



CARBON MONOXIDE AND SYNGAS PIPELINE SYSTEMS

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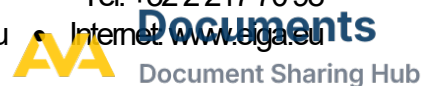
Revision of Doc 120/04

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CARBON MONOXIDE AND SYNGAS PIPELINE SYSTEMS

As part of a programme of harmonisation of industry standards, the European Industrial Gases Association (EIGA) has issued EIGA Doc 120, *Carbon Monoxide and Syngas Pipeline Systems*, jointly produced by members of the International Harmonisation Council and originally published by the Compressed Gas Association (CGA) as CGA G-5.7, *Carbon Monoxide and Syngas Pipeline Systems*.

This publication is intended as an international harmonised standard for the worldwide use and application of all members of the Asia Industrial Gases Association (AIGA), Compressed Gas Association (CGA), European Industrial Gases Association (EIGA), and Japan Industrial and Medical Gases Association (JIMGA). Each Association's technical content is identical, except for regional regulatory requirements and minor changes in formatting and spelling.

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Amendments to 120/04

Section	Change
4.2.2	Add reference to SDS
Appendix K	Add reference to EIGA Doc 919

Note: Technical changes from the previous edition are underlined.

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.

It must be recognized, however, that pipeline systems, developed over 40 years in the various European countries 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, which 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, national 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. The authors make 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.

ISO units and corresponding Imperial units in brackets are used in this document. Corresponding values may 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 which may 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, bulletins, etc. which provide useful information on materials of construction, metallurgy, environmental degradation mechanisms, etc. 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 transmission and distribution piping systems for carbon monoxide and hydrogen and carbon monoxide mixtures (referred as Syngas in the remainder of this document). Typical arrangements for these pipeline systems are shown in Diagram 1 of Appendix A. It is limited to gaseous products with a temperature range between -40°C (-40°F) and 150°C (302°F), pressures from 0,1 MPa up to 15 MPa (2250 psig) and the purity criteria defined in Appendix G.

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
- Piping on specialized equipment and machines.

These systems have many specialized needs and requirements. However, this document may provide useful background information in other processes where CO is present.

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 Western Europe and North America as represented by their members on the CGA/ EIGA/ Ad-Hoc group on pipeline transportation systems.

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. It is suggested that the user reviews any special problems or concerns with his CO/Syngas supplier who should be able to provide advice and guidance.

Although the technical information provided in this document is not intended to be mandatory, the word « shall » is frequently used. The use of “shall” implies a strong concern that the particular practice referenced be followed for safety reasons. The use of « should » implies that the referenced practice is commonly followed, but recognizes that other safe practices are sometimes utilized.

3 Definitions

- **Distribution piping**

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

- **Plant piping**

Piping within the production facility

- **Transmission piping**

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

- **Copper based alloys**

Copper based alloys used in components for the transmission of industrial gases via 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 aluminium, silicon, manganese, tin, lead, etc) and copper nickels (copper alloyed with nickel).

- **Nickel base 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 may 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.

- **Stainless steel alloys**

Ferrous alloys become stainless when they contain a minimum chromium content of at least 10-13 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)
- Duplex (329, SAF 2205).

The preceding alloy designations were for wrought products but there are alloys such as CF-8, CF-3, CF-8M, CF-3M which 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.

- **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 minimise erosion damage and improve valve life.

- **Non ferrous alloys**

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

- **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.

- **Microalloyed steels**

The broadest description of microalloying is the use of small additions of alloying elements which achieve improvements of steel properties which seem to be out of proportion to the amount of alloying elements which are added. The steel characteristics which may 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 which are strong carbide and nitride formers to achieve improvements in strength, toughness and weldability through specific thermomechanical processing steps.

- **Carbon equivalent and the composition parameter**

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

Generally carbon equivalents of 0.55 and above are considered to be high and carbon equivalents 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 carbon equivalent relationships have been developed and published over the years. One of the earliest carbon equivalent relationships is the following:

$$C.E. = \%C + \%Mn/6$$

The most common carbon equivalent relationship currently in use is:

$$C.E. = \%C + \%Mn/6 + (\%Mo + \%Cr + \%V)/5 + (\%Ni + \%Cu)/15$$

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

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

- **Base Metal**

The material which is to be welded, brazed or soldered.

