. A functional specification shall be provided by the supplier, which shall:

   i. Describe the measurements provided by the MPFM.
   ii. Provide an overview of the methodology used by the MPFM, including specific technologies used.
   iii. Clearly describe any required inlet and outlet piping configuration.
   iv. Outline how constituent flow rates are determined from the meter in-situ physical measurements, flow models, and configuration input parameters.
   v. Clearly describe all required inputs, including specific fluid property data needed for the meter to perform to specification.
   vi. Clearly illustrate the elements of the flow computation process.
   vii. Form the basis of meter sizing, performance testing, verification, and uncertainty determination for the MPFM.
   viii. Clearly document the process for calibration of the MPFM, including proposed methods for obtaining calibration parameters required.
   ix. describe the intended relationship between sensor functionality and flow model versus expected performance. This demonstrates that the measurement technology is capable of achieving a specific uncertainty for a particular flow regime based on reliable process information.

b. The functional specification may also include a quantification (via a sensitivity study or similar) of how uncertainty in input variables impacts the uncertainty in output variables.

   NOTE 2 - All required inputs to the MPFM will have an inherent degree of uncertainty. The process of determining the impact of this uncertainty on MPFM performance is unique to each technology. Typically, this uncertainty is not addressed within the MPFM specification. Depending on data available for the fluid and application sensitivity to MPFM uncertainty, a sensitivity analysis to assess the impact of an error in MPFM configuration on overall measurement uncertainty may be completed.

c. The operating envelope and expected performance(s) shall be specified over the production profile by the supplier.
d. The impact of operational and flow-assurance concerns as well as PVT characterization shall be documented by the supplier.

4.3 Governing Specification

The design, manufacture, and factory acceptance testing of MPFMs shall adhere to the following standards in addition to vendor, local government, and project specific requirements:

— API 6A

— API 17D

— API 17F

— API 17N

4.4 Standard Meter Design Parameters

MPFMs shall be designed in accordance with API 17D service conditions and product specification levels.

Relevant information for meter specification includes pressure rating; temperature classification; sour service designation and marking; and product specification level.

As a minimum, the following shall be provided to the meter supplier:

a. desired/required design life;

b. meter location, orientation, and expected piping configuration;

c. water depth;

d. production profile detailing case flow rate estimates for oil, water, and gas (see annex A);

e. expected flowing pressure and temperature for various production cases over the meter life including shut-in pressure and temperature, as well as flowing pressure and temperature at the meter location for various production cases (see annex A);

f. expected sand production rates;

g. potential changes in production cases due to enhanced oil recovery techniques or water breakthrough;

h. field life, i.e. expected meter life without planned maintenance accounting for erosion, corrosion, fatigue, and all associated failure modes;

i. any specific shutdown/start-up scenarios that may effect the MPFM including injection of hydrate inhibitor, variance in gas lift, changes in water injection, and local injection of other chemical inhibitors;

j. Material requirements, including any provision for sour service;

k. Potential for wax/asphaltenes;

l. interfaces with the production system including material interfaces, control system, power, and equipment retrieval.

NOTE Annex A provides a multiphase flowmeter generic datasheet.

All relevant flow assurance studies should be made available to the meter manufacturer where possible, including the system sensitivity study referenced in 4.2. This may include fluid information for PVT and equation of state modelling. Changes to the production profile and salinity due to water breakthrough, increased gas lift, and commingling from other wells and production zones can affect both meter models and configuration parameters.

4.5 Meter Sizing

MPFMs are sized at actual (line, or operating) conditions.

a. expected well profiles and operating pressures / temperatures shall be provided for sizing the MPFM at actual (operating) conditions.

b. Equivalent flowrates at standard conditions should be provided if requested by the supplier.

NOTE 1 It is expected that multiple production cases are provided which reflect the progression of the well(s) lifetime and specify the anticipated flow of oil, water and gas at a single operating point. It will be helpful to avoid providing a summary of multiple operating points as a range. For example, if a field has a high GOR which declines and a low initial Water Rate that increases, sizing the meter for individual operating points throughout field life leads to a better MPFM selection than sizing for maximum GOR, maximum water cut and maximum flowrate simultaneously - a scenario that in practice may be impossible for the well.

c. If the MPFM is to be used for metering multiple wells the sizing data should include details for each well.

d. Erosion limits shall be addressed as part of the sizing study.

e. The meter application and operational philosophy shall be reviewed when selecting operating points to size the MPFM.

f. Supplier shall specify the expected operating uncertainty of the MPFM for each of the sizing cases specified.

NOTE 2 Determining the meter size required for an application as early as possible facilitates timely integration of the unit into the subsea architecture. The unit size and retrievability affects suitable locations, power and communication interfaces, tree and/or manifold layouts, and operational philosophies.

NOTE 3 Providing data for all wells in a field can enable interchangeability and a common spares program.

4.6 Meter application and performance evaluation

a. Supplier shall provide a meter application and performance evaluation which describes:
   - application requirements,
   - available flow data,
   - required sizing data,
   - expected measurement uncertainty
   - a test plan that verifies performance.

Each of the steps involved in flow measurement have either an inherent uncertainty or range of probable values. Overall evaluation of meter performance should consider both the quantifiable uncertainty of the equipment and the reliability of the system data. Further information on flow meter uncertainty is available in API *MPMS* Ch. 20.3.

b. The meter application and performance evaluation should evaluate the effect of the physical and system factors outlined in Table 1 on performance.

c. Appropriate performance testing should be used to validate assumptions made by the meter for the chosen application.

Table 1—Considerations for meter application and performance evaluation

Item	Notes

Well trajectory/measurement envelope	— There is inherent uncertainty in the production profiles used to develop the well trajectory and measurement envelope. This can form an important aspect of overall uncertainty if the meter is expected to operate across multiple flow regimes. — Clearly quantifying the expected ratios of liquid to gas can be used to set operational targets for sensors, and associated flow models and computations.
Sensor calibration	— Each sensor used in the flow parameter measurement has its own uncertainty, repeatability, inherent drift, and life expectancy. — The fundamental measurement of flow parameters is affected by the combined limitation of the sensors and appropriate data are required to quantify both individual and collective contributions to uncertainty. — The turndown of the sensors used in an application should be consistent with the projected well trajectory and operate across all the flow regimes encountered.
Meter location	— The orientation of the meter in the flow path may have an effect on the flow regime and hence the meters flow model. Some meters have a preferred installation orientation and an as-built reference should be considered as part of uncertainty. — Adjacent discontinuities both upstream and downstream of the meter can create flow instability at the meter which may affect the meters flow model. The effects of installed geometries should be considered as part of uncertainty and differs from meter to meter.
Assumptions of flow model	— Meters typically use a flow model to determine the specific flow regime being measured. The flow models coupled with the actual measured flow parameters constitute a fundamental element of the phase computation. Interfaces between different flow regimes are not distinct and it is common for incorrect regimes to be used. The sensitivity of the calculation to regime selection is an important aspect of performance. Sometimes flow regimes are enforced through flow conditioning to match the expectation of a flow model.
Composition	— Fluid compositional factors such as salinity, conductivity, permittivity and viscosity can directly affect the usability of certain technologies. The variation in these parameters across the well trajectory should to be considered. — Injected fluids like chemical inhibitors can affect the composition of the flow being measured and should be quantified as part of uncertainty. — Commingling of fluids with distinct properties from wells or multiple completions / zones from the same well has a distinct influence on meter performance. Commingling plans should be defined and quantified for different mixing ratios.
Actual to standard conversion	— Computation of individual phase flow rates typically involves the measurement of a series of flow parameters, a model to determine the flow regime, a detailed composition of the fluid being measured and an algorithm to determine flow rates at operating temperature and pressure. Generally, flow rates at standard temperature and pressure are required and therefore a final conversion is required. This conversion uses compressibility and saturation equations to establish the final oil, gas and water volume at standard temperature and pressure (STP). — The phase behavior model used for conversion of gas and liquid volumes from actual to standard conditions should be suitable for the operational range of the meter. Most models show inconsistencies across their usable range and there are competing solutions including virial algorithms, modified cubic equations (Peng-Robinson), and multiparameter equations of state. — As the fluid depressurizes the evolution of gas from the liquid phase should be accounted for properly. Similarly liquid drop out in wet gas system should be accounted for. — Conversion should take into consideration the separation (multiple flash) processes from reservoir to sales point.

