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Appendix 13 Cleaning and Cleanliness

This Appendix specifies typical processes which conform to the requirements of the ITER Vacuum Handbook for the cleaning of vacuum vessels, components and assemblies which are required for the ITER Project. This covers vacuum vessels and any item which will be in a vacuum environment, whether individually or made up into assemblies containing a number of such items.

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ITER Vacuum Handbook
Appendix 13

Guide to Cleaning and Cleanliness for the ITER Project

	Name	Affiliation
Author/Editor	Liam Worth	Vacuum Group - CEP
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13 Guide for Cleaning and the Cleanliness of ITER Vacuum Components

13.1 Scope

As specified in the ITER Vacuum Handbook all vacuum components to be supplied to ITER are subject to the provision of a "clean work plan" and cleaning procedures. This requirement is waived for proprietary components which are compliant with the mandatory requirements of the ITER Vacuum Handbook and are supplied to ITER with Certification of Conformity.

This Appendix specifies typical processes which conform to the requirements of the ITER Vacuum Handbook for the cleaning of vacuum vessels, components and assemblies which are required for the ITER Project. This covers vacuum vessels and any item which will be in a vacuum environment, whether individually or made up into assemblies containing a number of such items.

This guide is intended to assist the *supplier* of vacuum components to ITER in the preparation of a clean work plan and cleaning procedures for submission to ITER for *acceptance.* Following the guidance in this Appendix should help *suppliers* to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components manufactured comply with the requirements of the ITER Vacuum Handbook.

13.2 General Cleaning Requirements

In general, all components classified as VQC1 will need cleaning to Ultra High Vacuum standards. Those components classified as VQC2, VCQ3 and VCQ4 will generally be operated in less stringent vacuum environments and will therefore not require cleaning to such rigorous standards.

However, it is the responsibility of the *supplier* to satisfy themselves that they understand fully the implications of cleaning to the requisite standard.

Any proposed deviation from the procedures and processes described in this Appendix need to be *accepted* in writing by ITER. This is particularly important where the use of any chemical product (solvent, etchant, detergent, etc.) other than those specified is proposed.

13.3 Health and Safety

Some of the chemicals or equipment used in cleaning processes may be classified as hazardous.

It is the responsibility of the *supplier* to satisfy themselves that any cleaning procedure complies fully with local legislative and regulatory standards regarding health and safety of any or all processes used and that all operatives have received the necessary training.

The *supplier* shall have the responsibility of ensuring that all staff fully understand all health and safety information issued by the manufacturer or *supplier* of any chemical or equipment to be used. Neither ITER nor any of its agents shall be held responsible for any consequences arising from the application of any cleaning process described in this handbook unless it is under their direct control.

13.4 Proprietary Items and Trademarks

Where propriety items from particular manufacturers or *supplier*s are mentioned in this specification any or all trademarks are duly acknowledged. Manufacturers or contractors are free to suggest alternative items from other manufacturers or *supplier*s provided that they are chemically identical. Any such substitutions need to be *accepted* in writing by ITER.

13.5 Design Rules for Cleanability

At the design stage for a vacuum item, careful consideration should be given as to how the item is to be cleaned. In particular, crevices, blind holes, cracks, trapped volumes, etc., should be avoided as these will act as dirt and liquid traps and it can be very difficult to remove both dirt and cleaning materials such as solvents from such areas. Fortunately, good vacuum practice regarding trapped volumes will also result in a component which is cleanable.

13.6 Initial Inspection and Preparation

Prior to cleaning any item, the following inspection should take place:

1. All vacuum flanges or covers should be removed and the item stripped down as much as is permissible, ideally to single components.
2. All items should be clearly identified by scribing a suitable identification mark on an external surface (never a vacuum surface). This identifier will often be a drawing number with component identifier or some such which is carefully recorded. Alternatively, for items which are either small and are to be exposed to a vacuum, a suitable metal label, preferably of the same material as the component and bearing a scribed identifier may be tied with clean bare wire to the component. If none of this is possible, the items should be stored in a suitable container which is marked with an identifier before and after the cleaning process. After cleaning, these items should be packed in such a way that they will not be re-contaminated by the container.
3. The item should be inspected visually to identify any possible traps, etc. (see 13.5 above) which could affect the vacuum performance of the item, taking into account the specified cleaning process and vacuum regime in which the item is to be used.
4. All vacuum sealing faces should be inspected to ensure that there is no damage to the seal area such as scratches, pitting or other defects. If the seal is of the knife edge type, the knife edge should be carefully examined for damage which could affect the sealing properties.

5. Any adhesive tape attached to surfaces of the item whether or not they are to be exposed to vacuum must be removed and any adhesive residue carefully removed with the solvent isopropyl alcohol or ethanol.
6. Any marker pen or paint or similar on any surfaces of the item whether or not they are to be exposed to vacuum should be carefully removed by scraping if necessary followed by washing with the solvent isopropyl alcohol or ethanol and rinsing in demineralised water.
7. Any threaded holes, etc., whether or not they are to be exposed to vacuum, should be examined to see if there are traces of lubricants, cutting fluids or swarf left inside. Any such should be removed carefully using brushing or blowing out with clean compressed air or nitrogen and/or washing with a suitable solvent followed by rinsing with demineralised water, taking care that no residue is transferred to a vacuum surface.

13.7 Mechanical Processes on Vacuum Surfaces

Abrasive techniques to clean or to attempt to improve the appearance of the surfaces of vacuum components should be kept to an absolute minimum and are preferably avoided. The use of grinding wheels, wire brushes, files, harsh abrasives, sand, shot or dry bead blasting, polishing pastes and the like is prohibited under normal circumstances and certainly without prior *acceptance* by ITER.

Accepted techniques are slurry blasting with alumina or glass beads in a water jet; gentle hand use of a dry fine stone or a fine stone lubricated with isopropyl alcohol or ethanol; hand polishing using fine mesh alumina in an isopropyl alcohol or ethanol carrier on a lint free cloth; hand polishing with ScotchBrite™ (Alumina loaded, Grade A).

If any such surface finish technique is employed, care must be taken that any powder or other residues are removed by copious washing in hot water.

Any other such operations may be carried out only with prior *acceptance*.

13.8 Use of acids

Acid treatment of any sort is to be avoided wherever possible and may only be carried out with specific prior *acceptance* by the ITER Vacuum RO. Most acid treatments are for cosmetic purposes only and may result in degradation of vacuum performance.

Where the use of acids is *accepted*, then exposure of the component must be kept to a minimum and must be followed by copious washing in hot demineralised water.

13.9 Treatment of Weld Burn

One particular use of acid pastes is in the removal of weld burn. In general such burns do not affect vacuum performance and are best left alone. Any scaling (i.e. loose oxides) should be removed using the techniques of Section 13.7.

If it is desired to remove burns, then slurry blasting with alumina in water or hand burnishing with alumina powder is a satisfactory alternative. Heavy abrading, grinding

or wire brushing is prohibited. Hand finishing with ScotchBrite™ or a dry stone is also *acceptable*.

13.10 Electropolishing for VQC1 Applications

Electropolishing should only be carried out where it is necessary to produce a smooth surface for reasons of electrical discharge or field emission minimisation, emissivity or similar purposes. It is usually unnecessary from a pure vacuum point of view and indeed can be detrimental to vacuum performance.

Electropolishing should be carried out in clean polishing tanks, using fresh electrolyte.

Local electropolishing can be carried out with tampons. Fresh clean pads dipped in clean electrolyte should be used and excessive pressure should be avoided.

After electropolishing, the item should be washed with copious quantities of hot demineralised water.

If required, vacuum Items for use in Class VQC 1 may be baked to 450 ^{o}C for at least 24 hours to remove the residual hydrogen and other contaminants introduced into the surface layers by the electropolishing process.

13.11 Handling and Packing

Handling and packaging of components should be in accordance with the requirements specified in the ITER Vacuum Handbook .

Specifically:

1. Once components have completed initial rough cleaning care should be taken that vacuum surfaces are never touched by bare skin. Powder free latex or nitrile gloves (over cotton or linen if desirable) should always be used when handling components. Coloured gloves are not *acceptable*.
2. Once components have started the cleaning process they should complete the cycle without a break. If it is unavoidable that a delay occurs between stages, then care must be exercised that the component is thoroughly dry before storage, and all seal faces and ports must be protected as below. There must never be a break between any chemical cleaning stage and a subsequent water washing stage.
3. After the component has been cleaned and is completely dry, it should be packed carefully to ensure that it remains clean and free from damage. All vacuum sealing faces should be protected with a clean metal plate or a hardboard or similar fibre free board covered with clean aluminium foil held in place by a number of bolts through the fastener holes. Knife edges should be protected with clean metal gaskets (which may have been used previously, but they should be completely free from loose oxide scale). All ports should be covered with strong clean new aluminium foil and plastic covers. Small items should be wrapped in clean aluminium foil and sealed in a polyethylene bag, under dry nitrogen if possible.

Clean conditions for the handling of vacuum components are also defined in the ITER Vacuum Handbook.

13.12 Spray washing

Where an item is cleaned by spray washing, it should be ensured that all hoses, lances, spray heads, etc are thoroughly cleaned out with clean hot water before the cleaning process starts.

Washing should start at the top of the item and the spray should be worked down to the bottom, ensuring good run-off.

13.13 Standard Cleaning Procedure for Stainless Steel Components

13.13.1 Preclean

All debris, such as swarf, should be removed by physical means such as blowing out with a high pressure air line, observing normal safety precautions. Gross contamination, e.g. greases or cutting oils, etc., should be removed by washing, swabbing and rinsing with any non halogenated general purpose solvent. Scrubbing, wire brushing, grinding, filing or other mechanically abrasive methods may not be used (see 13.7 above).

13.13.2 Wash

1. The item should be washed down using a high pressure jet of hot town water (at approx. 80°C), using a simple mild alkaline detergent. The detergent should then be switched off and the item rinsed thoroughly with hot water until all visible traces of detergent have been eliminated.
2. If necessary, any scaling or deposited surface films should be removed by stripping with alumina or glass beads in a water jet in a slurry blaster.
3. The item should be washed down with a high pressure hot demineralised water jet (at approx. 80°C), with no detergent, ensuring that any residual beads are washed away. Particular attention should be paid to any trapped areas or crevices.
4. The item should be dried using an air blower with clean dry air, hot if possible.

13.14 Chemical Clean for Stainless Steel, or similar Items, for VQC 1 application.

With the addition of the relevant safety precautions, the cleaning process below can also be applied to beryllium,

1. Where possible, the item should be immersed completely in an ultrasonically agitated bath of hot clean liquid solvent for at least 15 minutes, or until the item has reached the temperature of the bath, whichever is longer. The temperature should be the maximum specified by the *supplier* of the solvent.
2. Halogenated solvents are not permitted.

3. Suitable solvents need to be *accepted* by ITER before use. Isopropyl Alcohol, Ethyl Alcohol, Acetone, Axarel 9100™, Citrinox™, P3 Almeco™ P36 or T5161 are *accepted* for this purpose.
4. Where technically feasible, after the liquid immersion stage, the item should be immersed in the vapour of the solvent used for at least 15 minutes, or until the item has reached the temperature of the hot vapour, whichever is longer.
5. It must be ensured that all liquid residues have been drained off, paying particular attention to any trapped areas, blind holes etc.
6. The item is then be washed down with a high pressure hot (approx. 80°C) water jet, using clean demineralised water. Detergent must not be used at this stage.
7. The item is dried in an air oven at approx 100°C or with an air blower using clean, dry, hot air.
8. If the item is too large to be cleaned by immersion the item may be cleaned by washing it down with a high pressure jet of P3 Almeco™ P36 or T5161.
9. The item is cooled to room temperature in a dry, dust free area conforming clean conditions as defined in ITER Vacuum Handbook .
10. The item is inspected for signs of contamination, faulty cleaning or damage.
11. The item is baked to a temperature of 300°C or whatever other temperature has been specified for a minimum period of 24 hours at temperature in accordance with the ITER Vacuum Handbook Appendix 15
12. The item is packed and protected as in 13.11 above.

13.15 Chemical Clean for Stainless Steel or similar Items for use on VQC 2, 3 & 4 components

All items may be cleaned to the specification for items in Class VQC 1

It is also be permissible to use halogenated hydrocarbon solvents for cleaning items in these classes by analogy with 13.13 and 13.14.

For items for Class VQC 2, 3 and 4, baking will not normally be necessary with the exception of items specifically listed in the Vacuum Handbook.

13.16 Chemical Clean for Copper and Copper Alloys

Items manufactured from copper or copper alloys may be cleaned using the procedures for stainless steel, except that in this case Almeco P3-36™ is not acceptable.

Copper surfaces may alternatively be cleaned using a light chromic acid or citric acid etch, followed by thorough washing in hot, clean demineralised water.

13.17 Cleaning Ceramics

Ceramics such as alumina and beryllium oxide may be cleaned using the process described here. Other ceramics may not be able to withstand the high temperature air bake, so manufacturers specifications' must be checked.

Beryllium oxide must in no circumstances be ground or scraped except in specialist facilities.

1. Any surface contamination is removed by wet slurry blasting with alumina powder, or by hand polishing with fine-mesh alumina or diamond powder in an acetone, ethanol or isopropyl alcohol carrier.
2. Components are baked at 1000°C in atmosphere for 24 hours in accordance with Appendix 15. The maximum baking temperature may be limited by the system component materials.
3. Items are wrapped in clean aluminium foil and sealed under dry nitrogen in a sealed polyethylene bag

13.18 Cleaning of Aluminium

1. Components are sprayed with high pressure jets at 60 °C with a 2% solution of Almeco 29™ (an alkaline detergent).
2. This is be repeated with a 2 % solution of Amklene D Forte™.
3. Components are rinsed thoroughly with a jet of hot demineralised water.
4. Components are dried with hot air at 80 °C.

Alternatively,

5. Components are immersed in Sodium Hydroxide (45 g l^{-1} of solution) at 45 °C for 1 - 2 minutes.
6. Components are rinsed thoroughly in hot demineralised water.
7. Components are immersed in an acid bath containing Nitric acid (50% v/v) and Hydrofluoric acid (3% v/v).
8. Components are rinsed thoroughly in hot demineralised water.
9. Components are dried in warm air.

13.19 Air Baking

Items manufactured from stainless steel and the like may be air baked to provide a low hydrogen outgassing surface.

Note that this procedure is not suitable for materials that form a loose oxide, e.g. copper.

Items should be chemically cleaned using the procedures of 13.13 above

Items should then be heated in air at a temperature of 450 °C for a period of 24 hours in accordance with Appendix 15.

13.20 "Snow" Cleaning

A final clean after assembly of components into a large vacuum system may be achieved by the use of "snow" cleaning.

Snow cleaning uses a high velocity stream of soft microscopic particles of solid CO_2 to wash the surface and is effective for removing particulates and some organic contamination from surfaces.

Operatives undertaking this procedure must wear suitable protective clothing and personal safety equipment

The procedures used will be as specified by the *supplier*s of the equipment.

Snow cleaning will normally only be used for items to Class VQC 1, but may be used on all vacuum components.

13.21 Cleaning Procedures for Vacuum Bellows

13.21.1 General

Great care has to be exercised when cleaning thin walled metal bellows, particularly those of edge-welded, nested construction. If any cleaning residues are trapped between the convolutions, either inside or outside, these can result in corrosion which can rapidly cause leaks to develop. Similarly, if any particulates are deposited in the convolutions, mechanical puncturing can take place. Alkaline degreasing solutions such as Almeco are prone to particulate precipitation and therefore must not be used for bellows assemblies.

13.21.2 Procedure for Bellows for Class VQC 1 use

The bellows must be fixed in an extended position if possible.

1. Any traces of visible, loose contamination are removed with a gentle jet of clean, dry air or nitrogen.
2. The bellows are immersed in an ultrasonically agitated bath of isopropyl alcohol (IPA) or ethyl alcohol (ethanol).
3. The bellows should be vapour washed immediately in isopropyl alcohol or ethanol vapour.
4. The bellows, including the interspace where appropriate, must be thoroughly dried inside and out using a gentle jet of clean, dry, particulate free air or nitrogen.
5. The bellows should be placed in a dry air oven at 100 °C for at least 1 hour.
6. The bellows should be baked in a vacuum oven, for 24 hours at 250 °C with the bellows interspace pumped.
7. The bellows should be sealed under dry nitrogen in a polyethylene bag.

This procedure can be used for bellows used on VQC 2, 3 & 4 systems with the vacuum bake requirement waived.

13.22 Cleanliness

13.22.1 Wipe Test for Cleanliness

Gross contamination of a vacuum component may be assessed by means of a wipe test. This may be carried out “dry” or “wet”.

Gross contamination may also manifest itself as an “oily” or “solvent-like” smell.

Note that these tests are of a somewhat subjective nature and may not be conclusive and therefore should only be used as a guide to cleanliness and as a marker for subsequent cleaning operations should the tests result in a failure of cleanliness.

13.22.1.1 Dry test

The surface of the component is wiped gently with a clean lint free cloth.

If there is any evidence of a deposit on the cloth (i.e. a stain or a change in colour) then the item should be regarded as unclean.

Similarly if the surface of the component which has been wiped shows any evidence of a change in colour or reflectivity of light, then the item should be regarded as unclean.

13.22.1.2 “Wet” test

This uses a clean lint free cloth dipped in a solvent which evaporates at room temperature, such as isopropanol, ethanol or acetone.

Appropriate safety precautions against fire hazard, breathing in of solvent fumes, eye and skin protection must be taken.

1. The cloth is dipped in the solvent which is then be allowed to evaporate in a safe manner. There should be no change in the appearance of the surface of the dry cloth.
2. The cloth is dipped in the solvent and the surface of the component is wiped gently while the cloth is still wet.
3. The solvent is allowed to evaporate from the cloth and the surface of the component until they are dry.
4. If there is any evidence of a deposit on the cloth (i.e. a stain or a change in colour) then the item should be regarded as unclean.
5. Similarly if the surface of the component which has been wiped shows any evidence of a change in colour or reflectivity of light, then the item should be regarded as unclean.

If required, the deposit on the cloth may be analysed by a suitable means to determine the chemical nature of the contamination.

13.22.2 General Test for Cleanliness

An item shall be deemed to be clean for the purposes of this Appendix provided that it meets the following criteria.

Cleanliness is defined to mean that the concentrations of "contaminants" (i.e. unwanted gas species) in the residual gas spectrum of the item are less than the specified values.

The concentration of a species is defined as the fractional intensity of its measured partial pressure components related to that species defined in a particular way to the total pressure in the system expressed as a percentage.

The partial pressures of species in the vacuum system or related to the component being measured should be obtained using the equipment and procedures defined in Appendix 17 of the Vacuum Handbook.

The residual gas spectrum will have been recorded over 1 –200 amu

The spectrum will have been corrected for sampling error, mass discrimination and species relative sensitivities.

The definition of "general contaminants" is the sum of the partial pressures of all peaks present in the residual gas spectrum of mass to charge ratio (amu) equal to 39, 41-43 and 45 and above (*excluding* any above 45 specifically listed in the table below). Also to be excluded from this summation are any peaks related to the rare gases xenon (i.e. 132, 129, 131) and krypton (i.e. 84, 86, 83)

Table 13-1 Allowed concentrations of contaminants pertaining to VQC

Vacuum Class	General Contaminants	Perfluoropolyphenylethers Sum of (peak at 69 and 77 amu)	Chorinated species (Sum of peaks at 35 and 37 amu)	Comment
VQC 4	5	1	1	Excluding water (sum of 17 and 18 amu) from the total pressure
VQC 3	2	0.5	0.5	
VQC 2	1	0.1	0.1	If unbaked, excluding water as above
VQC 1	0.1	0.01	0.01	After bake

This general test for cleanliness can be carried out as part of the verification of component outgassing in accordance with Appendix 17

13.23 Definition of Terms

For the purposes of this specification, the words or terms listed in Table 13-2 below are taken to have the stated meanings.

Table 13-2 Definitions of terms used

Term	Definition
Contaminant	Any unwanted substance present on a surface
Brushing	Using a fibre glass or wire brush to gently remove loosely adhered matter (e.g. dust) from a surface
Swabbing	Vigorous rubbing with a lint free cloth or rag
Wiping	Gentle rubbing with a lint free cloth or rag, either dry or soaked in a liquid
Washing	Cleaning an item by total immersion in a liquid or by pouring or spraying a liquid over it
Dipping	Immersing an item in a liquid and removing it relatively quickly
Rinsing	Using copious quantities of a liquid to remove traces of a contaminant or other material from an item, usually by repeated dipping or pouring the liquid over the item
Scraping	Using a hand tool of a material harder that the item being scraped to gently remove a thin layer from a surface
Grinding	Using a wheel or stone to remove a substantial amount of material from a surface
Scribing	Marking a surface with a clean metal point, vibrating engraver or laser engraving device, usually for identification or marking out purposes
Sand or shot blasting	Using a stream of abrasive particles e.g. silica or alumina to remove a surface layer. The medium may be a gas or a liquid.
Polishing or burnishing	Using a paste of fine particles, e.g. diamond or alumina, or a dry tool to produce a smooth surface
Solvent	A material which removes a contaminant from an item by dissolving it to form a solution
Detergent	A material which removes a contaminant from an item by acting as a surfactant i.e. by hydrophobic or hydrophilic action. Often used interchangeably (but incorrectly) with the term soap.
Etching	Removing a surface layer by chemical action
Pickling	Stripping of the oxide layer from a surface by use of acids
Passivation	Modifying a surface so that it is left in an inactive state, usually by leaving a uniform oxide film on the surface
Electropolishing	Removal of the surface layers of a metal by immersing the surface in a buffered acid solution and applying an electrical potential.
Ultrasonic cleaning	Immersion of a component in a bath of liquid with ultrasonic agitation

Vapour washing	Immersion of a component in a hot vapour such that the vapour condenses on the item and runs off by gravitation, carrying any contaminant in solution or suspension
Glow discharge	An electrical discharge set up in a low pressure gas. Discharges may use dc or radio frequency potential (voltage) sources
Clean surface	A surface with the desired properties e.g. outgassing.

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Appendix 15 Vacuum Baking

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Appendix 15

Guide to the Vacuum Baking of Components for the ITER Project

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15 Guide for Vacuum Baking

15.1 Scope

This Appendix specifies typical procedures and processes which may be used when vacuum components and materials used for vacuum components for the ITER project are required to be baked.

It is intended that the *suppliers* using such processes should follow the guidance in this Appendix to achieve the requirements of the ITER Vacuum Handbook.

The *supplier* is at liberty to utilise other techniques not described in this Appendix provided that the components supplied comply with the requirements of the ITER Vacuum Handbook.

15.2 General Comments

Vacuum components for the various classifications may require to be baked to ensure satisfactory vacuum performance. Baking can be included as in the component leak testing procedure (Appendix 12) and/or the component cleaning procedure (Appendix 13). A bake temperature and duration will normally be specified in the specification documents and/or drawings for individual components or assemblies. If this is not the case, then the standard temperatures and durations listed in Table 15-1 should be used.

Vacuum baking has three functions, *viz.*, (a) the removal of contaminants which can break down to volatile components under the application of temperature (b) reducing the outgassing rate of the surface by accelerating the thermal desorption of molecular species (most often water) and (c) opening up incipient leaks, particularly porosity, where the leak path has been blocked by, for example, a carbon inclusion.

In order that the objectives of this Appendix are achieved, the times and temperatures specified for vacuum bakes have been based on considerable experience of using the processes.

In the following sections, the term “vacuum item” shall be taken to refer to an individual vacuum component, a sub-assembly or complete assembly as appropriate. It may also refer to material, e.g. steel sheet, being processed prior to manufacture.

Where the temperature is too high for a composite assembly the component part requiring higher temperature baking should be baked at that temperature prior to assembly and then the complete assembly baked at the lowest listed temperature of the component parts. Temperature requirements for baking materials not listed should be *accepted* in advance of baking operations.

Where the manufacturer is unable to carry out a bake procedure, either to the standard conditions in Table 15-1 or as otherwise specified, then any variation shall be *accepted* by ITER before proceeding.

Table 15-1Standard Temperatures and Durations for Vacuum Baking

Vacuum Classification	Temperature (°C)	Time (hr)	Comment
VQC 1	240	24	
VQC 1*	350	24	Stainless steel and beryllium
	450 - 2000	24	Carbon composites (see Appendix 16)
	250	24	Precipitation-hardened copper alloys
	350	24	Tungsten

* For vacuum items in line vicinity of plasma

15.3 General Procedures for Baking of Vacuum Items

15.3.1 Preliminary

Prior to baking, the vacuum item will have been thoroughly cleaned in accordance with the procedure of Appendix 13 of the ITER Vacuum Handbook.

If the vacuum item is not capable of being vacuum sealed and pumped down (e.g. it may be a batch of material or a part-finished vessel), then the vacuum item should be subjected to a total immersion bake (see 15.5.1 below)

All vacuum flanges should be sealed with a blank flange of material and thickness similar to that on the main vacuum item, using gaskets of the type to be used when the vacuum item is in service and fasteners of the appropriate strength.

Where a copper gasket is to be used and the bake temperature is greater than 100°C, then the gasket should be silver plated to avoid the formation of a loose oxide on the atmospheric side of the joint.

The vacuum item should be placed in or on a suitable bakeout stand which can safely support the vacuum item at the maximum temperature of the bake procedure. Any fixings should take into account the thermal expansion of the vacuum item and stand.

The vacuum item should be pumped down to an appropriate vacuum level and thoroughly leak tested to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook prior to starting any baking process.

