Manual of Petroleum Measurement Standards Chapter 4—Proving Systems

Section 9—Methods of Calibration for Displacement and Volumetric Tank Provers

Part 1—Introduction to the Determination of the Volume of Displacement and Tank Provers

FIRST EDITION, OCTOBER 2005

REAFFIRMED, JULY 2015

AMERICAN PETROLEUM INSTITUTE

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FOREWORD

This multi-part publication consolidates and standardizes calibration procedures for displacement and volumetric tank provers used in the metering of petroleum liquids. It provides essential information on the operations involved in obtaining a valid, accurate and acceptable prover volume by different calibration methods. Units of measure in this publication are in the International System (SI) and United States Customary (USC) units consistent with North American industry practices. Part 1 is the introduction and contains those aspects that are generic to the various methods of calibration, including waterdraw (WD), master meter (MM) and gravimetric (GM). Each subsequent part is intended to be used in conjunction with Part 1 for the particular calibration procedure described. This section consists of the following four parts:

Part 1—Introduction to the Determination of the
Volume of Displacementand Tank Provers"

Part 2—Determination of the Volume of Displacement
and Tank Provers by the Waterdraw Method of Calibration"

Part 3—Determination of the Volume of Displacement
Provers by the Master Meter Method of Calibration

Part 4—Determination of the Volume of Displacement
Provers by the Gravimetric Method of Calibration

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Suggested revisions are invited and should be submitted to the Standards and Publications Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Chapter 4—Proving Systems

Section 9—Methods of Calibration for Displacement and Volumetric Tank Provers

Part 1—Introduction to the Determination of the Volume of Displacement and Tank Provers

1.0 Introduction

Provers are precision devices, defined as volumetric standards, which are used to verify the accuracy of liquid volumetric meters used for custody transfer measurement. Both displacement and tank provers are used to prove a meter in order to obtain its meter factor, which is then used to correct for meter error caused by differences between the metered volume and the true volume. The base volume of a displacement or tank prover, determined by calibration, is an essential requirement in the determination of these meter factors. The accuracy of a meter factor is limited by several considerations, as shown below.

- Equipment Performance
- Observation Errors
- Prover Volume Calibration Errors
- Calculation Errors

All prover volumes used to calibrate meters shall be determined by calibration and not by theoretical calculation. Volumetric provers have an exact reference volume, which has been determined by a recognized method of calibration. Techniques for the determination of this reference volume include the waterdraw, master meter and gravimetric methods of calibration. Parts 2, 3 and 4 (currently under development) of this standard (API *MPMS* Chapter 4, Section 9) are used to accurately determine the calibrated volume of meter provers.

1.1 U.S. CUSTOMARY AND METRIC (SI) UNITS

This standard presents both International System (SI) and U.S. Customary (USC) units, and may be implemented in either system of units. The system of units to be used is typically determined by contract, regulatory requirement, the manufacturer, or the user's calibration program. Once a system of units is chosen for a given application, it is not the intent of this standard to allow the arbitrary changing of units within this standard.

1.2 NATIONAL WEIGHTS AND MEASURES AGENCIES

Throughout this document issues of traceability are addressed by references to NIST (National Institute of Standards and Technology). However, other appropriate national metrology institutes can be referenced.

1.3 SAFETY CONSIDERATIONS

There is no intent to cover safety aspects of conducting the work described in this standard, and it is the duty of the user to be familiar with all applicable safe work practices. It is also the duty of the user to comply with all existing federal, state or local regulations (for example, the Occupational Safety and Health Administration) that govern the types of activities described in this standard, and to be familiar with all such safety and health regulations.

2.0 Scope

Chapter 4, Section 9 covers all the procedures required to determine the field data necessary to calculate a Base Prover Volume (BPV) of either Displacement Provers or Volumetric Tank Provers. It will enable the user to perform all the activities necessary to prepare the prover, conduct calibration runs, and record all the required data necessary to calculate the base volumes of displacement and tank provers. Evaluation of the results and troubleshooting of many calibration problems are also discussed.

This component, Chapter 4, Section 9, Part 1, is the Introduction, and contains all those relevant aspects that are general in nature, yet essential and applicable to all the different methods of calibration. Therefore, each subsequent part, which describes a specific method of prover calibration, must be used with Part 1. Together the two parts contain all the information that is essential to complete the required method of calibration.

Detailed calculation procedures are not included in this standard. For the complete details of the calculations for each calibration method, refer to the appropriate parts of the latest edition of the API *Manual of Petroleum Measurement Standards*, Chapter 12, Section 2.

3.0 Reference Publications

Publications that provided background information, and are a source of reference material on subjects related to prover calibration include the following:

American Petroleum Institute
Manual of Petroleum Measurement Standards (MPMS)

Chapter 1,	"Vocabulary"
Chapter 4,	"Proving Systems"
Chapter 5,	"Metering"
Chapter 7,	"Temperature Determination"
Chapter 9,	"Density Determination"
Chapter 11,	"Physical Properties Data"
Chapter 12,	"Calculation of Petroleum Quantities"
Chapter 13,	"Statistical Aspects of Measuring and Sampling
Chapter 15,	"Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries"

NIST[1]

Handbook 105	*Specifications and Tolerances for Reference Standards and Field Standard Weights and Measures*
Part 3	*Specifications and Tolerances for Graduated Neck-Type Volumetric Field Standards*
Part 7	*Small Volume Provers*
Handbook 44	*Specifications, Tolerances and Other Technical Requirements for Weighing and Measuring Devices*

4.0 Terms, Symbols and Applications

There are no definitions unique to this document. However, the publications selected in section 3.0 may be referenced for definitions relating to the calibration of displacement and tank provers. Terms and symbols described below are acceptable and in common use for the calibration of meter provers. Where a term is specifically defined in another API *MPMS* Standard, that definition shall take precedence over the expanded definition used in the Terms section of this document.

4.1 TERMS

4.1.1 Base Prover Volume (BPV): The volume of the prover at base conditions, as shown on the calibration certificate package, and obtained by arithmetically averaging an acceptable number of consecutive Calibrated Prover Volume (CPV) determinations.

4.1.2 Calibrated Prover Volume (CPV): The volume at base conditions between the detector switches of a unidirectional prover, or the volume of a prover tank between specified "empty" and "full" levels, as determined by a single calibration run. The calibrated volume of a bi-directional prover is the sum of the two volumes displaced between detectors during a calibration round-trip.

