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Guidelines for a Material Verification Program (MVP) for New and Existing Assets

1. SCOPE

1.1. Purpose

The purpose of this recommended practice (RP) is to provide the guidelines for the owner/user to develop and implement a material verification program (MVP) as part of an asset integrity program. The MVP uses positive material identification and other methods to verify that the nominal composition of an asset, an asset component, or weldment within the pressure envelope is consistent with the selected or specified construction materials.

A well designed and implemented MVP is an important management system tool used to minimize the potential for release of hazardous materials due to nonconforming materials of construction.

1.2. About this Document

This RP provides the guidelines for material verification programs involving ferrous and non-ferrous alloys during the construction, installation, maintenance, and inspection of new and existing process equipment. This RP applies to metallic materials purchased for use either directly by the owner/user or indirectly through vendors, fabricators, or contractors and includes the supply, fabrication, and installation of these materials.

This Recommended Practice is applicable to all oil and petrochemical processing systems, and may be applied elsewhere at the discretion of the owner/user. It is intended to be applied by any owner/user wishing to verify and/or validate that the materials of construction received, fabricated, and/or installed are in accordance with material specification.

2. REFERENCES

2.1. Normative

There are no documents considered to be normative following referenced documents are indispensable for the application of this document. A bibliography is shown in Annex B. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

- API 510, Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration
- API 570, Piping Inspection Code: Inspection, Repair, and Rerating of In-service Piping Systems
2.2. Informative

The following referenced documents are informative in 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 RP 571, Damage Mechanisms Affecting Fixed Equipment In the Refining Industry
- API Recommended Practice 580, Risk-Based Inspection
- API 579-1/ASME FFS-1 Fitness For Service API Recommended Practice 751, Safe Operation of Hydrofluoric Acid Alkylation Units
- API RP 939-C, Guidelines for Avoiding Sulfidation Corrosion Failures In Oil Refineries
- ASME\textsuperscript{1} Boiler and Pressure Vessel Code: Section II Materials [\textsuperscript{2}]
  - Part A: Ferrous Material Specifications,\textsuperscript{2}
  - Part B: Nonferrous Material Specifications,\textsuperscript{2}
  - Part C: Specifications for Welding Rods, Electrodes, and Filler Metals,\textsuperscript{2}
  - Part D: Properties - Materials\textsuperscript{2}
- ASME PCC-2, Repair of Pressure Equipment and Piping
- ASME B31.3, Process Piping
  - NACE\textsuperscript{3} Paper No 03651, “Specification for Carbon Steel Materials for Hydrofluoric Acid Alkylation Units”
- PFI\textsuperscript{4} ES22, Recommended Practice for Color Coding of Piping Materials

Footnotes

\textsuperscript{2}U.S. Chemical Safety and Hazard Investigation Board, Office of Prevention, Outreach, and Policy, 2175 K Street NW, Suite 400, Washington, D.C. 20037-1848, 202-261-7600, www.csb.gov. Most CSB publications are posted on,
3.0 DEFINITIONS AND ACRONYMS

3.1 Definitions

3.1.1 Alloy Material - Any metallic material (including welding filler materials) that contains alloying elements, such as chromium, nickel, or molybdenum, which are intentionally added to enhance mechanical or physical properties and/or corrosion resistance. Alloys may be ferrous or non-ferrous.

3.1.2 Asset - piece or pieces of equipment working to manufacture products resulting from the processing of raw materials; hydrocarbons or chemicals within the context of this document.

3.1.3 Distributor - A warehousing supplier for manufacturers or suppliers of materials or components.

3.1.4 Extent of examination - The specified percentage of the number of items to be examined in an inspection lot.

3.1.5 Fabricator - An organization which utilizes the materials of construction affected by this recommended practice in order to create an asset.

3.1.6 Fabricator - An organization which builds the assets affected by this recommended practice.

3.1.6.1 Heat - A batch of metal made at the same time, able to be traced from its original constituents and manufacturing process.

3.1.6.2 Inspection Lot - A group of items or materials of the same type from a common source from which a sample is to be drawn for examination. NOTE: An inspection lot does not include items from more than one heat.

3.1.6.3 Extent of examination - The specified percentage of the number of items to be examined in an inspection lot.

3.1.6.4 Lot size - The number of items available in the inspection lot at the time a representative sample is selected.

3.1.6.5 Material Certifications, or Certificates of Compliance - see mill test report.

3.1.6.6 Material manufacturer - An organization that performs or supervises and directly controls one or more of the operations that affect the chemical composition or mechanical properties of a metallic material.

3.1.6.7 Material nonconformance - A positive material identification (PMI) result that does not conform with material specified.

3.1.6.8 Material supplier - An organization that supplies material furnished and certified by a material manufacturer, but does not perform any operation.
intended to alter the material properties required by the applicable material specification.

3.1.13 Mill Test Report (MTR) - A quality assurance document used in the steelmaking industry that certifies a material's compliance with appropriate standards, including physical and chemical specifications, and applicable dimensions. The MTR also includes a date of production and testing, and may include notation about method of fabrication. A mill test report is also known as: Certified Mill Test Report, Certified Material Test Report, Mill Test Certificate (MTC), Inspection Certificate, Certificate of Test, and by other names. However, MTR is the term that is used in this document.

3.1.14 Owner/user - The organization that exercises control over the operation, engineering, inspection, repair, alteration, pressure testing, and rating of the piping systems.

