

MANUAL

MATERIAL TRACEABILITY AND POSITIVE MATERIAL IDENTIFICATION (PMI)

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DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and provides recommendations for the development of a material traceability and positive material identification (PMI) programme for new and existing plants.

This DEP also addresses the materials quality assurance systems that shall be in place in all phases of a project or during maintenance (e.g. shutdown) activities to guard against the installation of rogue materials (RM) that may adversely affect the integrity of the plant pressure envelope and process reliability. For cost effectiveness, a risk-based approach has been applied.

This DEP is intended to apply to both new construction and also for when carrying out plant changes or replacing plant equipment and/or piping during maintenance. For simplicity, however, this DEP is written in terms of new construction projects.

Further guidance on material verification can be found in API RP 578.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by Shell GSI, the distribution of this DEP is confined to Shell companies and, where necessary, to Contractors and Manufacturers/Suppliers nominated by them.

This DEP is intended for use in oil refineries, chemical plants, gas plants, exploration and production facilities and supply/distribution installations.

When DEPs are applied, a Management of Change (MOC) process should be implemented; this is of particular importance when existing facilities are to be modified.

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

1.3 GENERAL DEFINITIONS

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

The **Manufacturer/Supplier** is the party that manufactures or supplies materials, equipment and services to perform the duties specified by the Contractor (see further definitions of material manufacturer and material supplier in 1.4).

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

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.4 SPECIFIC DEFINITIONS

Term	Definition
Alloy material	Metallic material (including welding filler materials) that contains alloying elements such as chromium, nickel, or molybdenum, intentionally added to enhance its mechanical or physical properties and/or corrosion resistance.
Alloy System	A piping system or pressure equipment for which a specific alloy material has been selected to suit the process conditions to which it will be exposed. <i>To simplify the wording of this DEP, the term alloy system includes special grades of carbon steel such as LT and sour service grades.</i>
Distributor	Warehousing Supplier for one or more Manufacturers or Suppliers of alloy materials or components.
Extent of PMI	Specified percentage of the number of components (or weldments, if specified) to be examined in an inspection lot.
Fabricator	One who fabricates piping, process pressure equipment, instrumentation or machinery.
Heat of material	Heat (melt) from which materials or components having the same physical or chemical properties are produced.
Inspection lot	Group of items or materials of the same type from a common source from which a sample is to be drawn for examination. An inspection lot shall not include items from more than one heat of material.
Lot size	Number of items available in the inspection lot when a representative sample is selected.
Material Manufacturer	Organization that performs or supervises and directly controls one or more of the operations that affect the chemical composition and/or mechanical properties of a metallic material.
Material Supplier	Organization that supplies material (with certified MTRs) furnished by a material Manufacturer, but does not perform any operation intended to alter the material properties required by the applicable material specification. NOTE: Material Manufacturer and Supplier may be the same party if the Manufacturer supplies directly to the shop fabricator, field fabricator, or purchaser.)
Mill Test Report (MTR)	Certified document that permits each component to be identified according to the original heat of material from which it was produced and identifies the applicable material specification and the results of all tests required by the material specification.
Positive material identification testing	Physical evaluation or test of a material to confirm that it is consistent with the selected or specified alloy material designated by the Principal. Evaluations or test may provide either qualitative or quantitative information that is sufficient to verify the nominal alloy composition (this DEP accepts only quantitative testing for PMI).
Pressure-containing components	Items that form the pressure-containing envelope of the operating components and piping systems. This generally includes on-line instrumentation up to and including the first isolation valve of off-line instrumentation.
Random	Selection process by which choices are made in an arbitrary and unbiased manner.
Representative sample	One or more items selected at random from the inspection lot that are to be examined to determine the acceptability of the inspection lot.

Rogue material	Equipment or piping components that accidentally end up in a specific alloy (or special carbon steel) system, but do not meet the materials selection criteria for that system. This includes welding consumables.
Standard reference materials	Sample materials for which laboratory chemical analysis data are available and which are used to demonstrate the accuracy and reliability of testing instruments.

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced by this DEP are listed in (9).

1.6 COMMENTS ON THIS DEP

Comments on this DEP may be sent to the DEP Administrator at standards@shell.com. Shell staff may also post comments on this DEP on the Surface Global Network (SGN) under the Standards folder.

2. GENERAL

For any project or plant modification that includes the use of alloy materials and special carbon steels (e.g. low temperature or sour service grades), a materials Quality Assurance system shall be put in place that will guard against rogue materials that can lead to loss of containment of the plant pressure envelope.

For existing plants, to ensure that the materials QA system is cost effective, a risk-based approach shall be applied.

NOTE: For new projects, if it is decided not to follow the risk-based approach specified in this DEP, the responsible Materials and Corrosion specialist shall determine the appropriate level of PMI in consultation with other stakeholders (e.g. Quality Assurance and Fabrication Assurance). Table 4 and Table 5 may be used for this purpose. See (8.4).

An effective materials QA system includes the following control elements:

1. A materials selection guide (MSG) [or a Materials Engineering Report (MER) with Materials Engineering Flow Scheme (MEFS)] for the project as a base document of the project specification. This is usually drawn up by the Principal's materials and corrosion specialists or the process licensor. At this stage, each material selection shall also be subjected to a risk ranking, which determines the level of materials management required through all the subsequent stages of the project
2. Evaluation of fabricators and material Suppliers to verify the adequacy of their materials control systems in line with the applicable risk ranking.
3. Adequate detailing of order specifications with respect to material certification, traceability, PMI, and colour coding during procurement of piping bulk materials and equipment.
4. Procedures for the control, receipt and storage of materials at site, including receiving inspection, segregated storage, (sample) PMI and identification.
5. The controlled issue of piping materials and welding consumables, and return of surpluses, according to their intended application (isometrics).
6. The segregation of site fabrication workshops by material grades. This includes segregation of tools where applicable.
7. Maintaining heat traceability throughout fabrication activities, like transfer stamping of heat numbers prior to cutting, and recording of component heat numbers on workshop isometrics for high and medium risk systems. This shall also include the traceability of surplus materials.
8. Assuring the traceability of pre-fabricated pipe spools through the stages of grit blasting, painting and field installation. This applies equally to straight lengths intended for installation in pipe racks.
9. Final checks on completed systems, including (sample) PMI as determined by the risk ranking, prior to testing and mechanical completion handover.
10. The compilation of auditable material traceability records as part of the handover documentation packages.

The above materials control elements also apply to equipment fabricators and should be assessed during the technical evaluation of fabricators.