4.1.3 calibration certificate package: A document package stating the Base Prover Volume (BPV) together with the physical data used to calculate the BPV. It also includes the witnessed field data, summary calculations, and the traceability documentation.

4.1.4 double block and bleed valve: A high-integrity valve with double seals that has provision for determining whether either seal is leaking.

4.1.5 prover calibration pass: A single movement of the displacer between two predetermined detectors.

4.1.6 prover calibration run: One pass of a unidirectional prover or one round trip of a bi-directional prover, or one emptying or filling of a volumetric tank prover, which provides the data which allows the calculation of a single value of the Calibrated Prover Volume (CPV).

[1]National Institute of Standards and Technology, 1655 N Ft. Myer Drive, Suite 700, Arlington, Virginia, 22209. www.nist.gov.

4.1.7 round trip: The combination of one OUT pass followed by one BACK pass of the displacer in a bi-directional meter prover. The OUT pass refers to the flow of the liquid in the FORWARD direction while the displacer moves away from the HOME position. The BACK pass refers to the flow of the liquid in the REVERSE direction while the displacer returns to the HOME position. The terms "Left to Right" and "Right to Left" are also used to name the pass directions. By convention, these directions are determined by facing the 4-way valve while standing near the 4-way valve but away from the prover skid. See Figure 1 for an illustration of the "Left" and "Right" sides of a bi-directional meter prover.

4.1.8 targeted BPV: A term associated with atmospheric tank prover calibration, and refers to adjusting the scales to an even nominal value, such as 500 gallons or 1000 gallons.

4.1.9 traceability: The property of the result of a measurement, or the value of a standard, whereby it can be related to stated references, usually National or International Reference Standards, through an unbroken chain of comparisons all controlled, and having stated uncertainties. It should be noted that traceability only exists, when scientifically rigorous evidence is collected, on a continuing basis, showing that the measurement is producing documented results, for which the total measurement uncertainty is quantified.

4.2 SYMBOLS

A combination of upper and lower case notation is used for symbols and formulas in this publication. An example of the symbol notation is T = Temperature of the Liquid. In order to be more specific, symbols have additional letters added at the end to help clarify their meaning and application. Some of these additional letters in this document are defined as follows: "m" always refers to a meter (Tm), "p" always applies to the meter prover (Pp) and "tm" always refers to the test measure (Ttm).

Units

SI	International System of Units (e.g. bars, cubic meters, kilograms, degrees C)
USC	US Customary Units (e.g. psig, cubic feet, pounds, degrees F)

Pipe Dimensions

ID	Inside Diameter of the prover pipe
OD	Outside Diameter of the prover pipe
WT	Wall Thickness of the prover pipe

Liquid Density

DEN	Density of the liquid in kilogram per cubic meter (kg/M^3) units
DENb	Base Density of liquid in kilogram per cubic meter (kg/M^3) units
DENobs	Observed Density of the liquid at base pressure in kilograms per cubic meter (kg/M^3) units
RHOb	Base Density of the liquid (for prover calibrations)
RHOp	Density of the liquid in prover (for prover calibrations)
RHOtm	Density of the water in test measure (for waterdraw calibrations)
RHOmp	Density of the liquid in master prover (for master meter calibrations)
RHOmm	Density of the liquid in master meter (for master meter calibrations)

Temperature

Deg C	Celsius temperature scale
Deg F	Fahrenheit temperature scale
T	Temperature in deg F or deg C units
Td	Temperature of detector mounting shaft or displacer shaft on displacement prover with external detectors and a captive displacer.

Ttm	Temperature of water in test measure, in deg F or deg C units
Tp	Temperature of liquid in Prover in deg F or deg C units
Tm	Temperature of liquid in Meter in deg F or deg C units
Tmm	Temperature of liquid in Master Meter in deg F or deg C units
Tmp	Temperature of liquid in Master Prover in deg F or deg C units

Pressure

kPa	Kilopascals (SI) in absolute pressure units
kPag	Kilopascals (SI) in gauge pressure units
psi	Pounds per square inch (USC) pressure units
psia	Pounds per square inch (USC) in absolute pressure units
psig	Pounds per square inch (USC) in gauge pressure units
P	Operating pressure in gauge pressure units
Pb	Base pressure, in psi or kPa pressure units
Pp	Pressure of liquid in prover, in gauge pressure units
Pmp	Pressure of liquid in master prover, in gauge pressure units
Pmm	Pressure of liquid in master meter, in gauge pressure units

Correction Factors

E	Modulus of Elasticity of the steel prover
F	Compressibility factor of the liquid
Fp	Compressibility factor of the water in the prover
Fmp	Compressibility factor of the water in the master prover
Fmm	Compressibility factor of the water in the master meter
Gl	Linear coefficient of thermal expansion
Ga	Area coefficient of thermal expansion
Gc	Cubical coefficient of thermal expansion of the prover
Gcm	Cubical coefficient of thermal expansion of the test measure

Volumes

BMV	Field Standard Test Measure base volume(from calibration certificate)
BMVa	Field Standard Test Measure base volume adjusted for the scale reading
BPV	The Base Volume of the Prover at Standard Conditions
CPV	Calibrated Prover Volume as determined by a single calibration run
SR	Scale Reading of the Field Standard Test Measure
SRu	Upper Scale Reading of Atmospheric Tank Prover
SRl	Lower Scale Reading of Atmospheric Tank Prover

4.3 APPLICATIONS

A prover calibration is initially performed at the manufacturing plant where the prover is built, and often again after it has been installed at the operating facility. From this time forward, regular calibrations shall be performed according to a predetermined schedule.

There are many reasons to account for the necessity of frequent and regular recalibration of a prover, some of these, but not all, are as follows:

- Frequency of use and general wear
- Detector maintenance, wear, adjustment or replacement
- Deposit build-up on the prover walls (e.g. wax, paraffin, etc.)
- Loss of, or damage to, the internal coating of the prover walls
- Physical damage to the prover
- Maintenance on the calibrated section of the prover
- Over-pressurization of the prover
- Constructional changes to the prover

Prover calibrations are often witnessed by the interested parties. See Appendix A for information on calibration witnesses.

All provers shall be re-calibrated at regular intervals. Some provers are re-calibrated more frequently than others to minimize the risk of measurement errors or to limit the level of measurement loss by lowering the overall uncertainty of the prover volume. The frequency of use of the prover and the volume throughput measured at the facility should be considered when determining the appropriate frequency for recalibration. See API *MPMS* Chapter 4.8 “Guide to the Operation of Provers,” for additional information.