Software and communication	— Within the meter the software responsible for managing the calculation of flow rates should be qualified to ensure no computational errors are introduced. The uncertainty of software errors should be quantified across the entire operational range — Due to the volume of data recorded by the meter, the uncertainty in transferring this information to the computational software should be considered. This software may not necessarily be local to the measurement system. Additionally, breakdowns in communication throughout the system generates inconsistent data for unsteady flows.

4.7 Mechanical Design

4.7.1 General

The supplier should ensure a comprehensive design file is available for the MPFM. Based on the design parameters detailed throughout Section 4 calculations should be completed for the following.

a. Design life should be determined based on mechanical and electrical reliability studies including mean time between failure (MTBF) data on electronics,

b. Pressure containment calculations shall be in accordance with API 17D.

c. The MPFM should be designed to API standard temperature ratings. This should include supporting calculations or qualification data for seals, sensors, controls, pressure containing materials, dynamic components, pressure balancing systems (contained fluids), and connectors used for retrieval components.

d. The design should define storage conditions on land and sea including environmental temperatures, atmosphere, and vibration.

e. Lifting and handling points should be reviewed for suitability based on project/integrator lifting plan.

4.7.2 MPFM Piping Requirements

Piping configuration upstream and downstream of the MPFM shall be in accordance with manufacturer guidelines and system integration requirements.

Supplier shall review the potential for upstream / downstream piping features (e.g. chokes / valves) to affect measurement performance.

NOTE Requirements for the flow geometry upstream and downstream of an MPFM are dependent on measurement technology and are provided by the supplier. Compliance with piping requirements is typically a pre-requisite for functional performance of the MPFM within its uncertainty limits. [mixing, pressure, temp, flowrates to align with uncertainty specification]

Choke valves in particular create significant disturbance to the flow and may cause a large pressure drop. As the MPFM will typically assume thermodynamic equilibrium, care is required to ensure that this assumption is not invalidated by ongoing recovery of the fluid. If an MPFM is to be installed downstream of the choke, a specialist assessment of flow behaviour may be required. This is particularly important for gas wells as the Joules-Thompson effect will impact the accuracy gas property prediction immediately downstream of the choke meaning the MPFM minimum distance from the choke may be very long.

4.8 Chemical Injection

The type and approximate quantity of each production chemical to be injected upstream of the MPFM and the location of the injection point relative to the MPFM shall be specified.

Supplier shall provide relevant guidance on the impact of any production chemical on MPFM uncertainty.

In many subsea applications, chemical injection is required in the wellbore, at the wellhead and/or at manifolds. Chemical injection may be required periodically or continuously. In many cases the MPFM will be used to regulate the flowrate of an injected chemical. Understanding the potential effect of any chemical injected upstream on MPFM performance is a critical step in correctly specifying and locating the meter.

4.9 Thermal Management and Insulation

a. A thermal analysis to determine whether insulation of the MPFM is required to meet process operating and/or flow assurance requirements shall be completed.
   Care should be taken to ensure that the potential for lower temperatures in small bore tubing (e.g. dP impulse lines) is considered.

b. Supplier should provide specific thermal analysis as required to support the thermal analysis.

c. Supplier should advise of any requirement for insulation which is identified by review of the flow conditions specified in the MPFM datasheet.

d. If insulation is specified, Supplier should ensure that MPFM electronics will remain within the operating limits specified by API 17F at all flow conditions specified in the MPFM datasheet.

   MPFMs are often insulated as part of the system flowline and production temperatures can exceed the given specification. MPFM electronics are not required to be insulated and should be designed such that heat transfer through the electrical containment housing is not detrimental to either the flowline or electronics themselves.

e. To ensure good thermal management a full analysis should be conducted of the MPFM control board and components using actual power dissipations. This should be used as part of the MTBF analysis recommended.

f. Temperature monitoring for the internals of enclosures used for control boards should be available during onshore testing and offshore operation.

4.10 Subsea Architecture Interface

NOTE The MPFM is normally flanged or welded directly into the flowline depending on the fabrication of the structure.

a. The specification of adjacent piping shall be provided to the supplier including outside diameter, wall thickness, material grade, and specification, as well as any specific welding requirements.

b. Welding to the MPFM risks damage to electrical components and shall only be done in consultation with the meter supplier.

c. In the case that a meter includes an independent flow line connector for retrieval as a separate component, the supplier should provide all the appropriate dimensions and details for remotely operated vehicles (ROVs) or subsea tooling accessibility as well as support or auxiliary structures required.

d. Access to a retrievable communication pod should be considered as part of the meter location and the parent structure layout.

e. Electrical flying lead connections and paths should be considered when determining location of meter and accessibility.

f. Any MPFM component that is retrievable shall have covers to protect the interface from debris or calcareous deposits for either long or short term, as required.

4.11 Electrical Connectivity

4.11.1 General

Power and communication can be provided using a variety of different philosophies; the most common ones include the following.

a. Utilizing subsea control module (SCM) to provide power and communications to a dedicated MPFM. This option is generally used in new field developments since SCMs require provisions for the supply of MPFMs.

For a meter connected to a SCM:

- The MPFM should be compatible with the SCM and not exceed the communication bandwidth and power load.
- The required data transfer rates and SCM power budget should be adequate for the MPFM under all operating scenarios.

b. Using a dedicated distribution module for distributing power and communications only to the MPFM is also a common practice. This method can be used for projects with limited capability on the SCMs to control the MPFMs, or for already producing fields which require the installation of MPFMs.

4.11.2 Connectors

Discrete electrical and optical connectors as well as hybrid connectors can be used for the provision of power and communication to MPFMs. The primary factor that governs the connector types used for MPFM power and communication is required/preferred data transfer rates. Connectors are typically pressure balanced wet-mateable electrical or optical connectors (rated for project design depth) and installable using an ROV.

4.11.3 Power

a. The electrical power interface shall be in accordance with API 17F power consumption categories. Meters and instruments have a range of power consumption requirement including; startup (inrush current), idle, back up monitor mode and primary monitor mode. All modes of operation have different power requirements.

b. The system supplying the MPFM should be able to supply the highest demand without causing a drop in the system voltage below the MPFM voltage operational threshold.

c. A power interface specification from the meter supplier should fully detail requirements for power, voltage, current and frequency across all operating conditions of the meter.

d. The design operating conditions should include extreme or abnormal situations that may arise during field life or those created during a meter error or fault.

e. An interconnection diagram should be provided to describe the electrical interfaces. .

MPFM power consumption requirements have a significant range between suppliers. It is important to provide sufficient and constant power in accordance with the peak power consumption requirements of MPFMs.

4.11.4 Communication

Data quantity and transfer rate is dependent on the meter application and supplier. Each supplier generally has a preferred communication interface and protocol to suit specific project requirements.

A communication interface specification from the supplier should be provided.

MPFM communication interface protocol should be SIIS Level 3 unless otherwise specified in the datasheet.

In some cases, raw data transfer from the MPFM instrumentation to the host facility is required. This larger amount of data may require higher data transfer rates. The same considerations apply for uploading data to the meter.

Alternative communication interfaces and protocols for MPFMs include:

a. Canbus/Can Open (moderate data transfer rate);

b. Modbus (RS-232 or RS-485) (moderate data transfer rate);

c. Ethernet on copper (TCP/IP) (moderate/high data transfer rate);

d. Fiber Optic (high data transfer rate).

Further reference should be made to API 17F for subsea control monitoring systems.

4.11.5 Software and Data Content

MPFM suppliers supply an operator interface software to provide monitoring and analysis of the meter. This software is typically installed in the topsides controller or other server and gives the operator any level of information required from the MPFM and is usually designed to work with singular or multiple meters, sensors and gauges and combines the instrument software with specialized flow assurance and production optimization software. The goal of each supplier's software package is to give the operator access to the flow information/conditions.