15.3.2 Vacuum Pumps and Gauges

Vacuum Pumps of the appropriate pumping speed and base pressure specification should be used in these processes.

Vacuum pumps used for these processes should be inherently clean (e.g. turbomolecular pumps with magnetic or greased bearings, dry backing/roughing pumps, cryosorption pumps or sputter ion pumps). Otherwise, the supplier needs to satisfy ITER that a suitable failsafe trapping system has been implemented to protect against back-streaming and/or pump failure.

Vacuum gauges (total and partial) with suitable measurement ranges and with appropriate calibration certificates should be fitted as required to monitor satisfactorily the progress of the bakeout process.

The manufacturer should provide ITER with complete details of all such equipment (including manufacturer, age, calibration certificates and history).

No bake procedure should be started before ITER has *accepted* the use of this equipment.

ITER will have the right to request documentary proof of the performance of the pumping equipment in the form of blank pump down characteristics and/or residual gas scans of the pumping equipment.

15.3.3 Temperature Monitoring and Control

The manufacturer should implement a suitable system to monitor, control and record the temperature of the baked vacuum item throughout the procedure.

It is important that the rate of rise and fall of temperature is controlled to within the *accepted* specification as detailed in the *accepted* baking procedure.

Full details of this system should be supplied to ITER.

No bake procedure may be started before ITER has *accepted* the use of this equipment.

15.3.4 Completing the Bake Process

When the temperature of the vacuum item has fallen to room temperature, the vacuum item should be leak tested thoroughly to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook.

The vacuum item should be vented to dry nitrogen (dew point –50 °C), removed from the bakeout stand and suitably packed and protected for transport or storage.

15.4 Control of the Bake Process

To avoid undue stress on the vacuum item being baked, the temperature should be controlled such that it is uniform to within ±20 °C at all points on the surface of the vacuum item, unless otherwise *accepted* by ITER.

The temperature differential across a metal sealed vacuum flange pair of greater that 200 mm diameter should be less than 10 °C at all times.

The rate of rise and fall of the temperature of the vacuum item should be held within specified limits and, unless otherwise *accepted* by ITER, should be no greater than 10 °C per hour.

When the temperature is falling, it is normally permissible to switch off the temperature control when the temperature falls below 50 °C and let the vacuum item cool naturally to room temperature.

Thus for a 200 °C bake, the rise time will normally be 18 hours, the dwell time 24 hours and the fall time 15 hours plus the natural final cooling time.

At no time during the bake process should the pressure within the vacuum item being baked exceed 10^{-3} Pa. If it should approach this level, the temperature must be held until the pressure falls again as the outgassing rate decreases.

The use of a residual gas analyser to monitor the bake process is strongly advised. This can indicate possible leaks opening up during the process. It can also be used for "end point" detection – e.g. when the water peak falls to below a specified partial pressure.

15.5 Types of Bake Procedure

15.5.1 Total Immersion Bake

In this procedure, the vacuum item is totally immersed in the vacuum environment of a vacuum furnace which is capable of reaching the required temperature and maintaining a pressure less than 10^{-3} Pa at the maximum temperature used.

The manufacturer should, before the start of any baking process, demonstrate to ITER, by the provision of residual gas analysis spectra of the furnace during a blank run at the temperature to be used for the bake procedure, that the vacuum level and the cleanliness of the furnace at the temperature at which the bake is to be performed is satisfactory for the purpose . This requirement may be waived by agreement with ITER where the furnace has not been used for any other purpose between two successive bake processes for the ITER organisation.

Any vacuum joints on the vacuum item to be baked shall be left open.

The vacuum item is placed in the furnace, which is sealed and pumped down to the starting pressure with equipment conforming to the requirements of Section 15.3.2 above.

The furnace is checked for leaks.

The appropriate time/temperature bake cycle is carried out.

15.5.2 Oven Bake

The vacuum item, which will be a sealed vacuum vessel or assembly, is placed inside a suitable insulated enclosure and connected by a suitable pumping manifold to a vacuum pumping system conforming to the requirements of Section 15.3.2 above.

The arrangement shall be *accepted* by ITER before use.

Wherever possible, a suitable vacuum gauge or gauges capable of being operated at the maximum temperature of the bake cycle should be attached directly to the vessel or assembly being baked. Pressure readings on these gauges should be scaled to room temperature values by the appropriate temperature correction factor.

The insulated enclosure may be heated by convection heaters, radiant heaters or hot gas. It is recommended that some form of circulation of the air inside the enclosure be used to assist temperature uniformity.

A suitable number of temperature monitors should be fixed to the vacuum item so that the temperature distribution may be adequately monitored to ensure that the appropriate limits are not exceeded (15.4 above).

If any glass or similar viewports or accessories are fitted, they should be covered in triple thickness aluminium foil for thermal protection and fitted with suitable mechanical protection against impact or implosion.

The assembly should be leak tested to the appropriate specification.

The appropriate time/temperature bake cycle is carried out

15.5.3 "Tape" Bake

In this procedure, the sealed vacuum item is wrapped with heater tapes. Rod heaters, heater plates or flange band heaters may also be used.

A suitable number of temperature monitors is fixed to the vacuum item so that the temperature distribution may be adequately monitored to ensure that the appropriate limits are not exceeded (15.4 above). In this case, it is very important to monitor the temperature on each side of every large (i.e. greater than 200mm diameter) flange pair. Temperature measurement sensors will normally be located close to the heating device (i.e. in the location of highest expected temperature)

Wherever possible a suitable vacuum gauge or gauges capable of being operated at the maximum temperature of the bake cycle are attached directly to the vessel or assembly being baked. Pressure readings on these gauges should be scaled to room temperature values by the appropriate temperature correction factor.

The vacuum item is connected by a suitable pumping manifold to a vacuum pumping system conforming to the requirements of Section 15.3.2 above.

The assembly shall be leak tested to the appropriate specification in accordance with Appendix 12 of the ITER Vacuum Handbook.

The vacuum item may then be wrapped in aluminium foil to assist in uniformity of the temperature distribution, taking care around electrical connections.

If there are glass or similar viewports or accessories fitted, they must be covered in triple thickness aluminium foil for thermal protection and fitted with suitable mechanical protection against impact or implosion.

The vacuum item is then covered with suitable thermal insulation, preferably a ceramic fibre filled flexible jacket or blanket.

The appropriate time/temperature bake cycle is carried out.

15.5.4 Air Bake

Where an air bake is specified for any item, the general procedures are as specified in this Appendix for the particular type of bake (Immersion, Oven or Tape) except that in this case all sections referring to pumping are ignored and all surfaces (interior and exterior) of the item shall be exposed to normal atmospheric air during the bake process.

Vacuum equipment conforming to the above requirements may still be required where a leak test and/or outgassing test has been specified as part of the bake process either before or after such a process.

15.6 Documentation to be Supplied

For each vacuum item, the following certificates and records will normally be supplied:

- If requested by ITER a record of the performance of the pumping equipment
- A certificate of the initial leak rate
- A certificate of the final leak rate
- A record of the temperature distribution for the item and pressure within the vacuum item against time for the full duration of the bakeout process
- If agreed between the manufacturer and ITER, a full record of any residual gas scans taken with appropriate time markers which identify the scans to the position on the component bakeout cycle
- Full documentation regarding any leaks or other problems which occurred during the tests and any remedial action taken

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Appendix 17 Guide to Outgassing Rates and their Measurment

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ITER Vacuum Handbook

Appendix 17

Guide to Outgassing Rates and their Measurement

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17.1 Scope

This Appendix is intended as a guide to the measurement of the total and partial thermal outgassing rates of materials, vacuum vessels, components and assemblies for the requirements of the ITER Project. It is intended that the guide be used to assist *suppliers* in producing outgassing test procedures to comply with the mandatory requirements of the ITER Vacuum Handbook. It also gives details on how the outgassing requirements for ITER systems have been derived.

It is envisaged that outgassing tests will normally be performed on components, parts of the component or "coupons" which have been subjected to the complete manufacturing process. Manufacturing operations which have been applied, including baking and cleaning operations, should be recorded and traceable to the coupon (where used) or to the manufactured component.

17.2 Limitations

This Appendix describes a set of procedures for the measurement of thermal outgassing from a vacuum item when used as part of the vacuum quality assurance procedures for the ITER Project. This Appendix describes the recommended procedures of the most widely used methods of measuring the outgassing rates; it does not consider all available methods. Despite this limitation, the techniques are more widely applicable and form a basis for more general good practice.

The supplier is at liberty to propose other methods of thermal outgassing measurement not described in this Appendix.

When this set of procedures is used to measure the outgassing from a component or coupon placed within a vacuum chamber, the outgassing of the chamber walls cannot usually be neglected and must be subtracted from the measured value to obtain that from the coupon. For this, an independent measurement of the wall outgassing from the empty chamber will be required – often referred to as a *blank run*.

Unless otherwise specifically indicated, outgassing measurements using these procedures will be carried out with the component under test at 100 °C

In these procedures the term *outgassing* shall be taken to mean *thermal outgassing* unless otherwise indicated.

The methods of measuring outgassing rates described in these procedures yield an average value of the outgassing rate for each surface exposed to the vacuum measurement system.

17.3 Specific Outgassing Rate

Outgassing is described in terms of the rate of desorption of gas from a vacuum surface.

The measured (or net) outgassing rate is the difference between the intrinsic outgassing rate (of the component) and the rate of re-adsorption on the surfaces of the test chamber.

The specific outgassing rate defined as the total gas load generated per unit time due to gas desorbing from a vacuum surface due to the temperature of the surface per unit area of desorbing surface. It is represented here by q_{th}. Units are $Pam^3s^{-1}m^{-2}$

Clearly,

$$Q_{th} = q_{th} \cdot A$$

Where:

Q_{th} is the total outgassing rate (Pa.m^3.s^{-1})

A is the area of the desorbing surface (m^2)

17.4 Generic Methods of Measuring Outgassing Rates

17.4.1 Rate of Rise of Pressure Method

This method of measuring outgassing rates is in principle very simple, but there are a number of considerations that need to be taken into account if the measurements are to be meaningful.

The principle of the method is that if one has a volume evacuated to a given pressure p_0 and then isolated from the vacuum pump, the specific thermal outgassing rate q_{th} is given by

$$q_{th} = \frac{V}{A} \cdot \frac{(p_t - p_0)}{t}$$

where V is the containing vessel volume

A is the total internal surface area of the desorbing surface

p_t is the pressure after a time interval t

provided that the outgassing rate is reasonably constant with both pressure (over the range $p_t \rightarrow p_0$) and the time interval t and that the temperature of the outgassing surfaces is constant.

Partial (i.e. species dependent) outgassing rates may be determined by using a calibrated gas analyser to measure the rate of rise of the partial pressure of a particular species.

What is actually measured using the rate of rise technique when the pressure remains in the high vacuum region or below, is the increase in number density of gas molecules entering the measurement volume of the “pressure” sensor. This increase can be affected by various processes, which can be classified as being either gas sources or gas sinks. A gas source is something which releases gas molecules into the interior of the vessel, and hence eventually into the measurement volume. A gas sink is something which adsorbs or absorbs a gas molecule which strikes it, i.e. it acts as a pump. This is further discussed later.

This method is quite simple to implement and requires the minimum of equipment. Since, during the measurement time the vacuum pump is valved off, there is no need to know the pumping speed (especially where the speed may be species dependent). Only one vacuum gauge is required. For absolute measurements, the gauge needs to be calibrated

for the outgassing species. Where only *relative* measurements of outgassing are required (e.g. before and after a process such as baking), provided the gauge is known to be reasonably stable in sensitivity, calibration may not be required.

No vacuum parameters of the system need to be calculated or measured, apart from the pressure.

This method works best for relatively low outgassing rates, where measurements can be take over a long time period. For high outgassing rates, the rise in pressure can be quite rapid, making time and/or pressure dependent measurements difficult.

The volume of the vessel (and all appendages) needs to be measured or calculated to a reasonable degree of accuracy.

This method is more suitable for the measurement of outgassing from vessels or assemblies rather than coupon samples, unless either the intrinsic outgassing rate of the coupon is very much higher than that of the containing vessel or the surface area of the sample is much higher than that of the vessel or both.

17.4.2 Dynamic Flow (Conductance) Method

In this method, the item being measured is pumped through a known conductance and the pressure difference across this conductance is measured. The specific thermal outgassing rate q_{th} is then given by

$$q_{th} = C \cdot \frac{\Delta p}{A}$$

where:

C is the conductance

Δp is the pressure difference across the conductance

A is the area of the desorbing surface

Partial (i.e. species dependent) outgassing rates may be determined by using calibrated gas analysers to measure the differences in partial pressure of the particular species.

The method is suitable for all but the lowest values of outgassing, since the value of the conductance can be chosen to give a sensible pressure difference. Variation in outgassing rate with time can readily be measured even when the outgassing rate is quite high or is varying relatively rapidly and the volume of the vessel is not required.

The method requires two vacuum gauges which must both be calibrated for the desorbing species for the most accurate results. Both must remain stable across the full range of measurement for the duration of the test. If partial outgassing rates are required, then two calibrated residual gas analysers (RGAs) should be fitted.

It requires the use of a pump whose speed is much larger than the conductance for all gas species.

The conductance, which is gas species dependent, must be measured or calculated to a reasonable degree of accuracy.

When measuring outgassing from coupon samples, the outgassing rate of the containment vessel must remain sufficiently stable for a blank run to yield a meaningful correction.

17.4.3 Variant Dynamic Flow Methods

One variant of this method assumes that the pressure on the pump side of the conductance is very much less than that on the sample side and so can be ignored. In this case only one calibrated gauge and one RGA is required, both situated upstream of the conductance. Good practice would require a total pressure gauge also to be fitted downstream of the conductance to ensure that the pressure conditions were being met, but this gauge need not be calibrated.

A second variant uses an arrangement of valves so that a single calibrated gauge can alternatively be exposed to either side of the conductance. This requires good linearity in the gauge and an outgassing rate which is stable over the time of measurement.

17.4.4 Weight Loss Method

The method of weight loss measurement can be used to measure outgassing rates from materials with high outgassing rates, for example organic materials.

The test consists of measuring the weight loss of a sample which has been subject to a defined thermal cycle under vacuum. The sample is placed in an effusion cell and heated. The outgassing flux is condensed on temperature controlled collectors which are placed in front of the sample. From the mass deposit on the collector the total mass loss (TML) and hence outgassing rate are derived, as function of time, and is usually expressed as %TML

The setup and procedure are described in the ASTM E595-93 standard and are widely used in characterisation of materials for use in space applications.

17.5 Sources of Errors in Measuring Outgassing

All methods of measuring outgassing are susceptible to errors which may yield misleading results. Detailed consideration should always be given to this.

17.5.1 System Effects

17.5.1.1 Vacuum Vessels and Conductance's

Either the internal volume of the outgassing measurement chamber, or the conductance between this and the pump, must be known to a reasonable degree of accuracy, dependent on the technique employed. Volumes are notoriously difficult to measure or calculate to high accuracies and are temperature dependent. In some cases (e.g. where bellows are present) they may also be dependent on the atmospheric pressure in the laboratory. Volumes will change if there are movable items present, e.g. vacuum valves.

The value of a conductance element is also temperature dependent and, more importantly, dependent on the mass of the gas species traversing the conductance. To some extent the transmission probability of gas molecules through a conductance is dependent on the size and shape of the vacuum chamber at each end.

It is usually assumed that in measuring outgassing, free molecular flow conditions prevail. This may or may not be the case and needs to be checked.

In the dynamic flow method, it is assumed that outgassing of the vacuum system downstream of the conductance does not influence what is happening in the measurement chamber upstream of the conductance.

17.5.1.2 Vacuum Gauges

The calibration of both total pressure and partial pressure gauges is non trivial and the stability of many gauges is not good. Clearly this may introduce significant measurement errors, especially in the two-gauge dynamic flow method.

17.5.1.3 Vacuum Pumps

Pumping speeds of vacuum pumps vary with the species being pumped, so for the dynamic flow method it is important to ensure that a sufficiently high pumping speed (i.e. compared to the conductance for the particular gas species) is maintained at all times.

17.5.1.4 Temperature

Some of the effects of temperature have been discussed above. However, outgassing is itself strongly dependent on temperature, so it is important that for the most accurate measurements, the entire apparatus is maintained at a constant temperature during the period in which measurements are being taken.

17.5.2 Gas Sources and Sinks

Errors in measured outgassing rates may be affected by sources of gas other than true outgassing entering the measuring volume of the gauge or gauges used. In this case an enhanced value will be measured. Likewise any pumping in the vessel for which outgassing is being measured will lead to an apparent value being measured which is lower than the true value. In extreme cases, negative values of apparent outgassing may be measured.

17.5.2.1 General Types of Gas Source or Sink

Possible sources of gas include:

- any surfaces exposed to the vacuum which release molecules by desorption other than thermal desorption or by permeation
- all joints, which tend to be areas of increased permeation
- leaks, real or virtual
- any gauge
- gas bursts from items moving in the vacuum system

Possible sinks for gas include:

- any surfaces exposed to the vacuum which can exhibit wall pumping, particularly "active" surfaces found in capture pumps even when switched off
- any gauge which can act as a pump

17.5.2.2 Surfaces as Sources

The point of the measurement is to measure thermal desorption from the surface of interest, i.e. gas molecules released by the absorption of phonons, so it is important that extraneous forms of desorption are minimised. Details are not discussed here, but it should be noted that the surfaces under investigation should not be exposed to significant fluxes of photons of wavelengths shorter than the short-wavelength end of visible or to electrons of energy greater than a few eV. It is also important that the temperature of the surfaces under test is kept constant as thermal desorption is an exponential function of temperature.

For metals at room temperature, permeation is only significant for hydrogen and even that would normally be very low unless very thin walls are present or when measuring very low outgassing rates. However it should be remembered that hydrogen is by far the dominant species in such cases and there is some debate as to whether hydrogen permeation is in fact the rate limiting step in outgassing from metals. The source of the hydrogen may be either dissolution from the bulk metal or passing from atmosphere on one side of the wall to the other. In practice, both will happen.

Glasses, plastics and elastomers may have quite large permeabilities for hydrogen, helium or water. Care must therefore be exercised when these are exposed to both atmosphere and vacuum.

A special case of thermal outgassing is evaporation or sublimation of the wall material (vapour pressure). For most normal vacuum materials, this is only a problem when measuring extremely low outgassing rates.

17.5.2.3 Surfaces as Sinks

When gas molecules strike a surface, in general they stick. They may stick for a short time before being re-emitted or they may stick for a long time. Here, the former process is ignored although it is important for the thermodynamics of the system. However, the latter process gives rise to the phenomenon known as wall pumping. In some cases this process can be enhanced by preparing a surface which is chemically active and deliberately used as a pump in, for example, a Titanium Sublimation Pump (TSP) or a Non-Evaporable Getter (NEG). A similar effect is seen when a surface is cooled to cryogenic temperatures. In normal circumstances the walls of a vacuum system are sufficiently inert that wall pumping is insignificant. However there are circumstances where this may not be the case. A surface which has been glow discharged will have had its chemistry altered somewhat and until a passivation film, usually an oxide, is formed may exhibit wall pumping. Similarly a surface where the gas concentration has been reduced by photon desorption, electron or ion desorption or high temperature thermal desorption may be sufficiently far from equilibrium to exhibit wall pumping.

It is very difficult to estimate what wall pumping speeds might be in such circumstances.

17.5.2.4 Joints

Vacuum joints can be regions of enhanced permeability, especially demountable joints using elastomer gaskets. However, welds and brazes may also be suspect. If components have been hydrogen brazed, then enhanced hydrogen outgassing may be experienced from all surfaces. Joints which have been welded using the Tungsten Inert Gas (TIG) process may exhibit enhanced outgassing of (usually) argon.

17.5.2.5 Leaks

Naturally, the presence of leaks can vitiate any sensible measurement of outgassing and so thorough leak checking of the test system is a necessity.

17.5.2.6 Moving items

When items move in a vacuum, gas molecules can be desorbed. The most common moving item in an outgassing measurement system will be a vacuum valve. These can generate significant gas bursts when moving. This can be minimised by operating them slowly and by thorough outgassing.

In practice, this is not usually very important in measuring outgassing rates. In the case of rate-of-rise measurements, the system is sealed and static. Any gas generated when the valve is closed at the start of measurement forms part of the base pressure. In the two gauge dynamic flow technique, valve states do not change during the measurement. In the variant of this technique where a single gauge is exposed successively to either side of the conductance to eliminate gauge errors, some care has to be exercised to minimise any such effects.

17.5.2.7 Gauges as Sources

Hot filament gauges are clearly potentially major sources of error in measurements of this type, since they not only run at high temperatures but will also cause local heating of the vacuum system. Enhanced outgassing will be experienced from the gauge and walls.

Cold cathode gauges are better than hot filament gauges in this respect since they operate at room temperature.

Ionisation gauges, hot or cold cathode, are also sources of x-rays, ions and electrons of sufficient energy to cause desorption when they strike surfaces. Cold cathode gauges may also generate energetic neutrals which may themselves cause desorption.

17.5.2.8 Gauges as Pumps

All ionisation gauges will act as pumps. Hot filament Bayard-Alpert Gauges typically exhibit pumping speeds of around 0.1 $l.sec^{-1}$ but this will normally be swamped by the outgassing.

Cold cathode gauges of the Penning or magnetron (whether inverted or not) type may well exhibit (net) pumping speeds of up to 1 $l.sec^{-1}$.

17.5.3 Some Practical Considerations

17.5.3.1 Minimising Errors

Clearly if one wishes to measure an outgassing rate, all of the above effects may play a part in introducing errors. Good vacuum practice will help in many cases to vitiate the worst of these. Leak testing should be carried out with a sensitivity of at least an order of magnitude better than the measured total outgassing rate. Permeation (but not of course bulk dissolution) can be reduced by surrounding the measurement chamber with a guard vacuum. Wall pumping may be reduced by waiting or by saturating the surface with an inert gas. This may of course make nonsense of what one is trying to do!

In practice, the bulk of the errors will come from the gauge. A hot cathode gauge should be mounted on a water-cooled side arm, preferably with a cooled baffle in the gauge throat. It should be well-degassed, and any pressure difference between the gauge and the measurement chamber carefully evaluated. If possible a cold cathode gauge should be used or a gauge specially designed to minimise outgassing.

The gauge head must be mounted out of line of sight of the surfaces being tested and tubulation to the gauge head should have as large a conductance as possible. As is so often the case, such requirements are to some extent contradictory so some compromise is necessary. There is not a lot one can do to eliminate the effects of gauge pumping. Recent developments using stable field ion emitters as the electron source for a Bayard-Alpert gauge may offer a good compromise for measuring low outgassing rates. The temperature effect is eliminated and gauge pumping is relatively low. Energetic electrons and X-rays are still produced however.

The most troublesome effect is gauge pumping. In many cases it is relatively easy to guess what the minimum outgassing rate to be expected from a sample might be. The surface area of the sample should then be such that the expected gas load generated is significantly greater than the gas load pumped by the measuring gauge. If this is not the case, then the measurement is not meaningful.

In some cases, where the measured pressures are within it's operating range, a suitable gauge is the spinning rotor gauge. Outgassing form this type of gauge is simply that of its rather small internal surface area and there is no pumping effect. It is best suited to rate of rise measurements.

Because not all sources of error can be eliminated, rate-of-rise measurements, for example, can only set a lower bound for the outgassing rate. It may be possible to estimate an upper bound by guessing the gauge pumping speed. If these two values are reasonably close, then the result may be meaningful. This assessment cannot be done unless a real effect, i.e. a measurable pressure rise, is obtained.

It will be apparent that in the rate of rise method, sufficient time must be allowed for the pressure to rise significantly. Initially after isolating the main pump, there will be a period when the system is not in a steady state as the various gas sources and sinks settle down, but in a well-behaved and well designed experiment, this should be relatively short and for a constant outgassing rate a log-log plot of pressure against time should yield a straight line of positive slope. For outgassing rates close to the pumping speed of the system sensible measurement times may well be of the order of hours, not minutes.

17.5.3.2 Time Zero for outgassing

As noted earlier, the outgassing rate measured is a function of the time that a surface has been exposed to vacuum (i.e. has been pumped), and an idealised characteristic is shown in Figure 17.5.3-1 (Note that no great significance should be attached to the actual values of outgassing rate shown in the figure.) It is clear that the measured value of outgassing will depend on when the measurement is made.