3.1.15 Pressure-containing components - Items that form the pressure-containing envelope of the equipment and/or piping system.

3.1.16 Positive Material Identification (PMI) - A physical evaluation or test of a material performed to confirm that the material which has been or will be placed into service is consistent with what is specified by the owner/user. These evaluations or tests may provide either qualitative or quantitative information that is sufficient to verify the composition.

3.1.17 Random - Selection process by which choices are made in an arbitrary and unbiased manner.

3.1.18 Representative sample - One or more items selected at random from the inspection lot that are to be examined to determine acceptability of the inspection lot.

3.1.19 Standard reference materials - Sample materials for which laboratory chemical analysis data are available and are used in demonstrating the accuracy and reliability of a test instrument.

3.1.20 Weld Button (button): a sample of welding filler material deposited on relevant base metal in order to provide basis for PMI of the filler.
4.0 CONSIDERATIONS AND GENERAL CONCERNS

4.1 Carbon Steel Substitutions in Low Alloy Steel Systems

When considering the likelihood of material nonconformances, it is worth noting that historically the greatest number of material nonconformances with serious consequences have involved placing unapproved carbon steel components into low alloy steel (e.g., 1¼Cr-½Mo, 2¼Cr-1Mo, 5Cr-½Mo, 9Cr-1Mo) piping systems. There have been fewer nonconformances in stainless steel and nonferrous systems because of appearance and weldability issues.

4.2 Alloy Substitutions for Carbon Steel

When determining the need to perform material verification on carbon steel, the owner/user should evaluate the effect that the process stream could have on substituted materials. In some cases, the substitution of hardenable alloy materials for carbon steel has resulted in failure and loss of containment. Examples of such systems include those handling wet hydrogen sulfide (H₂S), hydrofluoric acid (HF), or sulfuric acid (H₂SO₄). Where material substitution could lead to failure and/or loss of containment, the extent of verification should be planned and/or increased in effectiveness to validate the materials specified for use.

4.3 Stainless steel and Non-ferrous Substitutions within High Alloy Systems

There are a wide variety of stainless steels with varying compositions and varying corrosion resistance to different process streams. PMI should be considered by the owner/user depending upon the level of risk (probability and consequence of failure) based upon the potential damage mechanisms and damage rates associated with the installation of an unapproved high alloy during fabrication and installation. Examples of these situations include the substitution of stainless steels for Alloy 400 in HF Alkylation services, the substitution of a non-stabilized grade of stainless steel for a stabilized grade in a high temperature service, or substitution of type 304 SS for type 316 SS where the molybdenum content is important for corrosion resistance.
4.34.4 Residual Elements In Carbon Steels In Hydrofluoric Acid Alkylation Units

Carbon steels in some specific locations in HF acid service have can experience increased corrosion rates based on the residual element (RE) content in the steels e.g., Cr, Ni, Cu (refer to API RP 751.) PMI methods can be used to measure the RE content of carbon steels to determine whether they meet specified levels. PMI methods can be used to assess the suitability of materials for HF service in carbon steels according to RE content.

Consideration should be given to the ability and/or the reliability of the PMI method to detect the various elemental concentrations, which are miniscule in comparison to the bulk analysis.

4.44.5 Process Units Susceptible To Sulfidation

Carbon steels with low silicon \( \text{Si} < 0.10\% \) content can corrode at a greater rate than carbon steels with higher silicon \( \text{Si} > 0.10\% \), when exposed to hydrogen-free sulfidation conditions, an accelerated rate when exposed to hydrogen-free sulfidation conditions. These phenomena are discussed more extensively in API RP 571 and API RP 939-C. Owner/users with assets at risk from this type of degradation should consider the risks and the requirements needed to apply PMI material control in order to verify silicon levels and the effect on predicted corrosion rate. Alternatively, the owner/user may want to consider locating and conducting thickness measurements on all potentially susceptible carbon steel materials in a circuit exposed to hot sulfidation. Owner/users with assets at risk from this type of degradation should consider the risks and the need to apply material control in order to verify silicon levels and the effect on predicted corrosion rate.

4.54.6 Gasket Materials

Gaskets in incompatible service may result in premature failures. The principles outlined in this document can be applied to gasket materials. The owner/user should define the material control methods to be used. The actual test procedures may be complex due to the construction of the gasket.

4.64.7 Refractory Installation Systems (anchors)

Testing to verify the refractory anchors match specifications should be considered by the owner/user. Material specifications and maximum design temperatures for selected materials are discussed API Standard 560.

4.7 Stainless steel and high alloy systems

There are a wide variety of stainless steels with varying compositions and varying corrosion resistance to different process streams. PMI should be considered by the owner/user depending upon the level of risk (probability and consequence of failure) by having inadvertent material substitutions during fabrication and installation. For example, having...
Type 304 SS substituted for Type 316 SS where the molybdenum content is very important to the corrosion resistance.

5.0 MATERIAL VERIFICATION PROGRAMS

5.1 General

The owner/user shall establish a written material verification program indicating the extent and type of PMI to be conducted during the construction of new assets, retroactively on existing assets, and during the maintenance, repair, or alteration of existing assets.

For higher-risk systems, the owner/user should consider the need for employing a higher extent of examination (up to 100%) rather than random sampling which may be more appropriate for lower-risk systems. Unapproved material substitution problems tend to be sporadic; therefore, small sample sizes may not locate all unapproved alloy substitutions. The owner/user should also consider the need to conduct examinations after fabrication is complete at the point-of-installation, to provide assurance that inadvertent substitutions did not occur. The owner/user should also consider the need to conduct examinations after fabrication is complete, to ensure that inadvertent substitutions did not occur at the work site.