- **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 may also result in a discernible heat affected zone.

- **Metastable Austenitic Alloys**

These are austenitic alloys which have a chemistry which 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.

- **Stable Austenitic Alloys**

These are alloys which 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 will not transform to martensite.

- **Austenite Stabilizers or Formers**

These are elements which promote austenitic formation and stabilize austenite when stressed at reduced temperatures. They include: nickel, carbon, manganese, nitrogen, cobalt and copper. There are various empirical relationships which quantify the strength of various alloying elements as austenite stabilizer or formers.

- **Ferrite Stabilizer or Formers**

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

- **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:

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

and the « modified Post and Eberly » formula (see reference Hydrogen and Materials)

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

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

If Ni content is greater than 10.5% in a 300 serie stainless steel, Δ is usually positive and the steel is stable.

- **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:

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

Md30 is the temperature at which 50% austenite will transform to martensite at 30% strain. Shown below is the relationship developed by Angel []:

$$M_{d30} (^{\circ}F) = 413 - 462(C + N) - 9.2Si - 8.1Mn - 13.7Cr - 9.5Ni - 18.5Mo$$

- **Chromium and Nickel Equivalents**

The most common relationship for the calculation for the chromium equivalent is as follows:

$$Cr_{eq} = \%Cr + \%Mo + 1.5 \%Si + 0.5 \%Nb$$

The most common relationship for the calculation of the nickel equivalent is as follows:

$$Ni_{eq} = \%Ni + 30 \%C + 0.5 \%Mn$$

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 which include the effects of other elements which affect austenite and ferrite formation or stability do exist.

- **Velocity**

The volumetric flowrate at the actual pressure and temperature divided by the pipe inside cross-sectional area

- **Gas Pressure**

The Gas Pressure is the operating pressure of the piping system.

4 Design philosophy

4.1 General criteria

The safe operation of a transmission piping system depends on various factors which can influence each other. This chapter describes the principal risks and hazards associated with CO and Syngas systems and the manner in which the hazards can be minimized by good engineering design.

A safe carbon monoxide or Syngas 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 non metallic materials.
- National laws and regulations which apply to gas transmission pipelines generally and flammable systems specifically
- Standards of cleanliness for service
- Industry codes of practice relating to CO and Syngas systems
- Hazard considerations such as flammability and toxicity of Carbon monoxide and Syngas systems

Transmission or distribution pipelines fabricated from non metallic material, such as plastic or composite material are not recommended because of potential exposure to external damage.

4.2 Properties of Syngas

Syngas, as the term is meant in this document and for the most part in general industry parlance, refers to a mixture primarily of hydrogen (H₂) and carbon monoxide (CO) which may also contain significant but lower concentrations of methane (CH₄) and carbon dioxide (CO₂) as well as smaller amounts of impurities such as chlorides, sulphur compounds, and heavier hydrocarbons.

It is particularly important to exclude water from pipelines in CO or Syngas service since the presence of water introduces serious corrosion issues, which are not addressed in this document.

If it is known or suspected that water above the level specified in Appendix G is present in the gas stream, then methods and requirements beyond those of this document must be used to ensure a safe and reliable system.

Within the concern of this document, there are many similarities between H₂ and CO as well as some important differences. The requirements for Syngas are a combination of safe practices for H₂ and CO, since both are present in significant proportions. In practice this means that the more restrictive of both the H₂ and CO requirements apply.

To accommodate this it is very helpful to set some thresholds on mixtures of them beyond which we start to consider them Syngas. The following practice can generally be safely used with the requirements of this document provided engineering judgment is applied to verify that no conditions exist in a particular application which would suggest other treatment.

See Appendix G for the composition criteria for application of this document for CO and Syngas services.

4.2.1 Flammability

Both CO and H₂ are flammable gases

4.2.1.1 Hydrogen

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), the corrosion concerns can multiply.

Hydrogen burns in air with a pale blue, almost invisible flame which increases the risk of injury in case of fire.

The lower and upper flammability limits in air are:

LFL : 4%

UFL : 75%

The minimum ignition temperature of hydrogen-air mixtures is 500°C.

Hydrogen-air mixtures are extremely easy to ignite requiring only 0.017 mJ ignition energy compared to 0.25 mJ for hydrocarbons.