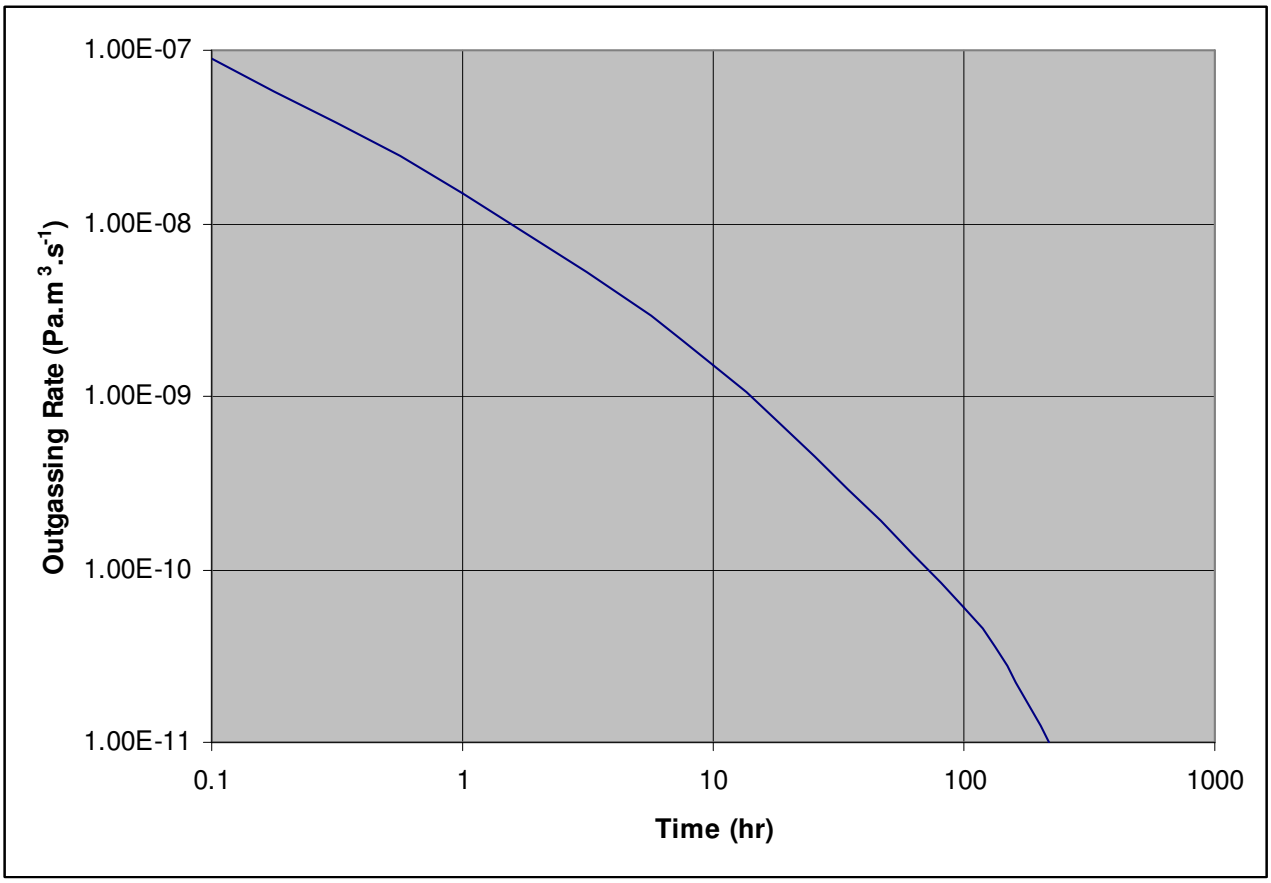

Figure 17.5.3-1 Idealised outgassing rate of a surface as a function of exposure time to vacuum

Because of the above, in order to achieve some sort of comparability, outgassing rates are often quoted as either 1 hour, 10 hour, 100 hour or “long term” rates. These are rates measured at these time intervals after time = 0. One matter of particular difficulty is determining just when time = 0 actually is. In a pump down, for example, when is the pressure determined by outgassing rather than removal of gas from the volume?

Since this set of procedures is intended for use in a quality assurance environment, this difficulty can be circumvented by careful specification of what should be done in individual cases.

17.5.4 Stating Outgassing Requirements

17.5.4.1 Vessel or Component Acceptance Tests as normally used in a Vacuum Quality Assurance Series of Procedures

In the specification for the vacuum item, if an outgassing test is required, then the specification should state the requirement in one of three alternative forms. These are as follows:

"*x* hours after the end of the procedure *y*, the specific outgassing rate shall be less than a value of *z* $Pa.m^3.sec^{-1}.m^{-2}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17."

or

"m hours after the end of the procedure *n*, the total outgassing rate shall be less than a value of *r* $Pa.m^3.sec^{-1}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17."

or

"k hours after the end of procedure g, the steady state specific outgassing rate shall be less than a value of *s* $Pa.m^3.sec^{-1}.m^{-2}$ using the measurement techniques described in the ITER Vacuum Handbook Appendix 17".

The steady state outgassing rate is defined at as the outgassing rate at the time when the rate of change of measured outgassing rate is less that 5 % over an elapsed time of 120 minutes.

That is to say:

$$\frac{q_t - q_{(t+120)}}{q_{(t+120)}} \leq 0.05$$

Where $q_{(t)}$ = specific outgassing rate at time *t* (minutes).

Procedures y, n and g will have been defined earlier in the specification and, unless there are good reasons otherwise, x and m will normally be 10 hours.

17.5.4.2 Testing items, materials or procedures for acceptability for more general use

Such tests are of a more generic nature and so some standardisation of results is necessary. There are two particular cases to be considered (a) where there is no form of processing and (b) where there is a processing stage included e.g. a bake.

Where no processing is involved outgassing measurements should be taken at intervals of 1 hour, 10 hours and (optionally) 100 hours after the start of pump down of the vacuum item. It should be noted that such results may be influenced by the pumping speed applied, so this should always be quoted.

Following a process stage, outgassing measurements should be taken at intervals of 1 hour, 10 hours and (optionally) 100 hours after the end of the process. In the case of a

bakeout, the end of the process may be defined as when the system returns to room temperature, unless a particular specification states otherwise. It should be noted that results may be influenced by the pumping speed applied, so this should always be quoted.

17.6 Procedures

17.6.1 General

17.6.1.1 Start Time

In the following procedures, it is assumed that the appropriate starting time for measurements has been set according to the considerations discussed earlier. This is referred to below simply as the start time.

17.6.1.2 Pump Set Conditioning

Before the start time, all pump sets will have been conditioned and proved to be leak tight and clean.

17.6.1.3 Vacuum Vessel Outgassing Measurements

The vessel should be assembled into the appropriate apparatus using flanges and gaskets appropriate to the vacuum regime for which the vessel is designed.

In the case of the measurement of outgassing of a vacuum chamber whilst being pumped from atmospheric pressure, a preliminary pump down should be made and the vessel and its appendages proved leak tight. Following this leak test, the vessel should be vented to either clean dry nitrogen (dew point < -50^{o}C) or normal atmosphere as specified in the test documentation. If nothing is so specified, then clean dry nitrogen is recommended.

In the (usually rare) circumstances of an outgassing measurement being required for a vessel in “as received” condition, then leak tests should be carried prior to the completion of the outgassing measurements to ensure that the results are not dominated by any leak being present. Clearly, great care must be taken during assembly to minimise the possibility of such leaks. If such a leak is detected, the originator of the request for test must be consulted before any further work is carried out.

17.6.1.4 Vacuum Component or Sample Outgassing Measurements

The component or sample should be inserted into a vacuum chamber for which the outgassing characteristics have been established in a blank run immediately prior to the tests.

For a meaningful measurement of outgassing, the expected outgassing load of the component or sample must be at least 10 times greater than that of the empty chamber.

The procedure to be followed will be the same as that for a vessel as specified in the request for test.

17.6.2 Rate of Pressure Rise Method

17.6.2.1 Equipment

The equipment used will typically take the form shown in Figure 17.6.2-1.

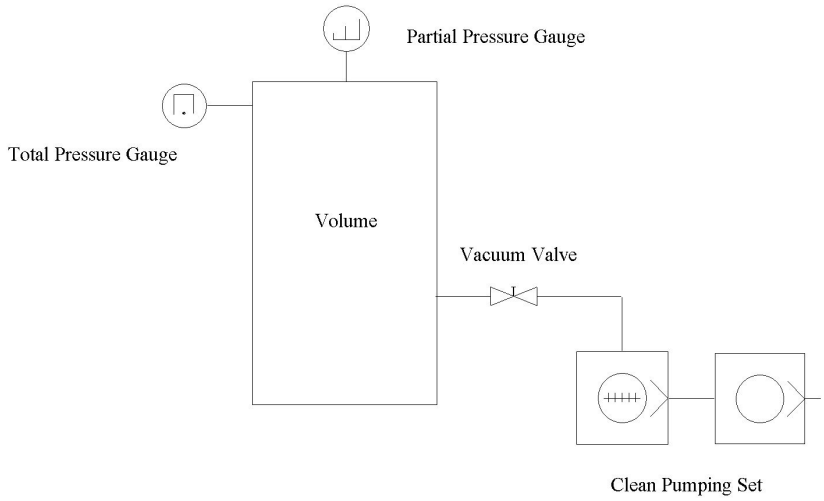

Figure 17.6.2-1 of outgassing - pressure rise technique.

The choice of pumping set and the type of total pressure gauge to be used will depend on the maximum total pressure expected during the measurements. The gauge is shown as a cold cathode device, but need not be. There are distinct advantages to using a Spinning Rotor Gauge if the pressures measured lie within its range of operation.

The use of a partial pressure gauge will normally mean that the total pressure should not normally rise above about 10^{-3} Pa during measurements unless some sort of sampling stage is used. The pump set should be chosen so that the volume may be evacuated through the valve to a reasonable pressure in a reasonable time. What “reasonable” means must be assessed on a case-by-case basis, but must be short compared to the time at which the first outgassing result is required.

17.6.2.2 Procedure

With the pump set under vacuum at or close to its ultimate, the vacuum valve is opened carefully and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The vacuum valve is closed and the pressure or partial pressure of the species of interest recorded at frequent intervals until a pressure rise of at least one decade is obtained. The times of recording each pressure should be noted. The use of a continuous record as on a chart recorder or a data logger is to be preferred.

If outgassing measurements are required at a number of values of pumping time, then the valve should be opened and the process repeated at the appropriate time.

The outgassing rate(s) are then calculated using the above formula.

17.6.3 Dynamic Flow Method

Note that only the two-gauge method is described here.

17.6.3.1 Equipment

The equipment used will typically take either of the forms shown in Figure 17.6.3-1. That on the left is more suited to measurements on vessels or assemblies, that on the right to coupon samples.

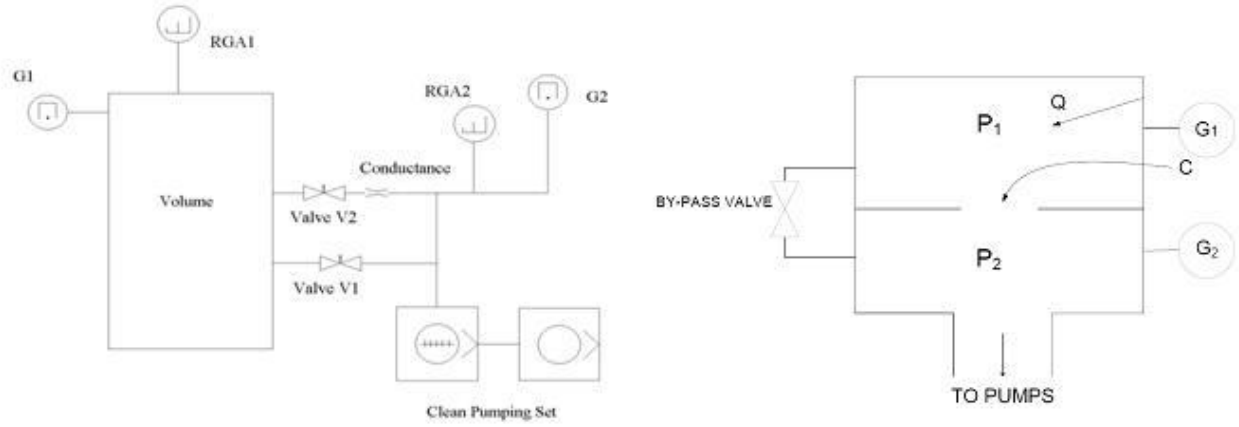

Figure 17.6.3-1 Equipment for the measurement of outgassing - dynamic flow technique.

The choice of pumping set and the types of total pressure gauges to be used will depend on the maximum total pressure expected during the measurements. The gauges shown are cold cathode devices, but need not be. The use of partial pressure gauges will normally mean that the total pressure should not normally rise above about 10^{-3} Pa at the gauge during measurements, unless some sort of sampling stage is used. The pump set should be chosen so that the volume may be evacuated to a reasonable pressure in a reasonable time. What “reasonable” means must be assessed on a case-by-case basis, but must be short compared to the time at which the first outgassing result is required.

The value of the conductance should be chosen so that a reasonable pressure differential is obtained.

17.6.3.2 Procedures

17.6.3.2.1 Outgassing measurements on a vessel

Here, the equipment shown on the left of Figure 17.6.3-1is the more suitable.

With the pump set under vacuum at or near its ultimate, vacuum valves V1 and V2 are opened carefully and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The vacuum valve V1 is closed and the pressures on either side of the conductance monitored until the values have stabilised over a period of about 15 minutes.

If quasi-continuous measurements of outgassing as a function of time are required, then sets of readings shall be taken at appropriate time intervals.

If outgassing measurements are required at a number of discrete values of pumping time, then the valve V1 is opened after a set of readings is complete and closed shortly before the next set is due, allowing sufficient time for the system to stabilise before each set of readings.

The outgassing rate(s) are then be calculated using the formula above.

17.6.3.2.2 Outgassing measurements on coupon samples

In this case, the equipment shown on the right of Figure 17.6.3-1 is the more suitable.

To be meaningful, the following procedure should be carried out first with the upper (test) chamber empty, then vented to clean, dry (dew point <-50^{o}C) nitrogen and the sample inserted. The sequence is then repeated, the sample removed and, ideally, a final sequence carried out on the empty system. The two blank (i.e. empty chamber) runs should give consistent results. The measured pressure in the upper chamber with the sample inserted must be significantly higher than the blank runs if a meaningful value of outgassing is to be calculated.

With the pump set under vacuum at or near its ultimate, the valve to the pumping set (not shown) and the by-pass valve are opened and the volume evacuated to its base pressure or for the time at which an outgassing measurement is required, whichever is less. The by-pass valve should be of sufficient size that adequate pumping speed is achieved above the conductance.

Any processes specified (e.g. a bake cycle) are completed.

If the pressure achieved is below about 10^{-6} Pa, then any hot filament measuring devices should be thoroughly outgassed and the outgassing products pumped away.

The by-pass valve should be closed and the pressures on either side of the conductance monitored until the values have stabilised over a period of about 15 minutes.

If quasi-continuous measurements of outgassing as a function of time are required, then sets of readings should be taken at appropriate time intervals.

If outgassing measurements are required at a number of discrete values of pumping time, then the by-pass valve should be opened after a set of readings is complete and closed shortly before the next set is due, allowing sufficient time for the system to stabilise before each set of readings.

The outgassing rate(s) are then calculated using the formula above.

17.7 Presentation of Results

On completion of outgassing tests a report should be issued recording:

- full details of the apparatus used (including volumes where appropriate)
- copies of calibration certificates for all gauges used
- details of the calculation of the value of the conductance (where appropriate)
- results of system leak tests
- proof of cleanliness of the pump set
- tabulated measurements of pressure with times at which readings were taken or copies of recorder traces as appropriate
- tabulated values of calculated total and partial outgassing rates as appropriate

17.8 Derivation of the ITER Outgassing Rate Requirements

The limits of outgassing rates for materials for use in ITER vacuum systems are given Table 17.8-1, which is Table 5-1 of the ITER Vacuum Handbook and the values are therefore mandatory.

These limits have been produced by taking into account the total surface area expected, available pumping speed, the desired pressure, and post assembly conditioning time, with due consideration of what is reasonably achievable.

		Maximum steady state Outgassing rate $Pa.m^3.s^{-1}.m^{-2}$		
VQC+	**Outgas temperature °C**	**Hydrogen isotopes**	**Impurities**	**Testing Guidelines**
1	100‡	1×10^{-7}	1×10^{-9}	Appendix 17
2	20	$1 \times 10^{-7*}$		Appendix 17
3	20	1×10^{-8}		Appendix 17
4	20	1×10^{-7}		Published data and conformity to clean work plan.

For VQC 2, 3 and 4, the outgassing rate excludes the partial outgassing rate for water and hydrogen.

‡ The outgassing test temperature can be reduced to 20 °C for components which normally operate at cryogenic temperatures.

+ For CFC, refer to the ITER Vacuum Handbook Section 26.7

* In the case of resins for magnets, it is considered that this target outgassing rate will be achievable. However a factor 10 increase will be permitted as an acceptance criterion.

Table 17.8-1 – Outgassing rates pertaining to VQC

17.8.1 Vacuum Vessel

In calculating the maximum outgassing rates specified for the Vacuum Vessel (VQC 1) the following assumptions and calculations have been used.

The approximate total surface area of vacuum vessel is 20000 m^2 and is calculated as the sum of the following:

- vacuum vessel+ports ≈ 3000 m^2
- port plugs ≈ 4000 m^2
- blankets ≈ 5000 m^2
- divertor ≈ 2000 m^2
- piping ≈ 1000 m^2
- in-vessel cabling ≈ 2500 m^2
- fixtures and fittings ≈ 2500 m^2

The ITER Project Integration Document (PID) specifies the vacuum vessel base pressure to be < 10^{-5} Pa for hydrogen and <10^{-7} Pa for impurities prior to ITER operations at the operating temperature of 100 °C.

Using a conservative estimate of the vacuum vessel pumping speed of 20 $m^3.s^{-1}$ yields a derived maximum hydrogen throughput of 2 x 10^{-4} $Pa.m^3.s^{-1}$

Thus, the maximum allowable outgassing rate of hydrogen prior to pulsing is calculated as,

$$q = \frac{Q}{A} = \frac{2.0x10^{-4}}{20000} = 1x10^{-8}\,\mathrm{Pa.m^3.s^{-1}.m^{-2}}$$

It is expected that a factor 10 decrease in the outgassing rate for hydrogen can be achieved by baking the vessel to 200 °C and hence the maximum outgassing rates for VQC 1 components has been defined in Table 17.8-1 as:

- 1x10^{-7} $Pa.m^3.s^{-1}.m^{-2}$ for hydrogen at 100 °C
- 1x10^{-9} $Pa.m^3.s^{-1}.m^{-2}$ for impurities at 100 °C

17.8.2 Cryostat

The outgassing requirement for VQC2 is derived from the need to manage three areas:-

1) To be able to pump down the cryostat initially in a reasonable time with limited pumping and conditioning capacity and to achieve a level of vacuum suitable for an insulation vacuum.
2) To avoid poisoning of the activated charcoal in the reference cryostat cryo-pumps with heavy hydrocarbons.
3) To ensure that over time, the build up impurities on the cold thermal shields does not adversely affect their emissivity and hence the heat load on the superconducting coils and the cryo-plant.

The specified outgasing limit for VQC 2 excludes water because it is considered that it will not be possible during the cryostat construction to avoid surfaces becoming water contaminated.

It is the case that for item 3 above water ice is likely to be the dominant issue. However other gasses which are condensable at 80K can also present a similar problem and these can be more difficult to condition once the cryostat is complete. To quantify an acceptable outgassing rate, water is used below, as there is a better database available for the relevant emissivity change.

In calculating the maximum outgassing rates specified for the ITER cryostat (VQC 2) the following assumptions and calculations have been used.

Source[27]	A (m^2)[27]	qH_2O($Pa.m^3.s^{-1}.m^{-2}$)+	QH_2O_{tot} ($Pa.m^3.s^{-1}$)	Pressure in cryostat (H_20,Pa)‡
Metallic surface	2.5×10^4	1×10^{-7}	2.5×10^{-3}	5.0×10^{-5}
Vacuum facing epoxy	1.3×10^3	1×10^{-5}	1.3×10^{-2}	2.6×10^{-4}

‡Assumes 50 m^3s^{-1} H_2O cryostat pumping speed.[27]

+Values from Table 17.8-1 & equation Section 17.8.1 after 100 hours.

Table 17.8-2- Assumed cryostat areas and calculated H_2O outgassing rates

Using the figures from Table 17.8-1 the calculated partial pressure of water vapour in the cryostat prior to the cool down of the magnets is approximately 2.6×10^{-4} Pa.

The 2007 ITER PID value for partial pressure of H_2O before cool-down is quoted as ≤ 2×10^{-7} Pa. This figure is considered to be unachievable and the basis can not be found.

Assuming the cryostat thermal shield does not cool uniformly, residual water will initially condense on cold spots covering an estimated 10% of the thermal shield surface area with an equivalent thickness of 0.02 monolayers.

After baking the vacuum vessel and cooling the magnet structures and thermal shields, the remaining source of condensable water will be from the cryostat walls and internal components which are at ambient (or elevated) temperature, having an estimated total surface area of 3000 m^2.

Assuming a steady state outgassing rate of 1×10^{-7} (H_2O) $Pa.m^3.s^{-1}.m^{-2}$, the load to the thermal shield remains unchanged for 3 years. Over approximately 8 years a coverage of H_2O of 2000 monolayers (1μ thickness) will form on the cryostat-facing thermal shield. The change in emissivity of the thermal shield due to formation of this water layer results in a calculated increase in heat load to the cryo-plant of approximately 50% [28].

The ice crystal size significantly affects the infra-red absorption and consequently the emissivity of a panel: the larger the crystals, the higher is the emissivity; therefore the morphology of the ice formation significantly effects the change in emissivity.

In this estimation, it is assumed that the water forms a uniform layer of ice over the thermal shield with the coverage rate constant over the time period considered. If the coverage rate is not constant, and it is assumed water condenses on the thermal shield in batches as “snow”, the time taken for a similar change in emissivity decreases to approximately 3 years.

The effect on emissivity due to the build up of ice can be seen in Figure 17.8.2-1[28] and the effect on the additional load to the cryo-plant due to water condensing on the cryostat-facing thermal shield is shown in Figure 17.8.2-2[28].

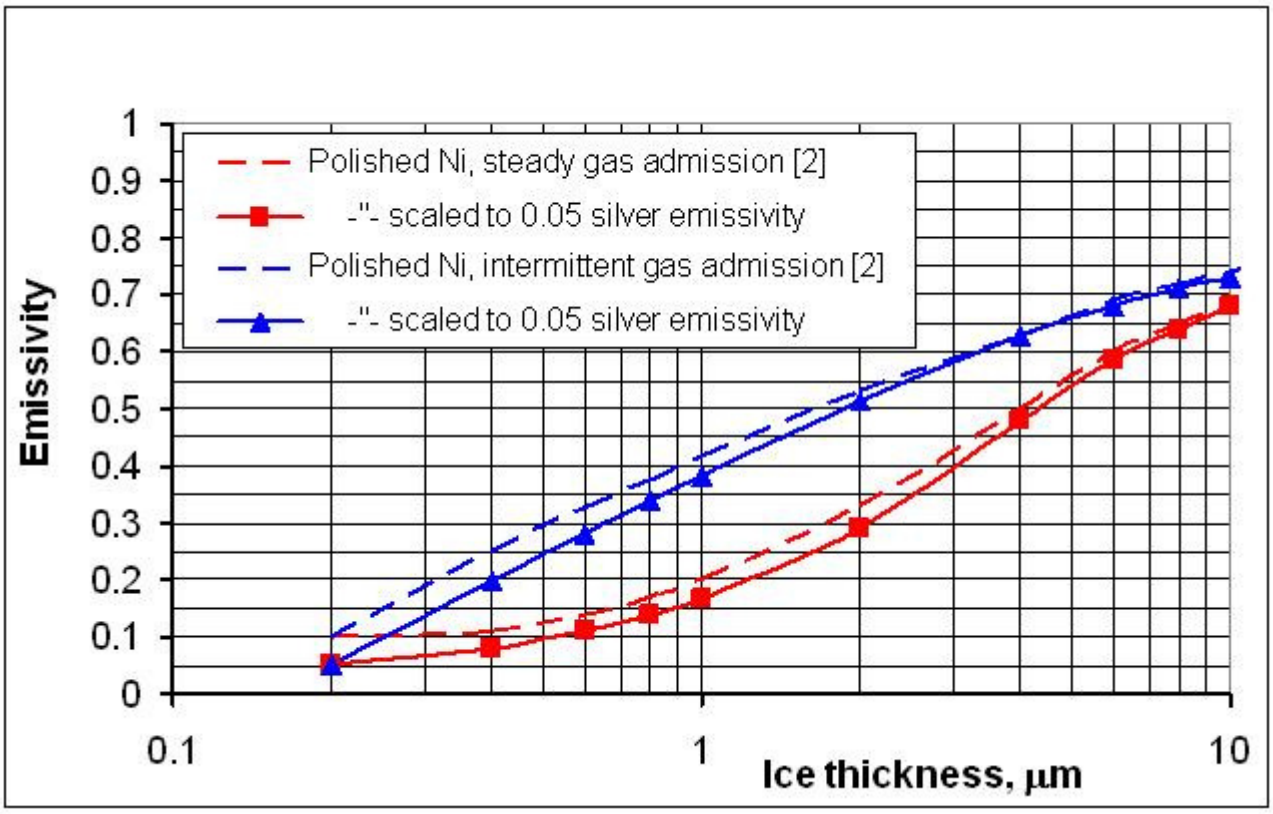

Figure 17.8.2-1 Effect on emissivity due to ice layer formation

It is considered that the effect on the emissivity of the cryostat thermal shields will be greater due the condensation of hydrocarbons outgassing from the cryostat internal components. Hence the maximum outgassing rate from cryostat vacuum-facing surfaces is defined in Table 17.8-1 to be1 x 10^{-7} $Pa.m^3.s^{-1}.m^{-2}$ (excluding water and hydrogen) at ambient temperature

In order to reduce the steady state outgassing rate of water from the cryostat internal surfaces, a method of purging the cryostat with dry nitrogen prior to cool down of the magnet structures and thermal shields is being studied. The order in which the cryostat cryogenic surfaces are cooled, and the resulting effect on the emissivity of the cryostat cold surfaces due to condensed gas, is also to be studied. (See [28] for further recommendations)