3. RISK RANKING

3.1 GENERAL

Although risk ranking shall be carried out as part of the materials selection guidelines of the project specification, the ranking process is explained in this section for clarity and to provide an overview of material traceability and PMI requirements according to risk category.

To aid in risk assessments for all piping systems, the standard risk matrix as shown in Figure 1 shall be applied. Supplemental information on the use of the risk matrix can be found in the Shell Yellow Guide "Risk Assessment".

The matrix is similar to the matrix used for process hazards analysis (PHA); however, the matrix is used solely to evaluate the risk associated with rogue materials in all piping systems and pressure equipment.

Systems that are determined to be in the red or yellow boxes on the risk matrix are considered to be key piping systems for PMI verification. The RM risk level is determined from the matrix by assessing:

- 1) Consequence – the potential consequences to the plant and community if a leak were to occur, and
- 2) Likelihood – the likelihood of a rogue material resulting in a leak.

A list of typical refinery and chemical systems that have been reviewed and assigned risk scores is shown in Appendix 1. These examples can be used to assign risk levels to piping systems that are not shown in the list in Appendix 1.

3.2 CONSEQUENCE

The consequence levels of a leak due to rogue materials are shown below. The consequence level is based on the amount of hydrocarbon that could be released and the temperature of the hydrocarbon. This analysis classifies potential leaks into three consequence levels:

High Consequence level 4 and 5 (Red) consists of leaks of greater than 5 t of hydrocarbon in 5 min, where the hydrocarbon is above the flashpoint but below the auto-ignition temperature. These conditions could result in a vapour cloud or a large pool fire.

Medium Consequence level 2 and 3 (Yellow) may be due to two types of leak conditions:

- 1) Leaks of greater than 5 t in 5 min at temperatures above the auto-ignition temperature (the lowest temperature at which a chemical will spontaneously ignite in a normal atmosphere without an external source of ignition), and
- 2) Leaks of between 1 t and 5 t in 5 min at temperatures above the flash point (lowest temperature at which it can form an ignitable mixture in air).

These conditions could result in a jet fire or medium size pool fire.

Low Consequence level 1 (Blue) are all leaks that do not fit into one of the above criteria because they would be expected to result in a smaller, more manageable fire or a hydrocarbon spill with no fire.

Toxic leak consequences should be handled in the same way as toxic leak consequences in the Shell PHA risk analysis. The size of a potential leak and its impact should be determined by personnel familiar with the PHA process.

Appendix 2 lists a few potential consequences that could be typically anticipated if a rogue material were present in an alloy pipe system. Possible failure magnitudes are indicated that can be used in assessing the consequence level in the PMI Risk Matrix.

3.3 LIKELIHOOD/PROBABILITY

The likelihood levels in the RM risk matrix are shown in Figure 1.

The likelihood decision process considers two basic factors:

- a) The likelihood that a rogue material could be present;

If the expected size of a leak is small (e.g. a leak occurs before rupture or a pin-hole leak occurs before a large opening) then the likelihood level is considered "Low". Appendix 2 shows examples of potential failure sizes of rogue materials subjected to various degradation mechanisms.

- b) The expected size of a leak caused by material degradation of the rogue material.

This can be mitigated by ensuring that the materials control elements mentioned in (Section 2) are effectively implemented. This factor can also be seen as a confidence factor, i.e. the level of confidence the project team has in the material suppliers and equipment fabricators, the effectiveness of material control systems established by the site construction contractor, and the discipline exercised in segregation and control of welding consumables. These assessments can assist in determining the adequacy of a PMI programme for the project.

Severity	Consequences				Increasing Likelihood				
	People	Assets	Environment	Reputation	A	B	C	D	E
					Never heard of in the industry	Heard of in the industry	Has happened in the organisation or more than once per year in the industry	Has happened at the location or more than once per year in the organisation	Has happened more than once per Year at the location
0	No injury or health effects	No damage	No effect	No impact					
1	Slight injury or health effects	Slight damage	Slight effect	Slight impact					
2	Minor injury or health effects	Minor damage	Minor effect	Minor impact					
3	Major injury or health effects	Moderate damage	Moderate effect	Moderate impact					
4	PTD or up to 3 Fatalities	Major damage	Major effect	Major impact					
5	More than 3 fatalities	Massive damage	Massive effect	Massive impact					

Risk Assessment Matrix

NOTE: PTD means permanent total disability

Figure 1 RM Risk Matrix

4. MATERIAL TRACEABILITY

4.1 MARKING

All piping bulk materials shall be delivered with the original Manufacturer's markings clearly readable. The markings shall comply with the relevant material specification (e.g. ISO, ASTM, etc.). They shall include the Manufacturer's logo, which shall match the logo shown on the MTR.

When piping materials are ordered in the blasted and primed condition (e.g. straight length pipes), the Manufacturer's markings shall be preserved.

Markings applied by stockists and Suppliers may supplement the Manufacturer's markings (e.g. PO numbers or MESC codes) but shall not replace the Manufacturer's markings.

All metallic piping components intended for high- and medium-risk systems shall remain heat-traceable throughout the project. This can be achieved by copying the heat numbers onto the relevant shop fabrication isometric, which shall be kept as a permanent record. The same applies to straight lengths of pipe that go directly to field installation.

Low Temperature carbon steel and sour service carbon steel grades shall be treated as high-risk systems and remain fully heat traceable, since PMI testing of these systems is not feasible.

The heat numbers on completed piping spools shall be 100 % verified by the Piping Inspector prior to release of the spools for painting and field installation. This shall be a hold point on the piping ITP. This also applies to the transfer of heat numbers before these materials are cut.

Completed shop fabricated pipe spools shall be fitted with an identification tag identifying at least the Isometric number and spool number.

4.2 COLOUR CODING

4.2.1 General

Colour coding of piping bulk materials shall be applied on any job that includes alloy or special carbon steel systems, regardless of whether it is new construction, routine maintenance or shutdown activities. Colour coding is one of the QA system tools intended to maintain material traceability and shall not to be considered a substitute for any of the other material control tools.

The party responsible for the application of colour coding is the **material supplier** and the coding shall be checked by the Contractor's QC department before being released for shipment to site. The site procedure for colour coding shall clearly address the critical stage where pre-fabricated pipe spools are sent for blasting and painting. Colour coding is not necessary once the pipe spool is painted. For the spool to be released for painting, all components shall have been welded on and relevant NDE, including PMI shall have been done. The spool is then tracked by the spool tagging number and isometric.