5.2 Components included in a Material Verification Program

Examples of some pressure-containing components that are found in equipment and systems which may require an MVP, or PMI, include:

- pipe lengths;
- pipe fittings, such as tees, elbows, reducers, caps, special pipe components, blinds and plugs;
- flanges;
- forgings;
- valves – process valves, control valves, relief valves
- pressure-containing welds;
- instruments (all pressure containing parts);
- weld overlays, liners, and cladding;
- bolting;
- expansion joints and bellows;
5.3 Document issues in an MVP

5.3.1 Mill Test Reports

Mill test reports (synonymous terms found in Definitions and Acronyms) should not be considered a substitute for PMI because they have been proven to not always be accurate. They are not always accurate. However, mill test reports are an important part of an overall material quality assurance program.

5.4 Roles and Responsibilities

A material verification program may involve participation of several groups within the operating plant or the shop of a contractor, vendor, or fabricator. When establishing a material verification program, consideration should be given to the roles and responsibilities that each group has within the specific organization. These roles and responsibilities should be clearly defined and documented. In the operating plant, this can include those groups responsible for purchasing, engineering, warehousing/receiving, operations, reliability, maintenance, and inspection.

The owner/user or designee should specify the:

1. extent of examination of new construction and existing assets, with consideration for the number of items to be examined
2. acceptable method(s) of examination
3. locations for examination, if applicable
4. examination results acceptance criteria
5. timing of examination in the work process
6. process for managing material non-conformances

5.3.2 Material Certifications

Material Certifications or Certificates of Compliance should not be considered a substitute for PMI because they are not always accurate, but may be an important part of an overall quality assurance program.

5.4.1.5.1 New Construction MVP

This section discusses the fabrication stage, either in the shop or in the field, prior to the items being placed into service.
5.4.2 Roles and Responsibilities

A material verification program may involve participation of several groups within the operating plant or the shop of a contractor, vendor, or fabricator. When establishing a material verification program, consideration should be given to the roles and responsibilities that each group has within the specific organization. These roles and responsibilities should be clearly defined and documented. In the operating plant, this can include those groups responsible for purchasing, engineering, warehousing/receiving, operations, reliability, maintenance, and inspection.

The owner/user or designee should specify the:

1. extent of examination of new construction and existing assets, with consideration for the number of items to be examined
2. acceptable method(s) of examination
3. locations for examination, if applicable
4. examination results documentation requirements
5. timing of examination in the work process
6. process for managing material non-conformances

5.4.35.5.2 Material Verification Test Procedure Review

The owner/user or designee should review and approve the material verification program and the testing procedure(s) of the fabricator, material supplier, or third-party agency prior to testing.

5.4.45.5.3 Timing of Material Verification Testing

PMI should be performed at the point in time that helps ensure proper materials have been used in the fabrication of an assembly.

5.4.55.5.4 PMI of Components Supplied by a Distributor

A higher degree of PMI should be conducted on materials supplied by stocking distributors due to the potential for unapproved material substitutions as a result of frequent handling by a number of vendors.

5.56 Existing Installed Assets MVP

5.5.15.6.1 General
This section covers addresses assets that are already in service where the material verification program procedures for the construction are not documented or not completed according to this RP. Material verification coverage is only limited by the owner/user’s written program, but shall meet the minimum requirements as stated in this RP. It is important to recognize that previous maintenance activities, as well as new construction practices, may influence the likelihood of unapproved materials substitutions.

5.5.25.6.2 Prioritizing Assets for Retroactive PMI

5.5.2.45.6.2.1 General Factors to Consider

If the owner/user elects to prioritize equipment or systems for the material verification program or needs to determine whether PMI is needed at all, the owner/user should consider the following:

1. Likelihood of unapproved material substitutions during previous projects and maintenance activities. The effectiveness of the material verification program when these activities occurred is an important consideration.

2. Consequences of a failure due to improper material being installed. Flammability and potential for spreading fire, toxicity, proximity to other equipment or community, temperature, pressure, mode of failure, and size of release should be considered.

3. Reason for a specific material specification (i.e., corrosion resistance or product purity). This refers to the criticality of the material of choice.

4. Historical data relating to unapproved material substitutions. This may be related to previous experience with material nonconformities in the process unit or within the operating plant.

Taken together, these factors can be used to determine the risk associated with possible material non-conformances in an asset. Taken together, these factors can be used to determine the risk associated with possible material nonconformances in a process unit, a piping system, or an asset.

The owner/user should establish a methodology for estimating the relative priority for PMI within a given unit. This methodology may be based on a qualitative or quantitative risk analysis. API RP 580 discusses risk-based approaches and what should be considered when conducting a risk analysis (such as material, service conditions, service fluid, and mode of failure). The owner/user may also want to consider the opportunity to conduct PMI relative to upcoming planned maintenance opportunities (e.g. outages, turnarounds) relative to the upcoming TA schedules.
5.5.2.25 6.2.2 Site Specific Factors to Consider

Site-specific and/or experienced based factors should be considered when prioritizing equipment or piping systems.

(1) Construction and maintenance practices. In assessing the likelihood of material nonconformances, the owner/user should also consider the materials handling, material control, and any PMI procedures followed during construction of the process unit. Process-unit maintenance procedures are also important. Process units in which rigorous procedures for material verification are used would be expected to have a lower likelihood of nonconformances.

