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REAFFIRMED 2013

HYDROGEN PIPELINE SYSTEMS

FIRST EDITION



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PREFACE

As a part of a program of harmonization of industry standards, the European Industrial Gases Association (EIGA) and the Compressed Gas Association (CGA) formed an ad hoc task force and developed [CGA G-5.6, Hydrogen Pipeline Systems](#). This standard is intended as a joint EIGA/CGA international harmonized standard for the use and application of all members of EIGA and CGA worldwide. The CGA edition is identical in technical content to the EIGA edition except for regional regulatory requirements (noted), and it has changes in formatting and spelling.

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Work Item 09-022
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NOTE—No technical information has been changed from the 2005 edition. This reaffirmed edition may include minor editorial changes.

NOTE—Appendices C, G, H (Normative) are a requirement.

NOTE—Appendices A, B, D, E, F, I, J, and K (Informative) are for information only.

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1 Introduction

This publication has been prepared by a group of specialists in pipeline systems representing major industrial gases producers in various countries of Europe and North America and is based on the technical information and experience currently available to the authors.

This publication has been prepared by member associations of the International Harmonization Council, IHC, under the lead of EIGA and is intended for the worldwide use and application by all members of the International Harmonization Council. The International Harmonization Council is composed of members from the Asia Industrial Gases Association (AIGA), Compressed Gas Association, (CGA), European Industrial Gases Association, (EIGA), and the Japanese Industrial and Medical Gases Association (JIMGA). Regional editions may use non SI units and refer to national, and or regional legislation.

It shall be recognized, however, that pipeline systems developed over 50 years in the various countries of Europe and North America have shown good and comparable safety records, although national practices show many differences in design and operations. Some national authorities have also introduced legislation that is mandatory for the operators in those countries.

Thus, the information contained in this document applies only to future installations and not to existing installations or those in the project phase as of the date of this publication. Furthermore, to the extent that they exist, federal, state, provincial/territorial, and local laws supersede the suggested practices listed in this publication. It should not be assumed that every local standard, test, safety procedure, or method is contained in these recommendations or that abnormal or unusual circumstances may not warrant additional requirements or procedures. CGA makes no representations or warranties on the information in or the completeness of this document and disclaim all warranties, express or implied including, but not limited to, the warranty of merchantability and the warranty of fitness for a particular use or purpose.

SI units and corresponding customary U.S. units in brackets are used in this document. Corresponding values can be approximate.

Those involved in the safe design, operation, and maintenance of gaseous transmission and distribution systems should be aware of various documents, guidance, publications, and standards prepared by various multinational organizations that can be pertinent to such systems. These are listed in Appendix K. In addition to these documents, there are a number of pertinent publications, technical papers, and bulletins that provide useful information on materials of construction, metallurgy, and environmental degradation mechanisms found also in Appendix K. While the cited references provide valuable background, it cannot be stated that these are all of the standards, documents, or technical papers published by international organizations that could be pertinent to the subject of this publication.

2 Scope and purpose

The scope of this document is for metallic transmission and distribution piping systems carrying pure hydrogen and hydrogen mixtures as shown in Figure 1 of Appendix A. It is limited to gaseous products with:

- a temperature range between -40°C and 175°C (-40°F and 347°F);
- total pressures from 1 MPa (150 psi) up to 21 MPa (3000 psi) or for stainless steels only partial hydrogen pressure higher than 0.2 MPa (29 psi); and
- concentration criteria defined in Appendix G.

Specific guidance is provided in Appendix I concerning ultra high purity (UHP) hydrogen.

This document does not apply to the following processes:

- cylinder filling plants;
- producing plants;
- compressor units;

- bulk facilities (liquid or high pressure gas) at the customer's site up to the point where gas enters the distribution systems; or
- piping on specialized equipment and machines.

With regard to the preceding [see Appendix K, References 6.1, 8.1, 8.2, 9.1, 9.2, and 12.1].¹

The purpose of this publication is to further the understanding of those engaged in the safe design, operation, and maintenance of transmission and distribution systems. It is not intended to be a mandatory standard or code. It contains a summary of the current industrial practices. It is based upon the combined knowledge, experience, and practices of the major producers in Europe and North America.

Some of the practices represent conservative compromises and not all situations are described. The designer is cautioned that this document is not a complete design handbook and does not negate the need for competent engineering judgment and interpretation. The user should review any special problems or concerns with the hydrogen supplier who should be able to provide advice and guidance.

3 Definitions

For the purpose of this publication, the following definitions apply.

3.1 Publication terminology

3.1.1 Shall

Indicates that the procedure is mandatory. It is used wherever the criterion for conformance to specific recommendations allows no deviation.

3.1.2 Should

Indicates that a procedure is recommended.

3.1.3 May

Indicates that the procedure is optional.

3.1.4 Can

Indicates a possibility or ability.

3.2 Austenite stability factor (Δ)

Austenite stability factors have been developed to determine when an austenite stainless steel would be likely to transform to martensite at cold reductions as high as 80%. Shown below are:

- the Griffith and Wright Stability Factor Relationship:

$$\Delta = \text{Ni} - \frac{(\text{Cr} + 1.5\text{Mo} - 20)^2}{12} + 0.5\text{Mn} + 35\text{C} + \text{Cu} + 27\text{N} - 15 \quad (3.1)$$

and

- the modified Post and Eberly formula [see Appendix K, References 16.2.1 and 16.2.2]:

$$\Delta = \text{Ni} + 0.5\text{Mn} + 35\text{C} - 0.0833(\text{Cr} + 1.5\text{Mo} - 20)^2 - 12 \quad (3.2)$$

Negative numbers indicate a high tendency for austenite-to-martensite transformations when severely strained.

If the nickel content is greater than 10.5% in a 300 series stainless steel, Δ is usually positive and the steel is stable [see Appendix K, References 16.2.1 and 16.2.2].

¹ References are shown by bracketed numbers and are listed in Appendix K.

3.3 Austenite stabilizers or formers

Elements that promote austenite formation and stabilize austenite when stressed at reduced temperatures. They include nickel, carbon, manganese, nitrogen, cobalt, and copper. Various empirical relationships quantify the strength of various alloying elements as austenite stabilizer or formers.

3.4 Austenite to martensite transition temperatures

M_s is the temperature at which metastable austenite transformation to martensite occurs on cooling. The Eichelman and Hull Relationship is as follows [see Appendix K, Reference 16.4.3]:

$$M_s (^{\circ}\text{F}) = 75(14.6 - \text{Cr}) + 110(8.9 - \text{Ni}) + 60(1.33 - \text{Mn}) + 50(0.47 - \text{Si}) + 3000[0.068 - (\text{C} + \text{N})] \quad (3.3)$$

M_d30 is the temperature at which 50% austenite transforms to martensite at 30% strain. The following is the relationship developed by Angel [see Appendix K, Reference 16.4.3]:

$$M_d30 (^{\circ}\text{F}) = 413 - 462(\text{C} + \text{N}) - 9.2\text{Si} - 8.1\text{Mn} - 13.7\text{Cr} - 9.5\text{Ni} - 18.5\text{Mo} \quad (3.4)$$

3.5 Base metal

Material that is to be welded, brazed, or soldered.

3.6 Carbon equivalent and the composition parameter

Carbon equivalent (CE) is a parameter used to assess the weldability of carbon and low alloy steels and their susceptibility to cracking during welding. Steels with low CEs generally do not require any pre- or post-heating treatment. Those with intermediate CEs can require preheating, and those with high CEs require both pre- and post-heating.