Colour coding is intended to supplement, not replace, the normal identification requirements of the specification (for example, ASME, ASTM, MSS, etc.) to which the pipe was purchased.

4.2.2 Colour standard

Any one of the following colour standards may be applied:

- PFI ES 22
- BS 381C
- the example given in (4.2.3)

Paint shall be resistant to saltwater atmosphere and tropical climate, and shall be durable. It shall not cause corrosion of the material to which it is applied, neither during storage and construction nor during operation of the equipment.

Paints shall not contain sulphur, lead, zinc or other metals.

4.2.3 Example

Table 1 Example of a colour coding scheme

Copper alloys		
Admiralty (inhibited)		black
Brass (Red)		black and yellow
Copper		black and blue
70-30 Copper Nickel		black and green
Silicon Bronze		black and white
Aluminum Brass		black and brown
Steel and cast iron		
Carbon steel		none
Low temperature carbon steel, ASTM A 333 Grade 6		green and blue
Carbon steel, sour service		green and red
Cast iron		green
Nodular iron (ductile)		green and aluminum
Copper-bearing steel		green, black, and yellow
Ferritic alloy steels		
4140	low alloy carbon steel	aluminum and grey
4142	low alloy carbon steel	aluminum and grey
4340	low alloy carbon steel	aluminum and gold
P1	0.15 % carbon, 5 % molybdenum	green and red
P11	1¼ % chromium, 0.5 % molybdenum	aluminum
P3b	2 % chromium, 0.5 % molybdenum	aluminum and white
P22	2¼ % chromium, 1 % molybdenum	aluminum and brow
P5	5 % chromium, 0.5 % molybdenum	aluminum and blue
P9	9 % chromium, 1 % molybdenum	aluminum and red
P91	9 % chromium, 1 % molybdenum, modified	aluminum and yellow
Chromium steels		
Type 405	11 % to 13 % chromium	Red and Black
Type 410	12 % to 14 % chromium	Red and White
Type 416	12 % to 14% chromium	Red and Brown

Austentic stainless steels		
TP-17-4pH	17 % chromium, 7 % nickel	yellow and purple
TP304	18 % chromium, 8 % nickel	yellow
TP309	25 % chromium, 12 % nickel	white
TP310	25 % chromium, 20 % nickel	white and blue
TP316	17 % chromium, 12 % nickel	yellow and brown
TP317	19 % chromium, 12 % nickel molybdenum (spec)	yellow and red
TP321	18 % chromium, 11 % Ni-Ti	yellow and aluminum
TP347	19 % Chromium, 11 % nickel, Nb	yellow and white
*Alloy 20	20 % chromium, 30 % nickel	yellow and green
* Alloy 20 comes under the trade names of Durimet 20, Carpenter 20, Alloyco 20, and others.		
Nickel and nickel alloys		
Nickel		blue
Monel		blue and red
Inconel		blue and yellow
Hastelloy "B"		blue and brown
Hastelloy "C"		blue, brown and red
Incoloy 800		blue, red, and yellow
Inconel 600		blue, white and blue
Low nickel alloy steels		
Grade	Alloy	
3	3½ % nickel	brown and green
5	5 % nickel	brown and white
9	9 % nickel	brown and blue
Bolting		
Bolts	Nuts	
A 307-B	A 563-A	none
A 193-B7	A 194-2H	none
A 193-B7M	A 194-2H	none
A 193-L7	A 194-2H	white
A 193-B8M2	A 194-8M	red
A 193-B16	A 194-4	blue
B 473-N08020	B 473-N08020	none
A 453-660	A 453-660	yellow

Gaskets	
Spiral wound winding 304	yellow
Spiral wound winding 316L	green
Spiral wound winding 321	turquoise
Spiral wound winding 347	blue
Spiral wound winding Monel 400	orange
Spiral wound graphite filler	grey stripe plus winding colour
Octagonal ring soft iron/stainless steel	none

Figure 2 provides examples of the locations where the colour coding shall be applied for easy recognition.

Special notes

Paint shall not be applied, in any circumstances, to the following:

- inside surfaces of pipe, flanges or fittings;
- threads;
- weld bevels;
- symbols or markings as this would obliterate identification;
- gasket seating surfaces.

5. POSITIVE MATERIAL IDENTIFICATION (PMI)

5.1 EXAMINATION

5.1.1 Element contents

1. To ensure consistent material identification, alloying elements shall be determined on a percentage basis in accordance with the applicable material standard specified in the procurement documents.
2. Any deviation from the examination requirements shall be subject to the approval of the Principal's inspector or materials engineer.

5.1.2 Examination equipment/method

1. It is recommended to use portable alloy analyzers with a fluorescence device (either X-ray tube or isotope base), which will identify elements with periodic numbers from Ti to Pu as well as portable optical emission spectroscopy devices which can identify elements with periodic numbers less than aluminium.
2. Examination shall not be carried out with chemical spot testing or methods that use eddy current, triboelectric testing, electromagnetic, or thermoelectric tests. These techniques are mainly alloy sorters and do not provide specific alloy identification.

5.2 MATERIALS EXEMPT FROM PMI

Unless otherwise specified by the purchaser, the following material shall not be subject to PMI testing:

- a. All grades of carbon steel.
- b. Internal valve components that are standard from the Manufacturer. (High alloy valve trim upgrades that are performed in a valve modification shop are not exempt.)
- c. Valves, plate, and piping components made of type 304 stainless steel, except for welds that are subject to PMI.
- d. All standard cast 316 stainless steel valves, control valves and machinery components.
(Cast type 316 stainless steel is the normal type provided for 304 or 316 type services and has not been found to have non-compliance issues when they are produced in bulk from a manufacturer. However custom castings shall require PMI testing.)
- e. Material to be used for non-pressure components of exchanger tube bundles such as baffles, tie-rods, and support plates.
- f. Equipment and piping made of alloy material solely to maintain purity of the process product, except for welds that are subject to PMI.
- g. Internal parts of machinery and pumps made of type 304, 316 stainless steel or brass.
- h. Instrumentation, such as orifice plates, venturis internals, and tubing made from 304, 304L, 316 and 316L stainless steel or copper.
- i. All cast brass valves.
- j. Electrical components.
- k. Auxiliary equipment such as machinery lube oil systems, seal pots, hydraulic systems, steam tracing and steam turbine gland vacuum systems.
- l. All standard (304 stainless steel) spiral wound gasket materials in routine service. Higher alloy materials require PMI testing based on the service conditions.