4.12 Labelling and Marking

a. Product labelling and marking should be per API 6A.

b. The following information should be made visible on the MPFM using a process suited to subsea environmental conditions:

   i. project name,

   ii. project tag number,

   iii. supplier name and address,

   iv. design code,

   v. temperature rating,

   vi. rated working pressure,

   vii. maximum test pressure,

   viii. nominal bore (for connecting piping),

   ix. weight,

   x. serial number,

   xi. purchase order number or similar reference,

   xii. part number,

xiii. communication protocol,

xiv. IP address/Modbus slave address.

c. The flow direction should be clearly marked for fabrication and installation.

d. Lift points should be clearly marked.

e. Interface alignment and full engagement reference markings should be included where applicable.

f. Appropriate colors should be used to ensure maximum visibility for ROV interfaces (see API 17H).

g. The manufacturer's product size and reference should be included if not indicated as part of the serial number.

h. MPFMs that use radioactive sources for measurement shall comply with all regional requirements for identification and warnings.

NOTE These are covered in ISO 21482 (Ionizing-radiation warning), ISO 7205 (Radionuclide gauges), and ISO 2919 (Radiological protection, Sealed radioactive sources, General requirements and classification) for the various different radioactive categories. The radioactive labels are in accordance with ISO 361 (Basic ionizing radiation symbol) and IAEA TS-R-1 (Regulations for the Safe Transport of Radioactive Material), unless ISO 21482 (Ionizing-radiation warning—Supplementary symbol) and ANSI N14.7-2013 (Radioactive Materials: Guidance for Packaging Type A—Quantities of Radioactive Materials) are more stringent.

4.13 Additional Equipment

4.13.1 Service Computer

A service computer may be used to confirm the full and correct operation of an MPFM during all stages of delivery.

a. Service computer should be a portable test device designed to be easily transported.
b. The computer shall have the correct and latest revision of the supplier communication software.

4.13.2 Power and Communications Unit

Connection from the service computer to the MPFM whilst the meter is onshore and not connected to the subsea control system is typically made through a Power and Communications Unit (PCU)

a. The PCU converts the local power supply to the appropriate voltage/current requirements of the MPFM

b. The PCU provides the necessary communication ports/protocols which can be used to interface the service computer and the MPFM

4.13.3 MPFM Simulator

Simulators are required for system integration for power and communication when the actual meter may not be available.

Simulators shall replicate the correct power and communication behavior of the meter being delivered. This should be achieved by:

a. ensuring the same or equivalent simulated instruments with the actual flow computer present in the MPFM are used;

b. ensuring power load, communication, and accessibility is the same as the MPFM;

c. reproducing the inrush and continuous power consumption of the MPFM;

d. duplicating the full range of operating conditions and output data to the SCM.

e. Using the same revision of software as the installed MPFM.

5 Radiation Based Devices

5.1 General

In addition to the design requirements outlined in 4.3, meters with radiation based devices should conform to the following.

a. Use a suitable housing compliant to recognized industrial nuclear design and proven for subsea modification, see additional references in the Bibliography.

b. Meter design and performance (including uncertainty calculations) should account for decline in radiation source intensity as part of design life.

c. Use all appropriate markings and labels meeting international and local regulations during shipping, handling, and fabrication.

d. Ensure enclosure is designed to prohibit personnel from direct exposure to source.

e. Be suitable for remaining in place for entire design life even if not in service.

5.2 Transportation and Importation

The meter supplier and operator shall review the requirements for shipping radioactive materials.

All MPFM suppliers should clearly outline the handling requirements for their products, as well as address the logistical complications that a specific project may encounter.

NOTE Many countries require that equipment comply with maximum radiation exposure levels, set by a nuclear regulatory body, in order to import the meter systems. In addition, there are also registration requirements that each host country's government may require for importation and installation.

The operator's radiation safety officer (RSO) should be involved from the initial stages of meter specification to ensure all regulatory and documentation requirements are met.

5.3 Repair

Procedure for retrieval of a meter with a radioactive source should include the requirement for a supplier representative on site.

Consider precautions regarding registration and transportation where a unit is required to ship internationally for repair.

5.4 Decommissioning

Decommissioning of radioactive devices shall be managed by the supplier in cooperation with the operator's RSO and local and/or government regulations.

Radioactive devices shall be returned to the original equipment manufacturer or according to local and / or regulations.

6 Reliability

6.1 General

Reliability as a complete subject is outside the scope of this document. For detailed information on reliability reference API 17N and applicable operator requirements.

- Reliability requirements shall be specified in accordance with API 17N.
- Reliability should be managed by the supplier using a reliability plan which ensures maximum meter availability.
- A Reliability Plan shall address all aspects of meter development, analysis, qualification, testing and operation
- NOTE - See Figure 1 for a graphical representation.
- The reliability plan should detail the applicable reliability and risk analysis tools used at each stage of meter life.
- Primary consideration should be given to early life failure wherein a suitable qualification program can replicate component failure.

Full design life availability may require extrapolation from test results or statistical data with a focus on proven engineering solutions, high component specification, sub-supplier management, good manufacturing standards, and accurate quantitative data.

As a minimum, the Reliability Plan shall address:

a. **(i) Reliability Strategy**: Specification of meter reliability requirements including specification for availability, MTBF, mean time to failure (MTTF), mean time to repair (MTTR), and maintainability goals (cost and time). The strategy should outline the methodology for achieving and demonstrating the reliability goals have been met.

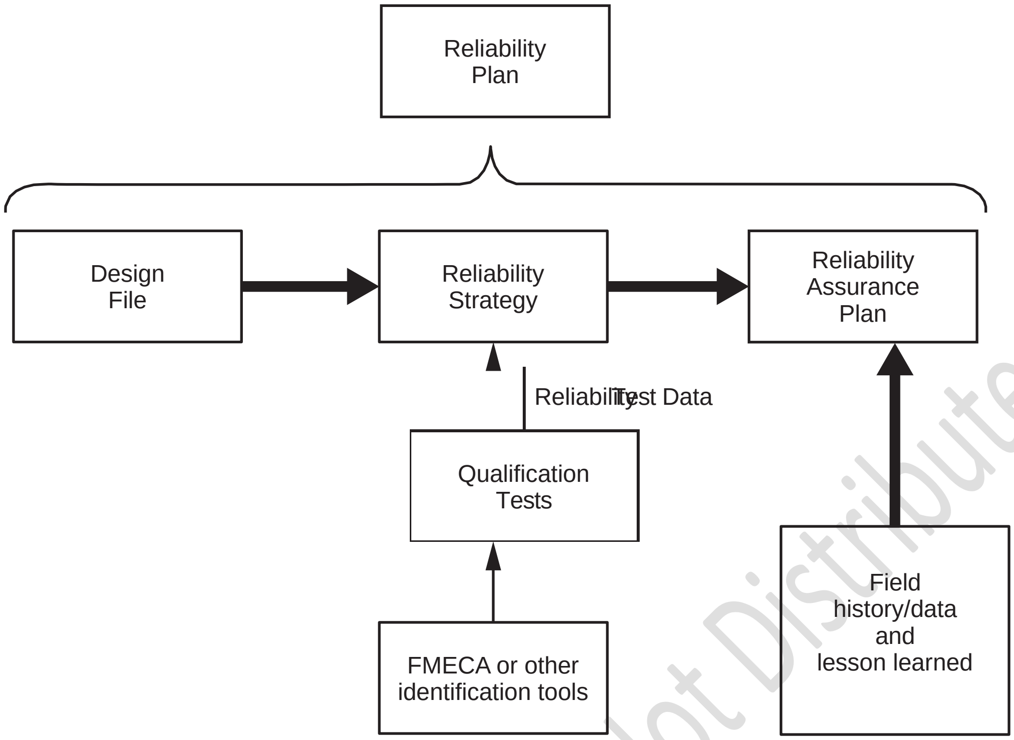
b. **Design File**: The design file, as outlined in 5.6, should address the mechanical design of the meter and present calculations related to design life. Design life calculations may include fatigue and thermal analysis, material degradation (elastomers), corrosion, erosion controls board component life, sensor drift, radioactive source half-life, and all other aspects of the meter that can be reviewed from a theoretical perspective. The reliability plan should identify the primary elements of the design file which have the greatest impact on availability and where they are incorporated into the reliability strategy.