Consideration of the following items will help to establish the possible loss exposure and measurement risk, and will help to determine a required frequency of calibration for all provers:

- Volume through the metering system associated with the prover between prover calibrations
- Number of meters regularly proved by the prover and their frequency of proving
- The total yearly value of each product metered
- Service conditions and properties of products being metered and proved
- Whether the prover is portable or stationary
- The different types products being metered
- The range of properties of liquids being metered
- The required yearly maintenance and repair
- The total overall condition, including detectors and sphere displacer

Portable provers can be subject to more severe conditions of operation. Even the total yearly road usage should be looked at when considering a recalibration frequency. Careful observation and evaluation should establish whether more frequent recalibration is required of a portable prover when compared to a stationary prover.

Present day industry practice has established recalibration frequencies for provers that range from one year up to five-year cycles. This is based on the determination of normal wear, measurement risk management, volume of loss exposure, and any other relevant measurement factors. In some extreme cases prover recalibrations on three month or six month cycles have been judged to be necessary. See Appendix B, and API *MPMS* Chapter 4.8, for additional information on the calibration frequency of provers.

5.0 Types Of Provers

The following describes the most common types of provers. See other sections of API *MPMS* Chapter 4 for additional detail on prover design.

5.1 DISPLACEMENT TYPE UNIDIRECTIONAL PROVERS WITH FREE DISPLACERS

- Unidirectional—Sphere Provers with Mechanical Detectors

These types of unidirectional provers may be subdivided into the following two categories depending on the manner in which the displacer is handled:

a. The manual-return unidirectional prover, sometimes referred to as the measured distance, is an elementary form of an in-line prover that uses a section of pipeline as the prover section. Prover detector switches that define the calibrated volume of the prover section are placed at selected points along the pipeline. A displacer-launching device is placed upstream from the prover section, and receiving facilities are installed at some point downstream from the prover section. Conventional launching and receiving scraper traps are usually used for this purpose. To make a proving run, a displacer (a sphere or specially designed piston) is launched and allowed to displace the reference volume before being received downstream and manually transported back to the launching site. This type of prover is no longer in common use.

b. The circulating-return unidirectional prover, often referred to as the endless loop, has evolved from the prover described above. In the endless loop, the piping is arranged so that the downstream end of the loop crosses over and above the upstream end of the looped section. The interchange is the means by which the displacer is transferred from the downstream to the upstream end of the loop without being removed from the prover. The displacer detectors are located inside the looped portion at a suitable distance from the inter-change. Continuous or endless prover loops may be automated or manually operated.

5.2 DISPLACEMENT TYPE BI-DIRECTIONAL PROVERS WITH FREE DISPLACERS

- Bi-directional—Sphere Provers with Mechanical Detectors
- Bi-directional—Piston Provers with Magnetic Detectors and Check Valves
- Bi-directional—Piston Provers with Mechanical Detectors and Check Valves

There are three types of bi-directional provers: the sphere prover with mechanical detectors; the piston prover with magnetic detectors and check valves; and, the piston prover with mechanical detectors and check valves. These types of bi-directional provers have a length of pipe through which the displacer travels back and forth, actuating a detector switch at each end of the calibrated section. Suitable supplementary pipe-work and a reversing valve or valve assembly that is either manually or automatically operated make possible the reversal of the flow through the prover. The main body of the prover is often a straight piece of pipe, but it may be contoured or folded to fit in a limited space or to make it more readily mobile. A sphere is used as the displacer in the folded or contoured type; a piston or sphere may be used in the straight-pipe type.

5.3 DISPLACEMENT TYPE METER PROVERS WITH CAPTIVE DISPLACERS

- Unidirectional Piston Provers with Optical (external) Detectors

A prover having a captive displacer has an attached shaft or rod, which moves with the displacer. The displacement of the shaft is constant except that it moves into and out of the calibrated section during a calibration run. Thus a prover with a captive displacer and a shaft attached to one end will have an upstream and a downstream volume. If a shaft is attached to both sides of the displacer and they have equal area displacement, the upstream and downstream volumes are equal. There is often one or two other detector and/or guide rods attached to the captive displacer.

Since these type provers have externally mounted optical detectors, the thermal effect on the steel may not be the same for the area aspect as for the linear aspect. For example, if both the prover chamber and the mounting that defines the linear distance between the detector(s) were the same, the thermal effects would be the same. But in many cases, a prover chamber might be made of a type of stainless steel while the detector(s) mounting which defines the linear distance between the detector(s) might be made of a special alloy having a different thermal coefficient of expansion. In terms of a prover calibration, the main effect is that it is necessary to obtain both a prover barrel temperature and a detector temperature.

5.4 DISPLACEMENT TYPE METER PROVERS WITH MULTIPLE VOLUMES

If a displacement prover has multiple volumes, each volume shall be considered to be a stand-alone and independent prover volume. Each of these prover volumes shall be calibrated by a separate and independent calibration. Each calibration shall meet the same criteria as described in the detailed calibration procedures. See Figure 2 for various detector switch configurations on multiple volume provers.

5.5 ATMOSPHERIC TANK PROVERS

An atmospheric tank prover is a volumetric vessel with an upper neck, upper sight glass, upper scale, and an upper and lower cone usually separated by a cylindrical section. Different types are identified by the way in which their bottom "zero" is defined. Atmospheric tank provers are described below:

- **Bottom-weir type:** This prover has a bottom neck beneath the lower cone. The bottom neck may or may not have a sight glass and scale, but in any case it has a fixed bottom "zero" defined by the weir.
- **Dry-bottom type:** This prover usually does NOT have a bottom neck under the lower cone. The closed bottom drain valve defines the bottom "zero" just as on a field standard test measure.
- **Wet-bottom type:** This prover has a bottom neck beneath the lower cone. The bottom neck always has a sight glass and scale. The bottom "zero" is defined by the "zero" on the scale. In practice, readings above and below the "zero" in the lower neck are common.

6.0 Equipment

Changes in fluid properties, operating conditions and equipment components may affect the uncertainty of the volume relative to the volume obtained at calibration conditions.