The maximum flame propagation rate is up to 3 m/s in air.

Although auto-ignition 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 auto-ignition of leaks and atmospheric vents, combined with the difficulty in seeing the flame make small leaks a serious potential personnel injury risk.

In order to mitigate fire risks, fire prevention practice and operator training shall be considered (see chapters 9 and 10).

4.2.1.2 Carbon monoxide

Carbon monoxide is a flammable gas.

Ignited in air, it burns with a little illuminating blue flame.

This combustion issues carbon dioxide (CO₂).

The flammability limits in air are:

LFL : 12.5%

UFL : 74 %

The minimum auto ignition temperature in air is 630°C.

In order to mitigate fire risks, fire prevention practice and operator training shall be considered (see chapters 9 and 10)

4.2.2 Toxicity

Carbon monoxide is a toxic gas (see note).

For this very reason, any CO or Syngas pipeline project should be considered as “critical” in the sense of requiring a detailed risk management review under the responsibility of the owner.

For more information, see the gas supplier’s safety data sheet (SDS), referenced in Appendix K

Note: Carbon monoxide is quickly fixed on haemoglobin, causing a decrease in cellular respiration, which is particularly harmful to the central nervous system. Therefore, it is important to understand the potential effect of exposure to various concentrations of carbon monoxide, which may be encountered so as to provide a safe environment.

A threshold limit value of 50 ppm is recommended for carbon monoxide, as a concentration in air to which nearly all workers may be exposed during a 8-hour workday and 40-hour workweek, without adverse effects.

The consequences of exposure to higher concentrations are shown in the table below:

Table of the effects of carbon monoxide on health and life

Concentration in ppm	Consequences
50	Limit of tolerance for long exposure
50 to 100	After some days ,chronic poisoning
200	Subacute poisoning
1000-1500	Headache,nausea, poisoning and fatal in case of prolonged exposure (more than 30 minutes)
2500	Rapid collapse , death in one or two hours
3760	LC50, one hour exposure
5000	Massive poisoning , death in less than one hour
10000	Death in 10 to 15 minutes
50000	Instantaneous poisoning , immediately fatal

The probability of fatality from a toxic exposure can also be determined using probit equations. Some information about probit equations is given in Appendix J.

To prevent workers from overexposure the general safety requirements according to 9.3 shall be observed .

Besides , special attention shall be paid on training (see chap.9.4)

Notably the following means shall be considered :

- Individual CO detection device
- Permanent CO detection and monitoring in stations
- Leak detection system on pipeline

In case of purging or venting chapter 9.7 shall be observed .

In addition to its own toxicity Carbon monoxide is subjected to dangerous chemical reactions

In contact with certain metals it may create volatile metal carbonyls

Combined with chlorine, CO produces phosgene which is lethal at 50 ppm.

Any toxicity related issue, such as protection against overpressure ,maintenance ,repairs , etc....., shall be dealt with considering this chapter.

4.2.3 Brittle fracture and environmental damage mechanisms

There are a number of brittle fracture mechanisms or degradation effects attributed to hydrogen. These are all described in Appendix B. However, not all of these are pertinent to dry hydrogen gas, dry carbon monoxide and their mixtures. Special attention shall be given to CO and CO mixtures as the simultaneous presence of CO, traces of CO₂ and traces of H₂O at temperatures below the dew point, will provide a susceptible environment for stress corrosion cracking in the use of carbon and low alloy steels. Brittle fracture and environmental damage mechanisms that are pertinent to the transmission of these gases via pipelines are as follows:

- For internal corrosion
 - Hydrogen gas embrittlement (HGE) at ambient temperature
 - Stress corrosion cracking (SCC) of carbon and low alloy steels in CO environments
- For external corrosion on all pipelines
 - Stress corrosion cracking (SCC) of line pipe materials in underground environments.

HGE covers a number of different effects which are described in detail in Appendix B. SCC of line pipe materials in underground environments is a phenomenon which may be linked to a number of factors such as defective coatings, improper cathodic protection and poor soil conditions. SCC of carbon and low alloy steels in carbon monoxide environments is usually attributed to the presence of contaminants in the carbon monoxide. Both SCC mechanisms are covered in more details in Appendix B.

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

Hydrogen attack only occurs at temperatures of 200°C or more and consequently is not relevant to hydrogen pipelines (see Appendix B for more information about high temperature degradation modes).