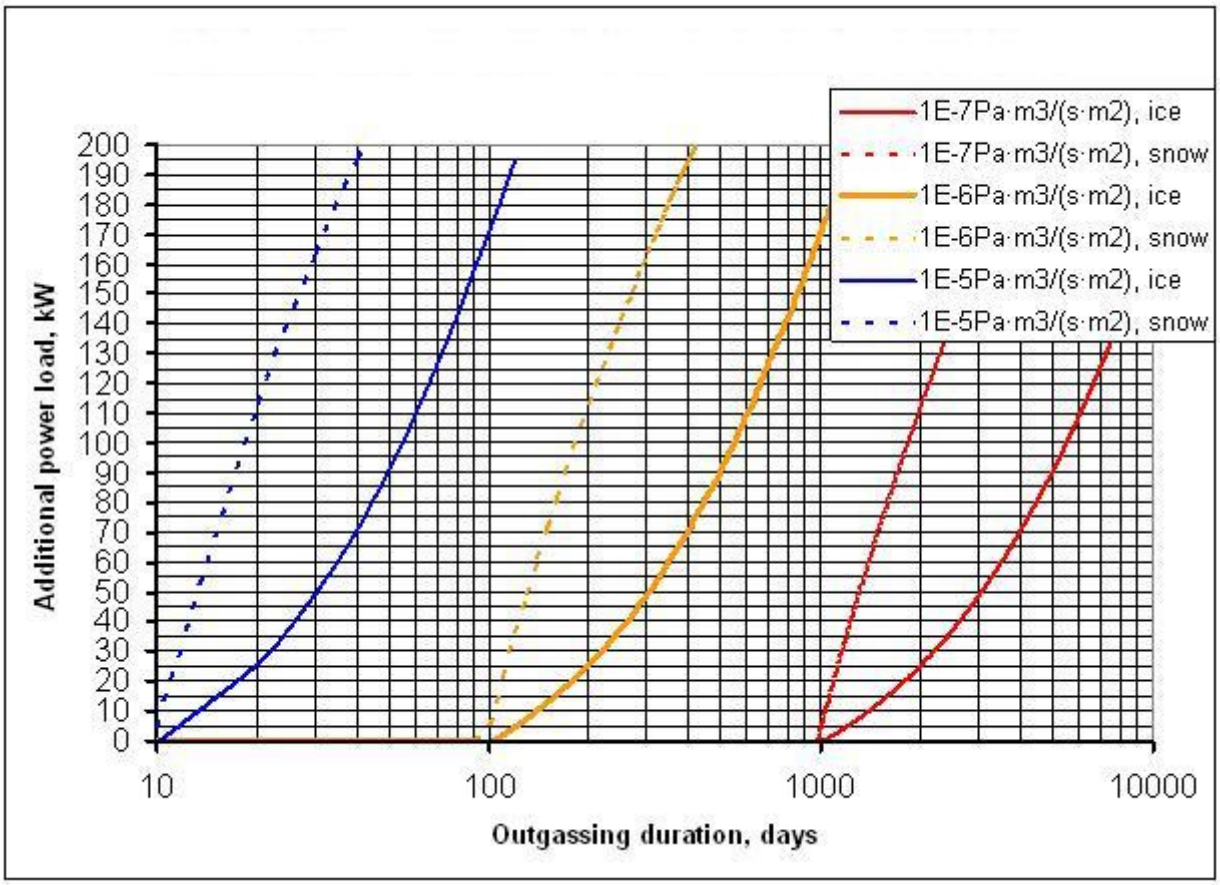

Figure 17.8.2-2 Additional power load on thermal shield coolant due to H_2O Outgassing

17.9 Outgassing Rates Review

The purpose of this section of the Appendix is to outline the methodology used in the assessment of outgassing rates from published data and to establish the relationship between common parameters which influence material outgassing rates

17.9.1 Material thermal outgassing

Thermal outgassing from material surfaces is time and temperature dependant and it can be shown that the measured outgassing rate from a metallic surface will increase by factor of about 10 by increasing the sample temperature from ambient to 100 ºC, and increases by a further decade by raising the sample temperature from100 to 250 ºC.[5]

The medium term (1 to 100h) outgassing from a surface can be described by a power law of the form:

$$Q = Q_0 . t^{-\alpha}$$

Where, α (the outgassing decay index) is typically near unity for metallic surfaces and 0.5 for epoxies and *t* is the time in hours [21].

The outgassing rate of a surface is also dependant on the surface condition. Factors affecting the outgassing rate include:

- chemical composition
- the presence of oxide layer's
- surface finishing
- cleaning and other processes

References to published data, listing outgassing rates for materials after varying surface treatments, are to be found in Section 17.10.

While a large record of outgassing rates can be found in literature for vacuum compatible materials comparisons of the reported data are difficult as, in many cases, for the same material differing surface treatments and measurement techniques are reported, some important factors may not be reported at all.

17.9.2 Unbaked Stainless Steel

The rate of outgassing from unbaked stainless steel is dependant of the process to which the stainless steel surface has been subjected. Outgassing rates gathered from literature (see Section 17.10) for Stainless steel after surface treatments are summarised in Table 17.9-1.

SST treatment	**q_{tot} ($Pa.m^3.s^{-1}.m^{-2}$) at 1h, 20ºC**
As received/fresh	$1x10^{-4}$
Degreased	$2x10^{-6}$
Surface finished (machined)	$2x10^{-7}$

Table 17.9-1 Outgassing rates of stainless steel after surface processing

Generally water is the dominant species outgassed from unbaked stainless steel and will evolve at a rate dependant on the elapsed pumping time of the surface. Generally, for unbaked stainless steel surfaces, water will remain the dominant outgassing species at pumping times in excess of 100 h.

17.9.3 Baked Stainless Steel

Baking at 150 ºC for a minimum of 24 h can reduce the total outgassing rate by a factor of 100 as water is desorbed from the metal surface. After this time the predominant outgassing species from clean stainless steel is hydrogen [5]. A reduction in the hydrogen outgassing rate can be achieved by vacuum firing or air baking the material.

After baking, stainless steel will generally exhibit outgassing rates between 10^{-9} and 10^{-10} $Pa.m^3.s^{-1}.m^{-2}$ (see Section 17.10.1)

17.9.4 Organic Material

For organic materials (epoxies etc), the method of weight loss measurement is usually used for the determination of outgassing rates with the outgassing rate quoted as a percentage of total weight loss, or gram/s.

Using the formula below the outgassing rate can be calculated from the total mass loss measurement

$$q = \frac{dM}{dt} \cdot \frac{RT}{M} \cdot 10^3$$

where:

q is the outgassing rate in $Pa.m^3.s^{-1}.m^{-2}$

R is the universal gas constant (83.14 $mbar.l.mol^{-1}.K^{-1}$)

dM/dt is the mass loss per unit time ($g.s^{-1}$)

T is the sample temperature (K)

M is the molecular mass of the outgassing species

Using the above formula it can be shown that for water outgassing from a surface at a rate of $1\mu g.s^{-1}$ the specific outgassing rate near room temperature will be approximately 1 $Pa.m^3.s^{-1}.m^{-2}$.

The outgassing rate of organic materials is also dependent on the fabrication process (curing temperature, chemical hardener, vacuum, inert gas process, etc.). There is a lack of published data on outgassing rates for material of the same composition which has undergone different fabrication processes, making comparisons difficult. Hence qualification of new organic materials for use on ITER will have to be performed using experimental data.

An analysis of weight loss measurements on epoxies shows that the ratio of water outgassing to impurity outgassing is approximately 100 to 1, so, assuming a well controlled fabrication process, a low outgassing epoxy should outgas at a rate in the range of 10^{-7} $Pa.m^3.s^{-1}.m^{-2}$ (excluding water) after 100 h baking (see Section 17.10.2).

17.10 Outgassing Rates - Published Data

Outgassing rates quoted in referenced publications are summarized in the tables below.

17.10.1 Stainless Steel

Published data on the outgassing rates of stainless steel following various surface treatments is given in Table 17.10-1.

Treatment	Total outgassing rate ($Pa.m^3.s^{-1}.m^{-2}$)	Time meas. (hours)	Reference
None	$2x10^{-4}$	1h	2
None	$2x10^{-5}$	10h	2
Polished & vapor degreased	$1.4x10^{-6}$	10h	2
None	$1.1x10^{-7}$	100h	2
Degrease + water rinse	$4.0x10^{-8}$	40h	2
Degrease + water rinse, baked in vacuum 150ºC for 12h	$4.0x10^{-9}$	5h after bakeout	2
Baked 24h @ 200°C	$9.3x10^{-10}$	100h	2
Unbaked	$2x10^{-7}$	10h	1
Baked (150º C,24h)	$2x10^{-9}$		1
Std cleaning	10^{-6}	1h	3
Baked	10^{-8}	1h	3
Untreated	$7x10^{-5}$		4
Degreased	$1x10^{-6}$		4
Baked	$3x10^{-10}$		4
unbaked	$9x10^{-7}$	20h	5
Electrochemical buffing	$5x10^{-8}$	50h	8
Electrochemical buffing followed by baking(215 °C,23h) and air (10days)	$1x10^{-8}$	50h	8
Electropolished, baked, air oxidation	$1x10^{-11}$		9
Air exposure/baking cycles	$1x10^{-10}$		10
UT cleaning + bake 250C,24h	$3x10^{-10}$		12
Various treatments	$2x10^{-6}$	100h	13
Annealing+bake	$2x10^{-11}$		14
Air firing	$3x10^{-11}$		15
Pre-baking+baking	$4x10^{-10}$		16
Chemical cleaning	$4x10^{-9}$		17
	$1x10^{-6}$	1h	18
Cleaned With bakeout	$8x10^{-7}$ $2x10^{-9}$		19
	$2x10^{-6}$	4h	20

Table 17.10-1 Outgassing rates for stainless steel – published data

17.10.2 Epoxies

Published data on the outgassing rates of various epoxies and resins is given in Table 17.10-2

Material	Outgassing rate (Pa.m3.s-1.m-2)	Outgassing rate % Total Mass Loss (TML)	Reference

Material	Outgassing rate (Pa.m3.s-1.m-2)	Outgassing rate % Total Mass Loss (TML)	Reference
RF4000 EV Roberts (baked)	$5x10^{-6}$ (10h)		22
ERL4221 union carbide (baked)	$1x10^{-5}$(10h)		
CY179 Ciba Geigy (baked)	$3x10^{-6}$(10h)		
1138 Ciba-Geigy (baked)	$2x10^{-6}$(10h)		
828 Shell chemical (baked)	$1x10^{-5}$(10h)		
DGEBA, + ≠ materials	10^{-3} -10^{-4}(10h)		23
Stycast	$4x10^{-5}$ (72h)	0.87	24
Redux 312UL	$7x10^{-6}$(72h)	0.40	25
Ablebond Ablestik		0.2	ESA database
Araldite resin	10^{-3}-10^{-4}(10h)		1
Polymers	10^{-5}(10h)		26

Table 17.10-2 Outgassing rates for epoxies and resins – published data

17.11 References

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2FMM4B
VERSION CREATED ON / VERSION / STATUS
05 Jun 2020 / 1.5 / Approved
EXTERNAL REFERENCE / VERSION

Baseline Report

ITER Vacuum Handbook Attachment 1 - Welding

This Attachment 1, to the ITER Vacuum Handbook, relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.
This Attachment is based on the international standards ISO 9606, ISO 15614 and ISO 15609, additional requirements are specified to achieve the high integrity and reliability of the vacuum systems to ensure the required ITER machine reliability – Additional requirements are identified in this document.
The requirements are designed to complement codes which may be used. Where requirements differ in general the more stringent standard should be applied or advice sort from ITER.

Approval Process			
	Name	*Action*	*Affiliation*
Author	**Bansal G.**	**05 Jun 2020:signed**	**IO/DG/CNST/MCD/TCD/VDI**
Co-Authors	**Worth L.**	**05 Jun 2020:signed**	**IO/DG/CNST/MCD/TCD/VDI**
Reviewers	**Pearce R.** **Yu X.**	**09 Jun 2020:recommended** **11 Jun 2020:recommended**	**IO/DG/CNST/MCD/TCD/VDI** **IO/DG/SQD/QMD**
Approver	**Becoulet A.**	**11 Jun 2020:approved**	**IO/DG/ENGN**
Document Security: Internal Use *RO: Chiocchio Stefano*			
Read Access	**GG: MAC Members and Experts, GG: STAC Members & Experts, AD: ITER, AD: External Collaborators, AD: IO_Director-General, AD: External Management Advisory Board, AD: EUROfusion-DEMO, AD: Auditors, AD: ITER Management Assessor, project administrator, RO, LG: VDI team member temp, LG: Section Scheduling...**		

Change Log			
ITER Vacuum Handbook Attachment 1 - Welding (2FMM4B)			
Version	***Latest Status***	***Issue Date***	***Description of Change***
v1.0	Signed	17 Dec 2008	
v1.1	Signed	26 Jan 2009	
v1.2	Approved	10 Apr 2009	
v1.3	Signed	19 May 2020	Updated list of codes and standards with current applicable versions and removal of obsolete ones. Welding clarifications (MUXMPR, MUZQFU and MUX8HR) and reflected in the new version. Document update required as a result of PCR-1141.
v1.4	In Work	05 Jun 2020	Minor formatting issues corrected
v1.5	Approved	05 Jun 2020	Formatting errors corrected

ITER Vacuum Handbook

Attachment 1
Inspection and Qualification of Welded Joints

Table of Contents

1 Scope

This Attachment relates to welding of vacuum boundaries and outlines the procedures for documentation, qualification, approval and testing.

Whilst this Attachment is based on the international standards ISO 9606, ISO 15614 and ISO 15609, additional requirements are specified to achieve the high integrity and reliability of the vacuum systems to ensure the required ITER machine reliability. Specifically this Attachment is more stringent in places than the standards in the range of approval for joint types, mechanical testing and acceptance criteria.

The requirements are designed to complement codes which may be used. Where requirements differ in general the more stringent standard should be applied or advice sort from ITER.

2 The Welding and Inspection Plan

Before fabrication can commence the *supplier* shall prepare for approval a weld plan. The weld plan is a drawing which cross references each welded joint to a supporting Welding Procedure Specification (WPS).

3 Welder and operator Qualification

The welder qualification is intended to show the competence of the welder/operator for implementing the specified WPS.
Welder qualification shall be in accordance with ISO 9606 or equivalent standards agreed in advance. For welding operators ISO 14732 shall be used.
Other standards may be approved by ITER on submission of documentation detailing the equivalence between the proposed standards and the standards quoted herein. All standards and documentation pertaining to equivalence shall be submitted in English and must be agreed in advance of welding operations.

The *supplier* shall establish and maintain a list of qualified welders and operators. This list shall include their individual identification and range of welds for which they are qualified.

4 Applicable Standards

The latest revisions of the standards listed in Table 4-1 shall be applied in the procedure, qualification, and acceptance testing etc. of any welding process and form, where applicable, part of this attachment. Alternative national standards may be submitted for approval but they must meet the minimum technical requirements of this Attachment. Alternatives must be formally accepted through written communication before welding can commence.
Where this attachment is more stringent than the standards, this document takes precedence. Where specified in this document, additional requirements to or requirements differing from the quoted international standards have been highlighted ***in bold italics.***

ISO 15607	Specification for the qualification of welding procedures for metallic materials – general rules
ISO 15614	Specification and qualification of welding procedures for metallic materials-welding procedure test
ISO 15609	Specification and qualification of welding procedures for metallic materials – Welding procedure specification
ISO 17637	Non-destructive examination of fusion welds. Visual examination.
ISO 4063	Welding and allied processes – Nomenclature of processes and reference numbers.
ISO 3452	Non-destructive testing. Penetrant testing.
ISO 17638, ISO 9934	Non-destructive examination of welds. Magnetic particle examination of welds
ISO 17636	Non-destructive examination of welds. Radiographic examination of welds.
ISO 17640	Non-destructive examination of welds. Ultrasonic Examination.
ISO 9606-1	Qualification test of welders – Fusion welding – Part 1: steels.
ISO 9606	Qualification test of welders – Fusion welding – Part 2: aluminium and aluminium alloys.
ISO 14344	Welding and allied processes – Flux and gas shielded electrical welding processes – Procurement guidelines for consumables.
ISO 5817	Fusion welded joints in steel, nickel, titanium and their alloys (beam welding excluded) – Quality levels for imperfections.
ISO 14732	Welding personnel. Approval testing of welding operators
ISO 9712	Non-destructive testing - Qualification and certification of NDT personnel
ISO 22825	Non-destructive testing of welds - Ultrasonic testing - Testing of welds in austenitic steels and nickel-based alloys
ISO 10380	Corrugated metal hoses and hose assemblies

Table 4-1 Standards relating to welding

5 Welding Procedure Specification

The Welding Procedure Specification (WPS) is a document which details all the variables which must be defined to produce a weld of acceptable quality. The qualification of the WPS shall be performed in accordance with this Attachment.

Each WPS shall detail each type of weld and shall include, but not be limited to, the following in accordance with ISO 15609:

- Identification of equipment manufacturer
- Equipment calibration records
- Examiner or test body
- WPS number
- Parent material(s), defining which joint element is comprised of a given material
- Filler material(s): classification, type, trade name, flux, diameter of electrode, rod, or wire

- Joint sketch and weld run sequence
- Range of qualified thicknesses and/or diameters
- Welding position
- Welding process (in accordance with ISO 4063)
- Welding technique (single, multipass etc)
- Groove or edge preparations (cleaning, degreasing, jigging etc)
- Shielding and backing gas (composition and flow rates)
- Welding equipment parameters which may include:-
  - AC or DC
  - Polarity
  - Current range
  - Voltage range
  - Pulsed welding parameters
  - Tungsten electrode diameter and type
  - Nozzle diameter
- Backing: method and type, materials and dimensions
- Back gouging: method
- Heating: pre-heat temperature, interpass temperature, post weld temperature
- Drying and preservation temperatures for covered electrodes (if applicable)

Additional Parameters for automatic welding may include:

- Welding equipment specification
- Tool and programme numbers (where applicable)
- Travel speed range
- Wire feed speed range
- Arc Voltage Control parameters

For special processes (remote welding etc) additional information may be required.

6 Welding Procedure Qualification Record

The Welding Procedure Qualification Record (WPQR) is used to record all the relevant data from the welding of test pieces in the qualification of the WPS.

- The qualification of the WPS provides proof that the defined welding process, will achieve a weld of acceptable quality. The welding and testing of this must be witnessed by an ITER recognised Independent Inspection Authority.

All welding data and results from the required non-destructive and destructive testing shall be documented using a Welding Procedure Qualification Record (WPQR). It can also be called Welding Procedure Approval Record (WPAR).

6.1 Qualification of the Welding Procedure Specification.

An existing Welding Procedure Qualification Record (WPQR or WPAR) is acceptable if the following conditions are met:

- The test must have been performed in the same environment as proposed for production, using the same welding technique, process, joint configuration and welding equipment (for mechanised welds)
- The allowable ranges are the same with regard to essential variables.
- The related Preliminary Welding Procedure Specification (pWPS) has been qualified in accordance with ISO 15614
- The test must have been witnessed by an ITER recognised Independent Inspection Authority

Weld produced for qualification must be performed by suitably qualified welders.

The *supplier* must also demonstrate that the welding equipment and plant use for qualification is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

6.2 Extent of Approval

6.2.1 Material Groups

For differing grades of stainless steel (304, 304L, 316, 316L and 316LN-IG), cross qualification can be accepted for manual welds when 316L filler is used. Cross qualification is not acceptable for automatic welds. Transition welds joining dissimilar materials other than those listed above must have specific qualification tests performed.

6.2.2 Base Materials

Qualification on production metal type and grade is mandatory. There is no requirement for the use of material from the production heat number for qualification of the WPS.
ISO9001:2000 (clause 7.5.2) states that welding is always a special process. Welding processes commonly used in the manufacture of ITER components with a vacuum classification (according to ITER Vacuum Handbook) and their classification in the context of ITER are listed in Table 1. For special welding processes (Table 6-2) Production Proof Samples shall be manufactured from the production heat number.

Name	N†	AWSϕ	Special (Yes/No)
Gas metal arc welding	131 135	GMAW	No
Manual Gas Tungsten Arc Welding	141	GTAW	No
Automatic, or mechanized Gas Tungsten Arc Welding			Yes
Electron Beam Welding	51 511	EBW	Yes
Laser Beam Welding	521 522	LBW	Yes
† N reference numbers as specified in ISO 4063 (in the European Union published as EN ISO 4063 ϕ AWS reference codes of the American Welding Society are commonly used in North America			

Table 6-1 Welding Processes

6.2.3 Thickness Range

6.2.3.1 Thickness Range for Welds Excluding Fillet and Branch

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-2 in accordance with ISO 15614.

Thickness of test piece 't' (mm) (where 't' is the thickness of the thinner material)	Range of Approval[1,2] (Dimensions in mm)		
	Parent material thickness		Deposited weld metal thickness for each process 's'
	For single run or single run from both sides	Multi-run	
t ≤ 3	0.5 t to 2 t		Max. 2 s
3 < t ≤ 12	0.5 t (3 min) to 1.3 t	3 to 2 t	Max. 2 s
12 < t ≤ 20	0.5 t to 1.1 t	0.5 t to 2 t	Max. 2 s
20 < t ≤ 40	0.5 t to 1.1 t	0.5 t to 2 t	Max. 2 s when s < 20 Max. 2 t when s ≥ 20
40 < t ≤ 100		0.5 t to 2 t	Max. 2 s when s < 20 Max. 200 when s ≥ 20
100 < t ≤ 150		50 to 2 t	Max. 2 s when s < 20 Max. 300 when s ≥ 20
t > 150		50 to 2 t	Max. 2 s when s < 20 Max. 1.33 t when s ≥ 20
1 - When impact requirements are specified but impact tests have not been performed, the maximum thickness of qualification is limited to 12 mm. 2 – The range of approval may have to be reduced in order to avoid hydrogen cracking.			

Table 6-2 Range of Approval for material thickness and weld deposit thickness– all welds

6.2.3.2 Thickness Range for Fillet Welds

The qualification of a welding procedure test on thickness t shall include qualification for thickness in the ranges given in Table 6-3 in accordance with ISO 15614.

Thickness of test piece 't' (mm)	Range of approval (Dimensions in mm)		
	Material thickness	Throat thickness	
		Single run	Multi-run
$t \leq 3$	0.7t to 2 t	0.75 a to 1.5 a	No restriction
$3 < t < 30$	3 to 2 t	0.75 a to 1.5 a	No restriction
$t \geq 30$	≥ 5	†	No restriction
Note 1: a is the throat thickness of the test piece ***Note 2: Fillet welds cannot be qualified by Butt welds*** † For special applications only. Each throat thickness has to be proofed separately by a welding procedure test			

Table 6-3 Range of qualification for material thickness and throat thickness of fillet welds

6.2.3.3 Thickness Range for Branch Pipes (Diameter Range)

The qualification of a welding procedure test on diameter D shall include qualification for diameters in the following ranges give in Table 6-4 in accordance with ISO 15614.

Diameter of test piece D[1,2] (in mm)	Range of approval
$D \leq 25$	0.5 D to 2 D
$D > 25$	$\geq$ 0.5 D up to plates (25 mm min)
1) D is the outside diameter of the pipe or the outside diameter of the set-on branch pipe 2) Approval given for plates also covers pipes when outside diameter is > 500 mm	

Table 6-4 Range of approval for pipe and branch connections

6.2.4 Range of Approval of Welded Joints

Lip weld and Automatic socket welds shall be qualified on actual size within nominal material specification tolerances. Pre-weld /socket/spigot gap shall be adequate to preclude post-weld abutment contact and minimise weld stress. The range of approval for other types of joint is given in Table 6-5.

6.2.5 Range of Approval Welding Consumables

All consumables shall be certified to a standard acceptable to the ITER IO (e.g. ISO 14344). In the case of manual welding processes the approval range of filler materials covers other filler metals as long as they are in the same range and chemical composition.

In the case of automatic and semi automatic welding processes the welding consumables used for qualification shall be the same batch as those used for production welds. Following any change during production, weld samples shall be welded and examined prior to the continuation of production with the new batch of consumables. Qualification using filler does not qualify autogenous (fusion welding with out filler material) welds or vice versa.

6.2.6 Welding Processes

In all cases, any change in the welding process will require a requalification of the process. In addition, in the case of automatic welding any change to the welding equipment will require requalification.

6.2.7 Welding Position

Welds for qualification shall be done in local conditions similar to the local conditions where the production weld will be made. Local access to the test piece (in terms of welder access) and the orientation of the test piece (relative to the welder) shall be similar to those for the production weld for which they qualify.