6.1 PROVER DETECTOR SWITCHES

A detector switch is a high precision device mounted on a prover, which is used to detect the passage of a displacer. The calibrated volume of a prover is the amount of fluid that is displaced between two detector switch positions. Additional detector switches may be used if more than one calibrated volume is required on the same prover, or they can also be used to signal the entrance of a displacer into the sphere resting chamber. Several types of detector switches are described below.

6.1.1 Mechanically Actuated Detector Switches

The mechanical type of detector switch is used primarily with an elastomeric sphere displacer, but there are applications where they are used with piston displacers, and are operated when the displacer contacts a rod or ball protruding into the prover pipe. At the point of operation a switch is closed or opened by means of a mechanically or magnetically driven contact.

Mechanically actuated detectors may or may not be pressure balanced. Pressure balanced detectors have ports or passages that allow pressure to be equally distributed on the switch rod, thereby offsetting the effect of pressure on the activation of the detector.

6.1.2 Proximity-Type Magnetically Actuated Detector Switches

This type of detector switch is used only with piston displacers and is mounted externally with no parts protruding into the prover pipe. An excitor ring on the non-magnetic piston displacer actuates the detector switch mechanism as it passes beneath the proximity type detector switch.

6.1.3 Optically Actuated Detector Switches

Conventional design of the optical detector has a light source, together with a photoelectric detector cell, mounted opposite each other on a small metal base plate. In normal operations the light source shines directly into the photoelectric cell until the light beam is interrupted by a lever or plate mounted to a moving rod on the displacer. Breaking of the light beam causes the detector switch to operate.

6.2 LAUNCHING CHAMBERS AND TRANSFER CHAMBERS

In both unidirectional and bi-directional provers, an area must be provided in which the displacer can rest when not in use. In bi-directional meter provers, this space is defined as a launching chamber. Bi-directional provers using sphere displacers require launch chambers at both ends of the prover pipe. Piston type bi-directional provers do not require expanded launch chambers at either end of the prover pipe because the flowing stream does not go around the piston, but is diverted upstream of the launch chambers by means of check valves. On unidirectional meter provers, a transfer chamber is used in combination with one or more valves, to store the sphere away from the flowing stream, and to provide a means to re-launch the displacer when required.

6.3 SPHERE INTERCHANGES

On unidirectional provers, the sphere interchange provides a means for transferring the sphere from the downstream end of the proving section to the upstream end. Transfer of the sphere may be accomplished with several different combinations of valves or other devices to minimize bypass flow through the interchange. A leak-tight seal between the upstream and downstream sides is essential and must be verified before the sphere reaches the first detector switch of the proving section.

6.4 FOUR-WAY VALVES

The four-way diverter valve is used on bi-directional provers to change the flow direction through the prover. It is designed to handle low-pressure differentials, and has a double block and bleed feature to verify the sealing integrity of the valve. A leak tight seal by the four-way valve is essential and must be verified before the sphere activates the first detector. An additional length of pipe is provided in the prover, prior to the detector switch, to allow the sphere to travel while the four-way valve is in operation and to ensure that the four-way valve is fully closed before the sphere contacts the first detector switch. This length of pipe is known as the pre-run section and is included in all prover construction based on the design flow rate.

6.5 DISPLACERS

In a displacement prover, the displacer is used to form a seal so that the flow pushes it through the measuring section. This seal prevents flow from bypassing the displacer, which is critical to the accurate calibration of the prover. The displacer actuates detector switches, which define the volume of the prover. There are three common types of displacers.

6.5.1 Sphere Displacers

The most common sphere displacer is the inflatable type. It has a hollow center with one or more valves used to inflate the sphere. A 50/50-glycol/water mixture is most often used to fill the sphere; however, water or glycol may be used separately for specific purposes. The sphere is typically inflated to approximately 2% – 5% larger than the inside diameter of the calibrated section of the prover.

The most common elastomers used in the construction of sphere displacers are neoprene, urethane and nitrile. No one material is ideal for all applications. The composition of the displacer used during the initial factory calibration may be different from the composition of the displacer that is field calibrated for its normal operation.

In some cases, usually in displacement provers below 6" in size, sphere displacers are made of solid nitrile, urethane or neoprene rubber, manufactured to a predetermined oversize and cannot be inflated.

6.5.2 Piston Displacers

Piston displacers are used in specially designed bi-directional provers and are usually lightweight and made of aluminum or non-magnetic stainless steel. These pistons are cylindrical in shape, have seals and wear-rings at each end, and usually have an exciter ring fitted. An exciter ring is a magnetic device fitted into the piston and designed such that the magnetic field will activate a proximity type detector switch as the piston passes beneath it. Teflon and polyurethane are the most commonly used elastomers in the construction of piston seals.

6.5.3 Captive Displacers—Piston with Shaft (Rod)

Some types of provers utilize a captive displacer piston. Captive displacers are typically constructed of aluminum or stainless steel with Teflon based elastomeric seals that contact the inside walls of the measuring section of the prover.

The displacer is normally attached to a shaft or rod that passes to the outside of the prover and is used to move it to the upstream end of the measuring section. This shaft may also be used to detect the position of the displacer and to activate the detector switches. Some types of captive displacer have dual seals that are self-checking - along the lines of the block and bleed valve. Some types have an internal valve constructed in the piston. The internal valve type also has elastomeric seals to prevent flow passing through the piston during a pass.

6.6 VALVES, RELIEF VALVES, DRAINS AND VENTS

The unidirectional prover sphere handling interchange, the bi-directional prover four-way valve, and all valves located between the calibrated section of the prover and the calibration unit, shall seal without any visible internal or external leakage when in a closed position.

It is essential that the sphere handling interchange in a unidirectional prover, the four-way valve or the older alternative four-valve systems in a bi-directional prover, and any valve in a line bypassing the prover, shall seal completely when closed. A prover valve, which does not shut off flow completely, will cause serious errors.

Types of valves known as the "double-block-and-bleed" are used on provers where leak detection is essential. These valves are double seated with a space between the two seats that is connected to a small bleed-valve. By opening this bleed valve the operator can make a positive check that the main valve is not leaking. Any leakage across either of the valve seats will reveal itself through the bleed. In some double-block-and-bleed systems, leakage is allowed to pass freely through the bleed to a location where it can be seen flowing; in other valves, the bleed is connected to a pressure gauge so that rising or falling pressure is the indication of leakage.

The prover and all the associated piping involved during the calibration may contain relief, drain and vent valves. All of these valves normally discharge into the drainage system and can easily hide an unknown source of leakage. All of these valves shall have a means to visually verify that no leakage is occurring or they are to be isolated during each calibration run.