The three above mentioned phenomena could lead to catastrophic failures. Approaches by which the risks associated with these mechanisms can be minimised include reductions in global stress levels as described in paragraph 4.3.2.1 and careful materials selection as described in paragraph 4.3. Procedures which minimise H₂O and CO₂ presence are beneficial for CO services as indicated in paragraphs 4.2.3.

4.3 Metallic Materials

4.3.1 Generalities

4.3.1.1 Strength, hardness and microstructure

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

Steels used in hydrogen – containing gas pipeline service should have a maximum hardness of approximately 22 HRC (Hardness Rockwell C) or 250 HB (Hardness Brinell). This hardness limit is approximately equivalent to a tensile strength limit of about 116 ksi (800 MPa). 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 may be necessary to use lower strength steels than indicated above (500 MPa). Special welding procedures and pre or post welding thermal treatments may be another approach.

In the pipeline systems, there may be a need for “buffers” which are usually seamless pressure vessels. Steels used for seamless vessels may have an ultimate tensile strength (UTS) up to 950 MPa (ISO 9809 and ISO 11120).

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, which can affect the severity of the embrittlement mechanisms encountered such as purity, temperature and pressure. It is generally recognised 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, see above.
- Use of steels with enhanced cleanliness so non-metallic inclusions, which reduce toughness and hydrogen embrittlement resistance are minimized.
- Components free from significant surface and internal defects

With respect to the above, there may be somewhat different positions on the degree to which the above are applied and at what pressures. Appendix D covers the preceding in great detail. Each user must determine which of the above considerations should be applied to their specific applications.

The stress requirement for carbon steel is detailed below in subparagraph 4.3.2.

4.3.1.2 Welding

- Mechanical Properties of Welds

Welding processes and operators qualification should verify that weld sample meet the same strength and toughness requirement as the parent metal.

- Weld and Weld Heat Affected Zone (HAZ)

The hardness level of welds and the weld HAZ should not exceed Rockwell C 22 which is equivalent to 250 HB or Vickers 248. The hardness determination is to be made via microhardness traverses on mounted metallographic samples removed from process/operator weld qualification samples. Production hardness tests should be considered (see subparagraph 7.7.2.4)

4.3.1.3 Surface Condition

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 specified minimum yield strength (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 gas transmission pipelines. Various carbon steel specifications for pipelines are listed in Appendix C. The choice of the specific grade will depend on many factors, such as the severity of the service and the availability. Due to the toxicity of carbon monoxide and Syngas and the possibility of stress corrosion cracking, consideration should be given to maintain low stress on the pipeline. A design factor between 25% and 30% SMYS is recommended in the literature. For example:

- The CO filling pressure is limited to 100 bar in steel cylinder whose service pressure is at least 150 bar. With these conditions, the maximum stress in the steel corresponds to 25% of the SMYS (refer to EIGA Doc 95).
- A design factor of less than 30 % of the SMYS is recommended by the BS 8010 for pipelines conveying category D substances. These category D substances are defined as flammable and toxic substances, which are gases at ambient temperature and atmospheric pressure conditions, thus including CO.

4.3.2.2 Heat Treatment

It is recommended that as-worked mill forms (not normalized) be avoided when practical to do so due to the toxicity of CO. Supplying carbon steel materials in the normalized condition assures the presence of fine grained homogenous microstructures which results in greater toughness and this is preferred. It should be noted that seam welded pipes must be normalized locally in the seam weld (see also subparagraph 7.2.3). Special attention also should be given to the surface condition of alloy mill forms during and after heat treatment

4.3.2.3 Chemistry

- General

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

- Carbon equivalent

The maximum carbon equivalent (CE) is 0.43

- Concentrations of Alloy Elements

All elements which are deliberately added are to be reported such as calcium and rare earths for sulfide shape control, aluminium for deoxidization and elements which may be used in carbon equivalent calculations.

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 or carbon monoxide environment, substituting a higher strength material is generally not an improvement. A maximum tensile strength of 800 MPa (116 kpsi) is recommended.

4.3.2.5 Toughness Requirement

As the pipeline pressure increases, toughness is increasingly important. Steels and the mill forms identified with the footnote (1) in Appendix C have to meet impact test requirements in the applicable API, ASTM specifications. Generally, the mill forms which have to meet impact toughness requirements are made from killed steel per a fine grain practice.