Type of Joint in Approval Test Piece			*Range of Approval*											
			Butt welds on plate				*T Butt welds on plate*		*Fillet weld on plate*	*Butt welds on pipe*		*Fillet weld on pipe*	*Branch welds on pipe*	
			Welded from one side		*Welded from both sides*		*Welded from one side*	*Welded from both sides*		*Welded from one side*			*Set on*	*Set through*
			With backing	*No backing*	*With gouging*	*No gouging*				*With backing*	*No backing*			
Butt weld on plate	*Welded from one side*	*With Backing*	✓	✗	Δ	Δ	✗	✗	✗	✗	✗	✗	✗	✗
		No Backing	Δ	✓	Δ	Δ	✗	✗	✗	✗	✗	✗	✗	✗
	Welded from both sides	*With gouging*	✗	✗	✓	Δ	✗	✗	✗	✗	✗	✗	✗	✗
		No gouging	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗	✗	✗
Butt weld on pipe	*Welded from one side*	*With backing*	Δ	✗	Δ	Δ	✗	Δ	✗	✓	✗	✗	✗	✗
		No backing	Δ	Δ	Δ	Δ	Δ	Δ	✗	Δ	✓	✗	✗	✗
T Butt weld on plate	*Welded from one side*		✗	✗	✗	✗	Δ	Δ	✗	✗	✗	✗	✗	✗
	Welded from both sides		✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗	✗
Fillet weld	*Plate*		✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✗	✗
	Pipe		✗	✗	✗	✗	✗	✗	Δ	✗	✗	✓	✗	✗
Branch weld in pipe	*Set on*		✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✓	✗
	Set through		✗	✗	✗	✗	✗	✗	✗	✗	✗	✗		✓

Key:
✓ Indicates the weld for which the WPS is approved in the approval test
Δ Indicates those welds for which the WPS is also approved
× Indicates those welds for which the WPS in not approved

Table 6-5 Range of approval for type of joint

6.3 Non –Destructive Examination

Supplier's inspectors shall be competent in accordance with ISO 9712.

6.3.1 Examination

After post weld heat treatment and prior to destructive testing, test pieces shall be examined by the following:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) or Magnetic particle testing (in accordance with ISO 9934)

  Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld qualification
- Radiographic examination (in accordance with ISO 17636)

and/or

- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

For a pipe or plate of 2 mm (or less) wall thickness, the method of examination shall be agreed prior to examination.

6.3.2 Acceptance Criteria

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with ISO 5817 level B. In particular acceptance criteria are detailed in Table 6-6. Table 6-6 is in accordance with ISO 5817 however contains additional requirements for production vacuum boundary welds.

Defect Type		Permitted maximum
Planar Defects	Cracks or lamellar tears Lack of root fusion Lack of side fusion Lack of inter-run fusion Lack of root penetration	Not permitted
Solid inclusions	Slag inclusions - individual	20% of t or 2 mm, which ever is smaller
	Slag inclusions - Group	Aggregate length not to exceed t in a length of 12 t, except when the distance between successive indications exceeds 6L where L is the longest indication in the group
	Inclusions – ***Tungsten*** or Copper	Not permitted
Cavities	Isolated pores - round	Diameter <20% t or 2 mm, whichever is smaller
	Gas pore uniformly distributed porosity	1% for single layer (2% for multi-layer) by area where the area of the radiograph to be considered is the length of the weld affected by the porosity times the maximum thickness of the weld
	Elongated pores - wormholes	***Not permitted***
	Linear Porosity	***Not permitted***
Profile defects	***Under cut***	***Some intermittent undercut permitted. Depth not to exceed 0.5 mm for t > 3 mm or 10% for t < 3 mm. Under cut to blend smoothly with the parent material.***
	Incompletely filled groove, sagging. Root concavity, shrinkage groove	0.05 t or 0.5 mm, which ever is smaller. Weld thickness shall not be less than the parent plate thickness
	Excess penetration - pipe	Not greater than 5% of the pipe internal diameter up to 2 mm max.
	Excess penetration – plate	t = 0.5 to 3 mm: , h ≤1 mm+10% b t > 3mm: h ≤1 mm+20% b max 3mm.

		h=height of excess penetration on backside of plate and b the width
	Excess weld material	Not greater than 10% weld width
	Misalignment	***Not greater than 10% of the parent material thickness***
	Fillet leg length (asymmetry)	Unequal leg length should not exceed 20% of the fillet throat thickness
	Burn through	Not permitted
Other	Root oxidation	Not permitted where a backing purge gas is specified in the WPS

Table 6-6 Acceptance levels

6.4 Destructive Tests

6.4.1 Test Specimens

The number of test specimens that shall be subjected to destructive testing is given in Table 6-7 in accordance with ISO 15614.

TEST SPECIMEN	No of Tests
BUTT WELD	
Transverse Tensile (room temp.)	2
Root Bend (for t <12mm)	2
Face Bend (for t <12mm)	2
Side Bend (for t >12mm)	4
Transverse Tensile (design temp. if required by tech. spec.)	1
Impact test (for t ≥12 mm one set from weld metal and one set from HAZ if required by tech. spec).	2
Macro-examination (with photo)	1
Micro-examination x 200 (if required by tech spec.)	1
Hardness test survey	1
Burst test†	1
FILLET WELD	
Fracture Test	1
Macro-examination (with photos)	***4***
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
T-BUTT/BRANCH CONNECTION	
Macro-examination (with photos)	***4***
Micro-examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
SOCKET/LIP WELD+	
Macro-examination (with photos)	4
Micro examination x 200 (if required by tech. spec.)	2
Hardness Survey	2
† Longitudinal butt weld on bellows (or flexible) tube to ISO 10380	

Table 6-7 Number of destructive test specimens

6.4.2 Test Results

Unless specified differently in Table 6-8 destructive testing and test results shall comply with ISO 15614.

Bend test (stainless steel and nickel alloy only)	***The bend angle shall be 180° round a former of diameter 2t, where t is the thickness of the specimen. The bend test specimen shall have no open defects exceeding 2 mm measured in any direction on the convex surface after bending.***
Micro - Examination	***In general micro-examination shall only be required for welds which form part of the vacuum boundary or are in contact with cryogenic liquids. If required micro-examination tests shall be specified in the technical specification.***
Macro Examination	***For lip welds, penetration shall be 0.7t where t is the thickness of the thinner material.***

Table 6-8 Acceptable test results

6.4.3 Qualification for Welds Under Stressed Applications.

Additional destructive tests to those listed in Table 6-7 to qualify welds under stressed applications may be required as defined in the technical specification.

7 Production Welds

Production welds shall be performed to qualified procedures by qualified welders.

The WPS shall be available for reference by welders or welding operators, by the responsible welding engineer and by the authorised inspector.

The contractor must also demonstrate that the welding equipment and plant is properly maintained and calibrated in accordance with the relevant operation and maintenance schedules.

7.1 Inspection of Fusion Welded Joints

After post weld heat treatment welds shall be subject to the following tests:

- Visual examination (in accordance with ISO 17637)
- Dye Penetrant testing (in accordance with ISO 3452) if permitted†. (Inspection using Photothermal camera is permitted in the case where the manufacturer has qualified the method/acceptance criteria prior to the weld)
- Radiographic examination (in accordance with ISO 17636)

  and / or
- Ultrasonic examination (in accordance with ISO 17640 and ISO 22825 for austenitic steels and nickel alloys)

† See ITER Vacuum Handbook Section 7.1.4.

The range of wall thickness and preferred volumetric examination method is given in Table 7-1 .

Defects which are detected by the relevant non-destructive examination method shall be assessed in accordance with Table 6-6.

For all VQC 1A, VQC 2A water boundaries and vacuum boundary welds which become inaccessible, 100% volumetric examination of production welds shall be performed, unless a method of pre-production proof sampling is approved.

For all other vacuum boundaries, volumetric examination of 10% of production welds shall be performed unless a method of pre-production proof sampling is approved. In the event of failures, this shall be increased to 100% examination of the batch, defined as same welder/same WPS/ same weld. ……. Acceptance criteria are specified in Table 6-6

On welds where it is specified that volumetric examination be performed and radiography or ultrasonic inspection is not possible, Production Proof Sampling is required.

Wall Thickness	Preferred Volumetric Examination Method
Wt < 12 mm	Radiography
12 mm > wt < 19 mm	Radiography & Ultrasonic
wt > 19 mm	Ultrasonic

Table 7-1 Range of wall thickness and preferred volumetric examination method

7.2 Production proof samples

Welds where radiography or Ultrasonic testing is impractical (e.g. welds that are not full penetration butt welds) must be covered by Production Proof Sampling (PPS). Each PPS will only represent a specific type of weld and must use the same materials, thickness and set-up as the production weld.

For VQC 1 and 2 vacuum boundary welds a PPS must be welded during the same shift as the production welds and by the same welder using the same equipment to be representative of the production welding.
If more than one welder welds the production welds, each must perform a PPS.
PPS's are required each shift production welding is being performed to represent the welds performed on that shift.

For VQC 3 and 4 vacuum boundary welds a PPS shall be welded for each welder performing the production welds.

PPS's should be sectioned and macro examined in four places (including one stop/start area). Photographs of the macros giving the date the PPS was welded, the welder's identity and identifying the production welds it is covering must be included in the final documentation package.

An ITER representative will normally witness PPS welding and all PPS macros shall be reviewed. Operations with witness and hold points to facilitate this must be incorporated in the Work Schedule.

As the PPS is a representative sample, rejection of the macro will result in rejection of all welds covered by this PPS.

7.3 Helium Leak Testing of Production Welds

100% of vacuum sealing welds (VQC 1A, 2A, 3A, 4A) shall be subject to helium leak testing in accordance with the requirements and procedures of the ITER Vacuum Handbook.

7.4 Repair by welding of production welds

No weld repair shall be performed with out qualification of the welding procedure. Welding procedures used for welding repair shall be qualified in accordance with this document.

8 Documentation

All quality assurance documentation required by this procedure shall form part of the delivery to ITER, and shall include:

- Weld plans
- WPS's
- WPQR's and test reports
- Welder qualification's and test reports
- PPS test reports
- Production weld test reports
- Reports on weld repairs
- Non-Conformance Reports

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Guideline (not under Configuration Control)

CAD Manual 12-2 Piping Design

This document describes the DO Piping design rules and methodologies.

Approval Process			
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china eu india japan korea russia usa

CAD Manual

Section 12-2 Piping Design Guidelines

Abstract

This document describes the DO Piping design rules and methodologies.

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1.2	4-02-2010	All	Figures reformatted to correct errors First Approved Version

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12.2 Piping Design Guidelines

12.2.1 Routing Basic Guidelines

1. The high energy lines need to be arranged in the High Energy Line Break (HELB) area where civil structure has been designed with the function of pressure retention and leak tightness in case of line break and other top priority class lines have to be laid out first such as safety related systems.

2. Large diameter pipes should be arranged at the back and small pipes at the front of supports. Pipes that require regular inspection or traced pipes should be positioned to enable access.

3. Non-seismically classified pipes need to be arranged as far as possible from the seismic pipes so as not to affect the seismic pipes in case of break.

4. The safety related components have to be protected from the potential risks of internal or/and external hazards such as impact, earthquake, missiles and high energy line break.

5. Pipes should not be routed above cable trays whenever possible.

6. Routing of pipes containing inflammable gases or fluids should be avoided in areas with potential risk of fire.

7. Pipes with temperatures above 100C should not be routed near a tank with inflammable material.

8. Insulation of pipes is required for heat retention or/and protection against touching if surface temperature >60C.

9. The slope should be followed for gravity pipes and instrumentation according to the requirement shown on the P&ID.

Drain – vent

10. The drain tap need to be designed in order to drain all liquid before inspection/ maintenance.

11. The vent tap need to be designed in order to fill the pipe with liquid without air pocketing after inspection/maintenance.

12. The vent and drain need to be designed as least as possible on which stress is focused, and so the piping dead zone is minimized.

13. The vent and drain valves should be designed for easy access and maintenance by providing platform or ladder, if necessary.

14. Double drain valves can be applied depending on the pressure rating shown on the P&ID. The support should be installed in case of double valves, and support for the double valves needs to be installed from the header line (Tie Back Support) so as to be less-affected from thermal movement and vibration of the header line.

Pump

15. (Pump suction side) 3 to 5 diameter straight pipe length is required at suction side of centrifugal pumps. For the other type of pumps the required straight pipe length is depending on vendor requirements.

16. High points in pump suction lines should be avoided.

17. Do not route piping over the pump, as this interferes with maintenance

18. Locate the pump as closely as practicable to the source of liquid to be pumped from storage tank with consideration of piping flexibility

Welding

19. Weld connections between special parts (e.g.: valve on elbow, T-Piece on elbow etc…) should be avoided where feasible. A distance of a least 1 DN should be considered between two special parts. The pressure drop should be limited.

20. Minimum distance between adjacent welds is 50 mm

12.2.2 Preferred pipe sizes

Preferred pipe sizes according to ASME B36.19 M

DN	NPS	OD (mm)	Schedule	Wall* (mm)	Weight* (kg/m)	Water* (kg/m)
6	1/8	10.3	10 S	1.24	0.28	0.05
			40 S	1.73	0.37	0.04
			80 S	2.41	0.47	0.02
8	1/4	13.7	10 S	1.65	0.49	0.08
			40 S	2.24	0.64	0.07
			80 S	3.02	0.80	0.05
10	3/8	17.1	10 S	1.65	0.64	0.15
			40 S	2.31	0.85	0.12
			80 S	3.20	1.10	0.09
15	1/2	21.3	5 S	1.65	0.80	0.25
			10 S	2.11	1.00	0.23
			40 S	2.77	1.27	0.20
			80 S	3.73	1.63	0.15
20	3/4	26.7	5 S	1.65	1.03	0.43
			10 S	2.11	1.29	0.40
			40 S	2.87	1.70	0.35
			80 S	3.91	2.21	0.28
25	1	33.4	5 S	1.65	1.30	0.71
			10 S	2.77	2.11	0.61
			40 S	3.38	2.52	0.56
			80 S	4.55	3.26	0.46
32	1 ¼	42.2	5 S	1.65	1.66	1.19
			10 S	2.77	2.71	1.06
			40 S	3.56	3.41	0.97
			80 S	4.85	4.50	0.83
40	1 ½	48.3	5 S	1.65	1.91	1.59
			10 S	2.77	3.13	1.44
			40 S	3.68	4.08	1.32
			80 S	5.08	5.45	1.14
50	2	60.3	5 S	1.65	2.40	2.55
			10 S	2.77	3.96	2.36
			40 S	3.91	5.47	2.16
			80 S	5.54	7.53	1.90

(*) Thickness and weight for information only to be validated by calculation (based on schedule)

Table 12.2-1 Preferred ASME pipe sizes (DN6 – DN50)

Non-preferred DN - to be avoided if possible

DN	NPS	OD (mm)	Schedule	Wall* (mm)	Weight* (kg/m)	Water* (kg/m)
65	2 ½	73.0	5 S	2.11	3.71	3.72
			10 S	3.05	5.29	3.52
			40 S	5.16	8.69	3.09
			80 S	7.01	11.48	2.73
80	3	88.9	5 S	2.11	4.54	5.63
			10 S	3.05	6.50	5.38
			40 S	5.49	11.36	4.77
			80 S	7.62	15.37	4.26
100	4	114.3	5 S	2.11	5.88	9.52
			10 S	3.05	7.42	9.19
			40 S	6.02	16.18	8.21
			80 S	8.56	22.46	7.42
125	5	141.3	5 S	2.77	9.52	14.48
			10 S	3.40	11.64	14.21
			40 S	6.55	21.91	12.91
			80 S	9.53	31.14	11.74
150	6	168.3	5 S	2.77	11.38	20.81
			10 S	3.40	13.91	20.48
			40 S	7.11	28.44	18.65
			80 S	10.97	42.83	16.82
200	8	219.1	5 S	2.77	14.87	35.82
			10 S	3.76	20.10	35.16
			40 S	8.18	42.82	32.28
			80 S	12.70	65.06	29.47
250	10	273.1	5 S	3.40	22.76	55.70
			10 S	4.19	27.96	55.04
			40 S	9.27	60.70	50.89
			80 S	12.70	82.08	48.19
300	12	323.9	5 S	3.96	31.44	78.42
			10 S	4.57	36.22	77.81
			40 S	9.53	74.28	72.99
			80 S	12.70	98.09	69.98
350	14	355.6	5 S	3.96	34.56	94.94
			10 S	4.78	41.62	94.05
400	16	406.4	5 S	4.19	41.83	124.42
			10 S	4.78	47.65	123.69

(*) Thickness and weight for information only to be validated by calculation (based on schedule)

Table 12.2-2 Preferred ASME pipe sizes (DN65 – DN400)

Non-preferred DN - to be avoided if possible

DN	NPS	OD (mm)	Schedule	Wall* (mm)	Weight* (kg/m)	Water* (kg/m)
450	18	457	5 S	4.19	47.09	158.07
			10 S	4.78	53.65	157.24
500	20	508	5 S	4.78	59.70	195.13
			10 S	5.54	69.09	193.94
600	24	610	5 S	5.54	83.11	281.73
			10 S	6.35	95.13	280.20
700	28	711	-	7.92	138.20	379.54
			-	9.53	165.91	376.03
800	32	813	-	7.92	158.25	499.09
			-	9.53	190.04	495.07
900	36	914	-	7.92	178.10	633.57
			-	9.53	213.93	629.04
1000	40	1016	-	7.92	198.15	785.65
			-	9.53	238.05	780.60
1100	44	1118	-	7.92	218.20	954.07
			-	9.53	262.18	948.50
1200	48	1220	-	7.92	238.25	1138.83
			-	9.53	286.30	1132.75

(*) Thickness and weight for information only to be validated by calculation (based on schedule)
For DN greater than 600, ASME B36.10 M does not define schedule.

Table 12.2-3 Preferred ASME pipe sizes (DN450 - DN1200)

12.2.3 Preferred tube sizes

Preferred tube sizes				
OD (mm)	OD (inch)	WT (mm)*	Weight (kg/m)*	Water (kg/m)*
6.35	1/4	0.89	0.1	0.1
9.57	3/8	0.89	0.2	0.1
12.7	1/2	0.89	0.3	0.1
19.1	3/4	1.24	0.6	0.2
25.4	1	2.1	1.2	0.4

(*) Thickness and weight for information only and shall be validated by calculation

Table 12.2-4 Preferred tube sizes

12.2.4 Lateral distance between pipes

12.2.4.1 Lateral Distance L between Pipes

The distance between pipes shall be respected as indicated in **Figure 12.2-1** and **Table 12.2-5**

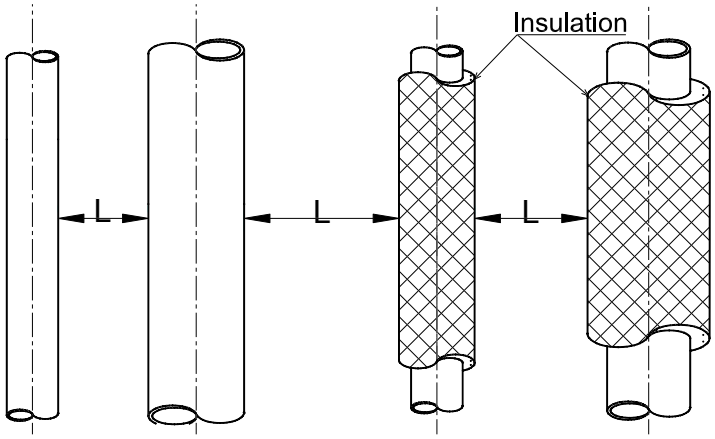


Figure 12.2-1 Distance L between pipes

Lateral distance L between pipes (mm)											
DN	**6 to 10**	**15 to 20**	**25 to 32**	**40 to 50**	**65**	**80**	**100 to 150**	**200**	**250 to 400**	**450 to 700**	**800 to 1200**
6 to 10	10										
15 to 20	20	20									
25 to 32	30	30	30								
40 to 50	50	50	50	50							
65	60	60	60	60	60						
80	80	80	80	80	80	80					
100 to 150	100	100	100	100	100	100	100				
200	150	150	150	150	150	150	150	150			
250 to 400	200	200	200	200	200	200	200	200	200		
450 to 700	250	250	250	250	250	250	250	250	250	250	
800 to 1200	300	300	300	300	300	300	300	300	300	300	300

Table 12.2-5 Lateral distance L between pipes

12.2.4.2 Lateral distance L between clamps

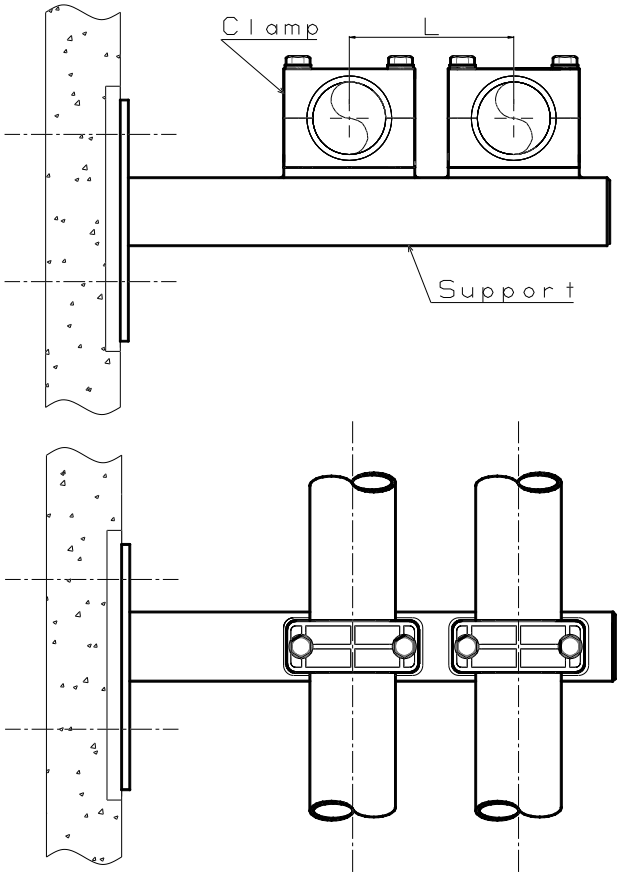


Figure 12.2-2 Distance L between clamps

Lateral distance between Clamps L (mm)										
DN	**NPS**	**6**	**8**	**10**	**15**	**20**	**25**	**32**	**40**	**50**
6	**1/8**	85	85	85	85	90	90	100	120	120
8	**1/4**	85	85	85	85	90	90	100	120	120
10	**3/8**	85	85	85	85	90	90	100	120	120
15	**1/2**	85	85	85	85	90	90	100	120	120
20	**3/4**	90	90	90	90	95	95	105	125	125
25	**1**	90	90	90	90	95	95	105	125	125
32	**1 ¼**	100	100	100	100	105	105	110	130	130
40	**1 ½**	120	120	120	120	125	125	130	150	150
50	**2**	120	120	120	120	125	125	130	150	150

Table 12.2-6 Lateral distance L between clamps

12.2.4.3 Lateral distance L between pipe and wall

The distance between pipe and wall shall be respected as indicated in the **Figure 12.2-3.**

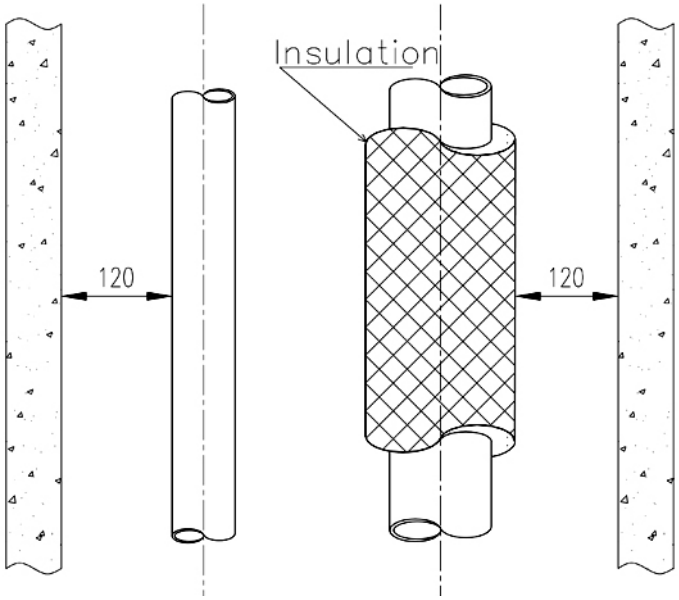


Figure 12.2-3 Lateral distance L between pipe and wall

12.2.5 Thermal Insulation

One of the main goals of the thermal insulation is to increase the efficiency of the facility. The insulation will reduce heat loss by conduction and/or by convection during the process. Personnel will be protected from injury by being prevented from coming into contact with the pipe surface. That is the reason why we have defined the following six functions:

i. HC: Heat Conservation
ii. CC: Cold Conservation
iii. FP: Freezing Protection
iv. CP: Anti-condensation
v. PP: Physical Protection
vi. DC: Double Containment

The material used to perform the insulation is given in the list below:

- Mineral fibre
- Glass-wool

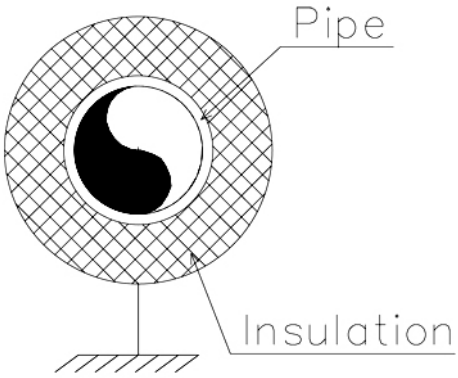


Figure 12.2-4 Insulated pipe

Types of insulation			
Spec	**From (°C)**	**To (°C)**	**Function**
HC	60	Above	Heat conservation
PP	60	Above	Physical protection
X	20	60	None required
FP	Under	0	Freezing protection
CP	-80	20	Anti-condensation
CC	-80	20	Cold conservation
DC	-269	-80	Double containment

Table 12.2-7 Type of insulation

12.2.5.1 HC: Heat Conservation

The minimum insulation thickness in case of heat conservation given in **Table 12.2-1** shall be respected for a preliminary design.