Generally, CEs of 0.55 and above are considered to be high and CEs less than 0.35 are considered to be low. However, thickness, weld heat input, and other factors enter the overall assessment.

It should be noted that various CE relationships have been developed and published over the years. One of the earliest CE relationships is the following [see Appendix K, Reference 1.2]:

$$CE = \%C + \frac{\%Mn}{6} \quad (3.5)$$

The most common CE relationship currently in use is [see Appendix K, Reference 1.2]:

$$CE = \%C + \frac{\%Mn}{6} + \frac{(\%Mo + \%Cr + \%V)}{5} + \frac{(\%Ni + \%Cu)}{15} \quad (3.6)$$

A major benefit of microalloyed steels is that low CEs can be achieved and the alloys are more resistant to weld cracking. For steels with lower carbon contents or CEs, the composition parameter P_{cm} has been used as an indicator of cracking susceptibility. An acceptable limit is 0.2% maximum for the following [see Appendix K, Reference 1.2]:

$$P_{cm} = \%C + \frac{(\%Mn + \%Si + \%Cu + \%Co)}{20} + \frac{\%Ni}{60} + \frac{\%Mo}{15} + \frac{\%V}{10} + 5\%B \quad (3.7)$$

3.7 Chromium and nickel equivalents

The most common relationship for the calculation for the chromium equivalent is as follows [see Appendix K, Reference 1.2]:

$$Cr_{eq} = \%Cr + \%Mo + 1.5\%Si + 0.5\%Nb \quad (3.8)$$

The most common relationship for the calculation of the nickel equivalent is as follows [see Appendix K, Reference 1.2]:

$$Ni_{eq} = \%Ni + 30\%C + 0.5\%Mn \quad (3.9)$$

In conjunction with a Shaeffler Diagram, chromium and nickel equivalents can be used to predict the ferrite and austenite forming tendencies of austenitic stainless steels in weld metals and cast metals. It should be noted that newer relationships that include the effects of other elements that affect austenite and ferrite formation or stability do exist.

3.8 Cobalt alloys

The commercial listings of cobalt alloys generally start with a minimum cobalt content of at least 40 weight %. Wear resistant alloys such as Stellite 6 or Stellite 6B are sometimes used as coatings on valve trims to minimize erosion damage and improve valve life.

3.9 Copper-based alloys

Copper-based alloys used in components for the transmission of industrial gases by pipeline generally contain at least 55 weight % copper. Included within this group are the coppers, brasses (copper alloyed primarily with zinc), bronzes (copper alloyed with aluminum, silicon, manganese, tin, lead, etc.), and copper nickels (copper alloyed with nickel).

3.10 Distribution piping

Piping contained on the property (generally owned by the customer) at the use point such as mains, feeders, station connections, and valves.

3.11 Ferrite stabilizers or formers

Elements that promote the formation of ferrite and stabilize it. These include chromium, molybdenum, silicon, and niobium. Empirical relationships that quantify the strength of the alloying elements in this capacity have been developed.

3.12 Ferrous alloys

Included in this category are carbon-steel, low-alloy steel, and all stainless steels irrespective of whether these alloy families are in cast or wrought form.

3.13 Gas pressure

Operating pressure of the piping system.

3.14 Heat affected zone (HAZ)

That portion of a weld, braze, or solder joint that has not melted but where mechanical properties or microstructure have been altered by the heat of welding, brazing, or soldering. It should be noted that certain cutting processes can also result in a discernible HAZ.

3.15 Metastable austenitic alloys

Austenitic alloys that have a chemistry that renders the austenitic microstructure susceptible to transformation to martensite when subjected to thermomechanical processes involving various combinations of strain and reduced temperatures. The relative ratio of austenite stabilizer to ferrite stabilizer is significant in the transformation process.

3.16 Microalloyed steels

The broadest description of microalloying is the use of small additions of alloying elements that achieve improvements of steel properties that seem to be out of proportion to the amount of alloying elements that are added. The steel characteristics that can be improved include strength, toughness, weldability, and formability. Reactive metals, rare earths, boron, and sulfide shape control additives would be included in the inventory of microalloying agents in the broadest definition. A more restricted definition of microalloying is the use of small amounts of alloying additions of elements such as vanadium, niobium, and titanium that are strong carbide and nitride formers to achieve improvements in strength, toughness, and weldability through specific thermomechanical processing steps.

3.17 Nickel-based alloys

Nickel-based alloys used in components for gas transmission pipeline systems contain at least 50 weight % nickel, and nickel contents up to 99+ weight % have been used. However, some tabulations of nickel alloys list alloys with nickel contents as low as 30 weight %.

Some of the major nickel alloy families and examples of each are as follows: nickel (Nickel 200), nickel-copper (Monel[®]-400 and Monel[®]-500), nickel-chromium (Inconel[®] 600 and Inconel[®] X-750), and nickel-chromium-molybdenum (Hastelloy[®] C-276 and Inconel[®] 625).

For hydrogen-containing gas transmission applications, the potential for hydrogen embrittlement, which is affected by metal strength and hydrogen partial pressure, should be considered.

3.18 Nonferrous alloys

When the term nonferrous alloys is used in this document, it includes only copper, nickel, and cobalt alloys. It does not include aluminum or reactive materials such as titanium or zirconium.

3.19 Plant piping

Piping within the production facility.

3.20 Stable austenitic alloys

Alloys that have a high ratio of austenite stabilizers or formers to ferrite formers or stabilizers. When subjected to high strain and reduced temperature, the austenitic alloy does not transform to martensite.

3.21 Stainless steel alloys

Ferrous alloys become stainless when they contain a minimum chromium content of at least 10 to 13 weight %. There are a number of stainless steel classifications, which are dependent upon the alloy content, crystalline lattice, strengthening mechanisms, and the ratio of ferrite stabilizers to austenitic stabilizers.

Stainless steel classifications, with examples of each type, are as follows:

- austenitic (304, 304L, 316, 316L, 321, 347);
- ferritic (430);
- martensitic (410);
- precipitation hardening (17-4 PH); and
- duplex (329, SAF 2205).

The preceding alloy designations are for wrought products but there are alloys such as CF-8, CF-3, CF-8M, and CF-3M that are the cast analogs of 304, 304L, 316, and 316 L, respectively.

Of the various stainless steels, the 300 series stainless steels and their cast analogs are the most commonly used in gas transmission piping systems and have excellent toughness even in high pressure hydrogen.

3.22 Transmission piping

Piping between the production plant boundary and distribution piping boundary including that which passes over public land and third-party property.

3.23 Velocity

Volumetric flow rate at the actual pressure and temperature divided by the pipe inside cross-sectional area.

4 Design philosophy

4.1 General criteria

The safe operation of a transmission piping system depends on various factors that can influence each other. This section describes the principal risks and hazards associated with hydrogen systems and the manner in which the hazards can be minimized by good engineering design. Appendix K, References 6.1, 8.1, 8.2, 9.1, 9.2, 10.1, 11.1 - 11.9, 12.1 - 12.4, 13.1, 14.1, 14.2, and 15.1 - 15.3 contain useful information pertinent to this service.

A safe hydrogen piping transmission or distribution system, including all its components, is one that is designed taking into account:

- local conditions, e.g., seismic zone, soil characteristics;
- applicable piping codes for mechanical design (including pressure rating and wall thickness) and installation;
- conditions of service with respect to fluid composition, gas velocity, pressure, temperature, and dew point;
- selection of metallic materials;
- selection of nonmetallic materials;
- federal, state, provincial/territorial, and local laws and regulations that apply generally to gas transmission pipelines and specifically to hydrogen systems;
- standards of cleanliness for service;
- industry codes of practice relating to hydrogen systems; and
- hazard considerations such as flammability of hydrogen systems.