It is recommended that toughness requirement be considered on certain steel mill forms to be used in Syngas and carbon monoxide pipeline applications. Toughness requirements may be found in References (Mohitpour, Golshan, and Murray, p 594 and 595). It is especially important for applications at pressures of 50 bars and above.

4.3.3 Microalloyed Steels

4.3.3.1 General

Microalloyed steels are described in more detail than other materials in this document 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 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 (1000 psi). Microalloyed line pipe is applicable to the transmission of Syngas and carbon monoxide.

This section covers special requirements for the production of microalloyed ERW linepipe intended for high pressure service. The application requires high toughness levels in the fabricated line pipe and relative insensitivity to welding problems as a consequence of possible embrittlement scenarios with may 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. 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.

Due to the toxicity of carbon monoxide and Syngas and the possibility of stress corrosion cracking, consideration should be given to maintain low stress on the pipeline. A design factor between 25% and 30% SMYS is recommended in the literature.

4.3.3.2 Codes, Standard and Grades

Pipe must be manufactured in accordance with all the provisions of the latest edition of API Specification 5L or equivalent except as may be modified by the additional requirements noted in this document.

The specific API 5L grades allowed in microalloyed form for Syngas and carbon monoxide 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 must be fully killed.

The weld seam and heat affected zone shall be heat treated so as 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 must be reported.

The maximum carbon equivalent (CE) is 0.35. (API 5L PSL 2 limit is 0.43%)

The concentration of any intentionally added element such as rare earths, Ti, Nb, B, Al etc must be reported. Also to be reported are any elements which affect carbon equivalent determinations.

4.3.3.5 Metallographic & Microscopic Examination

The final ferrite grain size shall be ASTM 8 or finer. Samples of the seam weld will be cut from one pipe length of each one hundred 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- heat affected zone of the parent metal and test sections. Hardness shall not exceed 95HRB.

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 24,000 psi (165 MPa)
X-42 25,000 psi (172 MPa)

The flattening acceptance test criterion for ERW pipe shall be increased to 1/2 of original OD without weld opening instead of that appearing in API 5L.

4.3.3.7 Impact Tests

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

The following table lists minimum acceptable absorption energies for different sizes of Charpy V notch specimens.

Specimen Size	Absorbed Energy, transverse Ft-lb (J)		Absorbed Energy, Longitudinal Ft-lb (J)	
	Average	Minimum Single	Average	Minimum Single
Full Size	69 (94)	52 (71)	87 (118)	65 (88)
3/4	52 (71)	39 (53)	65 (88)	49 (67)
2/3	35 (48)	35 (48)	58 (78)	43 (58)
1/2	26 (35)	26 (35)	43 (58)	32 (43)
1/3	17 (23)	17 (23)	29 (39)	22 (30)
1/4	13 (18)	13 (18)	22 (30)	16 (22)

Full wall thickness specimens will be used in the testing. Energy absorption values for these specimens will be obtained via linear interpolation between "Standard Sizes".

The largest size Charpy specimen that is consistent with the available wall thickness of the pipe will be utilized for the fracture testing. Transverse specimens will 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.

Ductile shear percentage will be a minimum of 75% for an average of 3 specimens with no single value below 60%.

4.3.4 Carbon-Molybdenum (C-Mo) and Carbon-Molybdenum-Chrome (C-Mo-Cr) Low Alloy Steels

Normally, these high temperature steels are not used in high pressure Syngas or carbon monoxide gas transmission pipelines but for "buffers" see subparagraph 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 C-Mo and C-Mo-Cr low alloy pipe standards and compositions are listed in Appendix C. It should be noted that the high Cr content grades may be more difficult to weld, subject to cracking and could have local hard spots in the weld HAZ. Consequently, preheating and post weld heat treatments are more often needed for these steels than for carbon steels.

Due to the toxicity of carbon monoxide and Syngas and the possibility of stress corrosion cracking, consideration should be given to maintain low stress on the pipeline. A design factor between 25% and 30% SMYS is recommended in the literature.

4.3.5 Stainless Steels

A chromium content equal or more than 13% mitigates the CO stress corrosion cracking and carbonyl formation. Special attention for the use of stainless steel is required only for Syngas service.