All valves located on the prover system and in-line, up to the test measures, that are part of the calibration, and operating in an open position, shall be regularly inspected for any signs of external leakage. Any leakage will cause an error in the certified volume.

6.7 TEMPERATURE AND PRESSURE INDICATORS

A temperature measurement is required at the location where the liquid being displaced exits the prover. Temperature measurements are usually made using certified or calibrated mercury-in-glass thermometers or calibrated electronic temperature devices. In the case of a large difference in temperature between the ambient air and the calibration liquid, a thermometer stem correction may be required in accordance with API *MPMS* Chapter 7. However, the need for stem corrections is unlikely in the case of prover calibrations which are normally conducted near ambient conditions. The thermometer scale shall be in increments no greater than 0.2°F (0.1°C), and its accuracy shall be within 0.1°F (± 0.05°C).

A certified or calibrated thermometer shall be on-site with a certificate of calibration accuracy. The certificate of calibration shall be traceable to NIST or other appropriate national metrology institute. The certified thermometer shall be used to verify the accuracy of all the other thermometers (working thermometers) used in the calibration procedures. The certified or calibrated thermometer and the working thermometers must agree within ± 0.1°F (± 0.05°C). Alternatively, working thermometers that have been certified to have been verified at three points (e.g., high, mid and low range points) within one year and a day of the time of the prover calibration by a thermometer that has a calibration traceable to a national standard may also be used providing that all of them agree among themselves within ± 0.1°F (± 0.05°C).

Electronic temperature measurement devices may be used in the calibration if there is agreement between all the represented parties. If using electronic temperature measurement devices then the requirements laid out in API *MPMS* Chapter 7 "Temperature Measurement", shall be followed. As part of the requirement that the device be verified before each calibration, this verification shall be carried out against a calibrated or certified thermometer, accurate to ± 0.1°F (0.05°C).

For waterdraw calibrations, a pressure measurement is required downstream of the displacer. A connection to fit a pressure measuring device shall be provided between the water outlet from the prover and the pipe work prior to the water entering the test measures. Because of the very low flow rate when the water is flowing only through the solenoid valve, and the resulting minimal pressure drop at that time, it is acceptable to install the pressure measuring device on the calibration unit.

Pressure measurements are usually made using a calibrated dial type pressure gauge that is accurate and readable to one pound per square inch (1-psig) increments, and shall have with it on-site a certificate of calibration accuracy. This certificate of calibration shall be traceable to NIST or other appropriate national metrology institute and shall be considered valid if within one year and a day of the date of calibration of the pressure gauge. Electronic pressure devices or digital pressure gauges may be used in the calibration if there is agreement between all the represented parties. Their readability and verifiable accuracy shall have exactly the same requirements as those specified for dial type pressure gauges, including an on-site valid certificate of calibration accuracy. All electronic pressure readings shall be rounded to the nearest one pound per square inch (1-psig) for recording.

6.8 HOSES, PUMPS AND CONNECTIONS

All hoses and connectors used shall operate leak free and be suitable for the liquid used in the calibration and for the maximum pressures to be expected throughout the calibration. Hoses used for calibrations should be wire-wound to prevent collapse and to minimize any inflation due to pressure. However, for calibrations using water, soft hoses may be used (if approved by user company policy) on the inlet side, since inflation of the inlet hose has no impact on the calibration. The total length of hoses in use should be kept as short as possible so that the volume of liquid contained in these hoses is minimized.

The pump (or pumps) used to circulate water throughout the system during calibrations should be in good working condition with no leaks. An electric motor driven centrifugal pump works best, since the flow rate can be easily varied or stopped with the outlet pressure remaining relatively low. Pump capacities of 20 to 100 gpm are typical, however higher capacity pumps should be considered when larger provers are to be calibrated. A static head pressure from the pump of 30 to 50 psig is normally sufficient. Pumps with higher pressures should be avoided, as the higher pressures can cause swelling, leaking or bursting of hoses, or as is more common, cause the hose connectors to leak.

6.9 SOLENOID VALVES AND LOGIC CIRCUITS

Solenoid valves and logic circuits may be used for any method of prover calibration. The discussion below is a short introduction to the subject.

6.9.1 For Waterdraw Calibrations

Solenoid valves, used in waterdraw calibrations, are a combination of an electromagnetic plunger and an orifice to which a disc or plug can be positioned to either restrict or completely shut off a flow. Orifice closure occurs when the electromagnet actuates a magnetic plunger. Typical orifice sizes range from $^{3}/_{32}$ to $^{1}/_{4}$ inch. Solenoid valves may be two-way or three-way acting.

Solenoid valves are actuated by detector switch closures and are usually arranged to stop the water flow to drain and divert it into the test measure or vice-versa. The use of a solenoid valve reduces the uncertainty in valve closure to stop the test measure filling when the displacer contacts the second detector switch. Other uses of the solenoid valve during the prover calibration permit the recording of the stop/start sequence at the same exact repeatable conditions every time. Solenoid valves control the final approach of the displacer so that it arrives at the same exact position each time that it actuates the detector switch.

6.9.2 For Waterdraw, Master Meter and Gravimetric Calibrations

A logic circuit is defined as an electronic device or devices used to govern particular sequences of operations in any given system. They can gate or inhibit signal transmission in accordance with the application, removal, or combination of input signals. They have become a necessary aid in calibration and provide assistance in locating and tracking the position of the displacer. At the actuation of a detector switch, the logic circuit is programmed to notify the operator, generally by means of visible or audible signals, of the position of the sphere displacer. Solenoid valves mounted above the test measures work in conjunction with the prover detector switches through the logic circuit as follows:

- A single cable to both prover detector switches.

In this configuration any time a detector switch is gated the logic circuit will NOT tell the operator specifically which detector switch was actuated.

- A separate cable to each prover detector switch.

In this configuration any time a detector switch is gated the logic circuit will tell the operator specifically which detector switch was actuated.

It is possible to perform prover calibrations without the use of logic circuits by direct wiring between the prover switches and the solenoid valves. Careful observation of the activation of the detector switches and the solenoid valves will be necessary by the operator to continuously track and follow the location of the sphere displacer, since external-signaling devices will not be available in this situation. General industry practice, however, is to make use of logic circuits when they are available.