c. **Failure modes, effects, and criticality analysis (FMECA)**: A FMECA should be conducted for any MPFM in accordance with the guidance provided in API 17N and suitable failure mitigation actions identified and implemented. Any mitigating actions (redesign, component specification, inspection, extended testing, redundancy, and qualification) that directly relate to resolving the identified failure modes are key elements of the Reliability Strategy.

d. **System Analysis**: In addition to a FMECA, a number of specific reliability tools can be used to assess the meter design including risk categorization and fault tree analysis. API 17N provides further guidance on these techniques. A system analysis should involve the entire process involved in specifying, purchasing, assembling, factory acceptance testing, integrating the meter into a subsea structure, commissioning, and operation of the meter throughout its life. Sub-supplier reliability is integral to overall meter availability and probably most associated with early life failure. A reliability assurance plan considers the system aspects of the meter and typically covers sub-supplier management, design for manufacture, and supply chain management. It is used in addition to a reliability plan to ensure consistent delivery of a reliable product.

e. **Qualification**: A comprehensive qualification plan should be aimed at increasing availability through identifying unknown system failures under operating conditions or by acquiring statistical data on component life through extended testing. Qualification is reviewed in section 8.

Figure 1—Reliability Plan Overview



f. **Operation**: The reliability plan should be maintained and updated with relevant operational data covering operating parameters, failures and lessons learned. A meaningful plan should show continuous monitoring, improvement and determination of availability.

I. Any changes to the meter design should go through the same cycle of assessment and review as the original design.

II. Within the reliability plan, particular attention should be given to both the control system and the meter software.

III. Updates and revisions to software should undergo a similar review.

IV. The software should ensure inputs and operations are managed at applicable user levels.

V. Software should apply best practices to continuously monitor, self-diagnose, and prevent run-time errors and to quickly recover from transient hardware faults.

VI. The supplier should ensure the reliability plan address maintainability including the cost and duration for replacement parts, refurbishment and repairs. This is particularly important when fields are located in areas with strict controls on radioactive sources or where no supplier base is located.

6.2 Redundancy

Redundancy is the duplication of critical components or functions of a system to increase availability. Redundancy can also be achieved by replicating functionality. For an MPFM, any alternate means of ascertaining pressure, temperature, velocity, density, void faction, or other measurement component should demonstrate similar accuracy, repeatability, and uncertainty as the primary means.

a. A reliability plan should be used to identify the essential elements affecting meter functionality, their life expectancy, and the associated failure modes.

b. Meter operation may be extended by using distinct and separate parts that duplicate the purpose of the original failed component.

c. Any duplicate part should function exclusively from the original element to ensure that the same failure mode is not repeated.

d. Redundant elements that are used to extend operational life and that do not operate until required, should be designed for long periods of inactivity.

e. If measurement redundancy, whether by component or functionality, reduces meter performance this should be highlighted by the manufacturer.

6.3 Retrievability

MPFM retrieval strategies are based on either recovering the entire meter, supporting structure (choke bridge or jumper), or a pod containing critical elements most prone to malfunction or those requiring maintenance. Pods typically contain electronics, transmitters, and sensors that are part of measurement and are prone to drift, degradation, or failure (pressure transmitters, temperature sensors, humidity sensors, etc.). Recovery of radioactive elements requires supplier assistance, see Section 6.

a. Requirements for MPFM retrievability (part, or whole) should be specified at the earliest point in the subsea system design process. Where retrievability of the meter is not required, options for redundancy should be considered, see section 6.2.
b. The expected reliability performance of an MPFM should consider the complexity introduced by adding retrievability requirements.

c. The retrieval design philosophy should ensure that the most complex component/connection is removed in its entirety with the fixed (non-retrievable) element being as simple as possible.

d. Testing should be performed to determine the reliability of the remaining elements when a pod is the sole recoverable element of a meter.

e. The location and application of the meter can influence the overall approach to retrieval. When defining a Retrieval Plan the following elements should be considered.

   — Availability of a suitable retrieval interface.

   — Availability of a back-up measurement method .

   — Supporting structure

   — Ability to operate the system without the MPFM.

   — Ability to bypass flow.

   — Support vessel: Does the location necessitate the use of a large vessel for retrieval of an integrated component (jumper, choke bridge)? Can a smaller vessel be used for retrieval and replacement of controls pods? Are periodic interventions required as part of the field design and are vessels continuously available for support? Can system design be used to continue production until that intervention?

   — Spares: Are replacement meters and/or pods available? For meters using gamma sources are spares available in country and if not are significant customs/delivery durations expected?

f. If the meter is integrated into a retrievable assembly the connection and seal of that element should become part of the meter reliability plan.

g. A dropped object analysis should be conducted on the meter location once the retrieval strategy has been complete. Adequate protection should be provided to ensure critical elements of the meter and flow line are shielded against items unintentionally released during operations in and around the meter. Protection should consider deflection of any item as part of the shielding design.

7 Test Requirements and Recommendations

7.1 General

This section details suitable technology qualification methodologies and requirements and considerations for the performance strategy. A series of shared tests that are required for all meters to verify mechanical integrity is also given. An MPFM requires a number of tests throughout its life cycle. Due to the differences in meter technology and applications there is no standard set of tests that can be used.

a. Initial tests should be used to validate meter design.

b. Production tests should be used to prove manufacturing integrity and consistency.

c. Performance tests should be used to validate the suitability of the meter for a specific application.

d. In situ commissioning and operational tests shall be required.

e. A meter test plan should be developed which is concurrent firstly with measurement principle, then required performance and finally optimized for operational use.

7.2 Design Validation

Design validation is the establishment of documented evidence to provide a high degree of assurance that a specific system, process, or facility consistently produces a product meeting its predetermined specifications and quality attributes. Evidence is generally produced by completing a series of relevant and representative tests or by developing accurate computational models which simulate functional parameters. This information is typically contained in a series of documents including the design file, the functional specification, the qualification plan, and the qualification results.

NOTE Some commonly recommended testing used as part of verification is addressed in 8.3. Due to the difference in meter technologies not all tests are detailed. DNV RP A203 provides a suitable guide for equipment qualification.

It is expected that all MPFMs designs adhere to a proven engineering process. Design validation requires the confirmation that documented evidence exists that provides a high degree of assurance that the meter consistently meets its predetermined specifications and quality attributes. A design file, as outlined in 5.6, should exist that documents a meter specification with supporting calculations for pressure containment, material compatibility, meter performance, reliability/field life, and meter lockdown mechanism based on operating and environmental conditions.

The meter functional specification, required as part of the performance strategy, can be used to provide relevant manufacturer details on the design of the relevant aspects of performance.

A qualification plan linked to the design file and functional specification should provide physical assurances that the meter can achieve predetermined acceptance criteria.

NOTE 1 DNV RP A203 details a suitable process for technology qualification. API 6A details a number of tests used for oil field equipment that can be used as a reference guide.

The qualification plan should verify the primary calculations presented in the design file and supply sufficient reliability test data to confirm the design life and availability.

The following contents should be included in a thorough qualification plan.

a. Specification of meter with description of operating principle.

b. Definition of key functional tests including:

- pressure containment,
- environmental operation at temperature and pressure,
- mechanical functionality for lockdowns and connectors,
- communication transfer rates and integrity,
- power requirements,
- software processing,
- measurement calculation and thus requirements from measuring sensors, relating their performance to uncertainty.

c. Determination of required reliability data to confirm operational life.

d. Assessment of meter technology for failure modes (failure mode and effects analysis [FMEA]).

e. Test proposals for:

- qualification tests,
- collection of reliability data,
- failure modes.

f. Definition of acceptance criteria and continuous performance measurement.

g. Test results.

h. Standardized tests for manufacturing.

The qualification plan should conclude with a recommendation for a factory acceptance test (FAT) program that is required to verify key requirements for each meter.