Appendix H covers the requalification of existing pipelines for hydrogen service. Piping fabricated from non-metallic material such as plastic or composite material is outside the scope of this document.

4.2 Properties of hydrogen

4.2.1 Flammability

Hydrogen is lighter than air, highly flammable, easily ignited, heats up when reduced in pressure, does not support breathing, and is one of the most difficult gases to prevent from leaking. In the pure state, it presents some unique corrosion mechanisms, and when combined with even small impurities (ppm), corrosion concerns can multiply.

Hydrogen is a flammable gas that burns with an almost invisible bluish flame. In daylight, the flame is so pale that the first indication of accidentally ignited hydrogen can be feeling the heat or being burned without even seeing the flame. The flammability limits of hydrogen in air at atmospheric pressure are 4% to 75% and the minimum autoignition temperature is 566 °C (1050 °F).² In oxygen, the range is 4.6% to 93.9% and the minimum autoignition temperature is 579 °C (1074 °F). All the precautions necessary for the safe handling of a flammable gas must be observed with hydrogen. The minimum ignition energy of hydrogen is 0.02 millijoule, which is an order of magnitude less than for hydrocarbons. Hydrogen can be ignited by an almost imperceptible spark or by static electricity discharge. Hydrogen fires are concentrated, rapid, and only slightly radiative compared to hydrocarbon fires.

The maximum flame propagation rate is up to 3 m/s (9.8 ft/s) in air.

Although autoignition of leaks and atmospheric vents is always a possibility with any flammable gas, hydrogen is especially prone to this phenomenon. This is due to hydrogen's low ignition energy and the fact that, unlike most gases, hydrogen increases in temperature when it expands from a higher to a lower pressure. This tendency towards autoignition of leaks and atmospheric vents, combined with the difficulty in seeing the flame, make small leaks a potentially serious personnel injury risk.

In order to mitigate fire risks, fire prevention practice and operator training shall be considered (see Sections 9 and 10) [see also Appendix K, References 5.1, 6.1, and 11.3].

² The U.S. Bureau of Mines has reported a minimum autoignition temperature of 500 °C (932 °F), although this value cannot be verified.

4.2.2 Brittle fracture and environmental damage mechanisms

There are a number of brittle fracture mechanisms or degradation effects, some of which are attributed to hydrogen. These are all described in Appendix B; however, not all are pertinent to dry hydrogen gas. Those that are pertinent to the transmission of hydrogen by pipelines are as follows:

- For internal corrosion:
 - hydrogen gas embrittlement (HGE) at ambient temperature; and
- For external corrosion:
 - stress corrosion cracking (SCC) of line pipe materials in underground environments.

HGE covers a number of different effects that are described in detail in Appendix B. SCC of line pipe materials in underground environments is a phenomenon that can be linked to a number of factors such as defective coatings, improper cathodic protection (CP), and poor soil conditions. See Appendix B for more details.

The two phenomena mentioned above could lead to catastrophic failures. Approaches to minimize the risks associated with these mechanisms include reductions in global or local stress levels and careful materials selection as described in 4.3.

NOTE—The term hydrogen attack is sometimes used improperly when hydrogen pipelines are considered. Hydrogen attack only occurs at temperatures of 200 °C (392 °F) or higher and consequently is not relevant to hydrogen pipelines (see Appendix B for more information about high temperature degradation modes).

4.3 Metallic materials

4.3.1 General

See ISO 11114-1 for compatibility with metallic materials [see Appendix K, Reference 10.2].

4.3.1.1 Strength, hardness, and microstructure

Many metallic materials can suffer embrittlement in hydrogen gas environments. These include steels (especially high strength steels), stainless steel, and nickel alloys.

Steels used in hydrogen pipeline service should have a maximum hardness of approximately 22 Rockwell Hardness C (HRC) or 250 Brinell Hardness (HB). This hardness limit is equivalent to a tensile strength limit of approximately 800 MPa (116 000 psi). Welds should also have a maximum hardness of 22 HRC or 250 HB. It shall be noted that the welded zone is often harder and therefore more susceptible to embrittlement than the base metal.

To achieve an acceptable weld zone hardness, it might be necessary to use lower strength steels than indicated previously such as 500 MPa (72 500 psi). Special welding procedures and pre- or postwelding thermal treatments can be another approach.

In the pipeline systems, there might be a need for buffers, which are usually seamless pressure vessels. Steels used for seamless vessels can have an ultimate tensile strength (UTS) up to 950 MPa (137 700 psi) (ISO 9809-1 and ISO 11120) [see Appendix K, References 10.5 and 10.6]. Comparable ASME steels are found in ASME SA-372, e.g., SA-372, Grade J, Class 70 [see Appendix K, Reference 2.5].

The engineering alloys used in critical locations should have high toughness levels in the fabricated condition and be relatively insensitive to welding problems, e.g., hard/brittle areas, microcracks, fissures, etc.

There are a number of variables such as purity, temperature, and pressure that can affect the severity of the embrittlement mechanisms encountered. It is generally recognized that the tendency for embrittlement in hydrogen atmospheres increases with increasing pressure.

In general, the following are significant metallurgical considerations for HGE:

- use of alloys with homogenous fine-grained microstructures is preferred;
- avoidance of excessively hard or high strength alloys, as indicated previously;
- use of steels with enhanced cleanliness so nonmetallic inclusions, which reduce toughness and hydrogen embrittlement resistance, are minimized; and
- components free from significant surface and internal defects.

With respect to these metallurgical conditions for HGE, there might be somewhat different positions on the degree to which they are applied and at what pressures. Appendix D covers the preceding in greater detail. Each user shall determine which of these considerations should be applied to their specific applications.

If these four cited conditions cannot be fulfilled, it might be necessary to operate the equipment at a reduced stress/pressure (below 30% of the specified minimum yield strength [SMYS] or 20% of the specified minimum ultimate tensile strength [SMUTS], whichever is lower).

4.3.1.2 Welding

4.3.1.2.1 Mechanical properties of welds

Welding processes and operator's qualification should verify that weld samples meet the same strength and toughness requirement as the parent metal.

4.3.1.2.2 Weld and weld heat affected zone

The hardness level of welds and the weld heat affected zone (HAZ) should not exceed HRC 22, which is equivalent to Vickers 248 or 250 HB. The hardness determination shall be made by microhardness traverses on mounted metallographic samples removed from process/operator weld qualification samples. Production hardness testing also should be considered (see 7.4.6).

4.3.1.3 Surface condition

The inside surface should be free of defects such as scratches, notches, carbon deposits, and corrosion.

4.3.1.4 Hydrostatic tests

Pipe shall be tested between 75% and 100% of the SMYS with a holding time at pressure of at least 5-10 seconds depending on the diameter.

4.3.1.5 Inspection

The materials, source of materials manufacturing, all phases of testing, test specimens, results, etc., shall be available for inspection and approval.

4.3.2 Carbon steels

4.3.2.1 General

Carbon steel is the alloy family most commonly used in hydrogen gas transmission pipelines. Various carbon steel specifications for pipelines are listed in Appendix C. The choice of the specific grade depends on many factors including the severity of the service, availability, and relative cost. There is an increasing tendency for pipe and piping steels to have dual or even multiple specification certifications for ASME, ASTM, and API specifications and grades or types within specifications.