Material calculation data: $\lambda = 0.042 + 0.00014\ T$ (λ in W/m.K and T in K)

Insulation thickness (mm)							
DN	NPS	OD (mm)	60 to 100°C	101 to 200°C	201 to 300°C	301 to 400°C	401 to 500°C
6	1/8	10.3	30	40	50	60	70
8	1/4	13.7	30	40	50	60	70
10	3/8	17.1	30	40	50	60	70
15	1/2	21.3	30	40	50	60	70
20	3/4	26.9	30	40	50	70	100
25	1	33.7	30	40	50	70	100
32	1 ¼	42.4	30	40	50	70	100
40	1 ½	48.3	30	50	60	80	100
50	2	60.3	40	50	60	80	100
65	2 ½	73.0	40	50	60	80	100
80	3	88.9	40	50	60	100	100
100	4	114.3	40	50	60	100	120
125	5	139.7	40	50	60	100	120
150	6	168.3	40	50	70	100	120
200	8	219.1	50	60	70	100	120
250	10	273.0	50	60	70	100	150
300	12	323.9	50	60	70	120	150
350	14	355.6	50	60	70	120	150
400	16	406.4	50	60	70	120	150
450	18	457	50	60	70	120	150
500	20	508	50	60	70	120	150
600	24	610	50	70	100	120	150
700	28	711	50	70	100	120	150
800	32	813	50	70	100	120	150
900	36	914	50	70	100	120	150
1000	40	1016	50	70	100	120	150
1100	44	1118	50	70	100	120	150
1200	48	1220	50	70	100	120	150

Table 12.2-8 Insulation thickness for heat conservation

12.2.5.2 CC: Cold Conservation

The minimum insulation thickness in case of cold conservation given in **Table 12.2-9** shall be respected for a preliminary design.

Material calculation data: $\lambda = 0.051 + 0.00015\ T$ (λ in W/m.K and T in K)

Insulation thickness (mm)							
DN	NPS	OD (mm)	+1 to +20°C	0 to -20°C	-21 to -40°C	-41 to -60°C	-61 to -80°C
6	1/8	17.2	30	40	50	50	60
8	1/4	21.3	30	40	50	60	70
10	3/8	17.2	30	40	50	50	60
15	1/2	21.3	30	40	50	60	70
20	3/4	26.9	30	40	50	60	70
25	1	33.7	30	40	50	60	70
32	1 ¼	42.4	30	40	60	70	80
40	1 ½	48.3	30	50	60	70	80
50	2	60.3	30	50	60	70	80
65	2 ½	73.0	30	50	60	80	90
80	3	88.9	40	50	70	80	90
100	4	114.3	40	50	70	80	90
125	5	139.7	40	60	70	90	100
150	6	168.3	40	60	80	90	100
200	8	219.1	40	60	80	90	100
250	10	273.0	40	60	80	90	110
300	12	323.9	40	60	80	90	110
350	14	355.6	40	60	80	100	110

Table 12.2-9 Insulation thickness for cold conservation

12.2.5.3 FP: Freezing Protection

The minimum insulation thickness for freezing protection given in **Table 12.2-10** shall be respected for a preliminary design.

Material calculation data: $\lambda = 0.051 + 0.00015\ T$ (λ in W/m.K and T in K)

			Thickness of insulation depending on the time without fluid flowing inside the pipe				Time possible to stop with 30mm thickness of insulation
DN	Inch	OD	72 h	48 h	24 h	12 h	Time (h)
6	1/8	10.3					
8	1/4	13.7					
10	3/8	17.1					1
15	1/2	21.3					1
20	3/4	26.9					2
25	1	33.7					3
32	1 ¼	42.4					4
40	1 ½	48.3				90	6
50	2	60.3			200	60	8
65	2 ½	73.0			135	45	9
80	3	88.9		220	70	25	13
100	4	114.3	250	120	50	20	18
125	5	139.7	170	90	40	0	22
150	6	168.3	100	60	25	0	28
200	8	219.1	65	40	20	0	38
250	10	273	50	30	0	0	49
300	12	323.9	40	25	0	0	59
350	14	355.6	35	20	0	0	66

Table 12.2-10 Insulation thickness for freezing protection

Electrical heat tracing to be provided

12.2.5.4 CP: Condensation Protection

The minimum insulation thickness for condensation protection given in **Table 12.2-11** shall be respected for a preliminary design.

Ambient temperature	Relative humidity			
	70 %	80 %	90 %	95 %
20°C (293 K)	14.2 °C	16.3 °C	18.2 °C	19.2 °C
30°C (303 K)	24.0 °C	26.2 °C	28.1 °C	29.1 °C
40°C (313 K)	33.5 °C	35.9 °C	38.0 °C	39.0 °C

Table 12.2-11 Dew point temperature

Material calculation data: $\lambda = 0.051 + 0.00015\ T$ (λ in W/m.K and T in K)

Insulation thickness (mm)							
DN	Inch	OD (mm)	+1 to +20°C	0 to -20°C	-21 to -40°C	-41 to -60°C	-61 to -80°C
6	1/8	10.3	30	40	60	70	80
8	1/4	13.7	30	40	60	70	80
10	3/8	17.1	30	40	60	70	80
15	1/2	21.3	30	40	60	70	80
20	3/4	26.9	30	50	60	80	90
25	1	33.7	30	50	60	80	90
32	1 ¼	42.4	30	50	70	90	100
40	1 ½	48.3	30	50	70	90	100
50	2	60.3	30	50	70	90	100
65	2 ½	73.0	30	60	70	100	110
80	3	88.9	30	60	80	100	110
100	4	114.3	30	60	80	100	120
125	5	139.7	40	60	90	110	30
150	6	168.3	40	60	90	110	130
200	8	219.1	40	70	100	120	140
250	10	273	40	70	100	120	140
300	12	323.9	40	70	100	120	140
350	14	355.6	40	70	100	130	150

Table 12.2-12 Insulation thickness for condensation protection

12.2.5.5 PP: Physical Protection

1. The minimum insulation thickness for physical protection given in **Table 12.2-13** shall be respected for a preliminary design.

Material calculation data: $\lambda = 0.042 + 0.00014\ T$ (λ in W/m.K and T in K)

Insulation thickness (mm)							
DN	Inch	OD (mm)	60 to 100°C	101 to 200°C	201 to 300°C	301 to 400°C	401 to 500°C
6	1/8	10.3	30	40	50	60	80
8	1/4	13.7	30	40	50	60	80
10	3/8	17.1	30	40	50	60	80
15	1/2	21.3	30	40	50	60	80
20	3/4	26.9	30	40	50	60	80
25	1	33.7	30	40	50	60	80
32	1 ¼	42.4	30	40	50	60	80
40	1 ½	48.3	30	50	60	70	100
50	2	60.3	30	50	60	70	100
65	2 ½	73.0	30	50	60	70	100
80	3	88.9	30	50	60	70	100
100	4	114.3	30	50	60	70	100
125	5	139.7	30	50	60	80	100
150	6	168.3	30	50	60	80	100
200	8	219.1	30	50	60	80	100
250	10	273	30	50	60	80	100
300	12	323.9	30	50	70	80	120
350	14	355.6	30	50	70	80	120
400	16	406.4	30	50	70	80	120
450	18	457	30	50	70	80	120
500	20	508	30	50	70	80	120
600	24	610	30	50	70	80	120
700	28	711	30	50	70	80	120
800	32	813	30	50	70	80	120
900	36	914	30	50	70	80	120
1000	40	1016	30	50	70	80	120
1100	44	1118	30	50	70	80	120
1200	48	1220	30	50	70	80	120

Table 12.2-13 Insulation thickness for physical protection

2. In all cases, the maximum surface temperature of pipes that personnel running the facility can come into contact with, shall not exceed 60ºC

12.2.5.6 Fabrication and Erection

Insulation on the valves

The clearance of the valves, including the insulation, shall be taken into account in the design as represented in the **Figure 12.2-5**.

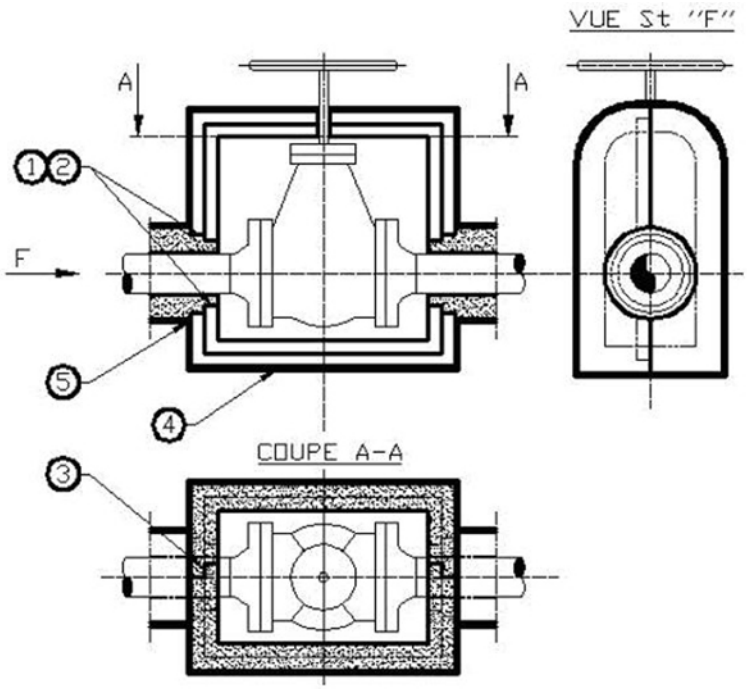


Figure 12.2-5 Insulation on valves

12.2.6 Bends/Elbows

12.2.6.1 Elbows

1. Preferably designers shall use butt welded fittings. Nevertheless, elbow for conventional fluids (without contamination) and services small bore could be socket welded.

2. For radioactive material piping with possibility of contamination, the use of socket welded type components is **prohibited**. Only butt welded type components are allowed.

3. The minimum size of the butt welded elbow clearance should be taken into account in the design (dimension in **Table 12.2-14**).

4. The minimum size of the socket welded elbow clearance should be taken into account in the design (dimension in **Table 12.2-15**).

5. Use of bends is strongly recommended up to DN32 except in particular conditions.

6. The following angles can be used: 15°, 22.5°, 30°, 45°, 60°, 67.5°, 90°.

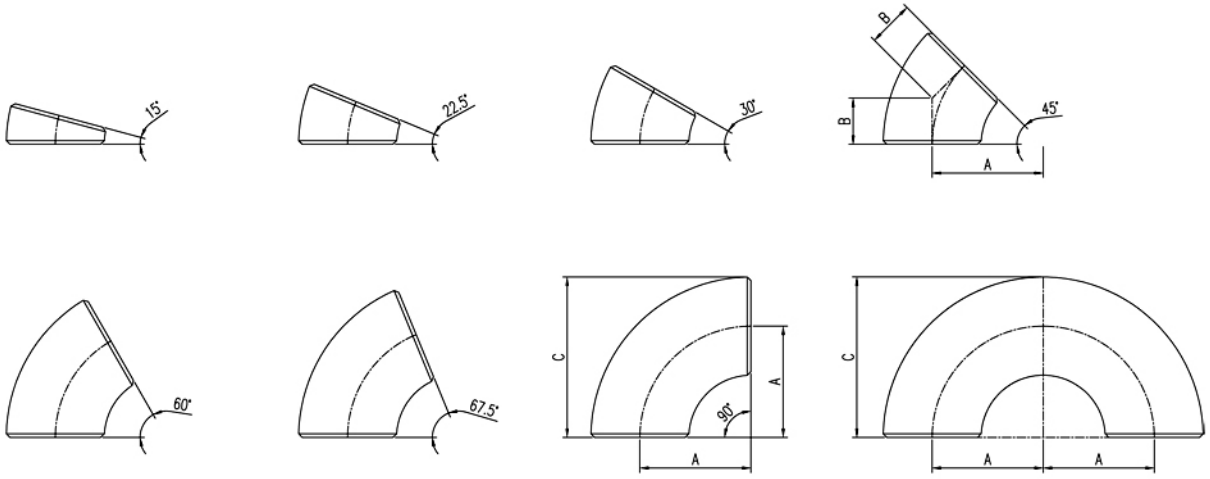
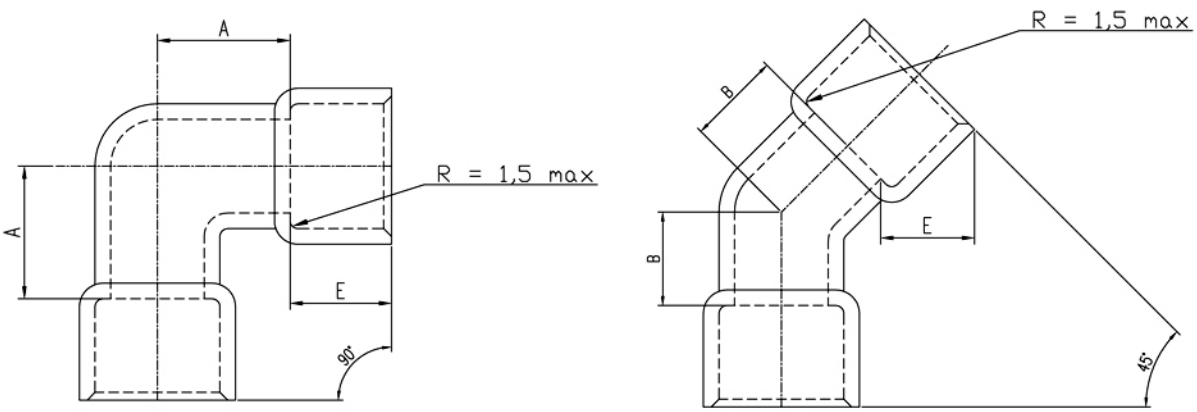


Figure 12.2-6 Butt weld elbows

3D Butt weld elbows according to ASME B16.9					
DN	NPS	OD (mm)	C (mm)	A (mm)	B (mm)
15	1/2	21.3	49	38	14
20	3/4	26.9	51	38	14
25	1	33.7	55	38	22
32	1 ¼	42.4	69	48	25
40	1 ½	48.3	81	57	29
50	2	60.3	106	76	35
65	2 ½	73.0	131	95	44
80	3	88.9	159	114	51
100	4	114.3	210	152	64
125	5	139.7	260	190	79
150	6	168.3	313	229	95
200	8	219.1	414	305	127
250	10	273.0	518	381	159
300	12	323.9	619	457	190
350	14	355.6	711	533	222
400	16	406.4	813	610	254
450	18	457	914	686	286
500	20	508	1016	762	318
550	22	559	1117.5	838	343
600	24	610	1219	914	381
650	26	660	1321	991	406
700	28	711	1422.5	1067	438
750	30	762	1524	1143	470
800	32	813	1625.5	1219	502
850	34	864	1727	1295	533
900	36	914	1829	1372	565
1000	40	1016	2032	1524	632
1050	42	1067	2133.5	1600	660
1100	44	1118	2235	1676	695
1200	48	1220	2439	1829	759

Table 12.2-14 3D Butt weld elbows

Bends to be used except in the case of a specific requirement.



90° ELBOW 45°ELBOW

Figure 12.2-7 Socket weld elbows

Socket weld elbows								
DN	NPS	E (mm)	ISO PN 250		ISO PN 240		ISO PN 600	
			A mm	B mm	A mm	B mm	A mm	B mm
6	1/8	10.0	11.0	8.0	11.0	8.0	-	-
8	1/4	10.0	11.0	8.0	13.5	8.0	-	-
10	3/8	10.0	13.5	8.0	15.5	11.0	-	-
15	1 /2	10.0	15.5	11.0	19.0	12.5	25.0	15.5
20	3 /4	13.0	19.0	12.5	22.5	14.0	28.5	19.0
25	1	13.0	22.5	14.0	27.0	17.5	32.0	20.5

Table 12.2-15 Socket weld elbows

12.2.7 Bends

1. The minimum size of the bend clearance should be taken into account in the design (dimension in **Table 12.2-16**).

2. Preferably the designer should use the 5D bending (regular radius bends **Table 12.2-16**). Only in really dense environments 3D bending (short radius bends **Table 12.2-17**) could be used. In all cases the system engineer should give his agreement.

3. The nominal bend takes into account the nominal fibre and the diameter of the pipes (without the tolerance).

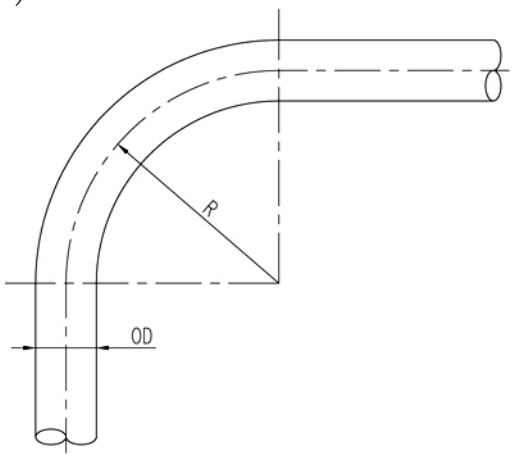


Figure 12.2-8 Bend definition

Regular bends (5D)					
DN	**NPS**	**OD**	**R**	**L1**	**L2**
6	1/8	10.2	51	110	20
8	1/4	13.5	68	110	20
10	3/8	17.2	30	110	20
15	1/2	21.3	45	110	20
20	3/4	26.9	57.5	110	20
25	1	33.7	72.5	110	20
32	1 ¼	42.4	92.5	110	20
40	1 ½	48.3	109	110	20
50	2	60.3	135	140	25
65	2 ½	73.0	365	140	25

Table 12.2-16 Regular bends (5D)

R: bend radius
L1: straight length between two successive bends
L2: straight length between end and tie in (or fillet) weld

The short radius bend will only be used for some restrictive cases with dense environments, and few possibilities of change to the routing of the pipe.

Short radius bends (3D)					
DN	**ND**	**OD**	**R**	**L1**	**L2**
6	1/8	10.2	15	110	20
8	1/4	13.5	24	110	20
10	3/8	17.2	24	110	20
15	1/2	21.3	38	110	20
20	3/4	26.9	38	110	20
25	1	33.7	38	110	20
32	1 ¼	42.4	48	110	20
40	1 ½	48.3	57	110	20
50	2	60.3	76	140	20
65	2 ½	73.0	219	140	25

Table 12.2-17 Short radius bends (3D)

12.2.8 Guidelines on using bends in the design

1. The designer should keep the correct distance between two bends to permit easy erection on site. See **Figure 12.2-9**.

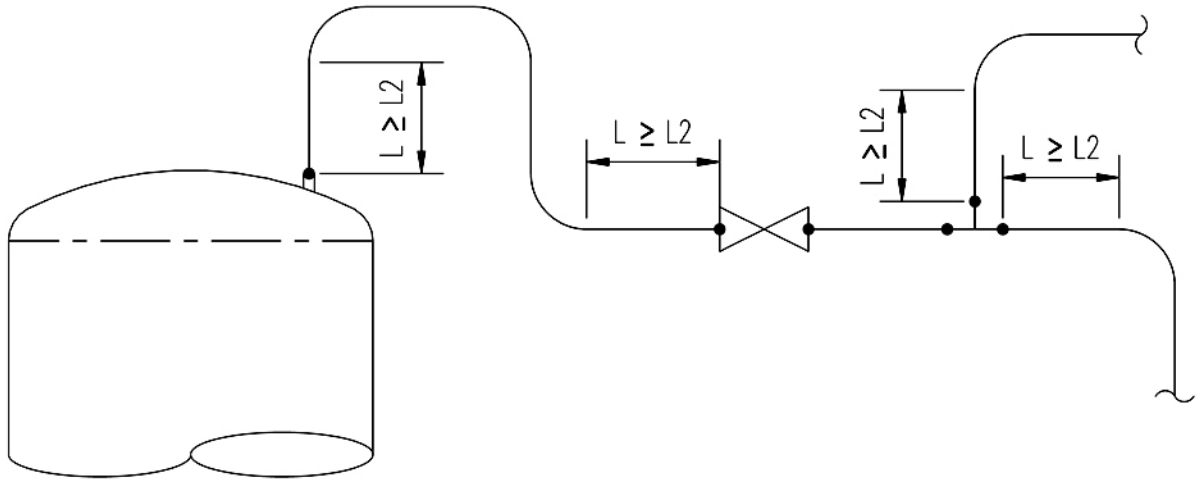


Figure 12.2-9 Distance between bends

2. The designer should check his design taking into account the bend configuration see **Figure 12.2-10** below.

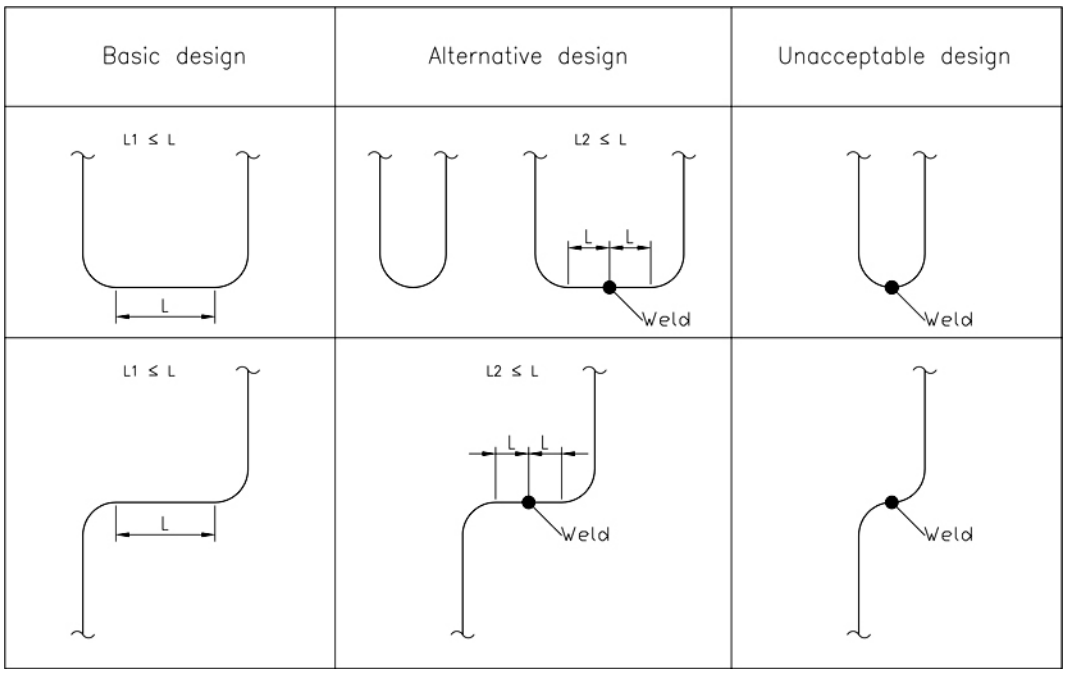


Figure 12.2-10 Bend configuration

12.2.9 Automatic Welding Machine

In order to assure the possibility to use an automatic welding machine, the distances shown in **Table 12.2-18** below shall be kept as clearance.

$Ø_{out}$ (mm)	L (mm)	Ø (mm)
6 to 16	60	85
16 to 32	82	110
32 to 80	82	190
80 to 114	100	280

Table 12.2-18 Clearance for automatic welding machine

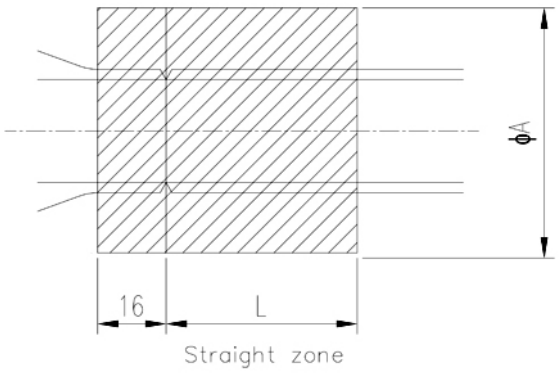


Figure 12.2-11 Welding Machine Clearances

12.2.10 Supports

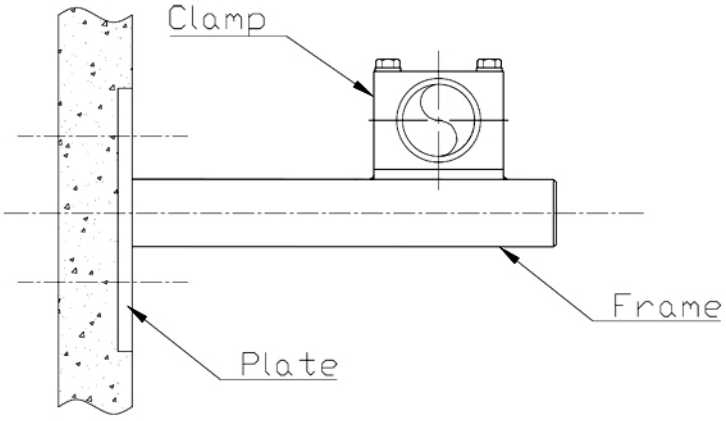


Figure 12.2-12 Support definition

The support is made up of two parts:

- The clamp directly linked to the pipe.
- The frame where the clamp is fixed.

The frame should be fixed on a structural steel frame or directly linked to the concrete by a plate.

Two different types of plate can be used:

- Embedded (the civil company is in charge of providing them)
- Anchored (the system sub-contractor is in charge of providing them)

No shared support.
There must be one support per system.