NOTE 2 A minimum number of qualification tests that are expected for a MFPM are detailed in 8.3. It is expected that additional tests are required to satisfy meter performance, reliability, and design life calculations. It is recommended that the application and project requirements of the meter be used to determine all appropriate tests and acceptance levels. Tests that are required as part of the performance strategy are outlined in 5.5.

7.3 Qualification Testing

7.3.1 General

The qualification of each component, subcomponent and part of the meter shall be subject to review in accordance with the API 17N reliability qualification process.

A comprehensive qualification plan should provide sufficient data to support confirmation of agreed minimum Technology Readiness Levels per API 17N.

Testing should be completed at both a component and system level to ensure the consequences of complex interactions are well understood.

7.3.2 Pressure and Temperature Rating Qualification

The meter shall be qualified to the test requirements of API 6A.

Minimum and maximum pressure and temperature ratings shall be per API 6A.

Any scaling used shall be in accordance with API 6A.

7.3.3 Hyperbaric Qualification

Hyperbaric testing shall be per API 17D at test pressures and temperatures corresponding to maximum water depth.

Meters that have no moving components shall be treated as static systems and shall adhere to the pressure cycling requirements of API 17D.

7.3.4 Electronic Systems Qualification

NOTE API 17F details the requirements for electrical stress screening and guidelines on the electromagnetic environment for subsea components respectively.

All MPFMs shall be qualified to API 17F.

Additional tests determined from API 17F shall be in accordance with Type 1 or 2 Location Classes as determined in the manufacturers design file.

7.3.5 Software Qualification

Software for MPFMs should be designed and qualified in accordance with a proven international standard or practice. Multiple standards exist and the most suitable and rigorous should be applied.

NOTE ISO/IEC 25010:2011 may be used for the evaluation of software quality. In the standard, quality is defined using a set of characteristics including; functionality, reliability, usability, maintainability and portability. Some of these characteristics have direct impact on the user and others on the manufacturer. For a robust measurement system, consider the following attributes; suitability, accuracy and interoperability. Reliability attributes include; maturity, fault tolerance, recoverability and reliability compliance. Usability considers understandability, learnability, operability, and usability compliance.

8.4 Factory Acceptance Testing

8.4.1 General

FAT tests should be derived from the manufacturers design file and qualification report. The qualification process proves that a design can function as intended throughout its operational range. The intent of FAT is to verify the integrity and consistency of the manufacturing process to ensure each individual meter meets the standards of the qualification unit.

Factory acceptance testing shall comply with API 20.3.

8.4.2 Hydrostatic Pressure Test

Depending on meter application and location API 17D, production specification level (PSL) requirements may apply.

It is recommended that PSL requirements be applied where possible. This may typically require specific hydrostatic pressure cycling testing per API 17D.

a. All meters shall conform to API 17D if part of an applicable assembly.

b. The meter shall be tested as a full assembly prior to incorporation into the system.

8.4.3 Gas Pressure Test

Gas tests shall apply to PSL 3G assemblies per API 17D. The referenced section is written specifically for valves and chokes but can be applied to MPFM where actuation of moving part can be disregarded.

8.4.4 Hyperbaric Pressure Test

Hyperbaric pressure tests shall be conducted on each assembly per API 17D with acceptance criteria given in API 6A.

8.4.5 Helium Leak Test

All electrical enclosures should be helium leak tested in accordance with API 17F.

8.4.6 Electrical Stress Screening (ESS)

All electronics shall be tested per API 17F at a component level.

ESS is designed to reveal failures due to manufacturing non-conformances and substandard components. Further tests may be required at subassembly and final assembly level. Additional tests can be designed to identify the specific defects associated with the level of assembly.

The minimum acceptance criterion for ESS testing of meter controls includes no errors during continuous function monitoring and no significant physical damage.

8.4.7 Final Inspection

a. A final inspection process should be used by the supplier to ensure all meter documentation is correct and representative of the unit being shipped.

   Documentation required for the meter delivery typically includes but is not limited to all signed inspection documents, accepted nonconformance reports, signed and completed FAT and EFAT test procedures, installation instructions and handling and storage documents.

b. Before shipping all serial numbers and identifying labels shall be verified and notated on a suitable protective packaging for the meter.

c. The shipping container should be suitable for sea freight and long term storage and have displayed all relevant identifying markings as required by local authorities.

d. The required shipping documentation should be validated.

8.5 Performance Tests

8.5.1 General

Performance tests are required to verify the ability of the meter to meet the requirements of the application based on reliable process data.

Performance tests are an inherent part of qualification, FAT and extended third party tests required by operator. Uncertainty can be calculated according to API *MPMS* Ch. 20.3. Verification of uncertainty is a requirement of performance testing.

Specific flow tests required for sensor / flow model calibration as part of FAT should be specified by the supplier.

A calibration procedure should be available from the supplier to ensure that meter is correctly configured during system integration and commissioning.

Due to the complexity of replicating all the variables in a multiphase flow application there are currently limited full scale test facilities. A full scale facility would be able to reproduce all suitable flow regimes for various gas-oil ratios (GORs) for different hydrocarbon compositions, at operating temperature and pressure across a number of operational cases. In essence a full test facility would be able to replicate the actual application the meter is intended for. Testing is generally accomplished by segmenting specific elements of measurement and verifying that the equipment can operate for that specific condition.
Regime testing may be accomplished by using air/water mixtures at standard temperature and pressure. Actual hydrocarbons may only be tested across a limited range for a particular composition at a site that may only facilitate low pressure tests. In situ tests can be used as part of meter commissioning and a limited number of points may be used to validate earlier assumptions used as part of factory testing.

8.5.2 Functionality Tests

Functional testing should occur during FAT or EFAT.

NOTE 1 API *MPMS* Ch. 20.3 details comprehensive recommendations for meter calibration, correction, performance testing and verification. The scope of testing is to ensure that all sensors, transmitters, receivers, software and communications are functioning within the given range of the meters functional specification.

Before performance testing can start each component in the uncertainty calculation has to be proven to be operating within specified limits.

Sensor functional testing usually includes:

a. pressure and temperature measurement devices;

b. DP measurement devices;

c. gamma ray instruments/densitometers;

d. electrical properties sensors, such as capacitance, conductance, and microwave systems.

Functional testing does not account for drift or long term maintenance. This should be included as part of any operational plan.

Power, communication, and software functional testing should be detailed as part of the qualification program.

NOTE 2 As few changes occur in the resultant system after original qualification, functional checks are used to ensure post ESS operation and that project specific software inputs are correct.

8.5.3 Static and Flow Loop Tests

NOTE Recording and trending meter readings under no-flow conditions with known fluids can help monitor for sensor drift. If the baseline parameters for these conditions are logged first at the factory, field commissioning, and at regular intervals thereafter, one can use trends to distinguish between random deviations of the measurement versus a systematic drift. Empty, water-filled, and oil-filled pipe are good examples of such measurements.

Meter flow loop testing shall be conducted in accordance with API *MPMS* Ch. 20.3.

Fluids used for performance verification should be sufficiently representative of the appropriate field application.

A specialist assessment may be required to determine whether a fluid is sufficiently representative. Typically, this assessment accounts for the fluid properties in the field application, the flow loop, and the meter design. This is because the fluid properties which are measured by the meter sensors and modelled by the meter software are replicated in the performance test. Examples of relevant fluid properties may include densities, composition, viscosity or electrical properties.

8.6 System Integration Test (SIT)

System Integration Test starts when a fully functional meter has left the supplier and ends once it is deployed subsea. Once the meter has left the control of the supplier it requires additional coordination to ensure correct integration into the system. This section details meter storage, fabrication into the subsea system (assembly as part of jumper, tree or manifold), site integration testing and verification up to installation. Meter commissioning is covered in Section 9.

a. A system integration test plan should be created in collaboration with the meter supplier.

NOTE 1 As some meters use radioactive sources there may be a number of shipping restrictions and documentation requirements.

b. Special shipping requirements should be established early in the project so delays do not occur.

c. Shock and vibration monitoring should be used as part of the shipping container or on the electronic control module of the meter.

d. Suppliers should set acceptable criteria for their meter and confirm measurements as part of the receive inspection test (RIT).