NOTE: All pressure retaining alloy welds are subject to some level of PMI (Full or Standard) even if the base metal is exempt.

Table 2 can be used as an example to develop further site specific tables for alloy elements analysis

Table 2 Alloy elements required for PMI

* All 300-series stainless steel welds shall have the ferrite controlled between 4 % and 8 %. The ferrite testing shall be tested at the same frequency as required for PMI

** 0.5 % to 0.75 % max Ni in base material and <1.1 % Ni for weld deposits.
0.1 % to 0.3 % Al.

0.2 % to 0.5 % Ti. *** Check alloying elements meet the ASTM specification

5.3 REJECTED MATERIAL

1. Rejected material shall be identified by markings and segregated from acceptable material.
2. Replacement of rejected material shall be in accordance with the procurement contract.
3. The Supplier, shop fabricator, or field fabricator, as applicable, shall submit to the purchaser an explanation for the rejected material. This shall identify the root cause and include a plan for corrective action.
4. If an item from a representative sample is rejected:
 - a) 100 % of the remaining components from which the sample was taken shall be examined;
 - b) 100 % of the components from the next delivery from the same Manufacturer or Supplier shall be examined;
 - c) If no further components are rejected in a) or b) above, the extent of examination shall return to that originally specified."

5.4 NOTIFICATION TO PURCHASER

Supplier shall give the Purchaser an advance notice of at least five working days for examination work to be witnessed by the Purchaser.

6. MATERIAL IDENTIFICATION

6.1 GENERAL

1. Alloy materials shall be identified by their alloy designation.
2. Components on which PMI tests are performed shall be identified with a PMI stamp stating the material identification codes, by means of a low-stress type marking tool. Vibroetching is permitted for thin wall materials or if the configuration of the component does not permit stamping.
3. Material identification codes specified in this DEP are required in addition to those required by the applicable material specification (e.g. ASTM).
4. Pressure equipment subject to PMI examination shall have a PMI stamp on the component nameplate including the material identification code. An additional nameplate for the PMI stamp may be welded on adjacent to the code nameplate.
5. Heat exchanger nameplate stamping shall identify the tube side and shell side separately.
6. On pressure vessels or heat exchangers the type of component, such as "Internals", "Clad", "Overlay", etc., shall be identified.
7. All piping components shall have a PMI stamp with material identification code, applied by means of a low-stress tool.
8. Paints and markers shall have a chemical composition that is not harmful to the alloy in hot service and does not contain harmful metals or metal slats containing zinc, aluminium, lead or chlorides, sulphur, or halogens. Material safety data sheet (MSDS) documentation and paint data sheets shall be available for review by the designated inspector.

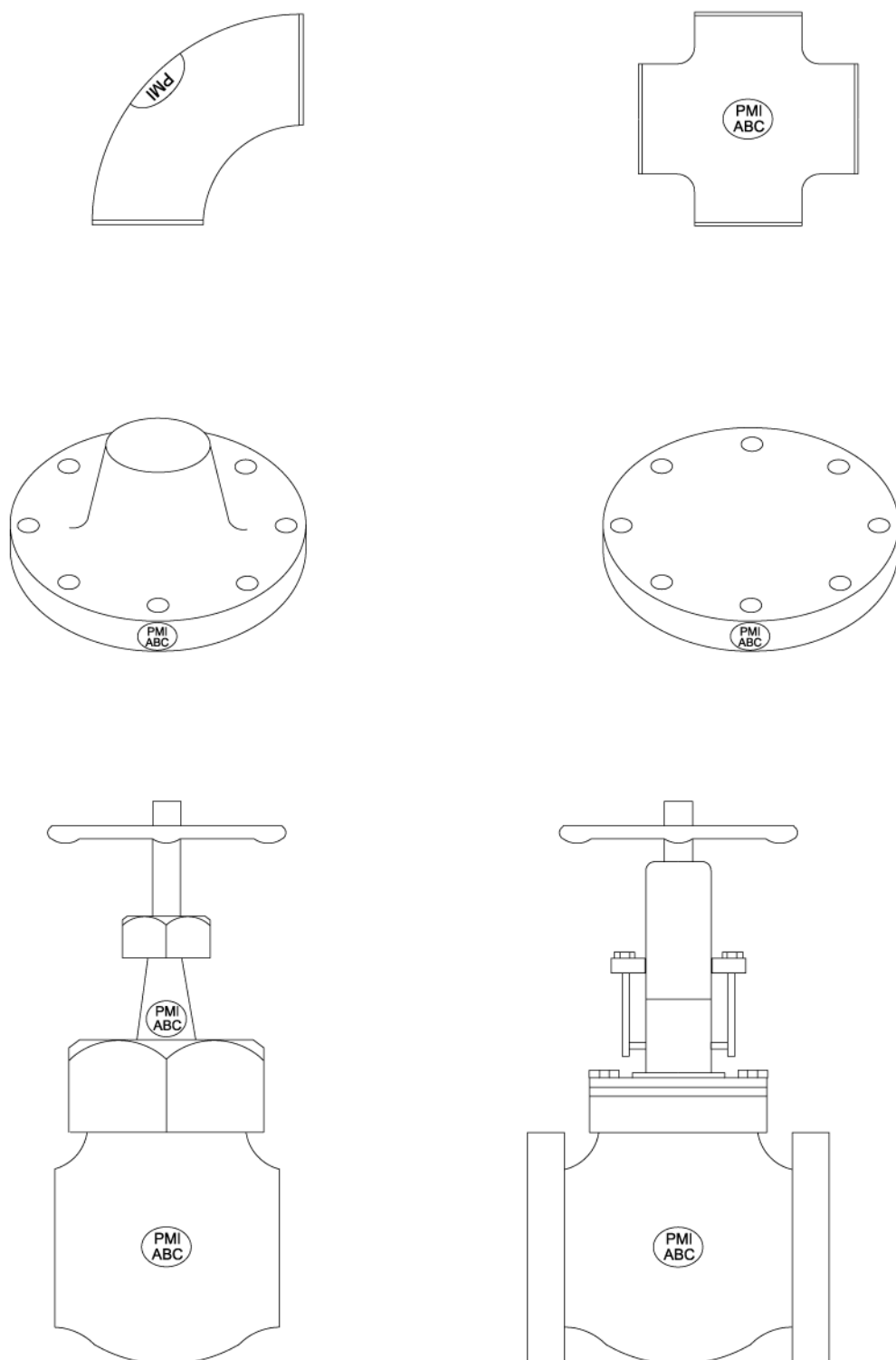
6.2 MATERIAL IDENTIFICATION CODES

1. Material identification codes shall be at least 6 mm high and shall be applied by means of a low-stress steel stamp.
2. The letters "PMI" shall be circled on the internal side of shells, channels, clad and overlay.
3. High and low carbon stainless steel material shall be stamped with the letters "H" and "L" respectively on the base material and the nameplate.
4. A material Identification code that identifies the alloy shall be stamped on the base materials and the nameplate. The code shall be located below the letters "PMI", within the same circle if possible, as shown for piping in Figure 2.
5. Examples of material identification codes for alloys are given in Table 3.