(2) Reason for alloy specification. In some cases, alloys are used in piping systems for reasons other than corrosion resistance or structural integrity. In these cases, the mechanical integrity of the system may not be compromised by material nonconformances. A material verification program may not be necessary in these systems. Two examples would be stainless steel lube oil systems in which stainless steel is used for maintaining oil purity, or stainless steel in a chemical manufacturing process where corrosion of carbon steel might cause product discoloration where any grade of stainless steel would be an acceptable substitution.

Based on experience, some types of piping system components can have a higher likelihood of unapproved substitution of a non-specified material. This can provide a basis for prioritizing specific equipment in a given system or process unit. Examples are:

- (1) warm-up and bypass lines on pumps or check valves;
- (2) small bore piping (2 NPS and below)
- (3) valves, valve assemblies and valve bonnets, and removable devices such as rupture discs, spacer blinds, blind flanges, plugs, or ring joint gaskets;
- (4) thermowells;
- (5) bolting;
- (6) piping as a part of a packaged system;
- (7) components without recognized marking;
- (8) specific process systems with known corrosion issues
- (9) welds
- threaded components

5.5.2.35 6.2.3 Factors to Consider When Determining the Extent of PMI

The owner/user should determine the extent of PMI. Factors to consider when determining the extent of PMI for an existing process unit include:
(1) most appropriate sampling method to use in selecting numbers/quantity of PMI points selection;

(2) historical inspection and material verification program records,

(3) number of plant modifications,

(4) materials control during original construction, equipment modifications, and maintenance activities

(5) material verification program quality during construction and fabrication,

(6) failure mode and consequence of a release loss of containment,

(7) likelihood of corrosion/degradation.

5.6.5.7 The MVP as an Element of Maintenance Systems

5.6.5.7.1 General

The principles associated with materials verification as part of a new piping installation should also be applied to provide confidence that proper materials are being used installed as part of maintenance activities. The concepts noted previously in 5.4 should be reviewed and applied as applicable to the maintenance function.

5.6.5.7.2 Responsibilities

It shall be the responsibility of the owner/user to evaluate maintenance systems so that material verification programs can be designed and implemented to effectively support the mechanical integrity needs of alloy assets. The owner/user should establish a written procedure for the material verification program to be used for repair of assets during maintenance and turnaround activities.

5.6.5.7.3 Control of Incoming Materials and Warehousing

A material verification program should be directly applied to activities associated with receiving materials into a warehouse system. PMI may be performed as part of this receiving function, or, when appropriate, may be performed at the supplier’s location as a condition of release for shipment. The material verification program that is adopted should provide for proper documentation and methods for indicating which materials have been tested and are approved for use.
The use of material verification program principles to check materials received into a warehouse system should be regarded as a Quality Assurance practice to minimize the potential for discovering an alloy material discrepancy during subsequent PMI. PMI within the warehouse should not be regarded as an alternative to PMI of the fabricated piping system or other equipment when PMI is specified.

5.6.4.5.7.4 Maintenance Activities

There are a number of in-service maintenance activities where material verification should be established. Some examples include, but are not limited to:

(1) Temporary removal of piping spool pieces. These activities need to be properly managed to minimize the potential for unapproved material substitutions. Incidents have occurred when same size spool pieces were removed and reinstalled in the wrong locations. Consideration should be given to a material control system such as ‘tagging’ spools as they are removed, or the use of PMI prior to re-installation to prevent these incidences from occurring.

(2) Replacement of small bore threaded pipe nipples and plugs, frequently found as drains and vents in process areas. An immediate need may necessitate the installation of nonconforming materials in a temporary repair; it is important to recognize even small changes need to be documented and reported for possible future follow-up.

(3) Replacement of welded-in valves. Manufacturers/distributors may substitute low alloy valves for carbon steel valves in higher temperature/pressure services, and if this is not communicated, the craftsmen may end up using the incorrect welding procedure during installation. This error may produce cracks in the new welds.

(4) In turnaround situations where many heat exchangers in varying services are disassembled for cleaning, inspection, and repair: it is essential that all original components, or correct replacement components, are returned to the same exchanger during re-assembly. An adequate marking and tracking system as well as PMI can be utilized to assure the proper components are returned to the correct service. A good marking and tracking system as well as PMI can be utilized to assure the proper components are returned to the correct service.

(5) When tower internals such as tray parts (e.g., clips, tray flapper valves or bubble caps, and fasteners) are replaced, one may consider performing point of installation PMI (or other material control program) to assure the replacement
parts are as specified, it is advisable to perform point of installation PMI to assure the replacement parts are as specified.

(6) Removal of blinds for access. Blinds are typically stored in a common location, especially during turnarounds when numerous blinds are removed to drain, purge, or dump systems in preparation for entry or hot work. Controls similar to those used in examples (1) (4) and (5) above can avoid errors. Removal of blinds for access. It is not uncommon for blinds to be stored in a common location, especially during turnarounds when numerous blinds are removed to drain, purge, or dump systems in preparation for entry or hot work. Controls similar to those used in examples (1) (4) and (5) above are needed to avoid errors.

It is important that repair procedures include consideration of PMI.

Much of this can be controlled through awareness of the issues at all levels within the repair process. Consulting with an Inspector prior to commencement of work can help ensure that systems, processes and activities are in place to provide material control and verification.