NOTE 2 Third-party testing at flow facilities may be required as part of meter performance testing. Supplier support may not be required during testing. However support for lifting, connecting and confirming meter integrity on arrival and departure is recommended.

e. As MPFMs are integrated into the subsea system as part of an assembly (tree, manifold or jumper) the meter supplier should be present.

f. If welding on meter is required, it should be witnessed by the meter supplier.

g. Instruction for grounding electronics should to be followed during welding.

h. Once integrated into the assembly, a hydrostatic pressure test of the assembly is required.

i. During further testing of the complete assembly (e.g. SIT) the meter needs to be used instead of the simulator.

j. A supplier acceptance checklist should be provided that confirms meter functionality before shipping to installation or storage.

k. Meter supplier best practice for storage should be implemented. Best practice can be region specific, i.e. drainage, shade, temperature controlled, covered, etc. Long term storage and recommissioning plans should include operation tests and checks.

l. Dock test and deck tests should be conducted through SCM, if possible.

m. Retrieval of meters for failures or maintenance should involve the original equipment manufacturer.

n. Meters using radioactive sources need to be tested on retrieval for radiant leakage.

o. The user RSO should be informed of any retrieval of such devices (see Section 6.3).

p. The decommissioning of radioactive type meters requires the presence of the original equipment manufacturer.

The safe and timely delivery of meters is best achieved using a preplanned logistics strategy coordinated in cooperation with the supplier. Figure 2 details the process flow for a typical integration and installation assurance plan.

9 Meter Commissioning and configuration

a. Prior to meter commissioning a full documentation package should be prepared that contains the system schematic, meter functional specification, meter installation and operation manual, FAT test results, EFAT test results and any third party flow test results.

b. If SITs have been conducted the resultant data book should also be provided. During testing some meters use a specific test configuration file that has to be changed back to the project specific file.

c. Test and project specific configuration files should be clearly identified and the correct revisions should be indicated in both software and documentation.

d. Before commissioning commences, the revision levels of all software associated with the meter and facility control system should be checked against the project documentation.

e. On first power up, the power loads should be measured and confirmed against specification.

f. A communication check should be completed.

g. Meter serial numbers should be confirmed to ensure the system is communicating with the correct meter.

h. Communication parameters, settings, and IP address should be confirmed as well as appropriate data allocation tables.

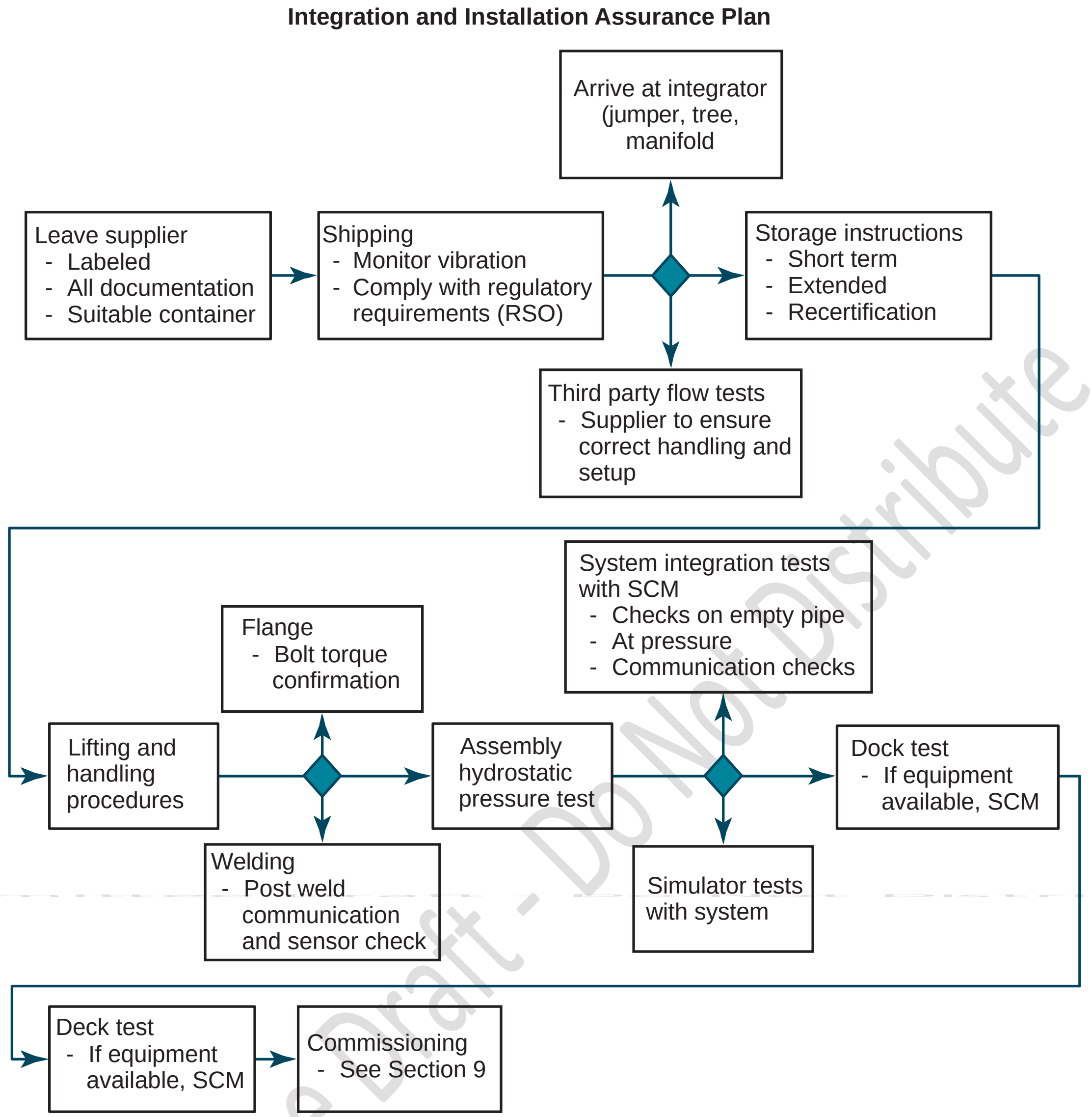


Figure 2—Typical Flow Chart for Integration and Installation Assurance Plan

i. Redundant channels should be verified by validating the automatic switch over and ensuring the voltage requirements are met.

j. Any specific supplier commissioning tests should be conducted. Meters are typically delivered ready for use and if a comprehensive Integration and Installation Assurance Plan has been followed minimal tests should be required.

k. A self-diagnosis routine should be completed to ensure all systems are in order.

l. Once the meter settings have been validated, a series of static and dynamic response tests should be conducted. These tests are reliant on field operations and therefore may not occur until after preliminary commissioning.

m. A series of opportunistic static tests may be conducted on a number of different fluids during field commissioning, depending on the meter location.

n. Hydrostatic pressure tests of the component the meter is integrated into may be conducted with test fluid (treated water) or methanol.

o. If required by the manufacturer, the meter should be characterized for these fluids prior to installation which requires preplanning with operational activities. This is typically achieved via configuration of in-situ calibration.

In addition to static testing of meter locations, tree commissioning and flow line flushing activities offer opportunities to confirm the dynamic responses of MPFMs, the meter may respond to valve openings and depending on meter type changes in composition due to chemical injection or commissioning fluids. Dynamic responses of this nature may be used to confirm the meter is operating and taking measurements.

During both static and dynamic tests it may be possible to check meter sensors against adjacent or local sensors on the integrated structure. Similar responses and trends will normally be replicated on both sets of sensors. This may be combined with a virtual metering system if available to highlight any inconsistencies or to prove matching trends and readings. These data may be valuable throughout the meter life and should be stored as required.

In some circumstances the well is unloaded through the meter and is subject to completion fluids. A dedicated clean-up configuration file may be required by certain metering technologies for this scenario. Unloading a well through the meter may not be a preferred operating condition and damage could be caused by drilling fluids. Each unloading scenario should be confirmed with the equipment supplier.