6.10 FIELD STANDARD TEST MEASURES

Field standard test measures are used for the waterdraw calibration method, and are accurate volume measures, usually made of stainless steel, which are used as the volumetric standards in the calibration of liquid provers. A field standard test measure is a vessel fabricated to meet specific design criteria and is calibrated by NIST or other appropriate national metrology institute. Test measures typically range in volume from one gallon to 1000 gallons, with 500 gallon being the largest size in regular use. Specific information on test measures, their methods of their calibration, the calibration frequency and their use, can all be found in API *MPMS* Chapter 4.7 "Field Standard Test Measures."

Test measures may have a "to contain" and/or a "to deliver" volume. When the "to deliver" volume is used, the test measures are filled and drained, and then left in a wetted condition before use. Only the "to deliver" volume of a test measure shall be used in a calibration. The "to contain" test measure volumes are not used in prover calibrations, because then the test measures must be completely clean and dry before every filling, usually an impractical field operations requirement.

Two permanently mounted, adjustable spirit levels are often installed and located at right angles to each other, on the body of the upper cone of the test measure. These spirit levels are usually equipped with adjusting screws, capable of being sealed, which have protective covers. As part of the preparation of a field standard test measure for calibration, it is recommended that it be filled with water and adjusted until level (usually using the legs). This level position is then verified by placing a precision machinist's spirit level across the top of the neck and verifying that the test measure is level in two directions, 90 degrees apart. After verification, it may be necessary to more finely adjust the test measure position for level by additional changes to the leveling system. The permanently mounted spirit levels shall then be adjusted so that they agree exactly with the precision machinist's spirit level as described above. Once set, the permanently mounted spirit levels should be sealed in place and covered for protection. This test measure level verification and adjustment procedure is recommended for all test measures prior to them being delivered to a standards agency (e.g., NIST), for calibration. This is to ensure that the levels on the field standard measure are in agreement with the precision machinist's spirit level when placed across the neck of the standard. On smaller size test measures, circular type bubble levels are sometimes used.

In all cases the NIST Report of Calibration of a field standard test measure, shall provide the criteria for determining the level state of any given test measure when filled with water. In case of any disagreement between the use of the permanently mounted levels and the use of a precision machinist's spirit level across the top of the neck, the NIST Report of Calibration definition of the level position for that test measure shall apply.

6.11 MASTER METER

The master meter is a meter used for master meter prover calibration. Meters with very good linearity and repeatability are used for master meter proving. These meters should be inspected annually to insure their integrity. Master meter performance (review of master meter calibration factors) should be routinely checked to determine if the master meter is performing properly. The master meter shall be installed and operated in accordance with API *MPMS* Chapter 5. Pressure and temperature instrumentation shall be installed in the meter run.

6.12 MASTER PROVER

A master prover should be designed and sized to work in conjunction with the master meter (see API *MPMS* Chapter 4.2 for design requirements). The master prover shall not be calibrated by the master meter method. The master prover should be equipped with pressure and temperature instrumentation on inlet and outlet of the prover. All drain and vent valves on the master prover shall either be of the block and bleed type or have other means for checking leakage.

6.13 MOBILE EQUIPMENT

Typically, the prover calibration equipment is mounted on a truck or trailer. It is important that the calibration equipment be rigidly constructed and securely mounted on the truck or trailer to prevent deformation or damage during transportation, usage, or storage.

6.14 GRAVIMETRIC EQUIPMENT

Reference to the Gravimetric Method and Equipment can be found in Part 4 of this standard, which is currently under development.

7.0 Documentation and Record Keeping

All observation data shall be hand written in ink; or collected, recorded, and reported automatically by a flow computer with audit trail capability. All of the observation data shall be proof read against the data input for the calculations before signing any documents. In case of discrepancies or errors discovered at a later date the hand written observation data shall be used to correct the final volume.

The calibration certificate package shall include the Calibration Report with the date of the prover calibration prominently displayed on the front of the Calibration Certificate Package. Other items applicable to the calibration shall also be recorded in the Calibration Certificate Package as follows:

For the Waterdraw, Master Meter and Gravimetric Methods:

- the location of the prover
- the serial number of the prover
- the serial number or seal number for each detector switch
- the owner or operator of the prover
- the type of prover
- the material of construction of the prover
- the inside diameter of the prover
- the wall thickness of the prover
- the temperature indicators and pressure indicator used
- Calibration Certificates for all the temperature and pressure indicators used
- the displacer type, the size, and the durometer (if applicable)
- in the case of multi-volume displacement provers
  a. a clear identification of the detectors used for this calibration
  b. the physical location of each detector
- A copy of the handwritten observation documentation (signed by all parties as witness to the original observation data);
- A copy of the calculation and summary generated documentation

For the Waterdraw Calibration Method:

- the field standard test measures used
- copies of the NIST Reports of Calibration for all of the field standard test measures used.

For the Master Meter Calibration Method:

- the serial number of the master prover
- the type of master prover
- the material of construction of the master prover
- the inside diameter of the master prover
- the wall thickness of the master prover
- Calibration Certificate Package for the Master Prover
- the type of master meter
- the size of master meter

For the Gravimetric Calibration Method:

- Calibration Certificates on the Standard Weights
- Calibration Certificate(s) on the Weigh Scale
- Note: This method under development so list is incomplete

8.0 Calibration Troubleshooting Guide

Full records of the complete data collected during all the calibration runs, whether valid or invalid, should be recorded and kept in a systematic manner.

The primary source of a questionable measurement can normally be identified as one or more of the following as specific to the calibration method:

- Air in the system
- Hydrocarbons in the system (when water is the calibrating medium)
- Leaks in the system
- Temperature or pressure instability

- Errors in determining test measure measurements
- Malfunctioning isolating valves
- Malfunctioning solenoid valves
- Damaged or under-inflated sphere displacer
- Damaged or improperly fitting seals
- Wear in the piston displacer
- Contamination to the circulating (calibration) medium
- Damaged or contaminated field standard test measures (for the waterdraw method)
- Damaged master meter or master prover (for the master meter method)
- Damaged weighing device or weight standards (for the gravimetric method)
- Damaged temperature and pressure measuring devices
- Malfunctioning prover detector switches
- Damaged or deteriorating internal surfaces of the prover
- Damaged or leaking sphere interchange
- Damaged or leaking four-way valve
- Human error
- Measuring equipment errors

Each of the above sources must be carefully examined until the cause of the abnormal measurements is found.