12.2.10.1 Type of Clamp

12.2.10.2 Horizontal pipe

LG: Longitudinal Guide
AP: Anchor Point

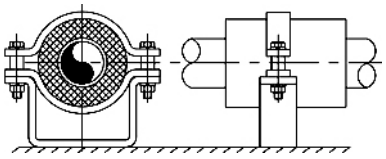
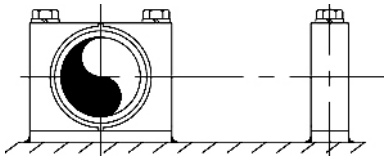
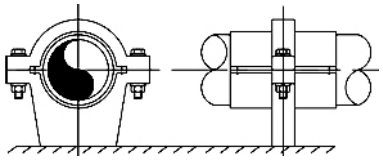
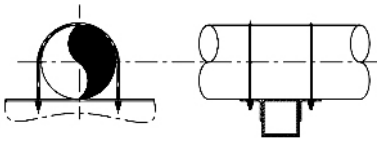
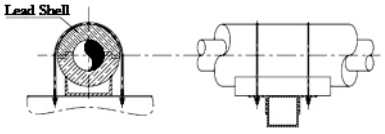
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
0°C to 20°C	15	350	CLA		LG
20°C to 60°C	6	50	CLB		LG AP
	65	200	CLC		LG AP
	250	900	CLD		LG AP
	250	900	CLE		AP

Table 12.2-19 Horizontal Pipe Temperature 0°C to 60°C

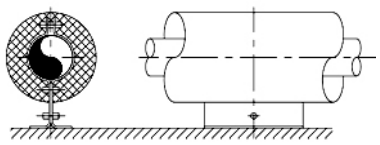
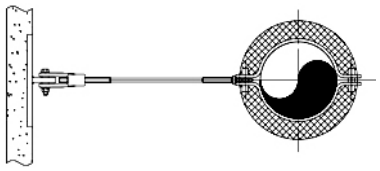
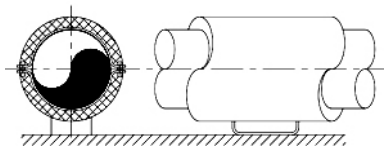
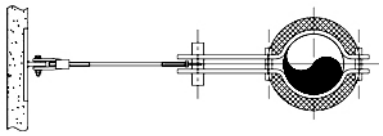
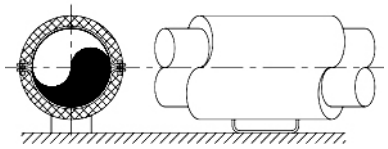
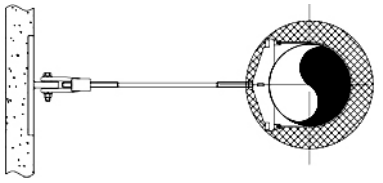
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
60°C to 350°C	15	125	CLF		LG AP
			HLA		Hanger
	150	450	CLG		LG AP
			HLB		Hanger
	500	900	CLG		LG AP
			HLC		Hanger

Table 12.2-20 Horizontal Pipe Temperature 60°C to 350°C

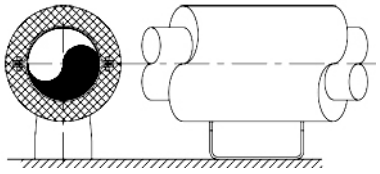
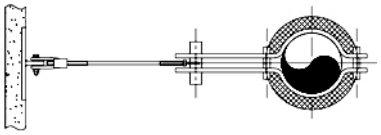
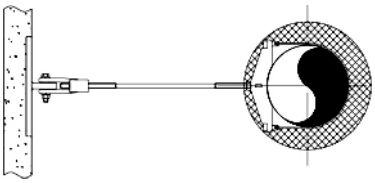
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
350°C to 500°C	15	900	CLH		LG AP
	15	400	HLB		Hanger
	450	900	HLC		

Table 12.2-21 Horizontal Pipe Temperature 350°C to 500°C

12.2.10.3 Vertical pipe

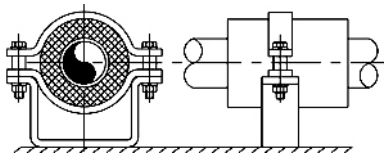
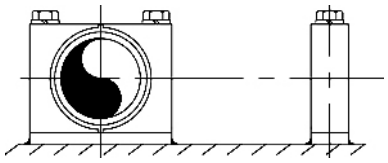
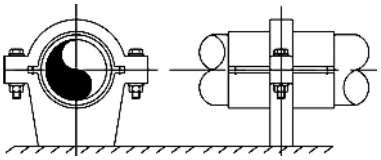
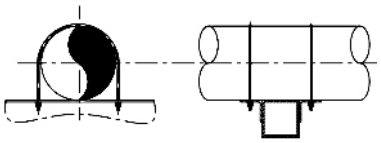
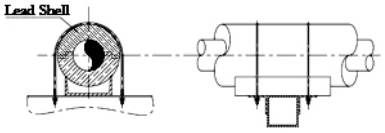
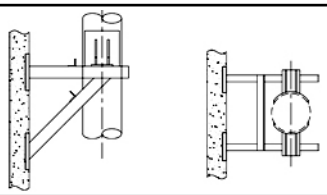
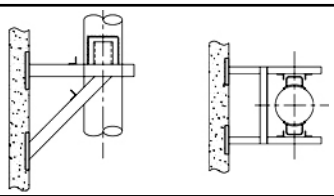
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
0°C to 20°C	15	350	CLA		LG
20°C to 60°C	6	50	CLB		LG AP
	65	200	CLC		LG AP
	250	900	CLD		AP
	250	900	CLE		AP
20°C to 60°C	200	1000	CLI		FP
			CLJ		LG

Table 12.2-22 Vertical Pipe Temperature 0°C to 60°C

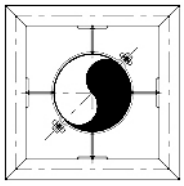
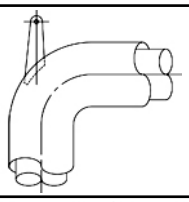
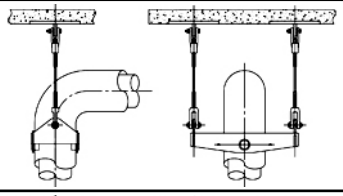
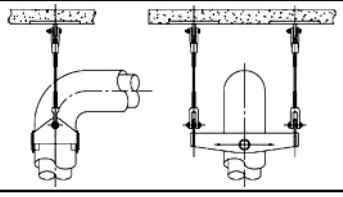
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
60°C to 350°C	40	900	CLK		LG
	32	700	HLD		Hanger
	65	900	HLE		Hanger
350°C to 500°C	65	900	HLE		Hanger

Table 12.2-23 Vertical Pipe Temperature 60°C to 500°C

12.2.10.4 Special support

When pipes up to DN50 are routed together, they can be supported by a special support as follow:

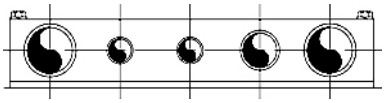
Temperature	DN		Ref. of support	Support preview	Type of connection
	From	To			
20°C to 60°C	6	50	CSA		LG AP

Table 12.2-24 Special support

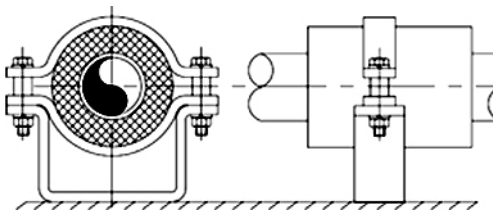


Figure 12.2-13 Clamp CLA

(DN15 to DN350)

Reference	DN	OD (mm)	Mass (kg)
CLA-0015-SS	15	21.3	1.9
CLA-0025-SS	25	33.7	2.1
CLA-0040-SS	40	48.3	4.1
CLA-0050-SS	50	60.3	4.1
CLA-0080-SS	80	88.9	9.5
CLA-0100-SS	100	114.3	14.5
CLA-0125-SS	125	139.7	20.0
CLA-0150-SS	150	168.3	23.0
CLA-0200-SS	200	219.1	32.0
CLA-0250-SS	250	273.0	41.4
CLA-0300-SS	300	323.9	62.4
CLA-0350-SS	350	355.6	76.7

Table 12.2-25 Clamp CLA (DN15 to DN350)

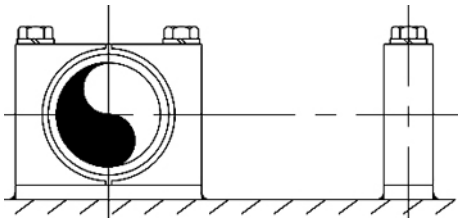


Figure 12.2-14 Clamp CLB

(DN6 to DN50)

Reference	DN	OD (mm)	Mass (kg)
CLB-0006-SS	6	10.2	0.1
CLB-0008-SS	8	13.5	0.1
CLB-0010-SS	10	17.2	0.1
CLB-0015-SS	15	21.3	0.2
CLB-0020-SS	20	26.9	0.2
CLB-0025-SS	25	33.7	0.2
CLB-0032-SS	32	42.4	0.3
CLB-0040-SS	40	48.3	0.3
CLB-0050-SS	50	60.3	0.4

Table 12.2-26 Clamp CLB (DN6 to DN50)

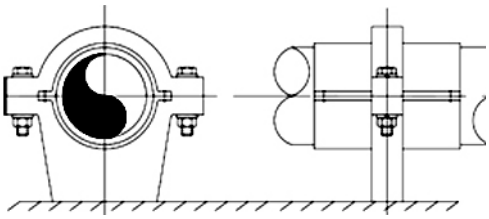


Figure 12.2-15 Clamp CLC

(DN65 to DN250)

Reference	DN	OD (mm)	Mass (kg)
CLC-0065-SS	65	73.0	3.0
CLC-0080-SS	80	88.9	5.0
CLC-0100-SS	100	114.3	11.0
CLC-0125-SS	125	139.7	18.0
CLC-0150-SS	150	168.3	28.0
CLC-0200-SS	200	219.1	33.0

Table 12.2-27 Clamp CLC (DN65 to DN250)

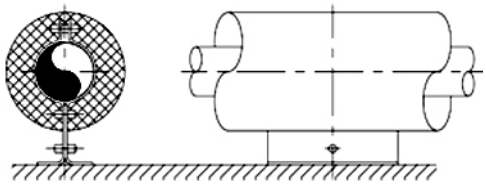


Figure 12.2-16 Clamp CLF

(DN15 to DN125)

Reference	DN	OD (mm)	Mass (kg)
CLF-0015-SS	15	21.3	2
CLF-0020-SS	20	26.9	2
CLF-0025-SS	25	33.7	2
CLF-0032-SS	32	42.4	2
CLF-0040-SS	40	48.3	2
CLF-0050-SS	50	60.3	3
CLF-0060-SS	60	73.0	3
CLF-0080-SS	80	88.9	4
CLF-0100-SS	100	114.3	7
CLF-0125-SS	125	139.7	9

Table 12.2-28 Clamp CLF (DN15 to DN125)

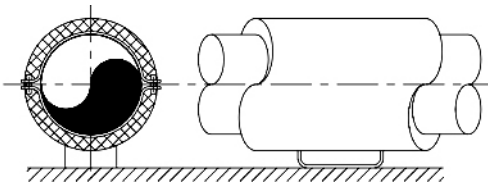


Figure 12.2-17 Clamp CLG

(DN150 to DN900)

Reference	DN	OD (mm)	Mass (kg)
CLG-0150-SS	150	168.3	12
CLG-0200-SS	200	219.1	17
CLG-0250-SS	250	273	25
CLG-0300-SS	300	323.9	27
CLG-0350-SS	350	355.6	34
CLG-0400-SS	400	406.4	47
CLG-0450-SS	450	457	51
CLG-0500-SS	500	508	70
CLG-0600-SS	600	610	107
CLG-0700-SS	700	711	130
CLG-0800-SS	800	813	143
CLG-0900-SS	900	914	177

Table 12.2-29 Clamp CLG (DN150 to DN900)

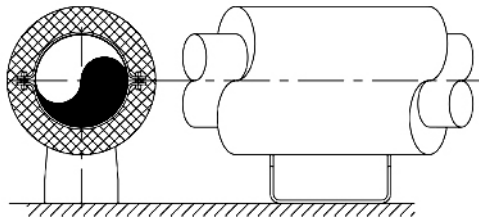


Figure 12.2-18 Clamp CLH

(DN15 to DN900)

Reference	DN	OD (mm)	Mass (kg)
CLH-0015-SS	15	21.3	2
CLH-0020-SS	20	26.9	3
CLH-0025-SS	25	33.7	3
CLH-0032-SS	32	42.4	3
CLH-0040-SS	40	48.3	3
CLH-0050-SS	50	60.3	4
CLH-0060-SS	60	73.0	4
CLH-0080-SS	80	88.9	6
CLH-0100-SS	100	114.3	8
CLH-0125-SS	125	139.7	10
CLH-0150-SS	150	168.3	13
CLH-0200-SS	200	219.1	20
CLH-0250-SS	250	273	28
CLH-0300-SS	300	323.9	32
CLH-0350-SS	350	355.6	46
CLH-0400-SS	400	406.4	64
CLH-0450-SS	450	457	68
CLH-0500-SS	500	508	81
CLH-0600-SS	600	610	120
CLH-0700-SS	700	711	145
CLH-0800-SS	800	813	157
CLH-0900-SS	900	914	195

Table 12.2-30 Clamp CLH (DN15 to DN900)

12.2.10.5 Fixed Hanger Rod

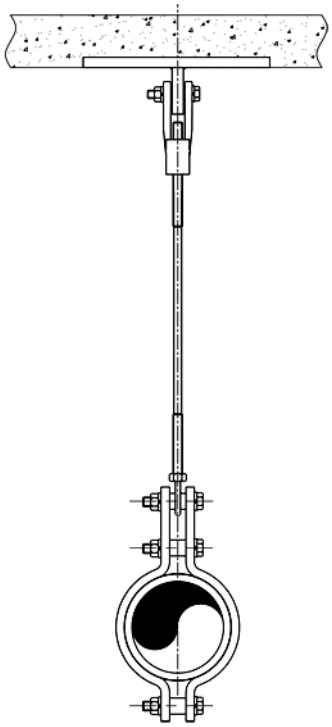


Figure 12.2-19 Hanger rod

Reference	DN	OD (mm)	Mass (kg)
HLA-0015-SS	15	21.3	1
HLA-0020-SS	20	26.9	1
HLA-0025-SS	25	33.7	1
HLA-0032-SS	32	42.4	1.5
HLA-0040-SS	40	48.3	1.5
HLA-0050-SS	50	60.3	2.5
HLA-0065-SS	65	73.0	2.5
HLA-0080-SS	80	88.9	3
HLA-0100-SS	100	114.3	4
HLA-0125-SS	125	139.7	4
HLB-0015-SS	15	21.3	1
HLB-0020-SS	20	26.9	1
HLB-0025-SS	25	33.7	1
HLB-0032-SS	32	42.4	1.5
HLB-0040-SS	40	48.3	1.5
HLB-0050-SS	50	60.3	2.5
HLB-0065-SS	65	73.0	2.5
HLB-0080-SS	80	88.9	3
HLB-0100-SS	100	114.3	4
HLB-0125-SS	125	139.7	4
HLB-0150-SS	150	168.3	5
HLB-0200-SS	200	219.1	7
HLB-0250-SS	250	273	13
HLB-0300-SS	300	323.9	18
HLB-0350-SS	350	355.6	25
HLB-0400-SS	400	406.4	30
HLB-0450-SS	450	457	60
HLC-0500-SS	500	508	100
HLC-0600-SS	600	610	110
HLC-0700-SS	700	711	170
HLC-0800-SS	800	813	270
HLC-0900-SS	900	914	320

Table 12.2-31 Hanger rod

12.2.10.6 Frame

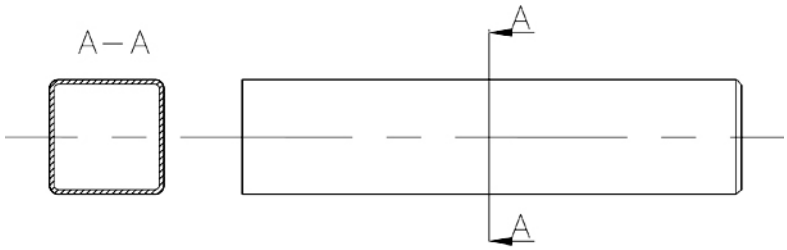


Figure 12.2-20 Square Frame

Reference	Frame dimension
FS-050-SS	50 x 50 x 5
FS-080-SS	80 x 80 x 8
FS-100-SS	100 x 100 x 8
FS-150-SS	150 x 150 x 12
FS-200-SS	200 x 200 x 16
FS-250-SS	250 x 250 x 16
FS-300-SS	300 x 300 x 16
FS-350-SS	350 x 350 x 16
FS-400-SS	400 x 400 x 16

Table 12.2-32 Square Frame dimensions

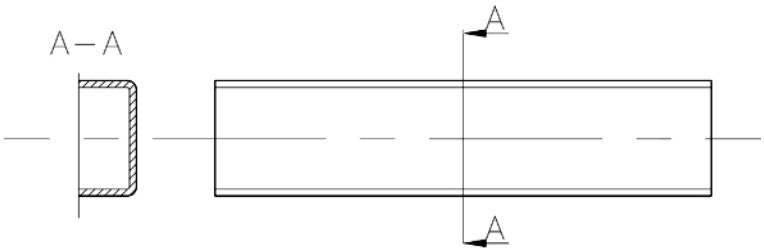


Figure 12.2-21 U Frame

Reference	Frame dimension
FU-080-SS	80 x 80 x 8
FU-100-SS	100 x 100 x 8.5
FU-150-SS	150 x 150 x 10.3
FU-200-SS	200 x 200 x 11.5

Table 12.2-33 U Frame dimensions

12.2.11 Embedded Civil Plate

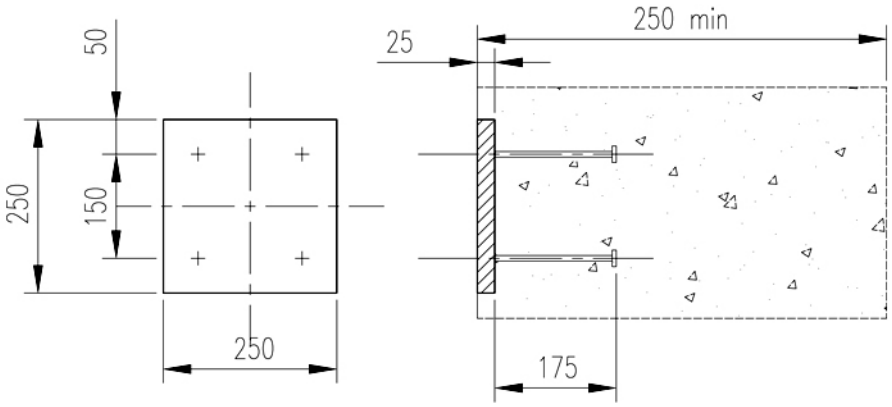


Figure 12.2-22 Embedded plate Type PE-250

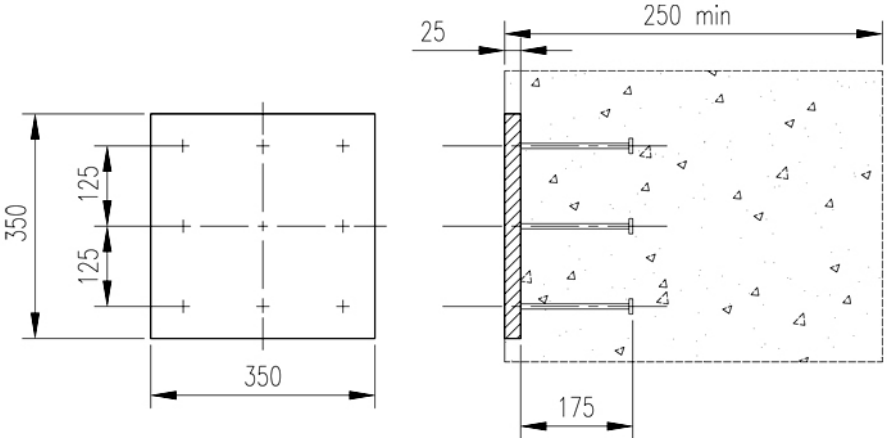


Figure 12.2-23 Embedded plate Type PE-350

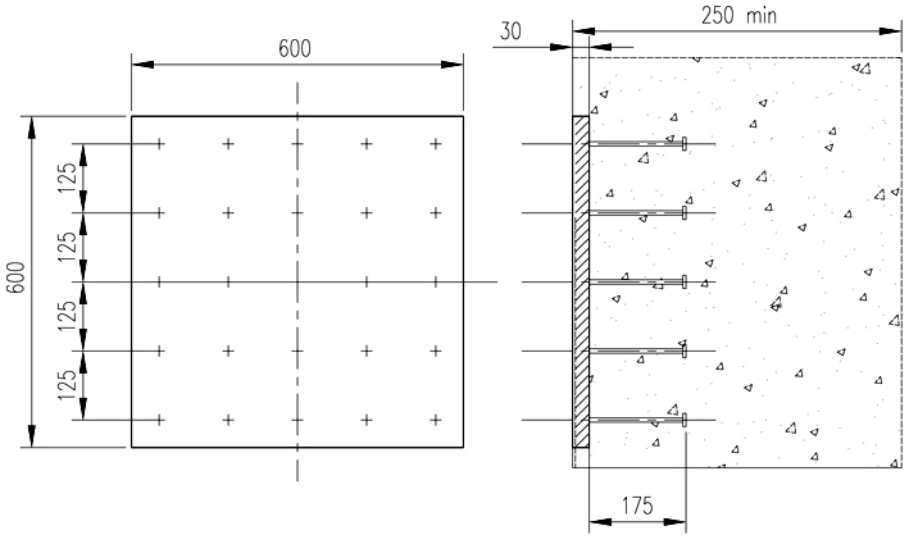


Figure 12.2-24 Embedded plate Type PE-600

12.2.12 Anchored Civil Plate

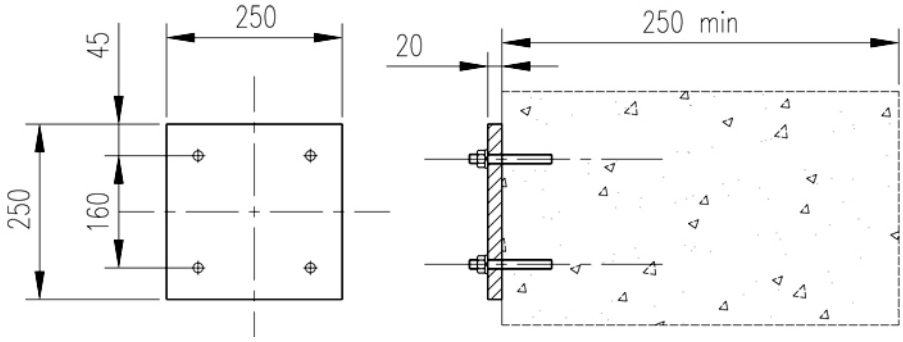


Figure 12.2-25 Anchored plate Type PA-250

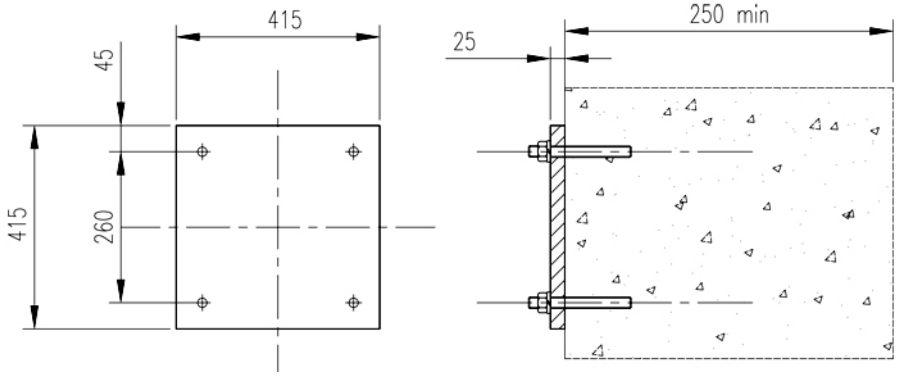


Figure 12.2-26 Anchored plate Type PA-415

12.2.13 Support Estimation

For space reservation during the preliminary layout, the tables below should be followed. This estimation is based on the following rule: the stiffness of the support must be at least 10 times greater than the stiffness of the pipe, considering the span between two supports defined in this document. A stress analysis and calculation shall be performed to confirm them before fabrication and erection.

Note: In the case of multiple supports, the bigger diameter needs to be taken into account. The plates and frames shall be oversized.

The estimation of the frame size and plate is based on the following configuration with different value for the cantilever length L.