6.0 PMI METHODOLOGY AND TECHNOLOGY

6.1 General

A variety of PMI methods are available to determine the identity of alloy materials. The primary methods include portable spectroscopy and laboratory chemical analysis. A description of several test methods is listed below.

In addition to these methods, there are a variety of alloy sorting techniques that may be appropriate for the purposes of this RP, including magnetic testing to differentiate between ferritic and austenitic materials. It is important that users define the objectives and accuracies required of the PMI tool they wish to apply. It is important that users define the objectives and accuracies required from the PMI tool desired. All of the tools have benefits and limitations on the elements that can be detected, in addition to the accuracy and ability to differentiate between different material grades which have only slight variations in alloying elements. Reference Annex A.

6.2 MVP Test Method Objectives

The test methods outlined in this RP are intended to identify materials and are not intended to establish the exact conformance of a material to a particular specification. Depending on the test method selected, the method may only identify the nominal composition of materials. Identification of materials by visual stamps/markings alone should not be
considered as a substitute for PMI but may be an important component of an overall quality assurance program.

6.3 PMI Procedure

The PMI procedure should identify and include:

(1) the techniques to be applied,

(2) equipment calibration,

(3) qualification requirements for personnel conducting the PMI,

(4) surface preparation

(45) the testing methodology and,

(56) acceptance criteria and

(67) the documentation requirements

6.4 Documentation Review TO BE DELETED holding place for ballot 1 edit item 160

6.5 Personnel Qualifications

Person(s) performing PMI should be knowledgeable about all aspects of operation of the PMI equipment and the test method being applied. Qualifications of the person performing the test, including training and experience, should be submitted for review and approval by the owner/user.

Owner/users should ensure help ensure that personnel using testing devices are adequately trained not only in the specific instrument but also educated about the materials they will be examining. In critical applications, a formal documented program and some form of testing and certification of personnel may be required. The higher the degree of operator analysis the more important this aspect of the whole procedure becomes.

6.6 Chemical Analysis Techniques

6.6.1 Laboratory Chemical Analysis

Owner/user-approved material analysis laboratories using X-ray emission spectrometry, optical emission spectrometry, or wet chemical analysis can provide the most accurate analytical results for all elements. The accuracy is typically much higher than is normally needed for PMI. Laboratory analysis may involve the removal of significant amounts of material, and is typically slower than field PMI techniques.
6.6.2 Chemical Spot Testing

The chemical spot test is typically accomplished by electrochemically removing a minute amount of surface metal and depositing it onto moistened filter paper. Reagents dropped onto the paper produce distinct colors that are indicative of the presence of specific elements in the sample tested. Chemical spot testing is much slower than the other field PMI methods and interpretation is subjective.

6.7 Sorting Analysis Techniques

6.7.1 Resistivity Testing

The principle employed in this test method is known as the Seebeck Effect, or thermoelectric principle. A heated junction of dissimilar metal is created when the heated probe [300°F (150°C)] and the metal being tested are in contact with each other. The voltage generated at this junction is representative of the chemistry and crystalline structure of the metal being tested. Every alloy of a given crystalline structure will generate the same voltage regardless of the geometry or size of the piece being tested or the pressure applied. By references to known standards, these instruments are capable of sorting and identifying a wide range of ferrous and nonferrous materials. Alloy sorters have not proved to be consistently capable of sorting low alloy (< 5% Cr) and austenitic stainless steels.

6.7.2 Other Techniques

Techniques such as eddy-current sorters, electromagnetic alloy sorters, triboelectric testing devices (e.g., ferrite meters), and thermoelectric tests are qualitative and as such may only be appropriate for limited sorting applications and not for specific alloy identification.

6.8 Spectrometer Technology

6.8.1 Portable X-ray Fluorescence

There are several variants of portable X-ray fluorescence (XRF) spectrometers available. The principle of operation is that one or more gamma ray or X-ray sources are used to generate a beam of low energy radiation to excite the material under analysis. The material under analysis then emits a characteristic radiation spectrum which can be analyzed both qualitatively and quantitatively to determine which elements are present and in what quantity. The results of this analysis can be reported in either of the following formats:

(1) as a match against one of many reference spectra stored in the instrument (i.e. ‘316 Stainless Steel’ or ‘5 Cr –½ Mo Steel’); and/or,
(2) each element present reported as a percentage (i.e., ‘Iron = 87.5%’ or ‘Iron = 0.875’ as part of an entire elemental list that should be normalized against 100%).

A number of PMI instruments are available. These instruments can have the sensitivity to determine the elemental levels that meet the ASTM limits. Advancements in XRF technology, such as 50KV, x-ray tubes, and Silica Drift Detectors (SDD), allow the user to detect light elements down to very low concentrations in steel substrates. For example, the latest generation of handheld X-ray fluorescence analyzers now measure light elements (Mg, Al, Si, P, and S) to very low limits of detection (see Annex A) and can provide for field measurement of silicon in steel down to a very low concentrations.

These advancements in technology allow for accurate, non-destructive measurements to be conducted. However, in order to get this near laboratory-quality measurement, significant care regarding surface preparation and cleanliness is required. Still, as contamination of the prepared surface can lead to inaccurate results. Most assets are exposed to environments that promote surface corrosion and contamination which can interfere with the analysis. Typically a small test area is prepared with a portable grinding disk (60 to 80 grit Zirconium Aluminum Oxide disposable abrasive disk) to properly clean the sample location prior to analysis.