4.3.5.1 Austenitic Stainless Steels

Some of the materials listed in Appendix C might be used to transmit Syngas, particularly, at higher pressures. The excellent toughness and ease of welding particularly in field locations are important attributes

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

Austenitic stainless steels with a positive austenitic stability factor according to a "modified Post and Eberly formula" (see reference Hydrogen and Materials) were found suitable for hydrogen service.

4.3.5.2 Other Stainless Steels

Other stainless steels such as ferritic, martensitic, duplex or precipitation hardened may be used in Syngas 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.

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 syngas gas service. Monel K-500 and Inconel X-750 which are precipitation hardened alloys may 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. Nickel alloys also suffer from a high propensity to form carbonyls. Alloys with less than 50% Nickel, such as the Incoloy may be acceptable.

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, greater 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 CO/Syngas service.

Certain cobalt alloys may be used where abrasion resistance or wear resistance is required. These usually are Stellite formulations. Cobalt alloys are considered acceptable for CO/Syngas service.

4.3.8 Carbonyl Formation

Carbonyl formation is briefly discussed in Appendix B3.8. Published literature suggests that the condition of metal surfaces is very important in the formation of carbonyls. Alloy selection and surface treatment may mitigate carbonyl formation.

4.4 Non metallic materials

See also ISO 11114-2 for compatibility with non metallic materials.

4.4.1 CO compatibility with Non Metallic Material

The chemical resistance of certain elastomers and plastics to carbon monoxide is given in the table below:

Material	Compatibility
Teflon ®	A
Natural rubber	C
Neoprene ®	C
Hypalon ®	B
Butyl rubber	C
Kel-F ®	A
Buna N ®	C

A: good resistance

B: fair resistance

C: poor resistance

4.4.2 H2 Compatibility with Non Metallic Material

Plastics exhibit varying behaviour in the presence of hydrogen.

The temperatures at which the resistance of some plastics in the presence of hydrogen seems assured are given in the table below. In certain cases these values do not exclude the possibility of resistance at higher temperatures.

Material	Temperature (°C)
Plasticized cellulose	20
Cellulose diacetate	20
Formo-aniline	20
Formo-urea	20
Phenol-formaldehyde	20
Furaphenol	20
Polyamides	20
Polyfuran	110
Polychloroprene	100
Polyepoxydiphenylpropane	90
Polyethylene glycol terephthalate	20
Polyurethane	20
Polyurethylmethacrylate	20
Polyvinyl acetate	20
Polyvinyl chloride	60
Polytrifluorochlorethylene	180
Polytetrafluoroethylene	250
Polyethylene	60
Polyisobutylene	100
Polystyrene	20
Polyacrylonitrile	20
Polyvinyl-vinylidene chloride (20-80%)	60

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

Most elastomers are compatible with hydrogen. Their chemical resistance is given in the table below:

Material	Compatibility
Natural rubber	B
Butyl rubber	A
Silicone rubber	B
Neoprene ®	A
Buna S ®	A
Hypalon ®	A
Viton ®	A
Buna N ®	A

A: good

B: fair

Permeation of hydrogen through elastomers at 25 °C
(multiply these values by 10^{-10} to obtain $\text{cm}^3 \text{ S.T.P.mm.sec.}^{-1}.\text{cm}^{-2} (\text{cmHg}^{-1})$)

Material	Permeation
Natural rubber	492
Butyl rubber	74
Buna S ®	399
Perbunan ® G	158
Neoprene ® G	133
Hycar or 15 ®	74
Polybutadiene	424
Polymethylpentadiene	428
Perbunan 18 ®	251
Isoprene-methacryl-nitrile copolymer	138
Hycar or 25 ®	118
Polydimethylbutadiene	172
Vulcoprene A ®	64
Isoprene-acrylonitrile copolymer	74
Thiokol S	16

4.4.3 Syngas

Non metallic material used in Syngas service should be compatible with H₂ and CO at the operating conditions.

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 1104, EN12732, EN 14161, EN 1594 (see Appendix K or any other recognized code). Underground piping must 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)

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 cathodic protection 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 is to be avoided wherever possible.

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

Due to the possibility of leaks it is preferable to have no 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 which provides access for inspection and maintenance e.g. in valve pits.