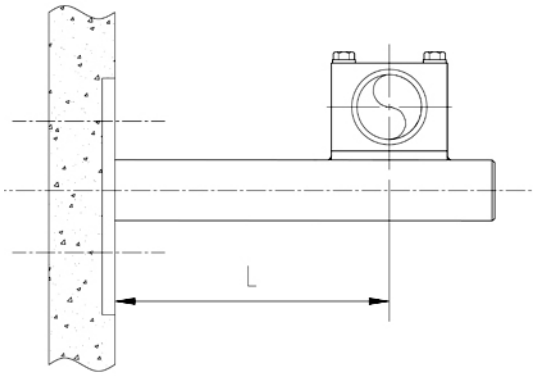


Figure 12.2-27 Cantilever support sizes

Support stiffness (N/mm)						
Section	L (mm)					
	250	500	750	1000	1250	1500
50x50x5	1.18E+04	1.48E+03	4.37E+02	1.85E+02	9.45E+01	5.47E+01
80x80x8	7.74E+04	9.67E+03	2.87E+03	1.21E+03	6.19E+02	3.58E+02
100x100x8	1.61E+05	2.01E+04	5.95E+03	2.51E+03	1.29E+03	7.44E+02
150x150x12	8.13E+05	1.02E+05	3.01E+04	1.27E+04	6.51E+03	3.77E+03
200x200x16	2.57E+06	3.21E+05	9.52E+04	4.02E+04	2.06E+04	1.19E+04
250x250x16	5.27E+06	6.59E+05	1.95E+05	8.24E+04	4.22E+04	2.44E+04
300x300x16	9.41E+06	1.18E+06	3.49E+05	1.47E+05	7.53E+04	4.36E+04
350x350x16	1.53E+07	1.91E+06	5.67E+05	2.39E+05	1.22E+05	7.08E+04
400x400x16	2.32E+07	2.90E+06	8.60E+05	3.63E+05	1.86E+05	1.08E+05

Table 12.2-34 Support stiffness

Cantilever L = 250 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
8	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
10	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
15	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
20	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
25	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
32	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
40	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
50	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
65	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
80	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
100	FS-050-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
125	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
150	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
200	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250

Table 12.2-35 Preliminary size of the plates and frames L = 250 mm

Cantilever L = 500 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
8	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
10	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
15	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
20	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
25	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
32	FS-050-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
40	FS-050-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
50	FS-050-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
65	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
80	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
100	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
125	FS-100-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
150	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
200	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
250	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
300	FS-150-SS + PE-350 / PA-415	FS-200-SS + PE-600/ PA-415
350	FS-150-SS + PE-350 / PA-415	FS-200-SS + PE-600/ PA-415
400	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
450	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
500	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
600	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
700	FS-250-SS + PE-600/ PA-415	FS-300-SS + PE-600

Table 12.2-36 Preliminary size of the plates and frames L = 500 mm

Cantilever L = 750 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
8	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
10	FS-050-SS + PE-250 / PA-250	FS-050-SS + PE-250 / PA-250
15	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
20	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
25	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
32	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
40	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
50	FS-080-SS + PE-250 / PA-250	FS-100-SS + PE-350 / PA-415
65	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
80	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
100	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
125	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
150	FS-150-SS + PE-350 / PA-415	FS-200-SS + PE-600 / PA-415
200	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
250	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
300	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
350	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
400	FS-250-SS + PE-600/ PA-415	FS-300-SS + PE-600
450	FS-250-SS + PE-600/ PA-415	FS-300-SS + PE-600
500	FS-300-SS + PE-600	FS-350-SS + PE-600
600	FS-300-SS + PE-600	FS-400-SS + PE-600
700	FS-300-SS + PE-600	Diagonal strut required
800	FS-350-SS + PE-600	Diagonal strut required
900	FS-350-SS + PE-600	Diagonal strut required
1000	FS-350-SS + PE-600	Diagonal strut required
1100	FS-400-SS + PE-600	Diagonal strut required
1200	FS-400-SS + PE-600	Diagonal strut required

Table 12.2-37 Preliminary size of the plates and frames L = 750 mm

Cantilever L = 1000 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
8	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
10	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
15	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
20	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
25	FS-080-SS + PE-250 / PA-250	FS-100-SS + PE-350 / PA-415
32	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
40	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
50	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
65	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
80	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
100	FS-150-SS + PE-350 / PA-415	FS-200-SS + PE-600/ PA-415
125	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
150	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
200	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
250	FS-250-SS + PE-600/ PA-415	FS-300-SS + PE-600
300	FS-300-SS + PE-600	FS-300-SS + PE-600
350	FS-300-SS + PE-600	FS-350-SS + PE-600
400	FS-300-SS + PE-600	FS-350-SS + PE-600
450	FS-350-SS + PE-600	FS-400-SS + PE-600
500	FS-350-SS + PE-600	Diagonal strut required
600	FS-400-SS + PE-600	Diagonal strut required
700	FS-400-SS + PE-600	Diagonal strut required
800	Diagonal strut required	Diagonal strut required
900	Diagonal strut required	Diagonal strut required
1000	Diagonal strut required	Diagonal strut required
1100	Diagonal strut required	Diagonal strut required
1200	Diagonal strut required	Diagonal strut required

Table 12.2-38 Preliminary size of the plates and frames L = 1000 mm

Cantilever L = 1250 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
8	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
10	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
15	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
20	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
25	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
32	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
40	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
50	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
65	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
80	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
100	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
125	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
150	FS-250-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
200	FS-250-SS + PE-600/ PA-415	FS-300-SS + PE-600
250	FS-300-SS + PE-600	FS-350-SS + PE-600
300	FS-350-SS + PE-600	FS-400-SS + PE-600
350	FS-350-SS + PE-600	FS-400-SS + PE-600
400	FS-350-SS + PE-600	Diagonal strut required
450	FS-400-SS + PE-600	Diagonal strut required
500	Diagonal strut required	Diagonal strut required
600	Diagonal strut required	Diagonal strut required
700	Diagonal strut required	Diagonal strut required
800	Diagonal strut required	Diagonal strut required
900	Diagonal strut required	Diagonal strut required
1000	Diagonal strut required	Diagonal strut required
1100	Diagonal strut required	Diagonal strut required
1200	Diagonal strut required	Diagonal strut required

Table 12.2-39 Preliminary size of the plates and frames L = 1250 mm

Cantilever L = 1500 mm		
DN	Frame + Plate	
	Gas	Liquid
6	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
8	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
10	FS-080-SS + PE-250 / PA-250	FS-080-SS + PE-250 / PA-250
15	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
20	FS-100-SS + PE-350 / PA-415	FS-100-SS + PE-350 / PA-415
25	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
32	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
40	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
50	FS-150-SS + PE-350 / PA-415	FS-150-SS + PE-350 / PA-415
65	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
80	FS-200-SS + PE-600/ PA-415	FS-200-SS + PE-600/ PA-415
100	FS-200-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
125	FS-250-SS + PE-600/ PA-415	FS-250-SS + PE-600/ PA-415
150	FS-300-SS + PE-600	FS-300-SS + PE-600
200	FS-300-SS + PE-600	FS-350-SS + PE-600
250	FS-350-SS + PE-600	FS-400-SS + PE-600
300	FS-400-SS + PE-600	Diagonal strut required
350	FS-400-SS + PE-600	Diagonal strut required
400	Diagonal strut required	Diagonal strut required
450	Diagonal strut required	Diagonal strut required
500	Diagonal strut required	Diagonal strut required
600	Diagonal strut required	Diagonal strut required
700	Diagonal strut required	Diagonal strut required
800	Diagonal strut required	Diagonal strut required
900	Diagonal strut required	Diagonal strut required
1000	Diagonal strut required	Diagonal strut required
1100	Diagonal strut required	Diagonal strut required
1200	Diagonal strut required	Diagonal strut required

Table 12.2-40 Preliminary size of the plates and frames L = 1500 mm

12.2.14 Standard Support

12.2.14.1 Wall mounted

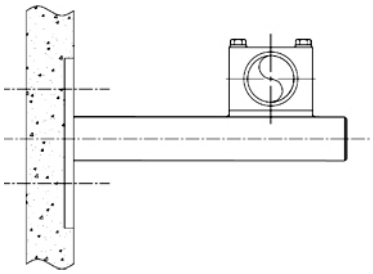


Figure 12.2-28 Cantilever support

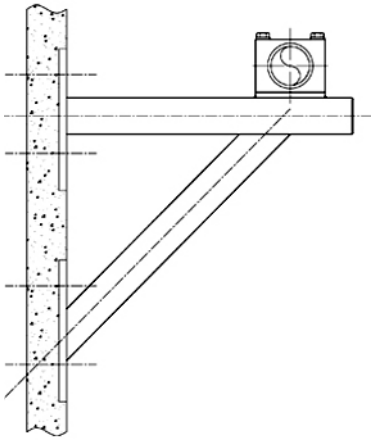


Figure 12.2-29 Braced cantilever support

12.2.14.2 Floor mounted

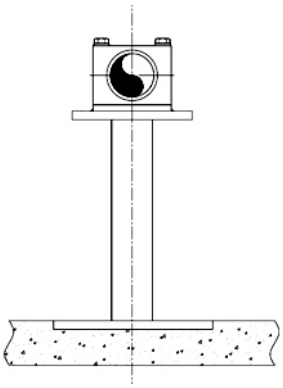


Figure 12.2-30 Column support

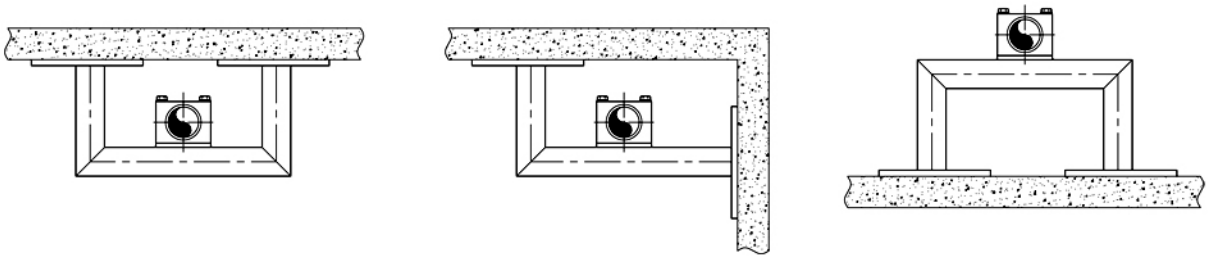


Figure 12.2-31 Plane box frame

12.2.14.3 Ceiling mounted

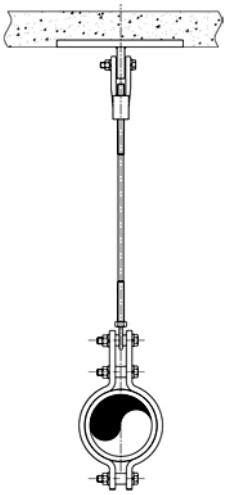


Figure 12.2-32 Single support

12.2.15 The maximum span between Supports

12.2.15.1 Non-seismic horizontal span for pipes

The span for non-seismic spacing should be respected for a preliminary design as indicated in **Table 12.2-41** below. These values are confirmed by detail piping stress analysis.

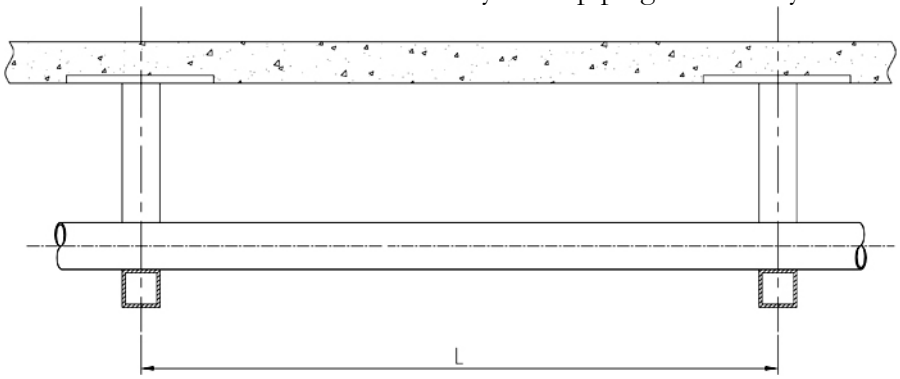


Figure 12.2-33 Span between pipe supports

DN	OD (mm)	WT (mm)	L insulated (m)			L not insulated (m)	
			e_{insul}(*)	Gas	Liquid	Gas	Liquid
6	10.2	2.0	50	0.8	0.8	1.3	1.3
8	13.5	2.3	30	1.1	1.1	1.5	1.5
10	17.2	2.9	30	1.3	1.3	1.8	1.7
15	21.3	3.2	30	1.6	1.5	2.0	1.9
20	26.9	4.0	30	1.9	1.8	2.3	2.1
25	33.7	4.5	30	2.2	2.1	2.6	2.3
32	42.2	5.0	30	2.6	2.4	3.0	2.6
40	48.3	5.6	30	2.8	2.6	3.2	2.8
50	60.3	6.3	30	3.3	3.0	3.6	3.1
65	76.1	7.1	30	3.7	3.4	4.0	3.5
80	88.9	8.0	30	4.1	3.7	4.3	3.8
100	114.3	8.8	40	4.7	4.1	4.9	4.3
125	139.7	10	50	5.2	4.5	5.5	4.7
150	168.3	10	50	5.8	5.0	6.1	5.2
200	219.1	10	50	6.7	5.2	7,1	5.4
250	273.0	10	50	7.5	5,7	7,9	5.8
300	323.9	10	50	8.3	6.0	8.7	6.1
350	355.6	10	50	8.7	6.1	9.1	6.3
400	406.4	10	70	9.1	6.2	9.8	6.4
450	457	10	70	9.5	6.4	10.5	6.8
500	508	10	70	10.0	6.6	11.2	7
600	610	10	100	11.0	6.8	12.2	7.2
700	711	10	100	12.0	7.0	13.4	7.4
800	813	10	100	13.0	7.2	14.5	7.6
900	914	10	100	14.0	7.4	15.4	7.6
1000	1016	10	100	14.8	7.6	16.2	7.6
1100	1118	10	100	15.4	7.6	17.0	7.8
1200	1220	10	100	16.0	7.8	17.6	7.8

(*) insulation taken into account to estimate the total pipe weight

Table 12.2-41 Non-seismic horizontal span between supports

12.2.15.2 Seismic horizontal spacing for pipes

The span for seismic spacing for stainless steel piping should be respected for a preliminary design as indicated in **Table 12.2-42** below:

DN	OD (mm)	WT (mm)	L insulated (m)			L not insulated (m)	
			$e_{insul(*)}$	Gas	Liquid	Gas	Liquid
6	10.2	2.0	30	0.6	0.6	0.8	0.8
8	13.5	2.3	30	0.8	0.8	1.0	1.0
10	17.2	2.9	30	1.0	1.0	1.1	1,1
15	21.3	3.2	30	1.1	1.1	1.2	1.2
20	26.9	4.0	30	1.3	1.3	1.4	1.4
25	33.7	4.5	30	1.5	1.4	1.6	1.5
32	42.2	5.0	30	1.7	1.6	1.8	1.7
40	48.3	5.6	30	1.8	1.8	1.9	1.8
50	60.3	6.3	30	2.1	2.0	2.1	2.1
65	76.1	7.1	30	2.4	2.3	2.5	2.3
80	88.9	8.0	30	2.6	2.5	2.7	2.5
100	114.3	8.8	40	3.0	2.8	3.0	2.8
125	139.7	10.0	50	3.3	3.1	3.4	3.1
150	168.3	10.0	50	3.6	3.4	3.7	3.4
200	219.1	10.0	50	4.2	3.7	4.3	3.7
250	273.0	10.0	50	4.7	4.1	4.8	4.1
300	323.9	10.0	50	5.1	4.4	5.3	4.5
350	355.6	10.0	50	5.4	4.4	5.6	4.5
400	406.4	10.0	70	5.7	4.7	6.0	4.8
450	457	10.0	70	5.7	4.8	6.3	5.1
500	508	10.0	70	6	4.9	6.7	5.2
600	610	10.0	100	6.6	5.1	7.3	5.4
700	711	10.0	100	7.2	5.2	8.0	5.5
800	813	10.0	100	7.8	5.4	8.7	5.7
900	914	10.0	100	8.4	5.5	9.2	5.7
1000	1016	10.0	100	8.9	5.7	9.7	5.7
1100	1118	10.0	100	9.2	5.7	10.2	5.8
1200	1220	10.0	100	9.6	5.8	10.5	5.8

(*) insulation taken into account to estimate the total pipe weight

Table 12.2-42 Seismic horizontal span between supports

12.2.15.3 Non-seismic vertical spacing for piping

The span for non-seismic vertical spacing for stainless steel piping should be respected for a preliminary design as indicated in **Table 12.2-43** below:

DN	OD (mm)	L (m)		DN	OD (mm)	L (m)
6	10.2	1		200	219.1	6
8	13.5	1		250	273.0	7
10	17.2	1		300	323.9	7
15	21.3	2		350	355.6	7
20	26.9	2		400	406.4	7
25	33.7	2		450	457	8
32	42.2	3		500	508	8
40	48.3	3		600	611	8
50	60.3	3		700	712	8
65	76.1	4		800	813	8
80	88.9	4		900	914	8
100	114.3	5		1000	1016	10
125	139.7	5		1100	1118	10
150	168.3	6		1200	1220	10

Table 12.2-43 Non-seismic vertical span between supports

12.2.15.4 Seismic vertical spacing for piping

The span for seismic vertical spacing for stainless steel piping should be respected for a preliminary design as indicated in **Table 12.2-44** below.

DN	OD (mm)	L (m)		DN	OD (mm)	L (m)
6	10.2	1		200	219.1	4
8	13.5	1		250	273.0	5
10	17.2	1		300	323.9	5
15	21.3	1		350	355.6	5
20	26.9	2		400	406.4	5
25	33.7	2		450	457	6
32	42.2	2		500	508	6
40	48.3	3		600	611	6
50	60.3	3		700	712	6
65	76.1	3		800	813	6
80	88.9	3		900	914	6
100	114.3	4		1000	1016	8
125	139.7	4		1100	1118	8
150	168.3	4		1200	1220	8

Table 12.2-44 Seismic vertical span between supports

12.2.16 Valves Integration/Location

General Valve recommendations (GV):

1. The valve must be positioned so that it is well placed for personnel to dismantle.
2. The vertical position should be used.
3. Dismantling of heavy valves should be only vertically.
4. The best location of the hand wheel is at chest height of the workers.
5. The main parameters for the valve arrangement are:
   - The orientation of the pipe supporting the valve,
   - The direction of the stem.

The integration of the valves shall follow the **Figure 12.2-34**.

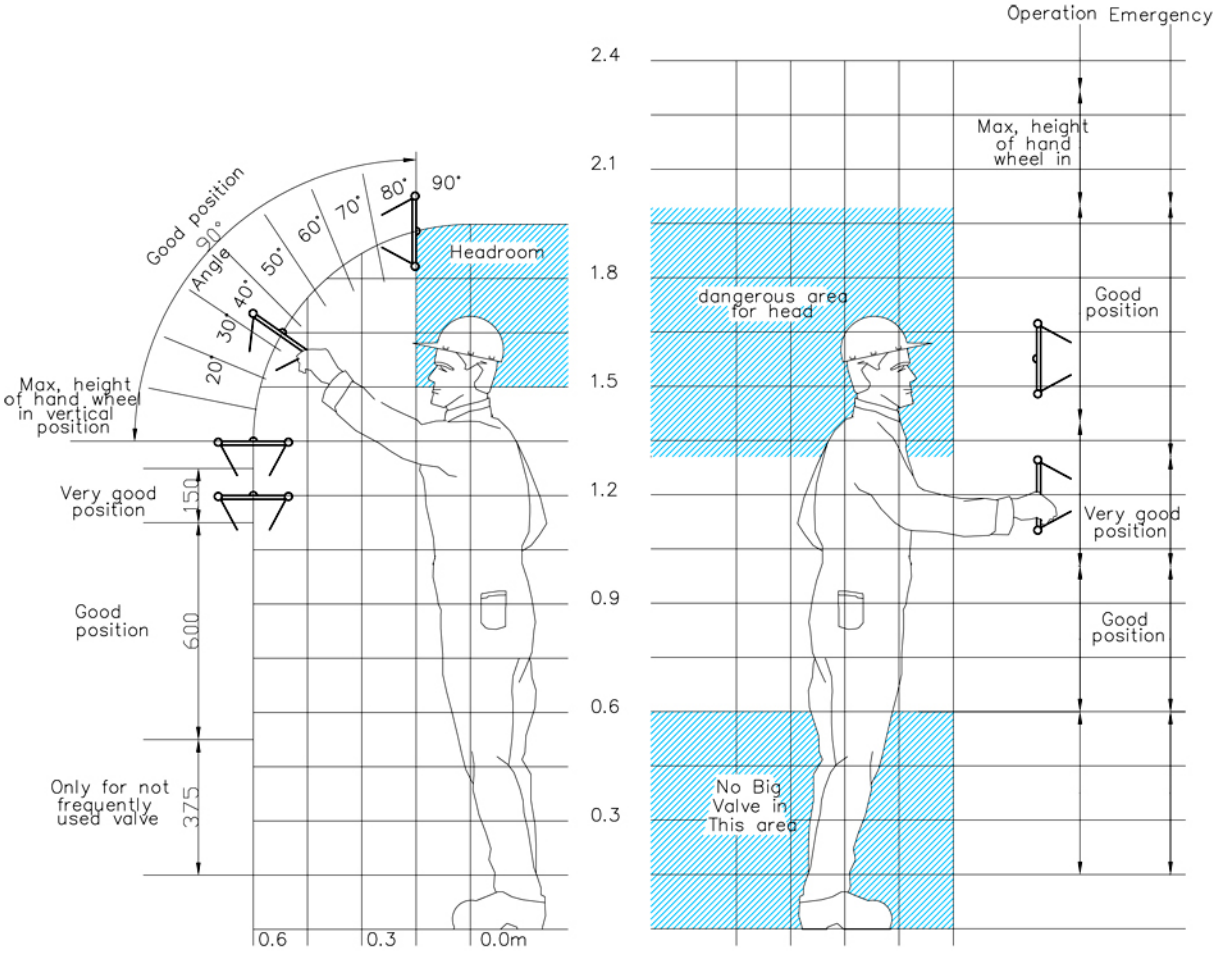


Figure 12.2-34 Valve location for operation and maintenance

Type of valve	Valve Orientation	Stem	Comment
Butterfly valve	Horizontal/vertical	Horizontal	Stem in downward direction to be avoided
Globe valve	Horizontal/vertical	Vertical/Horizontal	Stem in downward direction to be avoided
Gate valve	Horizontal	Vertical	Stem in downward direction to be avoided
Check valve	Horizontal only	Cover in upper position	

Table 12.2-45 Orientation of different valve types

6. Check valve: The minimum clearance distance is 500mm between the top of the valve and the ceiling. This space reservation is necessary for the dressing machine.

12.2.17 Tritium Piping Requirements

To be defined

12.2.18 Vacuum Piping Requirements

Tube will be used instead of pipe up to OD159.

Table 12.2-46 below shows the possible fittings and flange connections.

OD (inch)	OD (mm)	Double ring	VCR	ISO-KF flange	ISO-LF flange
1/4	6.35				
3/8	9.57				
1/2	12.7				
3/4	19.1				
1	25.4				
1 ½	38.1				
2	50.8				
3	76.2				
4 ¼	108				
6 ¼	159				

Table 12.2-46 Preferred tube size for vacuum

Recommended connections.

12.2.19 Cryoline Piping Requirements

1. Use of hanger rod is forbidden for supporting a pipe with an expansion bellow.
2. No pipe can be connected on the expansion below.
3. The number of elbows and welding should be kept as low as possible.

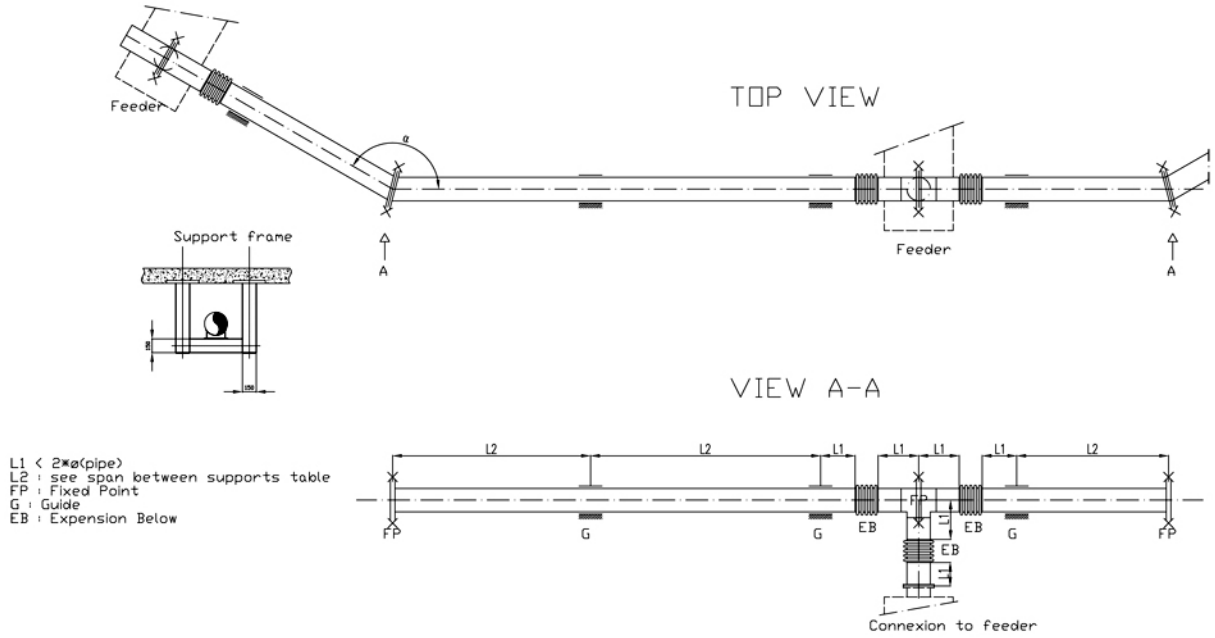


Figure 12.2-35 Support rule for Cryolines