The inherent limitations of the technique mean it is not possible to detect all elements. XRF analyzers are capable of detecting elements from magnesium (Mg) to Uranium (U) in the periodic tables. This may excludes some of the important elements in carbon steels such as carbon and boron. It is important to define exactly what elemental analysis is required and select an appropriate instrument.

6.8.2 Portable Optical Emission Spectrometry

In optical emission spectrometry (OES), an electric arc, spark, or laser, stimulates atoms in the test sample to emit a characteristic spectrum of light for each element in the sample. The combined light spectra from different elements are passed through a light guide to the optical analyzer. In the analyzer, the light is dispersed into its spectral components, and then measured and evaluated against stored calibration curves.

These devices fall into two-three groups:
(1) The first is a light-weight, portable and operator evaluated device that can typically identify up to sixteen (16) elements but depends upon operator evaluation of the light spectra. These devices do not directly indicate alloy grade or composition, but produce an output in the form of visible light spectra that permits semi-qualitative alloy identification. This technique is highly sensitive to operator skill and experience.

(2) The second group refers to field portable, laboratory grade analyzers. These were originally difficult to use due to their size and weight; however, modern units are now
available that can be considered light-weight, including the small Argon cylinders required for operation. Some of these analyzers operate in a pure arc mode for routine PMI applications while the more sophisticated units have a spark mode allowing laboratory quality analysis. The significant advantage of these instruments is the expansion of elements that can be analyzed including carbon. Another advantage of these advanced instruments is that they are not subject to operator interpretation.

Similar to X-ray fluorescence devices, results can be reported in either a spectral match or elemental percentage mode. As these techniques generate arcs and sparks, a potential ignition source occurs during their operation and therefore prior to use of this technique in the field a review shall be conducted in order to determine if gas testing and hot work permits are required.

6.8.3—(3) The third group is known as Laser-Induced Breakdown Spectroscopy (LIBS), in which

Laser-induced breakdown spectroscopy (LIBS) is an atomic emission spectroscopy technique that uses highly energetic laser pulses. The laser is focused to form a plasma, which atomizes and excites samples. Plasma light emissions provide the spectral signature of chemical composition for practically any material.

When calibrated for metal analysis, LIBS can provide both qualitative and quantitative information to determine which elements are present and in what quantity. The results of this analysis can be reported as metal chemistry based on stored grade library, also as metal grade identification.

Considerable progress has been made during the last few years in LIBS technology. Handheld LIBS metal analyzers are becoming available which can provide fast in situ chemical analysis with appropriate precision and detection limits (Annex A). The significant advantage of LIBS technology is its wide element range. In principle, LIBS can detect all elements, limited by the power of the laser as well as the sensitivity and wavelength range of the spectrograph & detector. The LIBS technology also can provide low level carbon analysis, which in principle enables LIBS to positively identify a wide range of ferrous alloys.

This technique generates a laser during operation, which is a potential ignition source. Therefore, before using this technique in the field, a review shall be conducted in order to determine if gas testing and hot work permits are required.

6.8.4 6.8.3 Equipment Calibration

Persons performing PMI should calibrate and/or verify the test equipment performance as specified by the equipment manufacturer. The PMI procedure should provide the frequency interval for this calibration/verification. If calibration procedures are not
provided by the equipment manufacturer, they should be established by the owner/user. Typically, these procedures should include calibration/verification using certified standards. Owner/user may consider requirement of equipment verification checks on a routine (e.g., once per shift) using certified standards of the same alloy family.

6.8.4 Equipment Precision

The precision of the test equipment should be consistent with the established test objectives (see 5.2). When elemental composition is desired, the owner/user should establish the acceptable precision and repeatability.

Accuracy and the method in which accuracy is determined need to be understood (reference, Annex A). For example, in some tools the sensitivity may depend on duration of the test in order to improve signal averaging algorithms. Failure to understand these issues may produce inaccurate results.[JLY7]

6.9 Safety Issues

6.9.1 General

The specific requirements for each PMI technique should be clearly reviewed as to the amount of mechanical preparation. Consideration should be given to the anticipated thickness of the sample before mechanical methods are used to prepare the sample. In addition, considerations for electrical arcing and “hot spots” should be considered as well as appropriate electrical and hot work permits. Chemical spot testing involves the use of a variety of chemicals. Appropriate safety precautions should be taken when handling these chemicals.

6.9.2 XRF Analyzers

6.9.2.1 Intrinsic safety

XRF Analyzers are not intrinsically safe. Pertinent Hot Work procedures should be followed in areas where non-intrinsically safe equipment is to be used.

6.9.2.2 Radiation Safety

The user should be aware of potential radiation exposure hazards when operating an XRF device. The user is expected to observe local jurisdictional requirements that govern radiation safety, and consult the manufacturer’s instructions for safe operation. The XRF Analyzer was designed so that virtually no measurable radiation external to any part of the analyzer can escape when the shutter is closed. Some XRF analyzers contain an x-ray tube, which emits no radiation at all unless the user turns the x-ray tube on.
Human exposure to radiation is typically measured in REMs, frequently reported in units of one-thousandths of a REM, called milliREMs (mREM). For a given source of radiation, three factors will determine the radiation dosage received from the source:

(1) Duration of Exposure

The longer one is exposed to a source of radiation, the more radiation strikes the body and the greater the dose is received. Dosage increases in direct proportion to time of exposure.