APPENDIX A
(Informative)
CALIBRATION WITNESSES

One technician usually performs the calibration in the company of several others who are designated as the witnesses. A witness is usually a representative of an associated company having operational, financial or other interests in the custody transfer functions at that facility. Company employees from the same or other divisions are often involved and occasionally federal, state or local government officials will be present. However, all the parties attending the calibration as witnesses (representatives of other involved interests), shall be equally responsible for the successful outcome of the calibration. It follows that all the witnesses should, therefore, be involved in all the required calibration activities.

Some of these required items are listed below. Generally, all the witnesses shall be ready to assist, advise, and participate in whatever tasks are necessary to produce a speedy, successful and accurate calibration:

- Validate the traceability of equipment by checking the calibration dates and the availability of valid calibration certificates and other records.
- Witness the cleanliness and interior condition of the prover.
- Witness the inspection and sizing of the sphere displacers or pistons.
- Witness the inspection and all maintenance of the detector switches.
- Witness the verification of the temperature and pressure devices.
- Witness all general set-up activities including setting up the liquid circulation, venting of the air, and leak checking.
- Witness patrolling of the area for leaks during the calibration runs.
- Witness checking the integrity of block valves during runs.
- Witness checking the integrity of four-way valves during runs.
- Witness checking the integrity of sphere interchanges during runs.
- Witness the filling and general operation of the test measures (waterdraw) or the general operation of the master meter and master prover.
- Witness the filling and general operation of the prover being calibrated.
- Witness and check that the test measures are level when read (waterdraw).
- Witness test measure scale readings and interpolations (waterdraw).
- Witness temperature and pressure readings and interpolations.
- Witness the draining of test measures and the adherence to draining times (waterdraw).
- Witness the accurate determination of necessary temperatures and pressures.
- Keep or witness the recording (hand written) of all the calibration data as log entries.
- Where requested, offer advice in troubleshooting all problems and difficulties, and assist with the reading of thermometers and gauges.
- In general, witness the resolution of all the operations, processes and problems encountered.

APPENDIX B
(Informative)
A METHOD FOR DETERMINING THE FREQUENCY OF CALIBRATING PIPE PROVERS

Introduction

To assist readers a method that is sometimes used to estimate the frequency of prover recalibration is presented here as an option that can be used to define an appropriate time interval between prover calibrations. It is for the reader to decide if this method is appropriate and usable when applied to their methods of operation and the calibration intervals selected for their pipe provers.

This method recognizes that each pipe prover is an individual unit, which has its own amount of use over time, its own severity of conditions during use, and its own specific wear patterns. Therefore, it is reasonable to expect that each pipe prover should have a unique frequency of calibration. However, the important question is how well is the prover holding to its present calibrated volume. If the prover volume is staying within specific tolerances then there is no need to re-calibrate until the volume has changed by some acceptable defined amount.

The method sets the allowable change in prover volume before re-calibration at 0.050%, and uses the actual volume change between successive calibrations, together with the time (in months) between the two calibrations, to calculate a projected time (number of months) when the volume can be expected to change by 0.050%.

The only part of this discussion that may be arguable is whether or not the amount of allowable change to the prover volume should be 0.050%. Arguments have been made that the volume change should be set at 0.020%, because that is the tolerance of the calibration of the prover. However, putting the activation point at 0.02% may result in calibrating some provers more frequently than necessary. Based on this argument, 0.050%, is a reasonable compromise.

For the purposes of clarity, the example illustrated below uses 0.050% as the volume change from the above discussion. If a different tolerance (e.g., 0.030%) is the stated policy of the operating company, then this number should be substituted in the example in place of the 0.050 shown. (Note: No tolerance greater than ± 0.05% should be used. This method only applies once a baseline has been established.)

PROCEDURE

To use this method determine the number of months between the most recent calibration and the previous prover calibration, together with the amount of volume change, as a percentage, between the two calibrations. Using this data and the allowable change of 0.050%, calculate the projected number of months until the next calibration will be required.

Example Calculation

Date of Calibration	Months between Calibrations	Prover Volume (Barrels)	Volume Change (Percentage)	Calculation	Time to Next Calibration (months)
7/02/2004	13	11.9958	0.026%	(13 x 0.050) / (0.026)	25
6/01/2003	0	11.9927	0		

In the above example, this prover should be scheduled for recalibration again in 25 months. A new projected calibration date can then be calculated based on the time and volume change between the 7/02/2004-calibration volume, and the new volume at the actual date of the next calibration, which should be about 8/01/2006.

The following guidelines should be adhered to with regard to the use of the above calculation:

- Under no circumstances should the projected time to the next calibration exceed 60 months 5 years.
- If the allowable change in volume is less than absolute 0.02% (i.e. – 0.02% or + 0.02%), then set the projected time to the next calibration at 12 months.
- If mechanical repairs, alterations or changes which affect the certified volume are made to the prover before the next projected calibration date, then calibrate the prover immediately after completion of this work, and then schedule another prover calibration for 12 months ahead.