Table 3 Material identification codes

Alloy	UNS number	Material identification code
1¼ Cr ½ Mo	K11597	1 CR
2¼ Cr 1 Mo	K21590	2 CR
2¼ Cr 1 Mo ¼ V	K31835	2CR V
5 Cr ½ Mo	K41545	5 CR
9 Cr 1 Mo	S50400	9 CR
13 Cr-4Ni/CA6NM	J91540	CA6NM
12 Cr/CA15	J91150	CA 15
304	S30400	304
304L	S30403	304L
304H	S30409	304H
308	S30408	308
308L	S30883	308L
309	S30900	309
309L	S30983	309L
310	S31000	310
316	S31600	316
316L	S31603	316L
316H	S31609	316H
317	S31700	317
317L	S31703	317L
321	S32100	321
321H	S32109	321H
347	S34700	347
347H	S34709	347H
410	S41000	410
410S	S41008	410S

Alloy	UNS number	Material identification code
430	S43000	430
Alloy 2205	S31803	2205
Alloy 20	N08020	20
6 Mo Alloys	N08367 and N08925	6 Mo
Alloy B2	N10665	B2
Alloy C-276	N10276	276
Alloy 600	N06600	600
Alloy 625	N06625	625
Alloy 625LCF	N06626	626
Alloy 800	N08800	800
Alloy 825	N08825	825
90/10 CuNi	C70600	90/10
70/30 Cu/Ni	C71500	70/30
Alloy 400	N04400	400
Nickel 200	N02200	200
Titanium Gr 2	R50400	T-2
Titanium Gr 7	R52400	T-7
Titanium Gr 12	R53400	T-12
Titanium Gr 16	R52402	T-16
Zirconium 702	R60702	Z-702
Zirconium 705	R60705	Z-705
Tantalum	R05210	R05210
Tantalum 40 % Nb	R05240	R05240
Admiralty Brass	C44x00 x = 3,4 or 5	C44x00 x = 3,4 or 5
Naval Brass	C46x00 x = 5,6 or 7	C46x00 x = 5,6 or 7



ABC = MATERIAL IDENTIFICATION CODE

Figure 2 Location of PMI identification marks for piping (examples)

7. INSPECTION REPORT

1. A signed and dated record, documenting the PMI examination, shall be provided to the owner/user. Fabricated items with multiple components and welds shall include a map showing the location of each test. In particular, the Inspection Report shall identify:
 - a) Each component PMI-tested by the Manufacturer.
 - b) Each piece of equipment (with item number) PMI-tested by the shop fabricator, including a test location map.
 - c) Each pipe line (with line number and pipe spec, including the spool or fabrication drawing) showing the locations of PMI tests by the shop/field fabricator or field constructor.
2. Results of PMI examinations shall be recorded on a PMI Inspection Report, which shall include all the chemical elements required to be verified by Figure 1, and all additional data as required by this DEP. Reports downloaded from the alloy analyzer are acceptable.
3. The Inspection Report shall indicate at least the following for each inspection lot examined:
 - a) Manufacturer/fabricator's name.
 - b) Date(s) of testing.
 - c) PMI Procedure.
 - d) Name of person and company performing the test.
 - e) Material Manufacturer, MTR number, heat number and lot number, as applicable.
 - f) Method of examination (laboratory or field analyzer).
 - g) Type of analyzer, if applicable.
 - h) Inspection lot size and number of pieces or items examined.
 - i) Results of the test and resolution of non-conformance material. Number and type of each component inspected, rejected, and reason for rejection and the corrective action taken.
 - j) Mass percentage of elements, if specified by the material specification.
4. All of the above information and Inspection Reports shall be transmitted to the owner/user.
5. Inspection Reports shall become part of the permanent record and included in the final data package or equipment file folders.
6. Documentation associated with the PMI program shall be available for audit by the purchaser for a period of three years after the material/equipment has been supplied.

8. PMI PROGRAMMES

8.1 GENERAL

Besides the risk ranking, there are many other variables that can influence the selection of an appropriate PMI programme.

Each ranked piping system/equipment shall be individually assessed. When all assessments have been completed, a decision shall be made whether to apply a number of different PMI programmes or whether to standardise on one or two. The cost and complexity of managing different PMI programmes should be considered. If a single PMI programme is selected it shall cover the requirements of the highest Risk Ranked system.

Examples of influencing factors include:

- The TAMAP listing of material and equipment Suppliers/Manufacturers or the Principal's list of approved material and equipment Suppliers/Manufacturers.
- Bulk material procurement directly from fabricators (big projects) or from stockists.
- The quality and experience levels of site contractors and sub-contractors responsible for implementing and maintaining material QA systems as described in (2.).
- The fact that material fabricators and Suppliers cannot be expected to understand the potential consequences of a material mix-up in a live plant.

8.2 PMI PROGRAMME ELEMENTS

PMI programme elements can be applied at different stages of a project to meet specific needs. For alloy piping bulk materials, a number of options are listed below with their justification. These can also be applied to alloy equipment manufacturing and shall then be stated in the purchase order or requisition.

- a) 100 % PMI by a PMI Contractor at the material fabricator/Supplier's works prior to delivery. When carried out in compliance with (5.), this element provides assurance that the materials delivered comply with their specifications.
- b) 100 % PMI during receiving inspection when items arrive at site, prior to storage in the warehouse. This is in addition to routine verification such as material certificate checks, quantity verification etc. This element can be selected if bulk materials come from multiple sources and/or from sources which instill less than optimal confidence levels.
- c) Sample PMI of each purchase order line item during receiving inspection at site, with the sample size specified by the purchaser. This element should only be applied to medium and low risk systems to provide a degree of confidence in the materials suppliers.
- d) Sample PMI on completed piping systems (including welds), after field installation of pipe spools but before release for testing. This element has limited value and shall not be applied to high or medium risk systems.
- e) 100 % PMI on completed piping systems (including welds), after field installation of pipe spools but before release for testing. If properly managed, this provides the best assurance that a system has no rogue materials.
- f) A combination of the above elements.