(2) Distance from the Source

The closer one is to a source of radiation, the more radiation strikes the body. The dosage increases in inverse-squared relation to distance from the source of radiation. For example, the radiation dose one inch from a source is nine times greater than the dose three inches from the same source, and 144 times greater than the dose 12 inches from the source. Always keep hands and all body parts away from the front end of the analyzer when the shutter is open to minimize exposure.

(3) Shielding

The analyzer emits no radiation at all unless the x-ray tube is turned on, and virtually no radiation with the x-ray tube on and the internal shutter closed (as during calibration). When the x-ray tube is on and the shutter is open, as during a measurement, the analyzer emits a directed radiation beam. Always hold the analyzer so to avoid the radiation beam. Consider using a test stand to add shielding for analysis.

Note: Wearing a dosimeter badge does not protect against radiation exposure. A dosimeter badge measures exposure.

Note: Pregnant workers may want to take special precautions to reduce their exposure to radiation. It has been recommended that the radiation dose to pregnant women should not exceed a total of 500 mREM/gestation period. [Refer to U.S. NRC Regulatory Guide 8.3 “Instruction Concerning Prenatal Radiation Exposure,” which lists typical radiation doses encountered in daily life and the annual occupational radiation dosage limits for adults set forth in O5CMR120.200].

The allowable limit in the U.S. for occupational exposure is 5,000 mREM/year (50 mSv/years) for a whole-body and 50,000 mREM (500 mSv) for shallow penetration of extremities. Extremity exposure from a properly used XRF
6.10 Testing of Welds and Weldments

6.10.16.9.3 PMI of Welding Consumables

Performing PMI of a weld cap does not assure the root pass or subsequent weld passes are made with the specified chemistry.

Prior to use in fabrication, sample “buttons” should be welded using each heat of bare wire, lot of covered electrodes, or flux-cored electrodes. PMI can then be used to confirm weld metal meets specification. It is not necessary to test a button of bare wire if the test chosen can identify the composition of the wire before welding. The size the weld button should be adequate to assure accurate test results.

When welding is conducted, one electrode or wire sample from each lot or package of alloy weld rod should be positively identified. The remainder of the lot should be compared to the sample to verify that the markings of the wires/electrodes are correct.

Some weld rods have the alloying elements contained in the flux, and do not meet the alloy specification until welded. PMI of weld metal (e.g. deposited weld metal or undiluted weld “buttons”) is an acceptable alternative to PMI of an electrode or wire sample provided it is conducted immediately prior to welding or during the welding process (especially when changing lot numbers of electrodes or welding wire).

6.10.26.9.4 Longitudinal Pipe and Fitting Welds

Where there is reason to suspect problems, longitudinally welded alloy pipe and fittings should receive random PMI verification of the base metal and weld metal.

6.10.36.9.5 Autogenous Welds

If the owner/user determines that material verification testing is required on autogenous-welded (with no added filler metal) alloy pipe or fittings, it is necessary to conduct testing on only the base metal.

6.10.46.9.6 Dissimilar Metal Welds and Weld Overlays

Results from testing dissimilar metal welds should take into account the effects of dilution, which occurs during weld deposition. The owner/user should establish the minimum compositional requirements of the as-deposited weld metal necessary for the intended service.
7.0 EVALUATION OF TESTING RESULTS

7.1 Material Acceptance Methods

The owner/user may elect any one of the following methods of material acceptance.

1) Materials can be confirmed to contain the nominal amounts of alloying elements specified in the relevant materials specification (e.g., ASME Section II or ASTM specifications).

2) Materials can be classified through a qualitative sorting technique (see 6.7) to establish the conformance with the intended material.

3) When PMI indicates alloying elements are outside the ranges indicated in the material specification, the owner/user may still choose to allow the use of the tested materials in situations where a person knowledgeable of the appropriate damage mechanisms confirms that the material will perform satisfactorily in the service.

4) If testing using one of the portable or qualitative analysis methods leads to the potential rejection of a component, a more accurate analysis may be used to determine component acceptance (see section 6).

7.2 Follow-up PMI after Discovery of a Nonconformity

If any one of a representative sample is rejected, all items of that inspection lot should be considered suspect. A more extensive inspection of the remaining lot should be considered.

8.0 MATERIALS IDENTIFICATION

8.1 Identification Process

Alloy materials should be identified by their alloy designation or nominal composition. Examples of some acceptable identification methods are:

1) color coding by alloy,

2) a low-stress stamp marking indicating that the test has been performed,

3) documentation showing both the PMI results and the PMI locations.

Test locations should be shown on appropriate drawings so that each test site can be traceable to the fabricated piping components.

8.2 Color Coding/Marking

8.2.1 If the material verification program procedure established by the owner/user requires a visual identification such as color coding or marking, the owner/user should maintain a record of the alloy material/color code combinations. PFI
Standard ES22 is an example of one such system. Materials identification by color coding is not a substitute for permanent manufacturers’ markings required by applicable ASTM or other materials specifications.

8.2.2 Where reliance on color marking is used, persons responsible for reading the colors should be confirmed as being able to distinguish difference between the colors being used.

8.3 Marking of Components

If the owner/user’s documentation process requires physical marking of piping components, it should specify one of the following:

1) Whether or not the marking system should remain legible for the expected life of the component without deterioration due to corrosion or elevated temperature.

2) Whether or not the marking system is only temporary to facilitate proper handling and identification from the point of PMI to final installation. This marking can be semi-permanent paint applied to each item. The markers should not contain additives such as metallic pigments (Al, Pb, or Zn), sulfur, or chlorides.