In general, the common carbon steel piping grades such as [API 5L X52](#) (and lower strength grades) and [ASTM A 106 Grade B](#) have been widely used in hydrogen gas service with few reported problems. This good service is attributed to the relatively low strength of these alloys, which imparts resistance to hydrogen embrittlement, and the other brittle fracture mechanisms. [API 5L](#) pipe is available in two product specification levels

(PSL 1 and PSL 2). PSL 2 incorporates desirable requirements not included in PSL 1 including minimum notch toughness energy, maximums for tensile strength, and CE. These requirements help ensure base metal and weld hardness are maintained at acceptable values and hydrogen embrittlement concerns are minimized. Therefore, PSL 2 material is advantageous for hydrogen piping. Further, only lower strength [API 5L](#) grades (X52 or lower) should be used. [API 5L](#) PSL 2 grades meet the requirements discussed below [see Appendix K, Reference 3.1].

Further, some pipeline operators use design stress values lower than standard values resulting in a heavier wall, lower stress pipeline than would be required by typical national codes. One approach is to limit the hoop stress at normal operating pressure to less than 30% of the SMYS of the alloy or 20% of the SMUTS, with a 6.4 mm (0.250 in) minimum wall thickness. This lower stress design is used primarily to mitigate third-party damage to the pipeline, but the low stress also reduces the potential for hydrogen damage.

4.3.2.2 Heat treatment

It is acknowledged that as-worked mill forms (not normalized) can be used successfully in hydrogen applications. However, for pipe that is to be used at high stress levels, it is preferable to normalize carbon steel for hydrogen service. This ensures the presence of fine-grained homogenous microstructures. It should be noted that seam-welded pipes shall be normalized locally in the seam weld (see 7.2.4). Also, special attention should be given to the surface condition of alloy mill forms during and after heat treatment.

4.3.2.3 Chemistry

4.3.2.3.1 General

All of the line pipe steels and products from Appendix C have specified compositional ranges for chemical elements. Chemical composition limits as practiced in conventional carbon steel metallurgy generally have been found to be suitable for hydrogen pipeline applications. With newer melting processes, reduced sulfur and phosphorous are possible. The use of lower sulfur and phosphorous levels is an approach that enhances steel toughness and therefore should be considered for severe applications.

4.3.2.3.2 Carbon equivalent

The maximum CE is 0.43.

4.3.2.3.3 Concentrations of alloy elements

All elements that are deliberately added such as calcium and rare earths for sulfide-shape control, aluminum for deoxidization, and elements that can be used in CE calculations shall be reported.

4.3.2.4 Tensile strength requirements

The carbon steel alloy grade that is selected should have the lowest possible tensile strength consistent with the actual application. Because of greater susceptibility to some forms of corrosion in a hydrogen environment, substituting a higher strength material is not an improvement. A maximum tensile strength of 800 MPa (116 000 psi) is recommended [see Appendix K, Reference 16.2.14].

4.3.2.5 Toughness requirements

As the hydrogen pressure increases, toughness is increasingly important. Steels and the mill forms identified with Footnote 1 in Appendix C must meet impact test requirements in the applicable API and ASTM specifications. Generally, the mill forms that must meet impact toughness requirements are made from killed steel per a fine grain practice.

Toughness requirements should be considered on certain steel mill forms to be used in hydrogen pipeline applications. Toughness requirements can be found in Mohitpour et al. [see Appendix K, References 2.1 and 16.3.1]. It is especially important for applications at pressures of 5 MPa (720 psi) and higher.

4.3.3 Microalloyed steels

4.3.3.1 General

In this document, microalloyed steels are described in more detail than other materials to familiarize readers with this relatively new and promising technology. Large-scale natural gas pipelines marked the first significant utilization of microalloyed line pipe in gas transmission applications. Since the early 1990s, a significant amount of microalloyed line pipe in the [API 5L](#) X52 grade has been used to transmit hydrogen gas at pressure in excess of 7 MPa (1020 psi).

This section covers special requirements for the production of microalloyed electric resistance welding (ERW) line pipe intended for high pressure hydrogen service. The application requires high toughness levels in the fabricated line pipe and relative insensitivity to welding problems because of possible embrittlement scenarios that can be encountered in service.

Note that none of the [API 5L](#) PSL 2 (or PSL 1) grades are listed as microalloyed steel in the standard [see Appendix K, Reference 3.1]. If microalloyed steel is preferred, the user should specify appropriate supplementary requirements including added chemistry and property requirements to attain the benefits of microalloyed steel. It is the responsibility of the user to determine the necessary supplemental requirements. The following sections provide guidance.

4.3.3.2 Codes, standard, and grades

Pipe shall be manufactured in accordance with all provisions of the latest edition of [API 5L](#) or equivalent except as might be modified by the additional requirements noted in this document [see Appendix K, Reference 3.1].

The specific [API 5L](#) grades allowed in microalloyed form for hydrogen pipelines are X42 and X52. The manufacturer shall not substitute steel intended for higher strength grades.

4.3.3.3 Process of manufacture and material

The material used in making the pipe shall be basic oxygen or electric furnace steel that is continuously cast. All steel used for hydrogen service shall be fully killed.

The weld seam and HAZ shall be heat treated to simulate a normalizing heat treatment. Low-temperature stress relief of fabricated pipe prior to hydrotesting is permissible.

4.3.3.4 Chemistry

The sulfur content shall not exceed 0.01% ([API 5L](#) PSL 2 limit is 0.015%). The phosphorus content shall not exceed 0.015% ([API 5L](#) PSL 2 limit is 0.025%).

The use of sulfide shape control agents such as calcium is permitted. However, all additions made for this purpose shall be reported.

The maximum CE is 0.35 ([API 5L](#) PSL 2 limit is 0.43%). The concentration of any intentionally added element such as rare earths, titanium, niobium, boron, aluminum, etc., shall be reported, as well as any elements that affect CE determinations.

4.3.3.5 Metallographic and microscopic examination

The final ferrite grain size shall be ASTM 8 or finer [see Appendix K, Reference 4.4]. Samples of the seam weld are cut from one pipe length of each 100 lengths or fraction and examined to ensure that proper weld fusion has been obtained across the thickness of the weld. In addition, Rockwell hardness surveys shall be conducted across the weld and HAZ of the parent metal and test sections. Hardness shall not exceed 95 Rockwell Hardness B (HRB).

4.3.3.6 Mechanical properties

Actual yield and tensile strengths shall be less than the following maximum above the minimum specified for different [API 5L](#) grades:

- X-52: 165 MPa (24 000 psi); and
- X-42: 172 MPa (25 000 psi).

The flattening acceptance test criterion for ERW pipe shall be increased to one-half of the original outside diameter (OD) without weld opening instead of that appearing in [API 5L](#).

4.3.3.7 Impact tests

The test temperature shall be 0 °C (32 °F). For each heat, a set of three transverse and three longitudinal impact specimens shall be impact tested. For small diameter pipes, only longitudinal specimens are required.

Table 1 lists minimum acceptable absorption energies for different sizes of Charpy V notch specimens.