9.1.1 Initial Flow Tests and Fluid Samples

Fluid sampling is detailed in API *MPMS* Ch. 20.3 and is typically conducted as part of a full meter operation strategy aimed at ensuring performance and availability. Sampling may not be possible for all subsea systems and often sampling can be an opportunistic activity. The sensitivity to fluid property variations is different between the MPFM technologies available, and some MPFMs implement methods to determine changes in fluid properties through measurements and analysis of sensor data. However taking fluid samples through the meter life is generally a robust way of checking that meter configuration parameters are still correct.

NOTE 1 The phases of commissioning are typically conducted before hydrocarbons are flowing. There may be an extended period between meter commissioning and multiphase flow measurement and typically a change in personnel conducting the activities.

a. There should be a handover of metering functional and operational specifications to the facility person responsible for flow measurement. This handover may include initial trials of flow measurement for the first hydrocarbons.

b. Initial flow measurements should cover flow tracking and verification with either a virtual meter or mass correlation system where possible.

c. Local sensors and overall system correlation should be used to ensure the meter is producing realistic measurements. Flow rate variations are produced during control choke operation and tracking data can be quickly captured during this period.

d. MPFM early production sample results should be compared to the meter configuration data developed during meter specification, if possible.

e. It should be noted that the initial flowback of completion fluids (particularly heavy brines) from a well may cause the MPFM to provide erroneous readings until the well has “cleaned up”.

NOTE 2 Maintaining correct configuration files for phase behavior and fluid properties throughout the meter field life maintains meter performance.

The collection of production samples is dependent on the field layout and operational philosophy. The goal of sampling is to gather fluid properties and pressure-volume-temperature (PVT) data to compare to initial meter configuration parameters set up during MPFM FAT. The following items may be incorporated in a sampling plan:

— duration of sample time;

— when to take a sample;

— size of sample;

— variation in samples—taking multiples;

— phase transition at STP versus flowing pressure and temperature;

— time to process a sample—onsite versus lab;

— ability to recombine samples obtained at high pressure from separate liquid and gas streams;

— procedures for safe handling of pressurised samples.

— coordination between the various disciplines that conduct sampling (e.g. reservoir management, flow assurance, production chemistry, measurement) can provide fluid information that may be necessary for the MPFM.

Sampling can be achieved through test separators, subsea equipment and workover type vessels. All interventions should be controlled as part of the overall field operation plan.

10 Operations and Maintenance

10.1 In service Verification and Fluid Property Update

A plan for in service verification of the MPFM shall be developed and include:

a. Alarms to indicate when a sensor is out of range.
b. Specification of out of range limits for the MPFM.
c. A description of available methods for verification of the MPFM, e.g. another MPFM, a process simulation model or separator “by difference” testing.
d. Documentation of uncertainty for the MPFM and proposed verification techniques.
e. Where appropriate, methods of verification of sensor outputs (e.g. shut in test).
f. Where appropriate, reference to any regulatory requirements / agreements for verification of the MPFM.

NOTE 1 Where the MPFM is to be used for fiscal allocation, a regulator may expect to see and approve the verification techniques described above.

The operator shall ensure that relevant fluid property inputs to the MPFM (specified in accordance with section 5) can be provided throughout the lifetime of application. Fluid property inputs will typically include:

i. Fluid density at line / standard conditions.
ii. Hydrocarbon composition at line / standard conditions.
iii. Pressure-Volume-Temperature (PVT) data for the hydrocarbon fluid.
iv. Viscosity at line conditions.
v. Water salinity.
vi. Sand content.
vii. Electrical properties (permittivity / conductivity) of the hydrocarbon fluids and water at line conditions (some MPFMs).

NOTE 2 Subsea MPFM fluid property data requirements vary by technology and by application.

It shall be ensured that fluid properties can be updated as required throughout the lifetime of the field.

NOTE 3 To ensure the operator can update fluid properties, the meter location and/or subsea architecture design will need to accommodate this. This is particularly important if the fluid properties are expected to change during field life. Alternatively, the operator can consider direct sampling of production fluids from individual wells throughout field life.

10.2 In Situ Checks

10.2.1 General

Meter checks during operational life should confirm the required accuracy of the meter against the potential changes in the original input parameters and meter configuration. Where possible, establish requirements for meter checks and work with operations to integrate them as part of scheduled activities. Include parameters or times for when meter verification should be conducted to ensure meter accuracy is maintained. This may be based on compositional parameters, specific points in field life, or some operational boundaries. Some meter checks are executed at moments of opportunity during shutdown, start-up or other operational activities.

Generally meter checks and verifications can be accomplished by some of the following which may occur opportunistically or be planned for high performance meters.

— Mass balancing for determining overall accuracy of metering by balancing the topside separation versus that measured by the meter(s). This can be achieved by looking at the meters individually, in groups or most likely a combination of both.

— Trending of virtual metering system (VMS) versus MPFM results, assuming they operate independently and the MPFM has not been used to calibrate the VMS.

— Periodic checking of the meter with a test separator if possible and if the application requires it.

— Independent periodic checking of some flow assurance parameter (like water break through) at the separator to ensure it is still tracking changes.

— Sampling of production fluid for verifying meter configuration and updating, as required.

— Checking meter configuration parameters against a known fluid in the bore, e.g. during chemical/dead-oil displacement at start-up or shutdown.

For applications where meter accuracy is critical the verification methodology selected should be shown to have a suitable measurement uncertainty. Unless a dedicated proving system is used this may not be possible. Continuous or periodic tracking to a reference measurement can be used to track any potential long term changes in meter accuracy. If this is associated with changes in fluid parameters the meter may have to be reconfigured.

10.2.2 Field Tracking of Meter Performance

Ongoing field tracking of meter performance should be conducted as part of general operations, which are outside the scope of this RP.

The Meter self-diagnosis should be run per supplier specification.

Self-diagnosis tools provide information on power usage, communication integrity, and sensor consistency. Typically these tools only give information regarding the mechanical status of the equipment rather than its measurement accuracy. Supplier support or review may be required for evaluating self-diagnosis reports.

A datasheet summarizing meter metrics that define standard operating ranges should be produced by the supplier to assist in continued tracking.

NOTE Comparison of meter sensors versus local or adjacent sensors can be used as an external reference. Historical data showing similar trends can be used as reassurance for meter integrity while divergent data may be used as confirmation for meter verification.

The PVT model used in the meters configuration file should be maintained throughout the project life based on the operation plans sampling scheme or in situ verification.

Verification of the configuration file revision level and security setting should be reviewed periodically.

Maintenance of meter performance is also covered in API *MPMS* Ch. 20.3.

10.2 Configuration Parameters Audit Trail

Changes to the meter settings and configuration files should be managed by a suitable security program that enables only appropriate, responsible users to have access to configuration menus.

A historical log of access dates and users should be maintained for all changes to the initial setup parameters.

Depending on meter application these data may form part of a legal contract and should meet all requirements of that contract. Prior to making changes to the configuration file it is useful to demonstrate offline the impact that any such change has on the measurement (possibly using raw data from the meter).

Read and write access menus and interfaces should be designed for the specific users' needs.

NOTE Further information on data configuration is given in API *MPMS* Ch. 20.3.

10.3 Maintenance

The meter should be designed not to require any routine maintenance when operating under agreed service conditions.

NOTE The meter is to be designed to maximize availability and eliminate or minimize the need for maintenance.

Any maintenance that is required should be done through the topside communication system where possible.

Retrieval of any subsea components is not considered maintenance and is covered in 7.3.

Any physical maintenance required should be designed to be completed with the minimum of system down time.

System uptime can be increased by developing maintenance plans that do not require the removal of the entire meter, that can be completed in a single intervention, that use commonly available vessels and ROVs and by having appropriate spares available locally. Where maintenance needs are identified throughout the meter life the supplier should endeavor to detail the extent, duration, methodology, and cost of executing the work scope.

ANNEX A
(Informative)

Example Multiphase Flowmeter Generic Datasheet
The following datasheet is provided for guidance only.