8.4 Traceability to Field Components

The information listed in 9.3 should be reported in such a manner that it is traceable to the point of installation.

9.0 DOCUMENTATION AND RECORDKEEPING

9.1 Shop and Field PMI Documentation

Those individuals performing PMI should obtain and follow the PMI procedure approved by the owner/user. This procedure should include the technique used, equipment calibration, the qualification requirements of PMI personnel, the testing methodology, and documentation requirements.

When documentation, such as drawings, is used in lieu of physical marking, the documentation should allow the owner/user to identify which components were tested.

9.2 New and Existing Equipment or System Documentation

When PMI is conducted on new or existing assets and systems, records of the results should be kept as long as the equipment exists in its original location. If equipment or portion of an
equipment system that has not received material verification is relocated, the owner/user should consider the need for PMI prior to placing the relocated components into service.

Some owner/users have created master PMI piping isometric drawings to track components tested and test results. These drawings are maintained the same as piping modifications occur from projects or MOCs. A single documentation system avoids searching for data in multiple locations.

9.3 PMI Records

Typical PMI records should contain the following:

1) Reference to the PMI procedure(s) used.
2) Date of testing.
3) Test instrument identification number or serial number, where appropriate.
4) Name of each person performing the tests, with identification of their respective employer.
5) Results of the tests.
6) Basis and action for resolving and documenting PMI nonconformances including those that have been left in service.
7) Documentation of the criteria used for prioritization of piping systems and extent of PMI performed.

Alternately, the owner/user may choose to include this within the written material verification procedure. When included in the owner/user’s written material verification procedure, the date and edition number of the written procedure should be documented in the test record.
Statistical Terminology
Below are listed some of the terminologies regarding statistics that may be encountered when using the methodology and/or technology discussed within this document.

- **Accuracy** - The closeness of agreement between the test result and the accepted reference value.

- **Precision** - The closeness of agreement between independent test results. The Precision depends only on the distribution of random errors and does not relate to the accepted standard certified value.

- **Bias** - The difference between the expectation of the test results and an accepted reference value. Bias is a systematic error in contrast to a random error. There may be one or more systematic error components contributing to the Bias.

- **Limit of Detection (LOD)** - the lowest concentration of analyte that can be reliably distinguished from zero concentration in a sample. By defining a 99% confidence to show that the analyte concentration is greater than zero. Therefore, 3-sigma calculations must be used to determine LOD. See SD, below.

- **Instrument Detection Limit (IDL)** - the lowest (best) detection limit generated by an instrument in a clean matrix (blank).

- **Method Detection Limit (MDL)** - the typical detection limit obtained when running a typical sample, it is matrix dependent, and will vary from matrix to matrix.

- **Limit of Quantization (LOQ)** - the lowest concentration that can be reliably measured to allow quantitative readings. It is typically defined as 10-sigma (or 3.33 times the LOD).

- **Standard Deviation (SD)** - The standard deviation is a statistic that defines how tightly all the data is clustered around the mean in a data set. It essentially measures the variability (spread or dispersion) from the mean (average) and is defined mathematically. For “normal” distributions, we can apply an empirical rule that states that 68% of the data is within one standard deviation of the mean, 95% of the data is within two standard deviations of the mean, and 99.7% of the data is within three standard deviations of the mean.

- **Relative Standard Deviation (RSD)** - The standard deviation is divided by the mean of the data and multiplied by 100 to give a % value. The bigger the % value, the “noisier” the signal and less confidence in the final value.

- **Repeatability** - The duplicate (or more) analysis within the shortest possible time, performed by the same person using the same method. The standard of many analyses using repeatability conditions indicates the minimum deviation achievable in the particular conditions.

- **Reproducibility** - This is a duplicate (or more) analysis performed by a different person preferably using a different method or (different instrument).
6.6.9 Bibliography style menu

6.6.9.1 A bibliography, if present, shall appear after the last annex. The bibliography should include the following:

   a) referenced documents that are cited in an informative manner,

   b) referenced documents that are bibliographic or background material in the preparation and application of the document.

6.6.9.2 If bibliographic items are cited in text, figures, or notes, the citation shall be placed in brackets at the point where reference is made and shall be numbered consecutively e.g. [1]. Lists of bibliographic references are normally arranged either alphabetically by the first element or in numeric sequence corresponding to the order of citation in the text.

6.6.9.3 Documents already listed in the normative references section shall not be included in the bibliography.
Bibliography

The following documents may reference this recommended practice, and have been used during its development.

- API 510, Pressure Vessel Inspection Code: In-service Inspection, Rating, Repair, and Alteration
- API Standard 560, Fired Heaters for General Refinery Service
- API 570, Piping Inspection Code: Inspection, Repair, and Rerating of In-service Piping Systems
- API RP 571, Damage Mechanisms Affecting Fixed Equipment In the Refining Industry
- API Recommended Practice 572, Inspection Practices for Pressure Vessels
- API Recommended Practice 573, Inspection of Fired Boilers and Heaters
- API Recommended Practice 574, Inspection Practices for Piping System Components
- API Recommended Practice 575, Guidelines and Methods for Inspection of Existing Atmospheric and Low-pressure Storage Tanks
- API Recommended Practice 576, Inspection of Pressure-Relieving Devices
- API Recommended Practice 577, Welding Inspection and Metallurgy
- API 579-1/ASME FFS-1 Fitness-For-Service
- ASME B31.3, Process Piping
- ASME PCC-2, Repair of Pressure Equipment and Piping