Table 1—Minimum acceptable absorption energies for different sizes of Charpy V notch specimens
[see Appendix K, Reference 16.3.2]

Specimen size	Absorbed energy, transverse J (ft-lb)		Absorbed energy, longitudinal J (ft-lb)	
	Average	Minimum single	Average	Minimum single
Full size	94 (69)	71 (52)	118 (87)	88 (65)
3/4	71 (52)	53 (39)	88 (65)	67 (49)
2/3	48 (35)	48 (35)	78 (58)	58 (43)
1/2	34 (25)	35 (26)	58 (43)	43 (32)
1/3	23 (17)	23 (17)	39 (29)	30 (22)
1/4	18 (13)	18 (13)	30 (22)	22 (16)

Full wall thickness specimens shall be used in the testing. Energy absorption values for these specimens shall be obtained by linear interpolation between standard sizes.

The largest size Charpy specimen that is consistent with the available wall thickness of the pipe shall be used for the fracture testing. Transverse specimens shall be flattened if necessary to obtain specimens more representative of the full wall thickness. The flattening should be done mechanically with no application of heat, e.g., torches [see Appendix K, Reference 16.6.2].

Ductile shear percentage shall be a minimum of 75% for an average of three specimens with no single value below 60%.

Testing performed below 0 °C (32 °F) shall use test criteria per a joint agreement of the user and pipe supplier.

4.3.4 Carbon-molybdenum and carbon-molybdenum-chromium low alloy steels

Normally, carbon-molybdenum and carbon-molybdenum-chromium low alloy, high temperature steels are not used in high pressure hydrogen gas transmission pipelines except for buffers (see 4.3.1.1). However, it is conceivable that these alloys might be welded to a gas transmission pipeline. Accordingly, some of the common ASTM carbon-molybdenum and carbon-molybdenum-chromium low alloy pipe standards and compositions are listed in Appendix C. It should be noted that the high chromium content grades can be more difficult to weld, subject to cracking, and could have local hard spots in the weld HAZ. Consequently, preheating and postweld heat treatments are more often needed for these steels than for carbon steels.

4.3.5 Stainless steels

4.3.5.1 Austenitic stainless steels

Some of the materials listed in Appendix C might be used to transmit hydrogen gas particularly at pressures at the high end of the hydrogen pressure range cited in the specification. The excellent toughness and ease of welding, particularly in field locations, are important attributes.

These materials might also be used for hydrogen transmission at elevated pressures outside of the application range cited in this document. Typically, the presence of even mildly corrosive environments can require that the low carbon (304L, 316L) or stabilized grades (316Ti, 321 and 347) be used when welding is used. In hydrogen applications, the most likely corrosion site can be on the outside of the pipe. For hydrogen service, stainless steels with high austenite stability are preferred (i.e., high austenite stability or high nickel equivalents).

Type 316L is preferred to 304L for hydrogen gas service because 316L has higher austenite stability and is less subject to hydrogen embrittlement.

Austenitic stainless steels with a positive austenitic stability factor according to a modified Post and Eberly formula were found suitable for hydrogen service [see equation 3.2 and Appendix K, References 16.2.1 and 16.2.2].

4.3.5.2 Other stainless steels

Other stainless steels such as ferritic, martensitic, duplex, or precipitation-hardened can be used in hydrogen pipeline components providing they are used at low stress. The toughness of these steels is generally not as good as the austenitic varieties. Strength levels should be minimal and consistent with the application. The fully annealed condition is preferred for the ferritic and duplex steels. Martensitic and precipitation-hardening grades should be heat treated to develop strength levels at the low end of the available range. Information on these can be found in the ASM Handbook "Properties and Selection: Irons, Steels, and High-Performance Alloys" [see Appendix K, Reference 1.1].

4.3.6 Nickel alloys

Many nickel alloys are susceptible to hydrogen embrittlement. Nickel alloys should be avoided unless the user verifies the alloy is suitable for hydrogen gas service. Monel® K-500 and Inconel® X-750, which are precipitation-hardened alloys, can be used with hardness limits in subcomponents where high strength is required. Again, modest strength levels and avoidance of high nickel levels are worth noting.

4.3.7 Copper and cobalt alloys

Copper alloys are subject to hydrogen damage when copper contains oxygen. Hydrogen can enter the metal and react with oxygen in solid solution or oxide inclusions to form water. At elevated temperatures higher than 370 °C (700 °F), steam pressure is high enough to cause cracking. Most copper alloys are deoxidized, and these generally do not suffer hydrogen embrittlement and are suitable for use in hydrogen gas.

Certain cobalt alloys can be used where abrasion resistance or wear resistance is required. These usually are Stellite formulations. Cobalt alloys are considered acceptable for hydrogen gas service.

4.4 Compatibility with nonmetallic materials

See ISO 11114-2 for compatibility with nonmetallic materials [see Appendix K, Reference 10.3].

4.4.1 Plastics

Plastics exhibit varying behavior in the presence of hydrogen. The maximum temperatures for various plastic materials in hydrogen service are given in Table 2. In certain cases these values do not exclude the possibility that the listed plastics can be used at higher temperatures.

In using other plastics, it is advisable to conduct suitable strength tests prior to use.

Table 2—Maximum temperatures for various plastic materials in hydrogen service
[see Appendix K, Reference 16.1.1]

Material	Temperature	
	°C	°F
Plasticized cellulose	20	68
Cellulose diacetate	20	68
Formo-aniline	20	68
Formo-urea	20	68
Phenol-formaldehyde	20	68
Furaphenol	20	68
Polyamides	20	68
Polyfuran	110	230
Polychloroprene	100	212
Polyepoxydiphenylopropane	90	194
Polyethylene glycol terephthalate	20	68
Polyurethane	20	68
Polyurethylmethacrylate	20	68
Polyvinyl acetate	20	68
Polyvinyl chloride	60	140
Polytrifluorochlorethylene	180	356
Polytetrafluoroethylene	250	482
Polyethylene	60	140
Polyisobutylene	100	212
Polystyrene	20	68
Polyacrylonitrile	20	68
Polyvinyl-vinylidene chloride (20% to 80%)	60	140

4.4.2 Elastomers

Most elastomers are compatible with hydrogen. Their chemical resistance is given in Table 3.

Permeation of hydrogen through elastomers at 25 °C (77 °F) is shown in Table 4.

Table 3—Chemical resistance of elastomers to hydrogen
[see Appendix K, Reference 16.1.1]

Material	Compatibility
Natural rubber	B
Butyl rubber	A
Silicone rubber	B
Neoprene®	A
Buna S®	A
Hypalon®	A
Viton®	A
Buna N®	A
KEY	
A: Good resistance	
B: Fair resistance	

Table 4—Permeation of hydrogen through elastomers at 25 °C (77 °F)
[see Appendix K, Reference 16.1.1]

Material	Permeation
Natural rubber	49
Butyl rubber	7.4
Buna S®	40
Perbunan® G	15.8
Neoprene® G	13.3
Hycar or 15®	7.4
Polybutadiene	42
Polymethylpentadiene	43
Perbunan 18®	25
Isoprene-methacryl-nitrile copolymer	14
Hycar or 25®	12
Polydimethylbutadiene	17
Vulcoprene A®	6.4
Isoprene-acrylonitrile copolymer	7.4
Thiokol S	1.6
NOTE—Multiply the permeation values by 10 ⁻¹⁰ to obtain cm ³ @ STP per cm, per second, per cm ² , per cm Hg.	

4.5 Piping systems

4.5.1 Underground piping systems

Piping should be of all welded construction in accordance with a specification and inspection code such as [API STD 1104](#), EN 12732, EN 14161, or EN 1594 [see Appendix K, References 3.5, 11.6, 11.2, and 11.1]. Underground piping shall be externally coated to an approved specification to protect against soil corrosion. Reference to current, internationally accepted coatings standards and specifications is recommended [see Appendix K, Reference 7.6].