General		
	Example	**Comments**
Instrument Type:	Multiphase Flowmeter (MPFM)	
Redundancy:	Power: Yes ☒ No ☐ Communication: Yes ☒ No ☐	Option for redundancy on dual electronics.
No. of Pressure Transmitters:	Two (2)	Options here also include use of multivariable sensors.
No. of Temperature Transmitters:	Two (2)	
No. of Differential Pressure transmitters:	Two (2)	
Design Life:	25 years minimum	
Storage Temperature Range:	-20°C to +50°C	
ROV Retrievable:	Yes ☐ No ☒	Typically refers to electronics, not whole instrument.
Functionality		
Measurement Mode:	Dual mode with automatic switching between Multiphase and Wetgas mode.	Vendor specific options.
Salinity Measurement:	Yes ☐ No ☒	
Sensitivity to process parameters:	Accuracy shall not be adversely affected by Storage, chemical injection, shutdown, salinity.	
Flowrate Uncertainty:	±5% gas, ±10% total liquid, ±5% water cut	
DP Range:	50 – 5000 mbar	
MECHANICAL/DESIGN		
General		
Design Water Depth:	3000m	
Max allowable pressure loss:	1 bar	
Spool Process connection Type:	API 6A Flange	
Spool Flange Size/ Designation:	4 1/16” 6BX 5 1/8” 6BX 7 1/16” 6BX TBC	
Meter size:	5” n.b.	
Inlet Pipe/Line Size:	Ø 150 mm	
Outlet Pipe/Line Size:	Ø 150 mm	
Flange bolt details:	1” 8UNC -2B (TBC)	
Installation Orientation:	Vertical	
Flow Direction:	Vertically up	
Blind T:	Yes ☒ No ☐	Detail who is responsible for this scope of supply.
Pressure retaining and/or process wetted Components (Spool Piece/Remote seals/pressure penetrations etc.)		
Product Specification Level (PSL):	**3G (API17D)**	
Design Temperature:	**-30°C to +121°C**	

Operating Temperature:	**+4°C to + 70°C**	
Design Pressure:	69.0MPa (690bar, 10,007psi)	
Proof Pressure:	69.0MPa (690bar, 10,007psi)	
Electronics Design		
Design Temperature:	**-18°C to +70°C**	
Operating Temp. Range:	**-5°C to 40°C**	
MATERIALS		
General:	Super Duplex	
Material Class (API 17D):	HH (for process wetted materials)	
Material Temperature Class:	LU (-46°C to +121°C)	
Fasteners (pressure retaining):	Super Duplex (API 20 E & F)	
Dimensions		
General:	See GA drawing	
MPFM Body Length:	See GA drawing	
Blind Tee:	See GA drawing	
Communications		
Output Signal Type:	SIIS L3 (TCP/IP over Ethernet)	
Supply Voltage:	24V DC (Nominal)	
Max. Power Consumption:	Reference API17F	
Electrical Interface		
Connector Type:	12 Way ROV (Exposed Pins)	
Configuration:	Integral Jumper Bulkhead Connector	
Key way orientation:	12 o'clock ☒ 6 o'clock ☐	
No. of Connectors:	One ☐ Two ☒	
Painting/Coating/Insulation		
Painted:	Yes	
Paint Specification:	NORSOK M-501 System 7C	
Paint Top Coat Colour:	RAL 1004	
Insulated:	Yes ☒ No ☐	
Extent of Paint:	External surfaces exposed to seawater and/or under insulation.	
PROTECTION - ELECTRICAL INTERFACE(S)		
Protection Type:	Short term transportation/protection cap Identification/Markings/Tagging	
Instrument Specific Markings (API 17D):	See GA Drawing	
Marking Method:	Chemical/Vibro Etch/Laser/Hard Stamp	
Tagging:	See GA Drawing	
Testing/ Verification		

Qualification Testing:	API 17N/ DNV RP A203.	
Production ESS Testing:	API 17F	
Factory Acceptance Test (FAT):	API 17 D/ F/ S	
Hydrostatic Pressure Test:	API 17D	
Nitrogen Gas Pressure Test (PSL3G):	API 17D	
Hyperbaric (external) Pressure Test:	API 17D	
Electrical Continuity Test:	≤ 0.1Ω between all bolted parts (Including fixings and fasteners)	
Electrical Insulation Test:	≥1GΩ @ 50Vdc	
Internal Flow Loop Testing:	Yes	
Independent Flow Loop Testing:	Requirement for third party flow loop ☐	

Notes

1. The MPFM shall be provided with a suitable lifting arrangement which shall as a minimum be designed to withstand twice (2x) the gross weight of the assembly.

2. The MPFM shall conform to all applicable EU directives. Electromagnetic Compatibility (EMC) testing shall be performed in accordance with API17F.

3. The required material certification level is EN 10204 type 3.1 for pressure containing equipment.

4. All process wetted metallic components and seal materials shall be ISO 15156-3[9] compliant.

5. Only metallic coatings shall be applied on seal ring surfaces for metal-to-metal seals, e.g. silver coating or equivalent metal coating may be applied. PTFE and MoS2 based coatings are not acceptable on metal-to-metal seal rings.

6. All critical fasteners i.e. pressure containing/ retaining/ load bearing applications shall be supplied in accordance with API 20 E and F.

7. The gasket hardness should be softer than the corresponding ring grove material to assist seating (face-to-face make-up) and reduce the risk for seat indentation and galling.

8. All non-metallic sealing materials shall be batch tested and fully traceable to a batch test certificate.

9. Non-metallic seals exposed to silicon oils, seawater, etc., shall be compatibility tested in accordance with an appropriate standard(s) and/or be field proven for at least three (3) years.

10. The supplier shall be responsible for insulating the MPFM. The insulation coverage and thickness shall be determined by the supplier, subject to customer approval, based on the below cool down requirements.

11. The supplier shall implement a PMI program for CRA materials to minimise the risk of a mix-up in material grade for components used in critical applications i.e. pressure retaining/ containing/ production wetted/ CP isolated/ load bearing.

Flow cases

Include here the project specific flow cases here.

	Units of measure	Case 1	Case 2	Case 3	Case 4	Case 5
Operating pressure						
Operating temperature						
Gas flow rate						
MW						
Gas line density						
Compressibility						

Gas viscosity						
Gas specific heat ratio						
Condensate flow rate						
Condensate line density						
Water flow rate						
Water line density						
Methanol flow rate						
Methanol line density						

Installation details / snapshots with dimensions for upstream and downstream of the pipe.

Bibliography

[1] API 17A, *Design and Operation of Subsea Production Systems General Requirements and Recommendations*

[2] API Recommended Practice 85, *Use of Subsea Wet-Gas Flowmeters in Allocation Measurement Systems*

[3] API Recommended Practice 86, *Recommended Practice for Measurement of Multiphase Flow* (superseded by API *MPMS* Ch. 20.3)

[4] API 2566, *State of the Art Multiphase Flow Metering*, First Edition

[5] ANSI N14.7 20013, *Radioactive Materials: Guidance for Packaging Type A—Quantities of Radioactive Materials*

[6] DNV-RP-A203, *Technology Qualification*

[7] *Guidance Notes for Petroleum Measurement* (UK Department of Energy & Climate Change DECC), Issue 8

[8] IAEA TS-R-1, *Regulations for the Safe Transport of Radioactive Material*

[9] IEEE Standard 1633, *Software Reliability*

[10] ISO 13628-1:2006 [1], *Petroleum and natural gas industries—Design and operation of subsea production systems*

[11] ISO-11631:1998, *Measuring of fluid flow—Methods of specifying flow meter performances*

[12] ISO 12807:1996, *Safe transport of radioactive materials—Leakage testing on packages*

[13] ISO 361:1975, *Basic ionizing radiation symbol*

[14] ISO 7205:1986, *Radionuclide gauges—Gauges designed for permanent installation*

[15] ISO 2919:2012, *Radiological protection—Sealed radioactive sources—General requirements and classification*

[16] ISO 21482: 2007, *Ionizing-radiation warning—Supplementary symbol*

[17] ISO/IEC Guide 98-3:2008, Guide to the expression of uncertainty in measurement (GUM:1995)

[18] *The Norwegian Handbook of Multiphase Flow Metering* (NFOGM)

[19] ISO/IEC 25010:2011, *Systems and software engineering—Systems and software Quality Requirements and Evaluation (SQuaRE)—System and software quality models*

1 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva, Switzerland, www.iso.org.