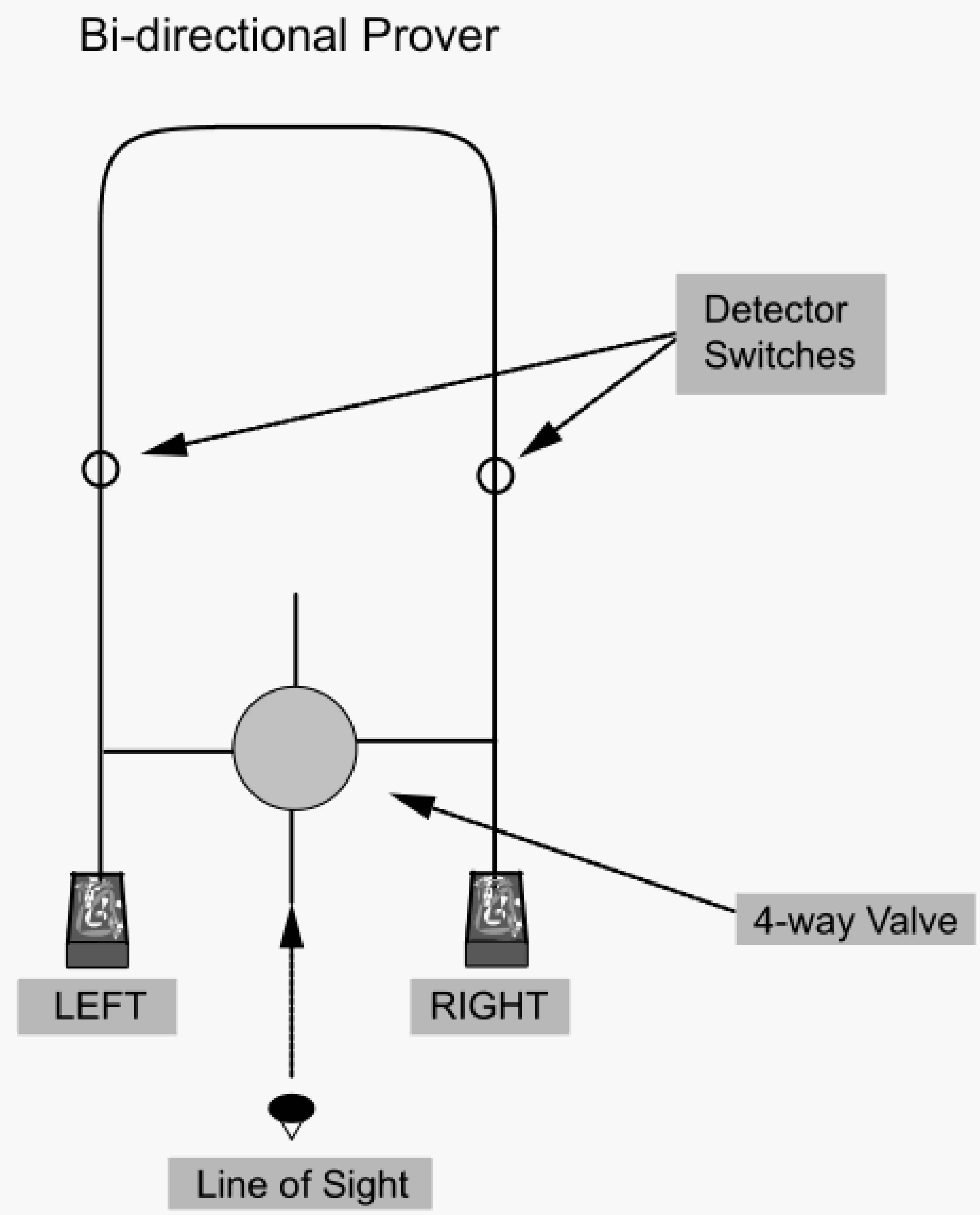
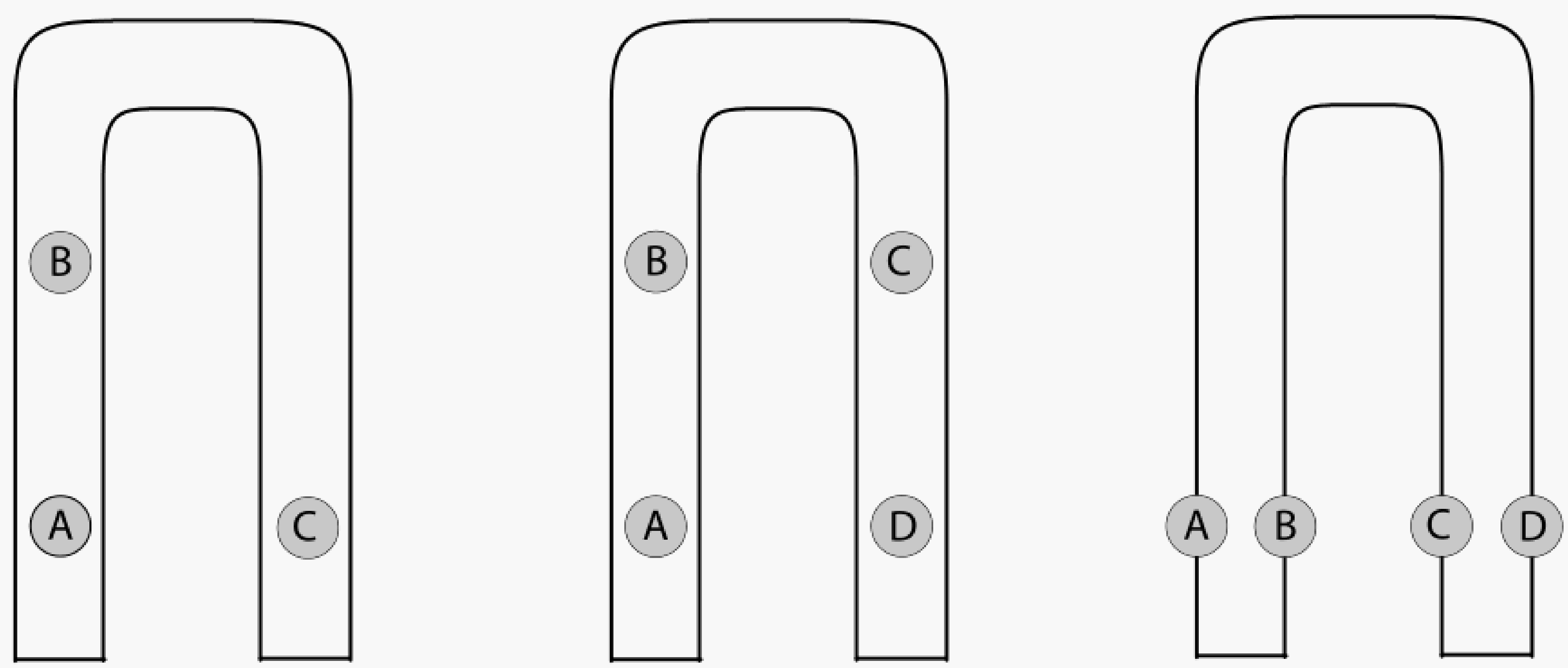


Figure 1—Bi-directional Prover Orientation of "Left" and "Right"



Example 1
A Three Detector Switch Prover
(A total of three volumes may be available for calibration in this configuration A-B, A-C, and B-C)

Example 2
A Four Detector Switch Prover
(A total of six volumes may be available for calibration in this configuration A-B, A-C, A-D, B-C, B-D, C-D)

Example 3
A Four Detector Switch Prover where the detector switches are adjacent to each other.
(A total of six volumes should be available for calibration, but volume A-B, and volume C-D, are so small that they are considered negligible)

Figure 2—Examples of Multi-volume Prover Detector Switch Configurations

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