Underground piping should be adequately buried to protect it from frost, casual surface construction, shifting due to unstable soil, back-fill damage to the external surface of pipe or the coating, and aboveground loads such as vehicles or equipment moving over the path of the pipeline. Pipe casings or load shields, if required by special agencies, should be installed at railroad or road crossings or where unusual aboveground loading can occur. Casings or sleeves require careful consideration and special measures to avoid CP problems and arcing, which can be caused due to an electrical connection forming between the sleeve and carrier pipe due to settlement, etc. In general the use of metallic casings or sleeves should be avoided wherever possible.

Underground hydrogen piping is vulnerable to damage by lightning strikes or ground fault conditions, which can rupture the pipe material. To reduce the likelihood of one of these occurring, electrical continuity between underground hydrogen piping and aboveground piping or other metal structures should be avoided.

Due to the possibility of leaks, it is preferable not to have flanged or other mechanical joints underground. If this cannot be avoided, then the number should be limited, and they should be installed in a way that provides access for inspection and maintenance, e.g., in valve pits.

4.5.2 Aboveground piping systems

Aboveground hydrogen piping systems should follow good mechanical design practices as applied to any other aboveground piping system. It should be noted that hydrogen is more prone to leakage problems than other

gases due to its small molecular size. The use of welded connections is recommended whenever possible. Aboveground piping should be painted to an approved specification to protect against atmospheric corrosion.

Aboveground portions of pipeline systems should connect to underground portions through an electrically insulated joint to isolate the underground CP system (see 5.6.4).

All aboveground pipelines shall have electrical continuity across all connections except insulating flanges and shall be earthed at suitable intervals to protect against the effects of lightning and static electricity. The electrical resistance to earth of the installed pipeline should not exceed 10 ohms for personnel protection against electrical or high voltage shock.

Flange bolting provides the necessary electrical bond provided the bolts are not coated with a dielectric material or paint and are well maintained to avoid rust.

In the case of short aboveground sections where insulating flanges are not used, the pipe should be insulated from the support structure by means of an isolating pad.

Hydrogen piping should not be exposed to external forces that can cause a failure or dangerous situation such as external impingement from hot gas or steam vents, vibration from external sources, or leaking oil dripping onto the line, etc.

Aboveground piping systems outside plant fence lines can be subject to deliberate or accidental damage. Consideration should be given to installing pipe and valves underground with extensions for aboveground operators and instrumentation.

4.5.3 Pipeline markers

Overhead piping should be color coded, identified, or both. Underground piping should be identified with markers placed on the ground near the buried pipeline. Markers should be suitably spaced to indicate the route of the line.

4.5.4 Corrosion protection

4.5.4.1 Underground pipelines

Corrosion caused by galvanic action between the outside of the pipe and the soil is probably the most frequent cause of leaks except for mechanical damage. It is caused by the difference in electric potential between the pipe and the soil, which sets up an electrochemical cell. This electrolytic cell acts to continuously remove metal from the pipe and deposit it in the soil. If not prevented or sufficiently inhibited, eventually hole(s) are made in the pipe during its working life. Corrosion protection is achieved by CP, either by sacrificial anode or by impressed current, both in combination with electrical isolation by coating. To achieve a good CP in a given circumstance, it is necessary to understand the soil conditions and the anti-corrosion methods used by nearby pipelines. The advice of an expert in these matters is strongly recommended in known difficult corrosion areas and is a worthwhile precaution in any area. CP can be done according to recognized standards such as NACE Standard RP0177, NACE Standard RP0169, or EN 12954 [see Appendix K, References 7.3, 7.6, and 11.4].

Electrical isolation (pipeline coating) plus either sacrificial anode or impressed current should be used on every underground pipeline.

- Electrical isolation—This method acts to prevent corrosion by electrically isolating the pipeline from the soil. It is the most basic technique and as a minimum should be practiced on every section of underground pipeline. The pipe is isolated from the soil directly by an external coating and indirectly by isolating flanges where it connects to aboveground piping. The weakness is that even small flaws in the coating become sites for what are often very rapid rates of corrosion. These flaws can be present in the coating as supplied, come from damage during installation, occur as the coating loses its dielectric strength, or after some time in service can be caused by bacterial activity. It should be assumed that a number of defects in the coating exists or will come to exist during the lifetime of the pipeline. This does not negate its value but does lead to the necessity of providing another means of protection together with electrical isolation.

- **Sacrificial anode**—This method acts to prevent corrosion of the pipe by providing a source of material that is more electrolytically active (anodic) than the piping material. Corrosion takes place preferentially on this sacrificial anode, and the pipeline is thereby spared at least until the anode is used up. Sacrificial anodes are most effective when used together with electrical isolation since they are well suited to protecting against small areas of corrosion such as occur at flaws in the pipe coating. However, there is a limited distance in which a sacrificial anode is effective; therefore, many of them are required at intervals along the pipeline.
- **Impressed current**—To be free of the limited driving voltage associated with sacrificial anode systems, current from some outside source can be impressed on the pipeline by using an anode ground bed and a power source, the most common of which is a rectifier. The rectifier converts AC to DC, and is usually provided with means of varying the DC output voltage in small increments over a reasonably wide range. Most pipeline rectifiers operate in a wide range between 10 volts and 50 volts and can be obtained with maximum current outputs ranging from less than 10 amps to several hundred amps. The anodes used in impressed current systems generally depend on electrochemical oxidation of water and other chemicals in the soil or electrolyte to exchange current with the environment. Specific materials used for anodes are graphite (carbon), high silicon iron alloys, platinized titanium or niobium, and certain conductive mixed-metal oxides applied to a titanium-metal base. Most anodes used in an impressed current system exhibit an electrical potential that is more noble than iron or steel. Therefore, the anodes themselves remain relatively inert and unaffected by the transfer of current. The source of electric current shall overcome this back potential as well as electrical resistance in the circuit before current flows in the proper direction. Steel anodes such as rails are also commonly used, but they exhibit wear of 9 kg/amp.yr (20 lb/amp.yr). Anodes have to be replaced when necessary.

Because of the complexity involved, proper implementation requires experience and specialized knowledge. It is strongly recommended that an expert be consulted.

Monitoring of the corrosion protection system at intervals over the lifetime of the pipeline is essential to achieving satisfactory results. In the case of sacrificial anodes and impressed current systems, this requires monitoring the electrical potential at the CP stations and at monitoring points in between stations.

4.5.4.2 Aboveground pipelines

Because aboveground pipelines can be visually inspected, corrosion can be more easily controlled. However, this is only the case if the inspections are frequent, methodical, and all the discovered problems remediated.

Uninsulated, aboveground pipelines should be protected against environmental corrosion by an appropriate coating system, usually paint. The selection of the system varies with the environment, but, as a general rule, a system suitable for a chemical plant environment should be used as a minimum.

Insulated aboveground pipelines are also subject to environmentally caused corrosion, which occurs underneath the insulation and is therefore not visible. This type of corrosion is quite common and is recognized as a significant problem in the industry. Reference may be made to standards such as NACE Standard RP0198 [see Appendix K, Reference 7.4]. The pipe should be painted before insulating to provide surface protection. The pipeline should be regularly inspected for corrosion under the insulation by removing small sections of insulation at various places and visually checking. A positive indication of corrosion is cause to remove further samples in the same area until the full extent of the corrosion has been identified. Remediation and reinsulation should then follow.

4.5.5 Leakage surveys

As hydrogen is more prone to leakage than other gases, it is particularly important to periodically survey pipelines with a hydrogen detector. Pipelines should be surveyed between one and four times per year, depending upon the population density in the area and as defined by federal, state, provincial/territorial, and local regulations. Particular attention should be paid to flanged connections, valve stems, and compression fittings.

4.6 Hazard analysis and risk assessment

4.6.1 General

Some level of risk is inherent in all human activities, and positive steps should be taken to reduce the risks to a reasonable level whenever this is possible. Every new transportation pipeline system shall be designed, constructed, and operated in such a way that the additional risk to people, property, and the environment is kept within acceptable limits [see Appendix K, Reference 16.6.5].

To this end, a safety analysis should be performed on every new pipeline system or significant modification to an existing system. The safety analysis is a proven way to assess the risks of the pipeline system to the environment and the risks to the pipeline from its environment, as well as to define the measures to be applied during design, construction, and operation to reduce the probability of occurrence and the consequences of abnormal events.

Normally, the level of detail of the safety analysis is based on the population density around the pipe route, the potential severity of an incident, and the likelihood an incident could occur.

The method typically used in a safety evaluation is to determine the individual risk and to show that it is within acceptable limits. It is not unusual to define individual risk as the probability of a person remaining at a given open-air location at all times being fatally injured because of any abnormal event affecting the pipeline and to give an acceptable limit in terms of fatalities per number of years. Local regulations often provide guidelines on performing safety analyses and specify acceptable limits.

A typical example of a full risk assessment for densely populated areas might comprise the following steps:

4.6.2 Identification of the hazards

The minimum list of hazards to be considered is:

- damage by third parties;
- use of incompatible materials and equipment at all operating conditions;
- HGE;
- external corrosion due to improper CP;
- leaks at valve packing and gaskets;
- overpressurization of the pipeline;
- improper inerting procedure;
- improper operation and maintenance of the pipeline;
- abnormal loads due to land slides, floods, earthquakes, crossing of roads, railways;
- influence of other structures such as high power electrical lines or electrical railways;
- damage due to an abnormal event on a parallel pipe;
- road accident or fire in the vicinity of aboveground parts of the pipeline; and
- the radiation of a vent fire or a flare.

4.6.3 Mitigating measures

For each hazard, mitigation measures shall be identified such as:

- control of third-party interference;
- increased thickness of the pipe;

- nondestructive test on welds;
- inerting of the pipe;
- pipeline marking;
- isolation valves;
- excess flow or low pressure shut-down valves;
- leak detection system by mass balance;
- physical protections such as concrete coating or casing and concrete slabs;
- rerouting pipelines;
- reducing pipeline operating pressure; and
- operating procedures including inspection programs, corrosion control programs, emergency plan, personnel training, information of third parties, and collaboration with local authorities.

4.6.4 Typical event scenario

For ease of analysis, the events frequently considered are:

- the full bore rupture;
- the 50% full bore; and
- a small leak (5% of the full bore).

4.6.5 Consequences of these events

The minimum consequences of these typical events to be considered should be a release of hydrogen, which ignites immediately or spontaneously rises and disperses in the open air, possibly with delayed ignition.

4.6.6 Selection of a model to simulate the impact of an incident

As a minimum, the following items should be taken into account in order to configure a proper simulation:

- pressure drop due to the dynamic flow in the pipe;
- transient flow regime due to the decompression of the pipe; and
- velocity of the gas at the breach.

4.6.7 Criteria for the feared event

One method to define the hazard zone is to use the radiation dose approach defined by Eisenberg [see Appendix K, Reference 16.6.4]. This considers that the effect of radiant heat on humans is a function of both radiation intensity and duration of exposure. Eisenberg et al. studied data on the lethality from thermal radiation and concluded that the dosage-response relationship for various probabilities of injury/fatality should be in the form:

$$D = tI^{4/3} \quad (4.1)$$

or

$$D = s \left(\frac{W}{m^2} \right)^{4/3} \quad (4.2)$$

Where:

- D = dosage for various probability of injury
 t = duration of the exposure, seconds (s)
 I = thermal radiation intensity, watts per square meter (W/m^2)

Eisenberg's data is adapted for radiation durations less than 45 seconds. Usage of the damage criteria should be limited to short exposure durations as shown in Table 5.

Table 5—Damage criteria for thermal radiation [see Appendix K, Reference 16.6.4]

Damage levels	Thermal dosage, D
Extreme pain	1.1×10^6
Second degree (blistering threshold)	2.4×10^6
Third degree threshold	7.2×10^6
Second degree under 9.3 oz/yd^2 (flame-retardant treated [FRT] cotton)	10.3×10^6
1% Fatality	10.6×10^6
Second degree under 6.8 oz/yd^2 (NOMEX)	13.1×10^6
50% Fatality	23.0×10^6
99% Fatality	65.7×10^6

For longer periods, the following thermal radiation intensity limits as compared to the damage criteria of Eisenberg listed in Table 5 can be used:

- 3 kW/m^2 —for an exposure time of 120 s - limit of approach for the public. This is outside the limits of the Eisenberg correlation since the exposure time is greater than 45 s.
- 5 kW/m^2 —taken as the radiation level at which breakage of glass by thermal effect occurs and also at which second degree burns on the skin of a unprotected person exposed for 30 s - limit of approach of the operators or other trained personnel. This corresponds to a dose of 2.6×10^6 , i.e., close to the blistering threshold.
- 12.5 kW/m^2 —taken as the radiation level at which fire propagates on vessels sprayed with water and the onset of pain on the skin of a unprotected person exposed for 6 s - limit of evacuation of housing and other normally occupied buildings. This corresponds to a dose of 1.7×10^6 , which Eisenberg's equation would categorize as extreme pain.

With these criteria, it is possible to transform in distances around the pipe the results of the simulations in order to identify the zones concerned by the occurrence of the major event.

This risk evaluation method is a deterministic approach and is required in certain countries.

4.6.8 Definition of the zone to be studied around the pipe

Within the distances of concern found by the simulation, the zoning shall be studied for the whole length of the pipe to identify points where compensatory measures should be considered.

Another widely used method to define the zone around the pipe that could be affected by a leak or rupture is using a potential impact radius. This method is documented in [ASME B31.8S](#) and is dependent on the maximum allowable working pressure (MAWP) and OD of the pipeline [see Appendix K, Reference 2.4].

4.6.9 Risk criteria

The risk criteria taken into account depend on the governing federal, state, provincial/territorial, or local regulations. The risk criteria of The Netherlands, Flanders (Belgium), and of the United Kingdom are given in Appendix J for information.

4.7 Site selection

Site selection for hydrogen systems shall be carefully studied, especially at points where venting to atmosphere can occur such as valve stations, vents, drains, safety valves, etc.

The location of potential vent sites should be chosen with care and, in so far as is practical, to avoid the immediate proximity of vulnerable areas and equipment such as electrical equipment, flammable product storage tanks, public roads, public buildings, car parks, and transfer stations.

Site selection and safety distances should follow established practices and applicable regulations. Typical arrangements for siting of hydrogen stations in relation to other areas and equipment can be found in Appendix E.

5 Piping, valves, and equipment

5.1 General criteria

This section describes how the design philosophy presented in Section 4 can be applied in practice to piping, valves, specific piping components, and equipment configurations.

5.2 Material selection criteria

Selection of material for pipes, valves, equipment, etc., shall be in accordance with 4.3, 4.4, and 4.5.