8.3 PMI PROGRAMME SELECTION

1. Red and yellow PMI risk ranked systems:

100 % PMI shall be performed on completed systems/equipment [i.e. section 8.2, element e)].

If the detection of rogue materials at this late stage of a project (nearing mechanical completion) could lead to unacceptable delays in project completion, it is advisable to combine element e) with elements a), b) or c) to ensure that errors in the delivery of materials can be detected early enough not to affect the project schedule.

2. Blue risk PMI ranked systems:

Although it may not be strictly necessary to apply a PMI programme to these systems, PMI may still be applied in the following cases:

- Where alloy materials are sourced from vendors who are not listed in the TAMAP database or are not approved by the Principal. Section 8.2, elements a), b) or c) should be considered for such cases.
- When confidence is low in the Field Fabricator's materials control systems. Section 8.2 elements d), e) or f) should be considered for such cases.

8.4 PMI ON WELDS

In general, the design of portable PMI equipment will not permit examination of a weld root pass. Only the capping pass can be examined by PMI.

The preclusion of carbon steel root passes in stainless steel piping systems can therefore only be effectively achieved by including a magnetic check of the root pass as a hold point in the ITP for each stainless steel weld.

The most likely location for this form of rogue welding materials is on field closing welds of large stainless steel piping systems, where the provision of backing gas becomes more difficult and costly. As this is a deliberate form of non-compliance with the welding procedure specification, the above hold point approach is the most-effective countermeasure.

8.5 ALTERNATIVE PMI PROGRAMME

For new projects, if it is decided not to follow the risk-based approach specified in this DEP, the responsible Materials and Corrosion specialist shall determine the appropriate level of PMI in consultation with other stakeholders (e.g. Quality Assurance and Fabrication Assurance). Table 4 and Table 5 may be used for this purpose.

Table 4 Alloy Material Subject to PMI

Material	Full	Standard
Piping		
Pipe	ALL - 100 %	10 % (1)
Fittings	ALL - 100 %	10 % (1)
Valves (7)	ALL - 100 %	10 % (1)
Expansion Joints and special items	ALL - 100 %	10 % (1)
Ring Joint Gasket	ALL - 100 %	10 % (1)
Heat exchangers, boilers, fired heaters		
Heater tubes	ALL - 100 %	10 % (1)
Heat exchanger tubes	1 % (2)	1 % (2)
Tubesheets	ALL - 100 %	10 % (4)
Fittings	ALL - 100 %	10 % (1)
Solid or jacketed gaskets	ALL - 100 %	10 % (1)
Expansion joints	ALL - 100 %	10 % (4)
Channels	ALL - 100 %	10 % (4)
Pipe	ALL - 100 %	10 % (1)
Furnace tube hangers	ALL - 100 %	10 % (1)

Furnace tube supports	ALL - 100 %	10 % (1)
Cladding	ALL - 100 %	10 % (4)
Pressure retaining components of pressure vessels		
Shell	ALL - 100 %	10 % (4)
Heads	ALL - 100 %	10 % (4)
Nozzles	ALL - 100 %	10 % (1)
Fittings	ALL - 100 %	10 % (1)
Flanges	ALL - 100 %	10 % (1)
Cladding	ALL - 100 %	10 % (4)
Pressure retaining components of machinery		
Pump casing	ALL - 100 %	100 %
Compressor casing	ALL - 100 %	100 %
Instrumentation		
Control valve (7)	ALL - 100 %	10 % (1)
In-line instruments (11)	ALL - 100 %	10 % (1)
Bulk material		
ASTM A193 bolts above B7/B7M only	5 % (3)	5 % (3)
Non-standard spiral wound gaskets (>304 SS)	5 % (10)	5 % (10)
Welding		
Welds (pressure equipment)	ALL - 100 % (5)	5 % (8,9)
Weld (repairs)	ALL - 100 % (5)	5 % (8,9)
Welds (piping)	ALL - 100 % (5)	5 % (6)
Weld overlay	ALL - 100 % (8,9)	5 % (6,8,9)
Pressure relieving equipment		
Bellows	ALL - 100 %	100 %
Body	ALL - 100 %	100 %
Bonnet	ALL - 100 %	100 %
Rupture disc	ALL - 100 %	100 %

NOTES:

- 10 % of all the components purchased shall be examined. Components to be examined shall be selected by the purchaser. If any given sample of components has fewer than 10 items, one item shall be examined.
- 1 % representative sample of the total number of tubes from each heat, lot and material specification of tubes.
- 5 % of bolts supplied in bulk or two bolts per box, and per heat and lot, whichever is greater, shall be examined. Bolts to be examined shall be selected randomly by the purchaser.
- One examination per heat of material.
- One spot on every cap pass of every pressure retaining weld shall be examined in accordance with Table 1.
- One spot on one cap pass per weld procedure per spool of piping shall be examined in accordance with Table 1.
- Valve body and bonnet only. However PMI testing of non-standard trim upgrades using high alloy material such as alloy 400 trim is recommended in the modification shop.
- One analysis per weld procedure shall be taken at the base filler material and/or overlaid weld on each major longitudinal and circumferential weld seam. For nozzles lined with alloy weld metal overlay, one analysis per nozzle is required. For sleeve lined nozzles, one analysis for the flange face overlay and of the shell tie-in overlay is required. One analysis is also required for the alloy weld overlay covering a base metal weld and joining the cladding of clad plates. In cases of in-accessibility, a test sample may be welded for analysis. A test sample shall be welded for each welding process and for each heat and lot of filler materials.

One analysis is required on each fabricated head. The analysis shall meet the same composition limits as the corresponding base plate and clad materials except that carbon maximum of 0.045 % is acceptable in a deposit joining L grade austenitic stainless steel cladding.

For alloy air cooler header boxes, one analysis for each welding procedure used for long seams, end plates, and nozzles is required.