4.5.2 Above-ground piping systems

Above-ground carbon monoxide and Syngas piping systems should follow good mechanical design practices as applied to any other above-ground piping system. Due to its toxicity, leakage concern are much more important than with other gases. The use of welded connections is strongly recommended whenever this is possible. Above-ground piping should be painted to an approved specification to protect against atmospheric corrosion.

Above-ground portions of pipeline systems should connect to underground portions through an electrically insulated joint to isolate the underground cathodic protection system (see 5.6.4).

All above-ground pipelines shall have electrical continuity across all connections, except insulation 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 will provide 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 above ground sections, where insulating flanges are not used, the pipe should be insulated from the support structure by means of an isolating pad.

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

Above-ground piping systems outside plant fence lines may be subject to deliberate or accidental damage. Consideration should be given to installing pipe and valves below ground, with extensions for above ground operators and instrumentation.

4.5.3 Pipeline markers

Overhead piping should be colour coded and/or identified. 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 electro-chemical 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 a hole(s) is made in the pipe during its working life. Corrosion protection is achieved by cathodic protection, either by sacrificial anode or by impressed current, both in combination with electrical isolation by coating. To achieve a good cathodic protection in a given circumstance, it is necessary to understand the soil conditions and the anti-corrosion methods used by near-by 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. Cathodic protection may be done according to recognized standards, such as NACE RP 177 or EN 12954. It is suggested that electrical isolation (pipeline coating) plus one other of the two methods listed below be employed on every underground pipeline.

- 1) Electrical isolation – this method acts to prevent corrosion by electrically isolating the pipeline from the soil. This 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 above ground piping. The weakness is that even small flaws in the coating become sites for what is often very rapid rates of corrosion. These flaws may 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 may be caused by bacterial activity. It should be assumed that a number of defects in the coating exist 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.
- 2) Sacrificial anode – this method acts to prevent corrosion of the pipe by providing a source of material which 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 so that many of them are required at intervals along the pipeline.
- 3) Impressed current – To be free of the limited driving voltage associated with sacrificial anode systems, current from some outside source may 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 and 50 volts and can be obtained with maximum current outputs ranging from less than 10 amps to several hundred amps. The anodes employed 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 must overcome this back potential as well as electrical resistance in the circuit before current will flow in the proper direction. Steel anodes, such as rails, are also commonly used, but they will exhibit a wear of 9 kg/Amp.year. They have to be replaced, when necessary.

Because of the complexity involved, it requires the most experienced and specialized knowledge to properly implement. 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 cathodic protection stations and at monitoring points in between stations.

4.5.4.2 Above ground pipelines

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

Insulated above ground 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 industry. Reference could be made to standards, such as NACE RP 01-98. 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 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

Pipelines for dangerous gases such as CO and Syngas may present high environmental risks. It is particularly important to periodically examine pipelines with a leak detector. The exact regimen for performing this examination will vary with the population density in the area and national regulations. A suggested minimum would be to examine pipelines once every three months with additional frequency for known leak prone areas such as flanged connections, valve stems, and compression fittings.

In addition, to mitigate the risk of leaks, the installation of a Leak Detection System (LDS) shall be considered, if the pipeline is in the public domain. Such a system can detect a leak in real time and estimates the size and location of the leak which allows operations staff to assess the severity of the leak and the type of response that is required. The Leak detection system and the related monitoring and controlling system must be designed with a high level of reliability.

4.6 Hazard analysis and risk assessment

4.6.1 General

Some level of risk is inherent to 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 must be designed, constructed and operated in such a way that the additional risk to people, property and the environment is kept within acceptable limits.

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, 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. See references, such as EIGA Doc 75 about determination of safety distances.

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 as a result of any abnormal event affecting the pipeline and to give an acceptable limit in terms of fatalities per number of years.

In specific areas, such as high population density zones, the societal risk must be taken into account due to the toxic properties of CO.

Local regulations often provide guidelines on performing safety analysis and specify acceptable limits. When no regulation exists, one of the generally accepted country codes such as the Dutch or British regulation is often referred to.

The risk assessment comprises the following steps:

- Assessment of the individual risk, which is the probability of a person remaining at a given open-air location at all times being fatally injured as a result of any abnormal event affecting the pipeline.
- Assessment of the societal risk, in order to take into account the number of fatalities which may occur in case of an abnormal event affecting the pipe, particularly in highly populated areas and in places of public assembly. The required maximum probability of the abnormal event decreases with the number of resulting fatalities.