Due to the hazardous nature of the gas, aboveground pressure-containing parts such as piping, valve bodies, strainer, and filter housings, etc., shall be made of metallic materials only. The use of nonmetallic materials shall be limited to services such as valve internals (inserts only), external coatings, etc., which do not provide primary mechanical strength.

One of the most important criteria is resistance to SCC and hydrogen embrittlement. The risk of these occurring is increased at higher temperatures and pressures and is mitigated by low stress levels. Therefore, material selection, fabrication processes, and material thicknesses should be chosen with a view towards achieving low residual stresses. Typical methods of lowering stresses once the operating temperature and pressure have been decided are closer pipe support spacing, thicker pipe walls, and thermal relieving residual welding stresses.

There are no special velocity restrictions for piping in hydrogen service other than the underlying economics. However, the sonic velocity of hydrogen is approximately four times that of most flammable gases. Therefore, close attention should be paid to possible erosion and abrasion at such items as control valves and relief valves, which usually have sonic or near sonic velocities. Because of the high sonic velocity, it is quite possible that problems will arise at differential pressures, which would not have caused a problem with most other gases.

5.3 Electrical hazardous area requirements

As hydrogen systems can pose a fire or explosion risk, electrical systems shall be in accordance with the applicable codes. These provide requirements and suggestions for determining the level of hazard (classification) and mitigating the risks involved. Typically used codes are:

- NFPA 70 [see Appendix K, Reference 12.2];
- IEC 60079 [see Appendix K, Reference 13.1];
- NFPA 496 and NFPA 497 [see Appendix K, References 12.3 and 12.4];

- API RP 500A, API RP 500B, and API RP 500C [see Appendix K, References 3.6, 3.7, and 3.8]; and
- European directive ATEX 94/9 [see Appendix K, Reference 5.1].

As a minimum, either NFPA 70 or IEC 60079 should be used [see Appendix K, References 12.2 and 13.1].

The type of electrical equipment that can be installed and the installation methods depend upon the level of hazard classification, and they are described in the prescriptive sections of the codes.

It is worth noting that the equipment and piping should be carefully bonded and grounded to drain static electricity and to carry electrical fault currents to earth ground to prevent the release of electric sparks, which could ignite hydrogen leaks in the area.

5.4 Piping

Welded connections are preferred and should be used wherever practical to minimize potential leak sources. Threaded connections that are seal welded are considered welded connections for this purpose. Seamless or longitudinally welded pipe and wrought or machined fittings shall be used except in exceptional circumstances, e.g., absolute unavailability.

5.4.1 Venting

The flammability and autoignition potential of hydrogen gas is a significant potential risk factor. Therefore, care shall be taken when venting. The discharge piping from all vent sources such as vent valves, safety relief valves, compressor packing vents, etc., shall be piped to a properly designed and sited disposal system, which can be as simple as a single pipe or as complex as a manifolded collection header connected to a flare. The back pressure this creates shall be properly accounted for in the design especially on safety relief valve discharges ([API RP 520 P2](#) and [API RP 521](#) are often-used references for this) [see Appendix K, References 3.2 and 3.3].

There are two types of systems that can be used—venting to atmosphere and destruction in a flare. The same materials used elsewhere in the pipeline should also be used for vent collection and disposal piping with one exception, which is discussed in 5.4.1.1.

5.4.1.1 Venting to atmosphere

When not prohibited by local regulation, very large flows of hydrogen gas can be vented directly to atmosphere at a safe outdoor location. When large quantities of hydrogen need to be vented to atmosphere, it is recommended to first perform a dispersion study to guide the vent design. Venting to atmosphere is most commonly used along the length of the pipe line since a flare is not usually available. However, where this presents advantages, it is also acceptable for use where a flare system is available.

The system shall collect and route the hydrogen either individually or in manifolded headers to a vent stack discharging outdoors in a location and direction that avoids impingement of escaping gas on adjacent equipment, structures, or personnel. The exit should allow the hydrogen to flow easily out to atmosphere, minimize water ingress from the environment, discourage creatures from entering, and provide quick dissipation of the hydrogen into the atmosphere. To minimize the possibility of autoignition when the hydrogen leaves the stack, the piping immediately upstream of the exit should be made either of stainless steel or a non-sparking metallic material.

There are varying opinions about the need for and efficacy of a flame arrestor to inhibit backward propagation of a fire into the vent pipe. Similarly, purging of the vent line with an inert gas such as nitrogen can help to prevent autoignition, but there are numerous reported instances where a purge was ineffective. Therefore, this document makes no recommendation either way at this time other than to point out that flame arrestors and nitrogen purges do no harm.

5.4.1.2 Destruction in a flare

The design of a vent collection and flare system for flammable gases is a complex task and should be performed only by persons familiar and experienced in this area. API RP 521 a good source for reference and a layman's understanding [see Appendix K, Reference 3.3].

When attaching to an existing vent collection and/or flare system it is essential to understand the basis of the system's design so that the designer's intent is not inadvertently compromised. The performance of the new attachment affects the performance of the existing system, possibly negatively. Issues such as backpressure on devices, backflow, instantaneous volume, inert purge, materials of construction, etc., are typically involved. The owner of the existing vent/flare system is usually the best resource to ensure compatibility, and it is greatly preferred that this individual be directly involved in reviewing the design and fabrication of the attachment and that his approval be obtained. If this is not possible, then an analysis of the existing system shall be performed from existing documents and inspection of the equipment and the results used to design the attachment.

5.4.2 Flanges and gaskets

Where welded connections are not practical, flanges are the next best choice. Leak-resistant flange types such as raised face, tongue and groove, or ring joint flanges shall be used. Gasket materials shall be appropriate for the design pressures and temperatures and be hydrogen compatible and leak resistant. In addition, consideration should be given to resistance to fire due to the flammability of hydrogen. In general, filled spiral-wound steel gaskets are preferred with raised flanges, but composition gaskets that are graphite based are also used at lower pressures. Soft metallic rings are preferred with ring joint flanges. A Teflon® or graphite-filled spiral wound gasket with a raised face flange or a copper ring with a ring joint flange are typical choices since they embody the desired features to a large extent. Since small leaks to atmosphere present a significant safety risk, flange covers should be considered.

5.4.3 Threaded connections

Threaded connections shall be used only where welded (including seal welded threaded connections) and flanged connections are not practical. The sealant shall be hydrogen compatible and should be high temperature resistant to reduce the risk of leaks during a fire. Typical uses of threaded connections are to match equipment, especially instruments.

5.4.4 Instrument tubing

Instrument tubing shall be stainless steel with compression fittings. The use of continuous runs shall be maximized to reduce the number of fittings since these can be leak sources.

5.5 Valves

5.5.1 General

The major concern specific to pure hydrogen service is to prevent leakage either to the ambient or across the valve.

Leakage to ambient is most frequently caused by packing and bonnet leaks and to a lesser extent by leaking castings. To minimize the potential for leaks the following or equivalent is recommended:

- Double seals or packing;
- Each casting is hydraulically leak tested;
- Soft seat in a metal retainer for in-line automatic valves and automatic vents, specify bubble tight shutoff;
- Metal-to-metal seat or soft seat in a retainer for in-line manual valves. These should be combined with a means of positive isolation if used to block flow before attempting maintenance or inspection inside the line;
- Metallic seat with valve outlet blocked. Typical arrangements used are double valves, blind flange, plug, or cap (threaded connections are acceptable);