9. Analysis of the base filler metal and/or alloy weld overlay shall be made at location determined by the purchaser's designated Inspector. If overlay has been applied for corrosion protection, the analysis shall be performed at 1/2 the minimum specified thickness as qualified in the welding procedures. If the function of the overlay is to ensure product purity only, the sample shall be taken at the surface. Chemical composition at the designated depth shall meet the minimum composition requirements for the weld overlay alloy applied.
10. 5 % of spiral wound gaskets shall be tested when the windings or ID ring are higher alloy than 304 SS. The PMI shall be of the area at the ends where there is no filler or if provided, the ID ring.
11. Includes venturries (external portion only), level bridles, Coriolis meter, magnetic level, displacer and other instruments installed in-line pressure retaining service. Only the accessible welds are to be tested in the field. Insertion type instruments such as thermowells, annubars, capacitance probes, FCI flow meters are exempt because of the low stress level and standard stainless construction. Insertion type instruments of alloys higher than stainless require PMI. Excludes items that are not pressure retaining or not in-line instruments (downstream of the primary block valve), such as pressure transmitters.

Table 5 PMI for instrumentation components

Instruments	No PMI *	10 % PMI	100 % PMI
Orifice plate	304/304L and 316/316L SS		Higher alloy **
Thermowell, other type insertion type instruments and positive displacement meters (analyzer probes, FCI meters and vortex meters)	304/304L and 316/316L SS		Higher alloy **
Instrument tubing including insertion type	304/304L and 316/316L SS		Higher alloy **
Control valve	Cast 316 SS bulk produced CV		Higher alloy ** or all Custom Cast
Valve trim	Standard trim from the manufacturer		High alloy trim upgrades at valve modification shops
Displacer, magnetic level gauges and level chamber	316, 316L or all in CS piping systems	304 welds and all 304L	Higher alloy **
Coriolis meters	316, 316L or all in CS piping systems	304 welds and all 304L	Higher alloy **
Fabricated meter runs and fabricated venturis (pressure retaining parts only)	All in CS piping systems	304 welds and all 304L and 316/316L SS	Higher alloy **
* No PMI is specified on some Instruments because they are the manufacturer's standard materials and not perceived to be a risk for error. ** Higher alloy is 321SS, 347SS, all chrome alloys and high nickel alloy.			

9. REFERENCES

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

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

AMERICAN STANDARDS

Material verification program for new and existing alloy piping systems

API RP 578

Issued by:
American Petroleum Institute
Publications and Distribution Section
1220 L Street Northwest
Washington DC 20005
USA

Standard specification for alloy-steel and stainless steel bolting materials for high temperature or high pressure service and other special purpose applications

ASTM A 193

Standard specification for seamless and welded steel pipe for low-temperature service

ASTM A 333

Issued by:
American Society for Testing and Materials
100 Barr Harbor Drive, West Conshohocken
PA 19428-2959
USA

BRITISH STANDARDS

Specification for colours for identification, coding and special purposes

BS 381C

Issued by:
British Standards Institute
389 Chiswick High Road
London W4 4AL
UK

APPENDIX 1 EXAMPLES OF RISK EVALUATION FOR TYPICAL ALLOY SYSTEMS

UNIT	ALLOY	SYSTEM	RISKLEVEL	REMARKS
Hydrocracker	Cr–Mo (1 % to 9 % Cr)	Feed Effluent Hot hydrogen	5C 5C 5C	Rogue carbon steel could cause large consequence due to sulphidation or high temperature hydrogen attack (HTHA).
	12 Cr	Hot effluent Hot hydrogen lines Cool effluent	5D 5D 5D	Rogue carbon steel could cause large consequence due to sulphidation or HTHA.
	Austenitic SS	Flanged branch connections on Cr-Mo systems	5E	Verify alloy can resist polythionic acid stress corrosion cracking (PASCC).
Hydrotreaters	Cr–Mo (1 % to 9 % Cr)	Feed Effluent Hot hydrogen lines	5D 5D 5D	Rogue carbon steel could cause large consequence due to sulphidation or HTHA.
	12 Cr	Hot Effluent Hot hydrogen lines Cool effluent	5E 5E 5E	Rogue carbon steel could cause large consequence due to sulphidation or HTHA.
	Austenitic SS	Flanged branch connections on Cr-Mo systems	5E	Verify alloy can resist PASCC.
	Alloy 20 Incoloy 825	Cool high pressure effluent	5C	Rogue austenitic could lead to chloride cracking in high pressure unit.
Crude Unit	Cr–Mo (1 % to 9 % Cr)	Gas oil lines *Low	3D	Rogue carbon steel could lead to relatively large leak, but consequence is medium due to low pressure service.
		Straight run residue *Low	3E	Rogue carbon steel could lead to relatively large leak, but consequence is medium since pressure is low and auto ignition is expected.
		Pitch	3E	Rogue carbon steel could lead to relatively large leak, but consequence is medium since pressure is low and auto ignition is expected.
	Cr–Mo or Austenitic	VFU heater outlets *Low	4B	Rogue material could produce relatively large leak, but risk is low because of vacuum service.
* Low = 10 bar (ga) and lower operating pressure NOTE: PMI of Carbon Steel material is NOT required.				

UNIT	ALLOY	SYSTEM	RISK LEVEL	REMARKS
Catalytic Cracking Unit	Cr–Mo (1 % to 9 % Cr)	Feed **Medium	3C	Rogue carbon steel could lead to a relatively large leak, but the consequence is medium since the pressure is relatively low.
		Reactor overhead *Low	3D	Rogue carbon steel could lead to a relatively large leak from sulphidation corrosion or creep, and the contents could form a vapour cloud.
		Regen overhead *Low	3D	Rogue carbon steel could lead to a large leak from creep or corrosion, consequence would be medium.
		Main fractionator Gas-oils *Low	3D	Rogue carbon steel could lead to a large leak from sulphidation corrosion, but consequence would be medium.
	Austenitic Stainless Steel	Reactor/regenerator Stainless steel transfer lines or stainless steel branch connections 304H, 347 and 321 *Low 304L or 316L *Low	3D	Rogue lower strength austenitic materials could cause a creep failure and rogue high nickel austenitic stainless or high nickel alloys could fail from sulphidation corrosion. Also, certain rogue materials would be more susceptible to PASC which could cause a relatively large leak, dependent upon line size and stresses present. Consequence would be medium. Rogue material could lead to failure by PASC which again could produce a relatively large size leak, consequence is medium.
* Low = 10 bar (ga) and lower operating pressure ** Medium = 10 bar (ga) to 20 bar (ga) operating pressure NOTE: PMI of Carbon Steel material is NOT required.				

UNIT	ALLOY	SYSTEM	RISKLEVEL	REMARKS
DELAYED COKER	Cr–Mo (1 % to 9 % Cr)	Feed lines to drums *Low	5C	Rogue carbon steel material could lead to a relatively large failure.
		Overhead vapour line from drums *Low	4D	Rogue carbon steel could lead to a relatively large failure, and the consequence would be high due to potential formation of a vapour cloud.
		Main fractionator Gas-oil lines *Low	3D	Rogue carbon steel could lead to a relatively large failure, but the consequence would be medium.
FLEXI-COKER	Austenitic Stainless Steel	Feed, slurry pump around system *Low	3E	Rogue 304 could lead to a relatively large failure due to nap acids, as could rogue non-L grade stainless steels due to PASCC. These could result in a relatively large consequence.
		321 SS transfer lines *Low	4D	Rogue stainless other than 321 SS could lead to PASCC and the consequence would be high, but good original PMI program lowers the risk to medium. 347 SS would not be considered a rogue material in this application.
CRU	Cr–Mo (1 % to 9 % Cr) and 12 Cr	Reactor feed/ effluent and regenerator lines **Medium	5D/E	Rogue carbon steel could lead to relatively large failure from either creep or from several corrosion mechanisms (particular HTHA) and the consequence is high.
* Low = 10 bar (ga) and lower operating pressure ** Medium = 10 bar (ga) to 20 bar (ga) operating pressure NOTE: PMI of Carbon Steel material is NOT required.				

UNIT	ALLOY	SYSTEM	RISKLEVEL	REMARKS
HYDROGEN PLANT	Cr-Mo (1 % to 9 % Cr) High Temp Alloy i.e., Incoloy 800 or 800HT	High temp process lines 85 bar (ga) and higher steam reformer furnace outlet pigtails and headers **Medium	4D	Rogue carbon steel could lead to a relatively large failure from creep or HTHA, but the consequence is medium. Rogue materials with lower creep resistant properties could cause unexpected creep failure of medium consequence. Adequate visual inspection and measurement of creep growth can be used in lieu of PMI.
	12Cr	Cooler sections of the plant where carbonic acid is present	4D	Rogue carbon steel could lead to a relatively large leak as a result of corrosion, but the consequence is medium.
OLEFINS	HP-45	Furnace tubes ***High	2C	Rogue HK-40 tube material could cause leak in the heater tubes due to creep rupture.
	304SS 3.5 Ni	Cold Section		Rogue carbon steel could lead to brittle fracture in cryogenic service.
SOLVENT EXTRACT DISTILLATION	316SS	NMP, benzene, butane, phenol and isoprene	3C	Rogue 304SS could cause high corrosion rate due to acetic acid.
ALKYL/IPA/SBA	Alloy 20 Cb-3	Neutralization of sulphuric acid	4D	Rogue 304SS/316SS could cause a leak due to very high corrosion rates.
ARU/TGTU/SRU/SWS	Titanium, 625 SS and 316 SS	Sour Water Overhead	3D	Rogue 304 SS could cause a leak due to very high corrosion rates.
ETHYLENE OXIDE PLANT	304 SS 316 SS	Cooler sections of the plant where carbonic acid is present	5D	Rogue carbon steel or diluted stainless steel weld overlay could lead to a relatively large leak from corrosion due to condensation of carbonic acid.
PHENOL-CLEAVAGE	Alloy 20 Cb-3	Neutralization of sulphuric acid	3D	Rogue 304 / 316 SS could cause a leak due to very high corrosion rates.
PHENOL FRACTIONATION	316 SS	Erosion/corrosion by organic acids	3D	Rogue carbon steel or 304SS could cause a leak due to very high corrosion rates.
** Medium = 10 bar (ga) to 20 bar (ga) operating pressure *** High = greater than 20 bar (ga) operating pressure NOTE: PMI of Carbon Steel material is NOT required.				

APPENDIX 2 POTENTIAL CONSEQUENCES OF INSTALLING ROGUE MATERIALS

Failure mechanism	Typical metallurgy	Possible failure magnitude if rogue material is present	Remarks
Sulphidation Corrosion	Cr–Mo (1 % to 9 % Cr)	General corrosion causing relatively large, near line size hole.	Near line size failure has occurred in a refinery coker.
Sulphidation Corrosion	300 Series SS (not normally used in Shell)	General corrosion causing relatively large near line size hole.	High nickel alloys could corrode at unexpected high corrosion rate.
H ₂ S/ H ₂ corrosion	12 Cr SS 300 Series SS	General corrosion causing relatively large, near line size hole.	Rogue carbon steel in 12 Cr service would be a problem as well as high nickel alloys in 300SS service.
High temperature hydrogen attack (HTHA)	Cr–Mo or 12 Cr	Cracking that could lead to brittle fracture in service.	Line size failure has occurred in refinery hydrocracker.
Ammonia Salts Corrosion Select HT Systems	12 Cr SS	General corrosion causing relatively large, near line size hole.	Known failures have occurred in carbon steel systems in hydrotreaters and hydrocrackers.
Chloride Cracking of alloy systems in HTs	Alloy 20 Incoloy 800 and 825	Chloride cracking could lead to a large leak if stresses are high enough.	If the rogue material is an austenitic stainless steel not containing enough nickel to prevent the chloride cracking.
Creep	Cr–Mo (1 % to 9 % Cr)	Opening can be relatively small or large, dependent upon the rogue material present, stress level, temp and time at temp.	Determine the expected impact of a given rogue material in the service being analyzed. Short term creep ruptures will tend to be bigger openings with a fish mouth, while the longer term creep ruptures will be smaller openings. "Grandfathering" is important in creep considerations since carbon steel rogue materials should have failed in a short time in many cases. This may not be the case for a rogue, lower strength Cr-Mo steel.
Naphthenic Acid Corrosion	316L, 317L and 904L	General corrosion causing large failure.	Rogue 304 SS is known to corrode in a general manner.
Polythionic Acid Stress Corrosion Cracking	304L, 316L, 321 and 347	Could have a large leak if stresses are high enough.	Rogue materials would be normal grade 304, 316. The industry has suffered a major fire in a catalytic cracking unit (CCU) caused by PASCC of a stainless system.
Carbonic Acid Corrosion	304 SS	General Corrosion causing large near line size failure.	Significant line rupture in EO Plant where overlay was machined down to diluted weld metal. Leaks in hydrogen plants where carbon steel materials were inserted in the wrong locations. Main rogue material is carbon steel.
Brittle Fracture	304 SS, 3 % Ni, Impact tested carbon steel	Inadequate toughness for temperature exposure.	If non-impacted tested carbon steel is put in service where 304 SS, 3 % Nickel or impact tested carbon steel is specified, sudden failure could occur. Most impact tested systems carry light hydrocarbons that would cause a typically high consequence.