4.6.2 Identification of the hazards

The minimum list of hazards to be considered is:

- Damage by third parties
- Use of non compatible materials and equipment at all operating conditions
- Stress corrosion cracking in the presence of CO₂ and H₂O impurities below the dew point
- Severe internal corrosion in presence of water
- Hydrogen embrittlement for mixtures with hydrogen
- External corrosion due to improper cathodic protection
- Leaks at valve packing, gaskets,...
- Over pressurisation of the pipeline
- Improper inerting procedure
- Improper venting procedure
- Improper operation and maintenance of the pipeline
- Abnormal loads due to land slide, floods, earthquakes, crossing of roads, railways, ..
- Influence of other structures, such as high power electrical lines, electrical railways
- Damage due to an abnormal event on a parallel pipe
- Road accident or fire in the vicinity of above ground parts of the pipeline
- The radiation from 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
- Ensuring that the gas feed remains dry
- Increased thickness of the pipe
- Increased pipeline depth
- Installation in pipe ways or corridors
- Non destructive test on welds
- Inerting of the pipe
- Pipeline marking
- Specific pipelines warning devices: marking matts or tapes
- Isolation valves
- Excess flow or low pressure shut down valves
- Leak detection system by dynamic flow analysis
- Physical protections: concrete coating or casing, concrete slabs
- Operating procedures, including: inspection programs, leak detection surveys, corrosion control programs, emergency plan, personnel training, information of third parties, collaboration with local authorities

4.6.4 Typical event scenarii

For ease of analysis, the events frequently considered for a pipeline are:

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

4.6.5 Consequences of these events

For carbon monoxide and syngas the consequences of a release is the forming of a toxic and flammable cloud in the vicinity. The cloud may ignite. Depending upon the model used for evaluating the toxicity, including possible self evacuation of individuals, the consequences of radiation on individuals may be greater than that of toxicity. Both types of consequences must be considered.

4.6.6 Selection of simulation model parameters

Models frequently used are dispersion calculation and thermal radiation of flame software, such as PHAST developed by The Det Norske Veritas.

The following items must be taken into account in order to run the simulation model:

- Pressure drop due to the dynamic flow in the pipe
- Transient flow regime due to the decompression of the pipe
- Velocity of the gas at the breach
- Wind speed and direction and air conditions

4.6.7 Criteria for the feared event

A way to evaluate the effect on the environment of a CO/Syngas release is to determine the toxicity risk and the magnitude of the thermal radiation in case of ignition at different distances from the pipe.

4.6.7.1 Toxicity risk

For toxicity, in the absence of local regulations which would take precedence, as a minimum the following two limits should be considered:

- The area of lethal effects : threshold value corresponding to an exceeding of 7000 ppm during 10 minutes (4.5% of fatalities, Probit DNV)
- The area of irreversible effects for human health : threshold value corresponding to an exceeding of 1500 ppm during 30 minutes (Immediately Dangerous to Life or Health equivalent)

It should be noted that circumstances may suggest that additional criteria be included. See also section 4.2.2 and Appendix J.

4.6.7.2 Thermal radiation risk

The Eisenberg method to define the hazard zone is to use the radiation dose approach. This considers that the effect of radiant heat on humans is a function of both radiation intensity and duration of exposure. Eisenberg et al. (reference listed in Appendix K) 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,

$$D = t I^{4/3} \text{ in units of } (W/m^2)^{4/3} - \text{sec}$$

where:

D	=	dosage for various probability of injury
t	=	duration of the exposure, sec
I	=	thermal radiation intensity, W/m ²

Damage Criteria For Thermal Radiation

Damage Levels	Thermal Dosage, D
Extreme Pain	1.1 x 10 ⁶
Second Degree (blistering threshold)	2.4 x 10 ⁶
Third Degree threshold	7.2 x 10 ⁶
Second Degree under 9.3 oz/yd ² (FRT Cotton)	10.3 x 10 ⁶
1% Fatality	10.6 x 10 ⁶
Second Degree under 6.8 oz/yd ² (Nomex)	13.1 x 10 ⁶
50% Fatality	23.0 x 10 ⁶
99% Fatality	65.7 x 10 ⁶

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

For longer periods, the thermal radiation limits listed above, compared to the damage criteria of Eisenberg may be used: