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Guideline (not under Configuration Control)

Cryogenic Handbook

This document provides guidance, reference, specific information, requirements and instructions on all of the ITER cryogenics components.

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1. Purpose

The purpose of this handbook is to ensure safety, reliability and, inasmuch as possible, to provide standardization regarding the ITER cryogenics system. It provides guidance, reference, specific information, requirements and instructions on all of the ITER cryogenics components. Due to the complexity and the multitude of interfaces in the ITER cryogenic system, the present manual shall be one of the baseline documents to be used as reference for cryogenic component design, procurement, manufacturing, delivery, installation, commissioning, operation and maintenance.

This handbook specifies standards, instructions and industrial practices and refers to other handbooks for specific areas such as vacuum, electrical engineering and PCDH.

It is completed by a series of appendices containing the normative and legal documents, references of codes and standards, directives and instructions currently in effect in the host country with regard to approved materials as well as developments of topics included in the main document. (While these appendices do not contain the entire statutory texts, they will provide references to them while quoting the pertinent passages precisely, as well as articles applicable to the components.)

2. Scope

The Cryogenics Handbook is intended for use by all ITER Organization departments and is addressed primarily to system designers and users of the cryogenic system and components. It shall also be used as a complement or reference in the production of procurement specifications for ITER cryogenic components.

This handbook is a high-level requirement document which shall provide guidance for all contributors and users of the ITER cryogenic system.

3. Definitions

Abbreviations and Acronyms

AB	As Built
AFGC	Association Française des Gaz Comprimé (French Association of Compressed Gas)
AISI	American Iron and Steel Institute
ALPEMA	Brazed Aluminium Plate-Fin Heat Exchanger Manufacturer's Association
ANSI	American National Standard Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers

ATEX	ATmosphere EXplosive (Explosive Atmosphere)
BP	British Petroleum
BSEI	Bureau de la Sécurité des Equipment Industriel (Security Office of the Industrial Equipments)
CE	Conformité Européenne (European Compliance)
CLAP	Comité de Liaison des Appareils à Pression (Liaison Committee for Pressure Equipment)
CODAC	COntrol and Data Acquisition, Communication
CTP	Cahier Technique Professionnel (Technical Professional Handbook)
DA	Domestic Agency
DDD	Design Description Document
DGAP	Department of Gas and Pressure Equipment
EAM	European Approval Material
EFTA	European Free Trade Association
EIGA	European Industrial Gases Association
EMC	Electro-Magnetic Capacity
ESR	Essential Safety Requirements
EU	European Union
FMEA	Failure mode Effects Analysis
FORS	Final Oil Removal System
FTA	Fault Tree Analysis
GN2	Gaseous Nitrogen
HAZOP	HAZard OPerability
HMI	Human Machine Interface
HP	High Pressure
HX	Heat exchanger
I&C	Instrumentation and Control
IO	ITER Organization
ISO	International Organization for Standardization
JT	Joule-Thomson
LAr	Liquid Argon
LHe	Liquid Helium
LN2	Liquid Nitrogen
LO2	Liquid Oxygen
MLI	Multi Layer Insulation
MP	Medium Pressure
MTBM	Mean Time Between Maintenance

ORS	Oil Removal System
P&ID	Process and Instrumentation Diagram
PCDH	Process Control Design Handbook
PE	Pressure Equipment
PED	Pressure Equipment Directive
PFD	Process Flow Diagram
PFH	Probability of Failure per Hour
PLC	Programmable Logic Controller
PMA	Particular Material Appraisal
PPB	Parts Per Billion
PPM	Parts Per Million
QA	Quality Assurance
QAP	Quality Assurance Program
R&D	Research and Development
RAMI	Reliability Availability Maintainability Inspectability
RCC-MR	Règles de Conception et de Construction (Design and Construction Rules)
RID	Regulation concerning the International carriage of Dangerous good by rails
RTD	Resistive Temperature Device
SHe	Super critical Helium
SIC	Safety Important Class
SIL	Safety Integrity Level
TAO	Thermo-Acoustic Oscillation
TEMA	Tubular Exchanger Manufacturer Association
TIG	Tungsten Inert Gas
TPE	Transportable Pressure Equipment
UNECE	United Nations Economic Commission for Europe
VLP	Very Low Pressure
WCS	Warm Compressor Station

4. Engineering

4.1 General Design

This chapter describes mandatory requirements and provides the guidelines, where necessary, for the choice of materials and for the design and manufacture of the various cryogenic components of ITER.

Most of these components are classified as Pressure Equipment and enter into the scope of the European Pressure Equipment Directive. The main requirements of this directive and the corresponding French regulatory texts are summarized below.
Guidelines for the design of components other than pressure equipment are also provided.

4.1.1 *Pressure Equipment*

In France, the basic regulatory texts are not specific design and manufacturing codes, but rather are documents formulating general Essential Safety Requirements (ESR) and describing the ways to meet these requirements from the technical and legal points of view. The philosophy of the regulation documents is to confer to the equipment manufacturer the possibility of selecting the design and manufacturing code, in which case the conformity and compliance with the ESR shall be demonstrated.

4.1.1.1 Applicable Regulations

The Pressure Equipment Directive 97/23/EC is one of a series of measures intended to create a single European market. The purpose of the Pressure Equipment Directive is to provide a legal and general structure whereby pressure equipment can be safely manufactured and sold throughout the European community. The means by which this is achieved is to ensure common standards of safety for all pressure equipment.
One of the major principles of this Directive is to set in a regulatory manner only the requirements essential to safety while the technical specifications are contained in each country's standards or codes.
The Directive defines a number of classifications for pressure equipment, based on the hazard associated with their use. Hazard is determined on the basis of stored energy (pressure-volume or pressure-nominal size product) and the nature of the contained fluid.
The assessment and conformity procedures are associated with the different design and manufacturing categories, ranging from self-certification for the lowest hazard (category I), up to full ISO 9001 quality management and/or notified body-type examination for category IV equipment. The assessment procedures are arranged in a modular structure and manufacturers have the choice of which modules to select in order to best suit their application and manufacturing procedures.
In most cases, manufacturers will have their equipment approved in their home country. Manufacturers outside of the EU may also have mandatory approval and test work undertaken in their own factory.
Particular attention shall be given to the fact that responsibility for compliance with the requirements of the Directive will ultimately reside with the party responsible for putting the product on the EU market place.
From a legal point of view, a European directive does not create a direct obligation for the industrial actors. To be applied, it must be transposed into the legislative and regulatory texts of each country of the European Union.
The French Decree of 13/12/1999 relating to pressure equipment made it possible to transpose

European Directive 97/23 of May 29, 1997 relating to pressure equipment and to define the new legal framework applicable in France.
The conditions of the application of the directive in France are also completed by:
French order of 21/12/1999 governing inspection bodies,
French order of 21/12/1999 relative to the classification of pressure equipment,
French order of 15/03/2000 relative to the exploitation of equipment under pressure.
These regulations are summarized in Figure 1.

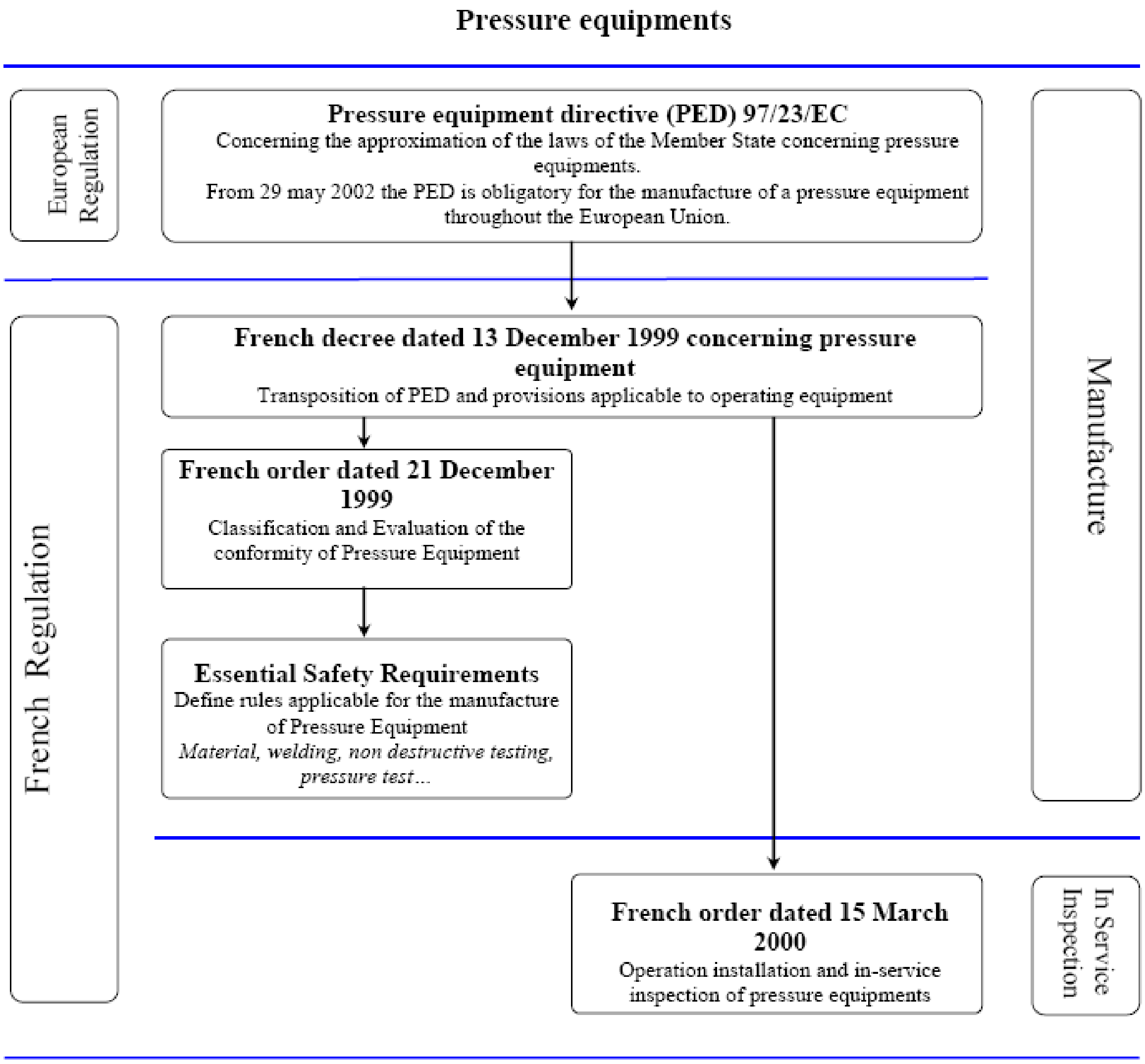


Figure 1: Applicable regulation on pressure equipment and French transposition

4.1.1.2 Definitions-Scope-Classification

4.1.1.2.1 Definitions

<u>Pressure equipment (PE)</u>: Pressure equipment means vessels, piping, safety accessories and pressure

accessories.

Maximum allowable pressure (PS): Means the maximum pressure for which the equipment is designed, as specified by the manufacturer. It is the pressure to which the equipment can be submitted during reasonably foreseeable conditions. This value (PS) must be greater than or equal to the opening pressure of the safety devices which are installed on the equipment.

PS shall be considered as pressure relative to atmospheric pressure for the assessment of the equipment category.

Maximum allowable temperature (TS): Means the maximum temperature for which the equipment is designed. It is the maximum temperature to which the equipment can be submitted during reasonably foreseeable conditions.

Reasonably foreseeable conditions: These conditions are defined in the safety report of the Nuclear Basic Facility and correspond to normal operating situations (normal operation, start, stop, and current incidents), exceptional situations (events with low level of probability of occurrence) and test situations.

Gas: Means fluids for whose vapor pressure at TS is greater than 0.5 bars above normal atmospheric pressure.

Liquid: Means fluids for whose vapor pressure at TS is lower than 0.5 bars above normal atmospheric pressure.

4.1.1.2.2 Scope

The French decree 99-1046 dated 13 December 1999[1] applies to the design, manufacture and conformity assessment of pressure equipment and assemblies with a maximum allowable pressure (PS) greater than 0.5 bar gauge, regardless of the fluid contained (gas or liquid).

Vessels, piping, safety accessories and pressure accessories are all included. The cryogenic equipment covered by the present handbook fall within this pressure range and therefore shall comply with the above-mentioned French decree.

However, some types of pressure equipment can be excluded from the scope of the French decree. This equipment is specified in article 2 of the decree, and listed below are some of the cryogenic system components:

§ b - Networks for the supply, distribution and discharge of water and associated equipment.

§ h - Equipment comprising casings or machinery where the dimensioning, choice of material and manufacturing rules are based primarily on requirements for sufficient strength, rigidity and stability to meet the static and dynamic operational effects or other operational characteristics and for which pressure is not a significant design factor. Such equipment may include:

Engines including turbines,

Gas/steam turbines, compressors, pumps and actuating devices,

§ l – Pressure equipment consisting of a flexible casing,

§ r – Vessels designed to contain liquids with a gas pressure above the liquid not greater than 0.5 bar.

4.1.1.2.3 Classifications

The French order dated 21 December 1999 pertains to classifications of pressure equipment, based on the hazard presented by their application. Depending on the type of the pressure equipment (vessel, piping), hazard is determined on the basis of stored energy and the nature of the contained fluid.
The classification of pressure equipment is made taking into account the following data for fluid group 2 (helium/nitrogen):
The fluid contained is a gas or a liquid (see definition above).
The value of PS
The value of the volume (V) for the vessels and the value of the nominal diameter (DN) for the piping
The value PS x V for the vessels and the value of PS x DN for the piping.
The data defined above allows the manufacturer of pressure equipment to classify it in one of the four categories of the French decree.
These Classifications are summarized in the Appendix 9.1 (classification by nature and by potential hazard).
These four categories correspond to sound engineering practices. These categories are designated from I to IV according to the risk.

4.1.1.3 Notified Body

According to the French decree 99-1046[1] the manufacturing process of pressure equipment classified in categories from I to IV is subject to a conformity assessment, in order to check that the equipment satisfies all the Essential Safety Requirements of the above mentioned decree.
For the pressure equipment in risk categories II to IV, an independent regulatory body selected by area of competence, must be involved in the conformity assessment, for the realization of the verifications, inspections and tests.
The authorization to practice of this organization is delivered by the qualified authority of each country, and this authorization must then be notified to the European commission and all the other European countries.

4.1.1.4 Essential Safety requirement (ESR)

Appendix 1 of the French Decree 99-1046 dated 13 December 1999 [1] defines technical requirements for the manufacture of pressure equipment which are within the scope of the decree [1]. These requirements are called Essential Safety Requirements (ESR).
The ESR concern design, material, welding, heat treatment, non-destructive testing, final inspection and marking requirements. The supplier shall ensure that the equipment supplied meets the requirements (refer to Appendix 9.6) in all aspects and no ITER approval or agreement of any sort

shall in any way dispense the supplier of its responsibility.

4.1.1.4.1 Hazard analysis

The notion of hazard analysis is introduced in the remarks of Annex I "Essential Safety Requirements" of French Decree 99-1046 dated 13 December 1999.
This analysis is performed by the manufacturer before the beginning of design and manufacture of the pressure equipment.
It consists of identifying, via ITER Organization specifications, the hazards and stresses (failure modes or potential degradation) to which the equipment will be subject during reasonably foreseeable conditions of operation (start-up, operation, stop).
The results of the hazard analysis (identification of essential requirements for risk) must be included in the technical documentation, established for the conformity assessment of the pressure equipment.
A template of general risk analysis is attached in Appendix 9.4. Residual risks that were not removed must be clearly identified and brought to the attention of the operator in the instruction manual.
Therefore, the pressure equipment must be correctly designed to support loads corresponding to the use under consideration and under reasonably foreseeable conditions identified in the hazard analysis.
This design must be founded on a method of calculation. An experimental method can also be used on certain conditions.
Provisions must be taken to ensure the safety of operation and handling: interfacing devices, safety devices. Equipment must also allow for the necessary safety-related inspections (access openings). Risks of corrosion, of abrasion, are also to be taken into account.

4.1.1.4.2 Manufacturing

The Essential Safety Requirements pertain to the whole manufacturing process, including production, permanent assemblies, materials, non-destructive tests and final assessment. Through the conformity assessments provided for at each stage of manufacture, the mandatory respect of the ESR shall be demonstrated.

4.1.1.4.2.1 Codes and standards

Before starting the design, the construction code must be identified unless already specified by the ITER Organization. Caution is necessary on this aspect since IO may also impose the construction code and in this case the DA and manufacturers must respect it.
Due to the difficulty of appreciation of some general objectives, the demonstration of ESR compliance may be difficult for the manufacturer. There are two possibilities:
Several European standards have been elaborated to convert the ESR into detailed technical specifications. These harmonized standards officially meet all the Essential Safety Requirements and

presumption of conformity to the Pressure Equipment Directive is granted.

The manufacturer can declare to apply one of these standards, but in this case, it must be clear *that the Pressure Equipment must be in accordance with all the requirements of this code.*

For cryogenic components and assemblies, the exhaustive list of harmonized standards is included in Appendix 9.3

The manufacturer can decide to apply any other construction code, even a proprietary code but must in this case demonstrate its compliance with all the Essential Safety Requirements applicable to the equipment.

For some manufacturing codes this demonstration has already been performed (ASME VIII div. 1, ASME I, RCC-MR 2007…) and the differences have been highlighted.

For other manufacturing codes the compliance with ESR must be demonstrated. In conclusion, pressure equipment must be manufactured in accordance with a manufacturing code which meets all the ESR of French decree [1], and this code is the technical reference document for the manufacturing process.

4.1.1.4.2.1.1 Harmonized standards

- Standard 1: EN 15164 Machines and plants for mining and tooling of natural stone – Safety – Requirements for chain and belt slotting machines
- Standard 2: EN 286-2:1992: Simple unfired pressure vessels designed to contain air or Nitrogen,
- Standard 3: EN 764: Pressure Equipment: Terminology, units, definitions,
- Standard 4: EN 1092-1:2007: Flanges and their joints-Circular flanges for pipes, valves, fittings and accessories,
- Standard 5: EN 1591-1:2001: Flanges and their joints-Design rules for gasketed circular flange connections,
- Standard 6: EN 13445:2009: Unfired pressure vessels

  Parts 3 and 4 of this standard specify the requirements for design and construction of unfired pressure vessels>

  The above list of standards applies for pressure equipment at room temperature.

  The following references concern more specifically cryogenic vessels and components:
- Standard 7: EN 1626: Cryogenic vessels-Valves for cryogenic service
- Standard 8: EN 12434:2000: Cryogenic flexible hoses
- Standard 9: EN 13275:2000: Pumps for cryogenic service
- Standard 10: EN 13371: Cryogenic vessels-Couplings for cryogenic service,
- Standard 11: EN 13458: Cryogenic vessels-Static vacuum insulated vessels.

4.1.1.4.2.2 Materials

The materials used must have adapted characteristics, a sufficient chemical resistance, absence of fragile rupture, and must not to be sensitive to ageing. Moreover, the use of materials at low

temperatures causes specific constraints which have to be addressed.

Within this framework, compliance with the Pressure Equipment Directive can be satisfied either by the application of harmonized standards or other standards, either by the use of a European Approval of Material (EAM) or by the means of particular material appraisal (PMA).

The template of EAM is available using the following link:

http://ec.europa.eu/enterprise/sectors/pressure-and-gas/files/pe-01-01-rev6_en.pdf.

Templates of PMA are available using the following link:

http://ec.europa.eu/enterprise/sectors/pressure-and-gas/files/pe-03-28-guiding-principles-for-the-content-of-pma_en.pdf.

For equipment in category III and IV, this particular evaluation must be performed by the notified body in charge of the conformity assessment of the PE.

4.1.1.4.2.2.1 Normative references

4.1.1.4.2.2.1.1 Materials for cryogenic vessel and cryogenic piping manufacture

- Standard 12: EN 1252-1 Cryogenic vessels. Materials. Part 1: toughness requirements for temperatures below -80 degrees Celsius

  It specifies the toughness requirements of metallic materials for use at temperatures below -80C.

  The method of test and the acceptance criteria are also developed in this standard.

  This standard refers also to other normative publications:
- Standard 13: EN 485-3: Aluminum and aluminum alloys –Sheet, strip and plate part 3.
- Standard 14: EN 1652: Copper and copper alloys – Plate, sheet strip and circles for general purposes.
- Standard 15: EN 1653: Copper and copper alloys – Plate, sheet strip and circles for boilers, pressure vessels and hot water storage units.
- Standard 16: EN 10028-Part 4: Flat products made of steel for pressure purposes – Nickel alloy steels.
- Standard 17: EN 10028-Part 7: Flat products made of steel for pressure purposes – Stainless steels.
- Standard 18: EN 10045-1: Metallic materials – Charpy impact test.
- Standard 19: EN 12163: Copper and copper alloys – Rod for general purposes.
- Standard 20: EN 1252-2 Cryogenic vessels - Materials - Part 2: toughness requirements for temperatures between -80 °C and -20 °C

  It specifies the toughness requirements of metallic materials for use at temperature between -80°C and -20°C.

  Test requirements are developed in this standard, which also refers to other normative publications, including the welding aspect:

- Standard 21: EN 10045-1: Metallic materials – Charpy impact test.
- Standard 22: EN 288-3: Specification and approval of welding procedures for metallic materials.
-

4.1.1.4.2.2.1.2 Material for other vessel manufacture

- Standard 23: EN 13445-3 V1 Unfired pressure vessels - Part 3 : design
  Defines the requirements for steel used in the manufacture of pressure vessels not subjected to flame.
  This standard refers also to other normative publications:
- Standard 24: EN 764-Parts1-2-3: Pressure equipment.
- Standard 25: EN 10002: Metallic materials–Tensile testing.
- Standard 26: EN 10028: Flat products made of steel for pressure purpose.
- Standard 27: EN 10045-1: Metallic materials – Charpy impact test.
- Standard 28: EN 10064: Steel products with improved deformation properties perpendicular to the surface of the product.
- Standard 29: EN 10204: Metallic products – Type of examination documents.
- Standard 30: EN 13445-8 V1 Unfired pressure vessels - Part 8: additional requirements for pressure vessels of aluminum and aluminum alloys
  This specifies additional requirements for pressure vessels of aluminum and aluminum alloys.
  This standard refers also to other normative publications:
- Standard 31: EN 573-3: Aluminum and aluminum alloys – Chemical composition and form of wrought products.
- Standard 32: EN 12392: Aluminum and aluminum alloys – Wrought products.

4.1.1.4.2.2.1.3 Material for warm piping manufacture

- Standard 33: EN 13480-2 Metallic industrial piping - Part 2: materials
  It defines the requirements for industrial piping and supports manufactured from metallic materials. This standard also specifies the requirements for the selection, inspection, testing and marking, and refers as well to other normative publications:
- Standard 34: EN 10028: Flat products made of steel for pressure purposes.
- Standard 35: EN 10045-1: Metallic materials – Charpy impact test.
- Standard 36: EN 10216: Seamless steel tubes for pressure purposes.
- Standard 37: EN 10217: Welded steel tubes for pressure purposes.
- Standard 38: EN 10222: Steel forgings for pressure purposes.
- Standard 39: EN 10269: Steels and nickel alloys for fasteners.
- Standard 40: EN 10272: Stainless steels bars for pressure purpose.

- Standard 41: EN 10273: Hot rolled weldable steel bars for pressure purpose.

4.1.1.4.2.3 Permanent assembly

All permanent joints shall respect the requirements defined in the chosen construction code.

All the welding procedures, as well as the welders, must be qualified. For equipment classified in categories II, III and IV, this qualification must be performed by a notified body or a recognized third party.

The respect of welding rules is ensured by the application of International (ISO) or European (EN) standards. A table of these standards and the definition of the various types of joints are also summarized in the Appendix 9.5 of this Cryogenic Handbook.

These standards are permanently implemented and the date of validity or the latest revisions must be checked each time before applying.

4.1.1.4.2.4 Non-destructive testing

The non-destructive tests provided for in the chosen construction code must be performed by qualified personnel. For the equipment classified in categories III and IV, this personnel must be certified by a recognized third party.

The level of non-destructive tests dictates the joint coefficient to be taken into account during the design.

4.1.1.5 Conformity module assessments

In order to check the respect of the essential requirements of the French decree, the pressure equipment must be submitted to a conformity assessment procedure, prior to being put on the market.

These procedures are clarified in the appendix II of the decree, according to the category of the PE, in the form of 13 different modules. Some of these modules relate only to the design of the equipment, others only to manufacture. These modules are also distinct according to the type of the equipment production (series or unit). Lastly, certain modules imply that the manufacturer sets up a system of quality assurance (Appendix 9.2).

It is thus the responsibility of the manufacturer to choose the modules to be applied according to its type of production and structure.

4.1.1.6 Final assessment

The equipment must be subjected to a final check intended to verify compliance with the directive. This verification includes an examination of the equipment, an examination of the manufacturing documents, as well as a hydraulic test. The value of the hydraulic test must be the greatest of 1.25*PS*f or 1.43*PS where f is the safety factor. The hydraulic test must be performed individually, except for the equipment of category I, for which statistical testing is allowed.

During this inspection, depending on the modules of conformity assessment applied, the presence or

the monitoring of the notified body is mandatory.

4.1.1.7 Marking

The CE Marking is the visual symbol affixed on the PE placed on the market. It means that the equipment is certified to be in conformity with the ESR.
According to appendix V of [1], this marking is always affixed by the manufacturer. However when the directive envisages a conformity check by a notified body, the identification number of this organization must also be reproduced near the CE marking.
There is no CE marking for the PEs subject only to article 7 of [1], "sound engineering practice", even if their manufacture is based on harmonized standards or compliant construction codes.
In addition, Pressure Equipment should bear at least the following markings:

- Identification of the manufacturer,
- Unique identification of model and serial number,
- The year of manufacture,
- Maximum/minimum allowable pressure limits in barg,
- Volume (vessel) in liters,
- Nominal diameter (pipe),
- Testing pressure in barg.

4.1.1.8 Instruction notice (part of documentation)

<u>Reference</u>: French decree 99-1046 dated 13 December 1999 / Appendix I / art. 3.4
When pressure equipment is placed on the market, it must be accompanied, as far as relevant, with instructions for the user, containing all the necessary safety information relating to:

- Mounting,
- Start-up,
- Use,
- Safe operating limits,
- Maintenance, including checks by the user,
- Wearable parts or replaceable components,
- Any other aspects related to residual risks identified during the hazard analysis.

Instructions must cover information affixed on the pressure equipment in accordance with appendix 1 of French Decree, with the exception of the serial number, and must be accompanied, where applicable, by the technical documents, drawings and diagrams necessary for a full understanding of these instructions.
If applicable, these instructions must also refer to hazards arising from misuse. Indeed, the potential risks that were not removed by design and which may result from foreseeable incorrect utilization, must be clearly identified and brought to the attention of the operator in the instruction manual.
The instruction manual can also refer to Design basis (operating conditions expected, calculation code

used, expected lifetime, the joint coefficients, the corrosion allowance, etc.).

4.1.1.9 Safety devices

- Standard 42: prEN 12456: Pressure protection devices for vacuum-insulated cryogenic vessel outer jackets

4.1.1.10 Technical professional book concerning equipment operated at low temperature

The acknowledgment of these documents are established by decisions of the Security Office of Equipment (BSEI) of the French “Ministère de l’Ecologie, du Developpement et de l’Aménagement Durables”.

Technical professional handbook 152-01 (CTP152-01)

This handbook includes specific provisions applicable to simple wall pressure equipment, constitutive of non-refrigerating installations functioning at low temperature.

Technical professional handbook 152-02A (CTP152-02A)

This handbook contains specific provisions applicable to double-wall pressure equipment used for the production or storage of liquid gases at low temperature.

Scopes, benefit, specific provisions for design and manufacture as well as specific in-service rules are given in chapter 5.4.1.5.

4.1.1.11 Guidelines concerning Pressure Equipment and the Pressure Equipment Directive

The CLAP (Liaison Committee for Pressure Equipment) is a Committee set up by the Ministry of Economy, Finance and Industry in order to defend the French point of view on the implementation of Directive 97/23/EC "Pressure Equipment".

The CLAP role is to:

- Collect the questions,
- Develop a common position on these issues,
- Defend this position with all European institutions,
- Spread this information.

The work of the CLAP is materialized in the form of "Question/Answer" files, which specify the level of acceptance of the response (French or European, with identification of the body (GTP)). These files are available on the website AFNOR.

The GTP ("Pressure" working group)

Working Group chaired by the European commission that brings together all member states of the European Union and representatives of Member States of EFTA (Norway, Switzerland), candidate countries for accession to the European Union as well as professional organizations.

4.1.2 *Sub-atmospheric process circuit protection*

4.1.2.1 Main Principles

All components operating below atmospheric pressure have to be protected from air ingress by a helium guard filled with pure helium at 1.05 bars.
In order to detect leaks it will be possible to isolate separately each helium guard circuit by means of a hand valve. The helium guard pressure will be monitored by a pressure transmitter exploitable by the process system. A control loop will regulate the helium guard pressure and will detect the frequency at which the feeding valve opens.
Periodic purge and rinsing of the helium guard circuits will be planned. Consequently, in order to prevent the opening of the safety valves when the helium guard is set under vacuum for purging, the safety valves under helium guard must be calibrated such that they do not open at a pressure difference of 1.5 bars.

4.1.2.2 He guard

All components operating below atmospheric pressure have to be protected from air intake by a guard filled with pure helium at about 1.05 bars. The following items are examples of such components:

- Safety valves
- Instrumentation
- Dynamic seals of valve stems
- Dynamic seals of motor shaft
- Instrumentation and components outside the vacuum vessel, in air environment and not completely welded.
- Space between dynamic seals and safety stuffing boxes

All static seals not completely welded and operating between air and sub-atmospheric helium must be doubled; the space between the seals must have a connection to the helium guard system.
In case of using pressure difference for level measurements of the sub-atmospheric LHe baths, He guards have to be used for the indicators.
All components to be protected by the helium guard shall be proposed by the supplier and approved by ITER Organization.
The principle of helium guards is shown in Figure 2. The helium guard feeding circuit is supplied from a pure helium refrigerator stream. The feeding circuit shall be kept at 1.05 bars. In order to detect leaks, it must be possible to isolate separately each helium guard by means of a manual valve. The helium guards shall be monitored by a pressure transmitter exploitable by the cryoplant control system. One pressure transmitter can be used to monitor several helium guards. Periodic rinsing and purging of all helium guards must be considered. Consequently, in order to prevent the opening of the safety valves when the helium guard circuit is set under vacuum for purging, the safety valves under helium guard must be calibrated such that they do not open at a pressure difference of 1.5 bars.

Single leaks from the helium guard system to the sub-atmospheric circuits must not exceed 10^{-5} mbar.l/s.

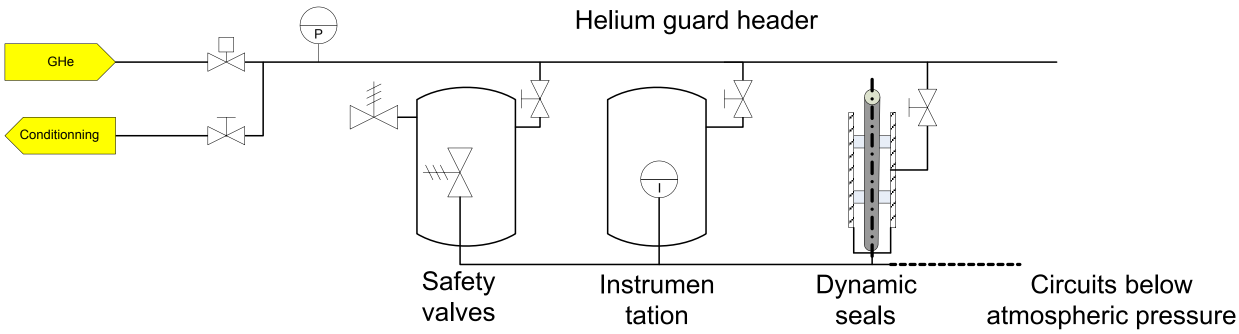


Figure 2: Principle of helium guard

The components of the warm compressor station operating below atmospheric pressure have also to be protected from air intake by a guard filled with helium at 0.105 Pa (1.05 bar):

- Safety valves,
- Instrumentation (pressure temperature and flow), if not equipped with KF flanges,
- Dynamic seals of valve stems if not equipped with bellows

Dynamic seals of motor shaft and slide valve of the sub-atmospheric compressor if located at the suction side and if not protected by double-filling with oil injection.

Except for compressor casing, all static seals of sub-atmospheric components must be welded or equipped with O-ring joints.

4.1.2.2.1 Safety valves

In order to avoid cooling down instrumentation and components during safety valve opening, the safety valves protecting cold volumes must be grouped in separate helium guards designed for cryogenic temperatures. This vessel for safety valves must be protected itself by one or several safety devices.

Attention must be paid to the sizing of safety valve protecting this dome. The circuit to be protected will have to consider the counter pressure of the two safety valves in series.

4.1.2.2.2 Instrumentation

All instrumentation (pressure, differential pressure, temperature, flow meter) if not equipped with KF flange and located in a sub-atmospheric circuit will be put under helium guard.

Instrumentation of the sub-atmospheric circuits will be enclosed in a specific dome filled with helium from the helium guard header which will consist of the helium guard as shown in the Figure 2.

The same protection principle will be used for safety valves protecting sub-atmospheric circuit.

They will be grouped in a dome filled with pure helium from the helium guard header.

4.1.2.2.3 Valves and actuators

All cryogenic valves below atmospheric pressure must be with sealing by metallic bellows connectable to the helium guard circuit. For valves connecting a circuit below atmospheric pressure and a circuit higher than 1.05 bars, it is possible to avoid the helium guard in case of connection of the high helium pressure circuit (valve connection reversed).
Control valves must be spindle valves with sealing by metallic bellows, backed by a safety stuffing box. The volume between the bellows and the safety stuffing must have a connection to a helium guard system. The same facility must exist on spindle-type shut-off valves.
Shut-off valves may be ball valves for a nominal diameter below 100 mm or butterfly valves for a nominal diameter of 100 mm or more. Ball and butterfly valves must have double O-ring shaft seals; the room between the seals must have a connection to the helium guard system. All valves must be leak-tight across the seat when closed.

4.1.3 *Vacuum barriers*

An insulation vacuum barrier is a leak-tight structure, mainly composed of several thin concentric cylinders as a long thermal path between the vacuum vessel and the cold enclosure.
The vacuum barriers are required to separate a vacuum volume in several vacuum compartments, allowing the following functions:

- Containment of an eventual vacuum degradation,
- Facilitate the locating of leaks,
- Facilitate the installation and commissioning of the vacuum system and the cryogenic system,
- Facilitate some specific maintenance operations.

The vacuum barrier must used to provide a separation between the vacuum of cryoline and the vacuum of the cold boxes (CVB, CTB, ACB and cryoplant cold boxes). The vacuum barrier must be part of cold box procurement. Vacuum barrier might be required to divide a cryoline into sectors depending on the functions listed above.
The insertion of a vacuum barrier into a cryogenic vessel or a transfer line introduces thermal loads from the vacuum vessel at room temperature to the pipe supplying the cryogens.
The vacuum barrier must be designed to comply with mechanical and thermal constraints.
As components entering in the constitution of high-vacuum systems, the design and the manufacture must be in accordance with the requirements and recommendations stated in the ITER Vacuum Handbook (Issue 2.3, IDM Ref :ITER_D2EZ9UM)

4.1.3.1 Mechanical Constraints

The vacuum barrier consists of several low thermal conduction cylinders or corrugated pipes welded

between the vacuum vessel and the internal cryogenic lines. It must be designed to withstand the differential thermal contractions between warm mass (vacuum vessel) and cold mass without vacuum leaks.

The vacuum barrier has to fulfill the following mechanical requirement:

Support the pressure difference between vacuum and set opening pressure of vacuum safety valves on each side.

Each vacuum compartment requires a leak-tightness of 10^{-9} Pa.m^3/s with respect to the adjacent ones and to the atmosphere (See the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §25.2 Maximum Acceptance Leak Rates).

In addition, the design must take into account fatigue constraints within the limits defined by the operation conditions and the number of cool-downs and warm-ups foreseen and stipulated in the technical specifications.

4.1.3.2 Thermal Constraints

The vacuum barrier constitutes a thermal bridge between the vacuum vessel at ambient temperature and the cold mass. It will bring solid conduction and radiation heat to the internal pipe supplying the cryogenic fluids (see Figure 3).

The vacuum barrier shall be designed to have the highest thermal impedance to reduce the heat loads. This protection can be reinforced by the use of Multi-Layer Insulation.

A thermal analysis of heat in-leak introduced by the barrier shall be carried out using a simplified model of calculation, including solid conduction, radiation heat transfer between the concentric structures and the Multi-Layer insulation effects.

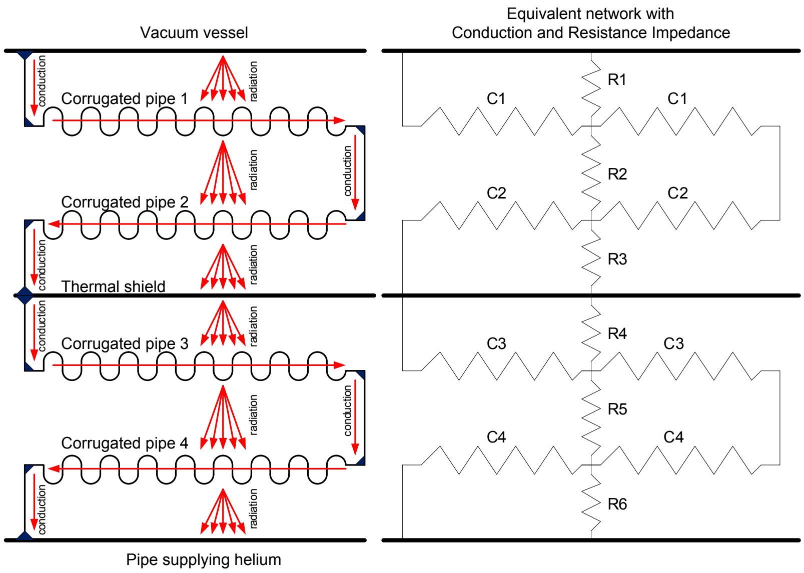


Figure 3: Example of modelling for thermal analysis

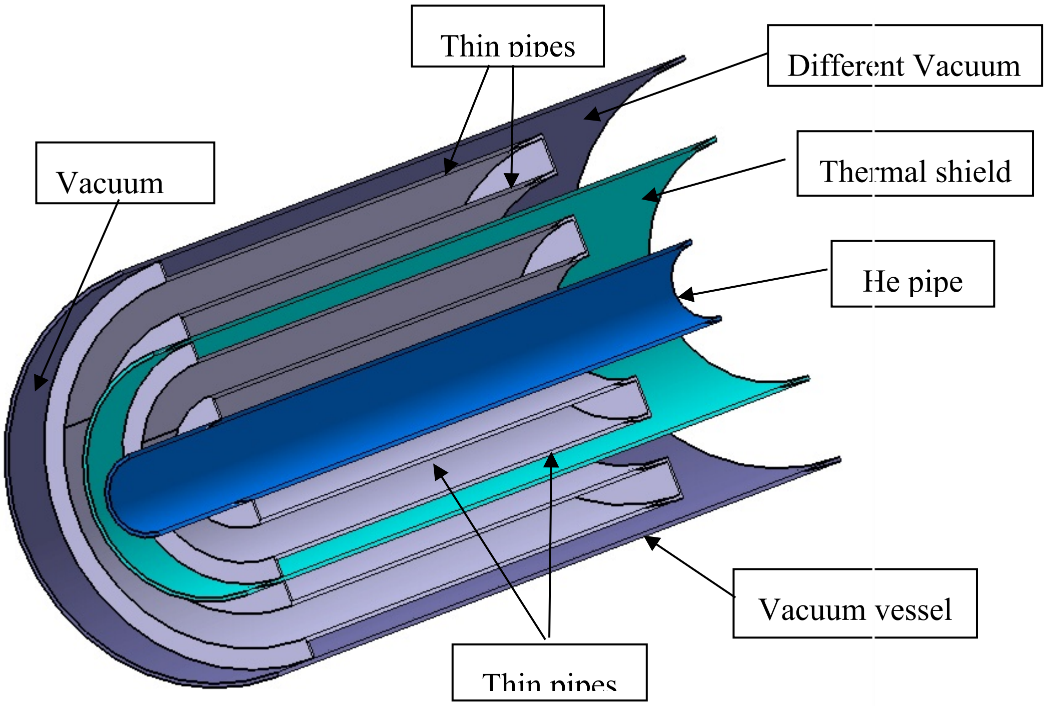


Figure 4: Example of vacuum barrier design

4.1.3.3 Principle of vacuum barrier design

The **Vacuum Vessel** is an envelope made currently in stainless steel (sometimes in carbon steel) which supports the differential pressure between atmosphere and vacuum. The thermal design shall be such that its temperature remains at room temperature with absence of water condensation or ice formation even within proximity of a vacuum barrier.

Thin cylinders or corrugated pipe will reduce the thermal conduction. It shall be designed to have the highest thermal impedance and shall present a compromise between stiffness and flexibility withstanding the mechanical constraints defined in 2.1.5.1 without leakage. Materials do not dilate during cool-down. The thickness must be low enough to ensure a relatively high thermal conduction impedance. The corrugated shape increases the length and thus increases the thermal path. However it should be used only when the concentric cylinder solution does not offer the required flexibility. It is made of stainless steel and welded between vacuum vessel/thermal shield and between thermal shield/helium pipe.

Figure 5 shows two corrugated pipes added concentrically.

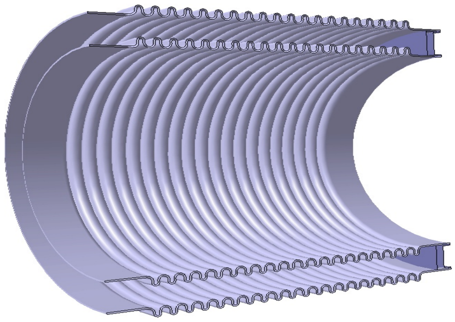


Figure 5: Corrugated pipes

The **Thermal Shield** is a cylindrical shell required for radiation heat protection of the cold mass. This shell is designed to have low thermal impedance. The thermal shield is made of aluminum or copper when it is not placed in a magnetic field; otherwise it is made of stainless steel.

The **Cold Pipe** will supply helium liquid or gas. This pipe must be designed to present high thermal impedance in order to reduce the heat load to the helium liquid or gas. It shall be made of stainless steel.

4.1.3.4 Materials

4.1.3.4.1.1 Useful links

See the **ITER Vacuum Handbook** (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §5 Materials for Use in Vacuum or refer to the chapter 4.1.1.4.2.2 “Materials” of the present Cryogenic Handbook.

4.1.3.5 Assembly of the insulation vacuum barrier

4.1.3.5.1 Welding

See the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §7.1 Welded Joints or refer to the chapter 4.1.1.4.2.3 “Welding” of the present Cryogenic Handbook.

4.1.3.5.2 Brazing

See the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §7.2 Brazed and Soldered Joints or refer to the chapter 4.1.1.4.2.3 “Brazing” of this Cryogenic Handbook.

4.1.3.5.3 Cleaning

See the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §24.1 Cleaning or refer to the chapter 4.1.6 “Cleaning” of this Cryogenic Handbook.

4.1.3.5.4 Qualifications, Inspections and Tests

The vacuum barrier must be considered as a vacuum component. The rules to apply for designing and manufacturing are the same described in the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM), Appendix 5.

The following paragraphs summarize the main rules:

4.1.3.5.5 Tests

The insulation vacuum barriers shall be pressure- and leak-tested, according to this Technical Specification. Prior to the testing, each weld shall undergo a thermal shock at the temperature of liquid nitrogen (77 K). The pressure and leak test to be proposed by the Contractor shall include:

- Pressure tests

When either side is under vacuum or atmospheric pressure the barrier shall be leak tight to helium at a rate greater than 10^{-9} Pa m^3 s^{-1}. Leak detection shall be performed with a calibrated helium mass spectrometer.
Each side of the insulation vacuum barrier shall be pressurized up to a test pressure (0.15 MPa) in accordance with the Safety recommendations stated in the ANSI / ASME standards or equivalent for vacuum components.

- Leak tests

See the ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM) §25 Leak Testing.

4.1.4 *Thermo-acoustic oscillation prevention*

Thermo-acoustic oscillations (TAO) occur in tubes and channels whenever the temperature ratio between the warm and the cold end is sufficiently high (>6) and the warm end is closed. Practically, oscillations often occur in the neck tubes of dewars and in the tubing of pressure sensors linked to low temperature vessels. Such oscillations may cause very high heat flux into the cold vessels and/or may cause important pressure measurement errors.
The principle of this phenomenon resides in the apparition of a thermo-dynamic cycle impacting the gas, producing energy and maintaining the oscillation.

4.1.4.1 Proper design of cryogenic piping to avoid TAO

For particular geometry applications, the theoretical approach allows identification of areas of stability where oscillations cannot occur due to fluid viscosity and inertia and instability region where they can continue and amplify. Examples of these curves are given in the Figure 6.

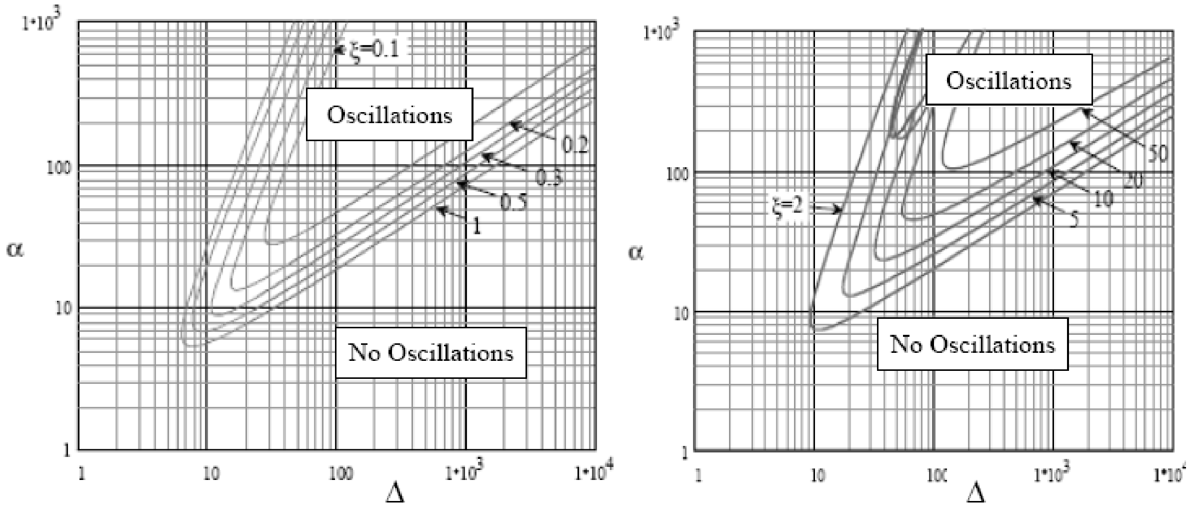


Figure 6: Thermo-acoustic oscillation area

- With α temperature ratio T_{hot}/T_{cold}
  - Δ depends on the radius of the tube and the thickness of boundary layer of the fluid, in which viscosity intervenes.
- $\xi = \frac{L - l_{cold}}{l_{cold}}$, where L is length of the pipe.

Research of stability will therefore consist in minimizing the excitation sources of the phenomena and in increasing viscosity and inertia parameters.

Excitation sources mainly depend on the temperature ratio between cold and warm ends, and the warm exchange surface, while the viscosity parameters must be optimized in the warm area, where they dominate.

The inertia parameters must be optimized by a cold mass increase, obtained by enlarging the diameter of the tube in the low temperature area. However, when the ratio between length and diameter of the pipe (L/D) is less than 100, the acoustic oscillation amplitude is not significant. Moreover, thermo-acoustic oscillations could appear in pipes or tubes for diameters (D) between about 1 mm and 10 mm.

In summary, it is recommended to use:

- Wide pipes in the low temperature area,
- Narrow pipes in the warm area,
- A progressive distribution of temperature over the length of the tube.

4.1.4.2 Design of dynamic dampers

A satisfactory method to design an additional dynamic damper is to adapt its impedance to that of the incoming wave.

When this second oscillator is properly designed, it usually suppresses the oscillations completely.

Formulas to calculate the impedance of various devices are given in classical acoustics literature.

The most common dynamic damper consists of a throttle valve and a reservoir. The valve may also be replaced by another resistive device, such as an orifice or a porous plug.
Consequently, in order to reduce the risk of thermo-acoustic oscillations, all components at ambient temperature which are connected to cold piping, such as sensors, purge and relief valves must be associated with a damping element. It is recommended to implement dampers even cases where calculations exclude possible surge of thermo-acoustic oscillations.

4.1.4.3 Various recommendations

- Restrictions at the cold end of tubes, such as elbows or baffles to insert,
- Small holes drilled into the tube, near the cold-warm interface,
- Forced thermalization of the warm end of the pipe,
- Check-valve with very low loading in the cold extremity of the tube,
- Copper wire in the warm extremity of the tube.
- Counter-flow devices equipped with small orifices.

4.1.5 *Insulation*

4.1.5.1 Main principles

The thermal insulation of cryogenic vessels or lines is necessary in order to limit the heat transfer to the cold parts. This aspect always requires specific assessment depending on the configurations and the temperature levels. In cryogenic applications, the space between the cold and warm vessels must be evacuated at a level depending on the adopted insulation technique. The values are given in the following paragraphs.
Then, actively cooled or non-thermal shielding could be located in the cryostat vacuum between the vacuum vessel at the room temperature and the cold surfaces. Insulation of such a multilayer insulation must be used in cryostats to limit radiation on cold surfaces in association with a high vacuum level.
In addition, thermal insulation must be used for all equipment working at high temperatures for safety purposes.
The following types of insulation could be accepted by IO depending of their cost, the simplicity of implementation, or their lifespan. Nevertheless, they must be approved by IO.

4.1.5.2 Thermal shielding

ITER will accept different types of thermal shields (active and passive shielding) and different type of materials (copper, aluminum, stainless steel …) depending of their location.
The thermal shields are located in the vacuum vessel cryostat between the vacuum vessel at room temperature and the surface close to 4.5 K.
Aluminum and copper materials are recommended for helium gas active cooling thermal shields even if other materials could be used. All materials must be approved for cryogenics. To reduce heat losses

between 80 K and 100 K, MLI should be applied on the thermal shielding when compatible with ITER radiation environment.

4.1.5.3 Vacuum

In case of necessity of dynamic pumping in a cryostat or cryoline, the vacuum equipment must include:

- A primary pump adapted to the secondary pump and to the volume and contents of the cryostat to be pumped.
- A secondary pump capable of pumping at room temperature the vacuum vessel to less than 10^{-3} Pa (10^{-5} mbar). Diffusion pump with a water-cooled baffle or turbo-molecular pump cooled by air or water must be used as secondary stage.
- Three primary vacuum valves, one to connect the primary pump directly to the vacuum vessel, the second to connect it to the suction of the secondary pump, and the third as a spare.
- An isolation valve between the secondary pump and the vacuum vessel, intended to protect the vacuum in the vessel.
- Valve actuators, vacuum gauges, etc. as required to allow remote automatic operation.

4.1.5.4 Multi-Layer Insulation (MLI)

One common radiation barrier used in cryogenic applications is known as Multilayer Insulation (MLI), or Super insulation. MLI consists of many radiation shields (Mylar aluminized) stacked parallel as close as possible without touching one another, separated by spacers (polyester, nylon or Mylar) with low thermal conductivity. The super insulation used must be of a non-flammable type.
Details about the insulation must be given by the manufacturers and must be accepted by IO.
MLI applications require isolation vacuum greater than 10^{-2}Pa.

4.1.5.5 Hot parts

Thermal insulation shall be applied, according to regulations, for high temperature equipment. This concerns equipment staying permanently at high temperatures such as oil retention vessels as well as equipment acquiring elevated temperatures during regeneration periods such as dryers, adsorbers, etc.

4.1.5.6 Insulation for cryogenics from 300 K to 80 K (perlite-insulated, foamglass …)

4.1.5.6.1 Foam Insulation

Foam material insulation requires no vacuum and must be used for temperatures above 200 K. Typical foam insulation includes polyurethane foam, polyamide foam, and foam glass. Foams generally provide a barrier to heat conduction due to their low density. Furthermore, foams inhibit convective heat transfer by limiting convection to the individual cells, fissures, or other spaces within the foam structure. Foam insulation generally includes some form of moisture barrier. When moisture is allowed

to accumulate within the spaces of the foam structure, thermal conductivity rapidly increases.
Foam insulation is generally not a solution of choice cryogenic applications. Such insulation is likely to crack due to thermal cycling and environmental exposure. Cracks permit incursions of moisture and humid air that will form ice and greatly increase the surface area for heat transfer.

4.1.5.6.2 Perlite

Perlite mineral powder insulation for cryogenic use (higher than 80 K) displays low thermal conductivity through a wide range of densities; however, the recommended density is from 48 to 72 kg/m^3. Due to the risk of cracking or compaction, the filling must be performed under vibration.
Vacuum perlite insulation renders thermal properties situated between foam materials insulation and super-insulation and offers the advantage of remaining, unlike super-insulation, effective in the event of severe degradation of the vacuum conditions. This is due to the fact that it completely fills the vacuum space with a relatively larger thickness than MLI. The operating pressure recommended is between 0.1 and 10 Pa but depends on the temperatures and densities. It could be also used with higher vacuum.
For cryogenic insulation of less than 200 K, vacuum-installed perlite offers higher insulation with lower thermal conductivity, depending on the vacuum and the temperature.
Perlite could be used for containers which require particularly low thermal conductivity, such as liquid storage (ex. Nitrogen) or transfer lines.

4.1.5.6.3 Indicative values

Table 1 and Table 2 show indicative values of thermal conductivity and heat flux depending on thermal insulation techniques.

Material	Vacuum level		
	<10^{-2}Pa	~ 100Pa	~ 10^5Pa
Vacuum, polished surfaces	0.5 – 5		
Nitrogen gas at 200K			
Fiberglass	2	14	20
Foam polyurethane (32kg/m^3)			21
Cellular foam glass (128kg/m^3)			33
Perlite powder (128kg/m^3)	1	16	32
MLI, (25 layers/cm)	0.05	10	~25

Table 1: Indicative range of thermal conductivity (mW.m^{-1}.K^{-1}) for different materials between 293K and 77K

Environment	Wall coating	Heat flux (W/m^2)
Air convection 3.5m/s	Without coating	2800
Static air environment	Without coating	1800
Static air environment	Water frost (2mm)	1000
Static air environment	Polyurethane foam (2 cm)	500
Static vacuum ≤10Pa	Perlite powder (10cm)	55
High vacuum (10^{-4} Pa)	Without coating	9
High vacuum (10^{-4} Pa)	Perlite powder (10cm)	4.5
High vacuum (10^{-4} Pa)	Multi Layer Insulation (2 cm with 20 layers /cm)	0.35

Table 2: Indicative range of Heat flux for various configurations between 293K and 77K

4.1.6 *Cleaning surface and treatment*

For cryogenic service, all components must meet all the requirements expressed in:

- Standard 43: NF EN 12300-Cleanliness for cryogenic service.

Considering that cryogenic components are most often contained in vacuum components, the requirements expressed in the Vacuum Handbook are mandatory.
Vacuum Handbook - Appendix 13. (Guide for cleaning and the cleanliness of ITER).
https://user.iter.org/?uid=2ELUQH&action=get_document
In addition, the manufacture of specific components shall require clean rooms and associated controlled environments.

- Standard 44: NF EN ISO 14644-1 to 8 Clean rooms and associated controlled environments

International Standard 44 covers all aspects of this field, namely:

Classification of air cleanliness, specifications for controlling and monitoring to prove continued compliance with standards, test methods, design-construction and start-up of clean room installations, operations, vocabulary, separative devices, classification of airborne molecular contamination.
For other components, the contractor shall at least establish cleaning procedures adapted to its manufacturing facilities. All components shall undergo cleaning prior to assembly, ensuring that they are free of contamination.
The completed components shall also undergo cleaning prior to helium leak testing, according to the following outline procedure. The procedure, including the properties of the cleaning agents, shall be submitted to I.O. for approval

- Degreasing,

Ultrasonic cleaning completely immersed in a bath of heated alkaline detergent solution, when possible,

- Immediate rinsing with demineralized water,
- Drying: the insulation vacuum barrier shall be ventilated with a flow of clean dry air that shall be maintained until values of relative humidity monitored at inlet and exit to the supply channel become identical within 5 %.

After cleaning, degreasing and drying, a local wetting test on an external visible surface shall reveal a film of water covering the wetted surface without showing single droplets.

4.1.7 *Useful documentation*

Several documents emitted by the European Industrial Gases Association (EIGA) can be useful for various aspects of cryogenic component conception and operation. These documents can be found in the linked web site:
http://www.eiga.org/fileadmin/docs_pubs/catalogs/Catalogue_EIGA_Publications.pdf

4.2 Main component requirements

4.2.1 *Storage*

4.2.1.1 Cold storage

4.2.1.1.1 Functional and technical requirements for cryogen storage

The functional requirements and specifications will be in accordance with the operating parameters. They will at least include:

- Design pressure,
- Maximum working pressure,
- Maximum outer dimensions,
- Working temperature range,
- Effective storage volume: liters,
- Maximum boil-off rate per day, under steady state conditions, at full liquid storage capacity,
- Maximum withdrawal flow rate:
    - liters of liquid cryogen per hour under average pressure,
    - liters of cold gas per hour under average pressure
- Planned layout (H/V position, indoor, outdoor, fixed implantation),
- Maximum lateral wind force in case of outdoor implantation,
- Maximum seismic horizontal acceleration,
- Usage of the liquid cryogen.

4.2.1.1.2 Tank equipment

Basically, the tank shall be equipped with:

- One fill line at the bottom and one fill line at the top of the inner tank for road tankers, both equipped with manually operated cold hand valves;
- One line to prevent overfilling of the tank. The line inlet must be placed at critical upper level that leaves an adequate volume for liquid expansion without generating over pressurization.
- One pneumatic on/off valve on liquid withdrawal line;
- One pneumatic on/off valve on gaseous withdrawal line;
- A line with two On/Off cold valves coupled with a vaporizer for the tank pressurization system. These valves can be used to regulate the pressure in the tank remotely. This line shall also be equipped with a mechanical pressure regulation valve placed after the depressurization valve, regulated such that the pressure in the tank cannot rise above the working pressure, even if the pressurization valve is blocked open. The vaporizer has to be calculated in order to maintain constant the dewar pressure at the maximal liquid withdrawal flow rate.
- (The on/off valves can be advantageously replaced by pneumatic control valves).

- An absolute pressure indicator and a differential pressure indicator for local use and a pressure transmitter and a differential pressure transmitter which can be read remotely.

4.2.1.1.3 Safety devices

The tank must comply with the Pressure Equipment Directive including the following points:
The inner tank has to be equipped with a safety block consisting of:

- a change-over valve upstream of the safety valves
- two safety valves set at the maximum working pressure;
- two rupture disks to protect the tank,

This safety block has to be connected to a gas vent line for pressure release.
A manually operated cold hand valve should also connect the vessel to this vent line for the depressurization of the tank in case of emergency.
The safety block, emergency valve and the mechanical pressure reducer have to be placed to avoid the risk of blockage of the safety valves or danger to personnel when operation of the vent valve or pressure reducer.

- The liquid fill line has to be equipped with a safety valve to protect the line and the tank against overpressure during the filling. This safety valve has to be set below the tank's maximum working pressure.

4.2.1.1.3.1 Inner vessel protection
The inner vessels shall be protected with the following pressure relief devices:

- Two stainless steel safety valves with DIN standard flange connections.
- Two reverse bursting disks
- One stainless steel bleed regulator
- One stainless steel change-over valve with DIN standard flange connects two safety sets; each set being constituted of one safety valve and one bursting disk. The change-over valve must be of a never closed type even if left in the middle position.

4.2.1.1.4 Design and manufacture

The vessel shall be designed and manufactured in accordance with standards and techniques satisfying the Pressure Equipment Directive, or sound engineering practice, depending on the pressure equipment category.
According to the Pressure Equipment Directive, prior to construction, the supplier must provide:

- An engineering file including: design calculations, the choice of the materials used,
- A complete set of mechanical drawings, the planned safety inspections, safety tests and quality

control.

- A welding file including: welding materials (filler and base material), welding procedures, welding qualifications, identification of the welders
- Results of destructive and non-destructive tests. The construction of the equipment may only start after ITER has approved the welding procedures.
- Thermal calculations shall allow the evaluation of:
- Thermal losses under operation conditions,
- Maximum mass-flow discharge in case of vacuum insulation breakdown and an external fire, in order to size the safety devices.

In case of foreseen operation in the vertical position, the vessel shall be suspended so as to allow safe transportation in the horizontal position and rotation for erection.
The vessels shall be equipped with suitable attachments for loading, unloading and erection on a concrete platform.
The lower part of the vacuum vessel shall be 1m above the floor level, to make it easy routing of lines and maintenance of associated equipment.
In the event an internal heater is to be associated with the tank, the following thermal calculations will be provided:

- Evaporation capacity of the electrical heater for maintaining the vessel pressure at working pressure,
- Maximum mass-flow discharge for maximum heating power with the gas outlet valves closed.

All valves (hand, electro-pneumatic and pneumatic regulation) have to be of the bellow sealed type.
The cold valves should be placed in vacuum insulated jackets which must be disconnected from the tank vacuum by an internal vacuum barrier, and mounted in a vertical or inclined (max. 45 degrees) position.
For the vacuum vessel, the perlite insulation technique shall be used. A connection with valves and ISO KF flange shall allow vacuum pumping and checking. To avoid perlite extraction during pumping, a filter must be foreseen.

4.2.1.1.5 Recommended materials

- Inner tank: stainless steel AISI 304 L or 316L,
- Outer tank and feet: stainless steel 304L / 304 LN or 316L ,
- All piping : stainless steel 316L,
- All valves : stainless steel AISI 304 L or 316L,
- Atmospheric heater: aluminum (finned pipes),

- Electrical heater (body) if any: stainless steel AISI 304L.

4.2.1.1.6 Cleaning and surface treatment

The proposed cleaning procedure shall be approved by ITER.
All surfaces of the inner vessel and pipe work must be clean and free from contamination, especially any material likely to impair the vacuum by degassing.
The external surface of the vacuum vessel shall be sand-blasted and painted with an 80 Xm coating of primer and two coats of white color for cryogenic vessels.

4.2.1.1.7 Inspection of welds

All welds shall conform to the most recent requirements of the construction code chosen.
Welders shall possess a valid certificate issued by an approved inspection authority.
Butt welds (longitudinal and circumferential) on inner vessel and piping shall be checked by 100 % radiography.
For the vacuum vessel, butt welds (longitudinal and circumferential) shall be subjected to 10 % and T-joints to 100 % radiography.

4.2.1.1.8 Leak rates

Leak testing shall be carried out using the helium leak detection method.
Pressure and leak tests of components, such as cold valves, safety valves, bellows, etc. shall be executed prior to integration into the vessel.
The single leakage from internal circuit at design pressure should not exceed: 10^{-9} Pa.m^3/s (10^{-8} mbar.l/s).
Individual leakage across valve seats at design pressure should not exceed: 10^{-5} Pa.m^3/s (10^{-4} mbar.l/s)
After the assembly of the vacuum vessel, vacuum leak tests at design pressure and room temperature shall be carried out to check total and individual leakage from ambient and from internal circuits. For this, the vacuum vessel shall be under vacuum.
The maximum integral leak rates at design pressure should not exceed:

- From ambient into vacuum vessel including pipe work:10^{-7} Pa.m^3/s (10^{-6} mbar.l/s),
- From inner vessel and piping into vacuum vessel: 10-^{7} Pa.m^3/s (10^{-6} mbar.l/s).

4.2.1.1.9 Sensors, transmitters and measuring instruments

The accuracy of each analogous instrument shall be greater than or equal to ± 0.5 % the calibrated span.

All transmitters and indicators must be equipped with process isolation valves and a connection for calibration, isolated with a valve.
All instruments shall be able to withstand all pressures, from vacuum to the maximum working pressure.

4.2.1.1.10 Pressure measurements

Absolute pressure transmitters shall be used and absolute pressures shall be displayed.
Pressure transmitters with a span and an offset adjustable by at least ± 10 % shall be used. The accuracy shall be greater than or equal to ± 0.5 % of the maximum span. The long-term drift shall be less than or equal to ± 1.0 % per year at maximum span.
Display unit: bar.

4.2.1.1.11 Level measurement

The level measurement must be continuous over the full range.
Measurement of static head by differential pressure transmitter is considered as the best choice. Curves for conversion from height to liquid volume must be provided.
Display unit: liters.

4.2.1.1.12 Spare parts

Some spare parts shall be included in the supply:

- Replacement safety valve for each type installed on the tank,
- Spare parts for each size of cryogenic valve incorporated on the tank circuits.
- The bidder can also propose as an option a list of all additional spare parts considered necessary for lifetime operation of the tank.

4.2.1.1.13 Interfaces

Bayonet coupling suitable for cryogen transfers from standard road tankers used in Europe.
ITER will supply the infrastructure necessary for the installation and make available the concrete foundations according to the specifications of the Contractor for the vessels.
These specifications must be provided several months prior to tank delivery.

4.2.1.1.14 Tests at the Contractor's premises

Hydraulic pressure test
According to the Pressure Equipment Directive, before assembly of the vacuum vessel, a hydraulic

pressure test at 1.5 times the design pressure of the inner vessels and associated piping is required.

4.2.1.1.15 Delivery and Commissioning

4.2.1.1.15.1 Transport and delivery

The packing shall ensure sufficient protection against damage and contamination, especially ingress of dirt and moisture into the fluid pipes and inner vessels.

During transport the inner vessels and piping shall be pressurized with gaseous nitrogen at 0.15 MPa.

The tank shall bear the regulatory marking in compliance with the Pressure Equipment Directive and shall be provided with an appropriate identification plate showing the following indications:

- Design pressure of inner vessel bar abs,
- Hydrostatic pressure test of inner vessel bar abs,
- Volume in liters of inner vessel,
- Nature of fluid stored,
- Overall mass in kg of the empty vessel,
- Vacuum-insulation at ambient temperature (Pa),
- Name of the manufacturer,
- Serial number,
- Year of manufacture.

4.2.1.1.15.2 Reception tests

Prior to delivery the supplier must provide the complete test certificates file of the tank.

ITER will control the setting of the safety relief valves before the first filling of the tank.

After delivery ITER could perform acceptance tests including a pneumatic pressure test on the inner vessels, atmospheric heaters and associated piping at the maximal working pressure and a measurement of the boil of rate of the filled tank.

After the pneumatic pressure test, leak testing shall be repeated to check the global leak tightness after transport, erection and installation.

The society providing the tank has to be installed it via the ITER infrastructure (crane, loader, etc...).

The firm also has to take care of the first filling after the installation of the tank.

4.2.1.1.15.3 Labeling

All instruments and valves shall be identified in conformance with the PID and nomenclature list provided by the manufacturer. Suitable permanent identification labels shall be affixed on components.

4.2.1.1.16 Documentation

The documentation must comply with the Pressure Equipment Directive regulation and will include, in particular:

- The design, manufacturing and engineering file notifying the mechanical code applied and providing all calculations on the tank, the safety valves and the rupture disks. This report has to be provided prior to tank delivery.
- All fabrication drawings with parts lists indicating all materials used.
- The specification and the certificates of the material used for the construction of:
    - inner vessel,
    - outer vessel,
    - pipe work,
    - gas vaporizer,
    - heater body if any,
    - feet of the tank.
- The tank test certificates (welding, pressure and leak tests).

Furthermore, the documentation must include:

- The maximum boil off rate expressed as a percentage of the liquid cryogen storage capacity per day.
- The flow scheme and P&I diagram of the proposed tank and its equipment,
- The outer dimension of the tank, including valves etc.,
- The empty weight of the tank,
- The drawings of cold couplings,
- A description of the insulation method for the tank (super insulation, perlite ...),
- The specification and the original documentation provided by the manufacturer of the proposed:
    - Safety valves,
    - Hand, pneumatic, electrical and electro pneumatic valves,
    - Pressure and differential pressure indicators and transmitters, with special settings notice if any.
- A list of spare parts.
- A complete technical documentation including operating and maintenance manual.

4.2.1.1.17 Acceptance and guarantee

On successful completion of the reception tests and delivery of all specified documents, ITER will issue a certificate of provisional acceptance. The Contractor shall guarantee the equipment for the

agreed duration, starting from the date of the certificate.
The Contractor shall guarantee for the whole agreed duration that all the equipment delivered will continue to comply with the requirements of the specifications.
A performance test of the vaporization system can be carried out during the guarantee period to prove that it conforms to the requirements of the specifications.
At the end of the guarantee period, ITER will issue a final acceptance certificate.

4.2.1.2 Warm storage

This technical specification defines the requirements for the design, manufacturing, inspection, tests, transport and installation of **carbon steel vessels** for the storage of gaseous helium.

4.2.1.2.1 Description and technical requirements

Vessel requirements:

- Geometric volume,
- Internal diameter,
- Working pressures : Minimal and maximal pressures,
- Working temperature range : -40°C to +60°C,
- Planned layout (H/V position, indoor, outdoor, fixed implantation),
- Maximum lateral wind force in case of outdoor implantation,
- Possibility of snowfall in case of outdoor implantation,
- Length between the saddle supports,
- Maximum seismic horizontal acceleration.

For particular aspects of space saving, the vessels should be stacked in several layers. This possibility must be stipulated in the technical specifications, to ensure that the supporting structure allows this configuration.

The vessel shall present the following connections:

- A manhole with a DIN standard flange,
- One connection pipe with DIN standard flange,
- At high location, an opening for ventilation with DIN standard flange,
- One purge connection pipe with DIN standard flange.

All connections must be equipped with blanked plate flange and sealed with Viton O-ring. To ensure the leak tightness, the roughness of the flange sealing surface shall be Ra ≤ 0.8 μm.

4.2.1.2.2 Design and manufacture

The design, manufacture, inspection and tests of the vessels before transport to ITER must be in conformity with the European Directive 97/23/EC.
According to the Pressure Equipment Directive, prior to construction, the supplier must provide:

- An engineering file including: design calculations, the choice of the materials used,
- A complete set of mechanical drawings, the planned inspections, tests and quality control,
- A welding file including: welding materials (filler and base materials), welding procedures, welding qualifications, identification of the welders,
- Results of destructive and non-destructive tests. The construction of the equipment may only start after ITER has approved the welding procedures.

In case of foreseen horizontal positioning, the vessel shall be suspended so as to allow safe transportation in horizontal position and rotation for erection.
The vessels shall be equipped with suitable attachments for loading, unloading and erection on a concrete platform.
The lower part of the vessel shall be 1m above the floor level, to make it easy routing of lines and maintenance of associated equipment.
The materials proposed for the vessels, the manufacturing drawings, as well as the stress calculations report will be submitted and approved by ITER before manufacturing.

4.2.1.2.3 Cleaning and protection

All sealing surfaces of the flanges and cover plate for the manhole must be surface treated to avoid any corrosion.
These surfaces must be mechanically protected until the mounting of the blanked plate flange.
All external surfaces subject to corrosion must be sandblasted and protected by an appropriate primer coating for metal surfaces. The supporting structure shall be made of standard carbon steel and must be treated and protected in the same way as the vessels.

4.2.1.2.4 Interfaces

The adapted concrete foundations will be provided by ITER IO in accordance with the dimensions of fixing supports and saddles provided by the manufacturer.

4.2.1.2.5 Transport and installation

The supplier will be responsible for the transport of the vessel and their supporting structures and for the unloading at the ITER site. The supplier will also provide the erection of the supporting structure and the installation of the vessel, with the necessary manpower and handling means.

4.2.1.2.6 Inspections and tests

4.2.1.2.6.1 General conditions

The testing program to be carried out during manufacturing must be in conformity with the European Directive 97/23/EC. A certified inspector from a notified body in the manufacturer's country must carry out the inspection during manufacturing and tests.

The manufacturer will be responsible for the organization and the unfolding of all the tests. The constructor shall inform ITER several weeks in advance of important milestones and of the dates of all important tests.

ITER representatives shall be granted free access to the supplier and subcontractor's site during manufacturing.

Each pressure vessel must be provided with an identification plate with the following indications:

- Mass of the vessel (kg)
- Design pressure (bar abs.)
- Hydrostatic pressure test (bar abs.)
- Maximum working temperature (°C)
- Minimum working temperature (°C)
- Volume of the vessel (liters)
- Type of fluid
- Name of the manufacturer
- Year of manufacturing
- Serial number

The manufacturer shall affix the CE mark and the notified body number in an indelible manner.

4.2.1.2.6.2 Welding

All welds must conform to the requirements of the construction code chosen. Welders must possess a valid certificate issued by a notified inspection organization.

4.2.1.2.6.3 Pressure and leak tests

After a hydrostatic pressure test as defined in section 4.3, the inner surface of the vessels must be carefully dried, shot-blasted, cleaned and degreased. In addition, each vessel must be filled, as soon as possible, with dry nitrogen gas at 0.15 MPa abs. pressure in order to avoid any corrosion by exposure to air during storage and transport. An appropriate pressure gauge must be installed on each vessel to allow the checking of the internal pressure during transport and installation.

Before transport to ITER, the following tests shall be carried out:

- A hydrostatic pressure test
- A global vacuum leak test: the vessel being at a residual pressure below 10-4 Pa (10-2 mbar), the helium leaks on the vessel must not exceed the value of < 10-4 Pa m3/s (=10-3 mbar l/s),
- A pneumatic pressure leak test: performed at 80% of the design pressure using helium gas. Compliance with the leak tightness specified hereafter will be checked by sniffing and monitoring the vessel pressure during 10 days:
- Overall leakage at 80% of the design pressure : < 1 Pa m3/s (10 mbar.litre/s),
- Single leak rate at maximum working pressure : $< 10^{-4}$ Pa m^3/s ($=10^{-3}$ mbar l/s).
- After installation of the storage vessels at ITER site, an incoming inspection of the external surface should be performed in order to detect any deterioration caused during transport, loading or mounting.

4.2.1.2.7 Documentation

As a complement to the documentation delivered prior to construction, the manufacturer shall provide:

- Drawings and calculations of the vessels and supporting structure,
- Mill certificates of all materials used for the vessels,
- Reports on the welding procedures and qualification tests,
- Radiography certificates by the authorized inspector
- Reports on pressure and leak tests
- Other test and inspection reports
- Identification plate on the vessel
- Acceptance and guarantee

Upon successful completion of the performance tests and receipt of all specified documents, ITER will issue a Certificate of Provisional Acceptance. The supplier shall guarantee the equipment supplied for an agreed duration, starting from the date of this certificate.
At the end of this guarantee period, ITER will issue a Final Acceptance Certificate.

4.2.1.3 Transportable Pressure Equipment (TPE)

4.2.1.3.1 Regulation

The Regulation on transportable pressure equipment is based on two European directives

- Directive 1999/36/EC

This Directive applies to the use of transportable cylinders, tubes, cryogenic vessels and tanks for transporting fluids. It provides a legal framework for the free use of the TPE in the European

community, introducing a single marking to identify conformity and mutual recognition of the inspection organizations.

This directive is transposed into French regulation by French Decree n° 2001-386 of May 3, 2001, which is completed by the French order of May 3, 2004 regarding periodical inspection, maintenance and repair of TPE.

- Directive 2008/68/EC

This Directive applies to the design, manufacture, conformity assessment and periodic reassessment aspects of the equipment by reference to part 6.2 of appendix A of ADR - the European agreement on the International Carriage of Dangerous Goods by Road.

This directive and links to ADR are transposed into French regulation by the French order “Transports des Matières Dangereuses (TMD)” dated May 25, 2005.

ADR also covers associated valves and includes both refillable and non-refillable cylinders.

The ADR specifies what needs to be marked on the equipment and included in the instructions.

In order to facilitate the directive and decree applications, the European Community establishes guidelines. In France, these guidelines are summarized in “Transport CLAP files”.

4.2.1.3.1.1 Useful links

The European Commission has a special section on transportable pressure equipment on their EUROPA server with links to the guidelines and the text of the directive.

- ADR requirements can be found on The United Nations Economic Commission for Europe (UNECE) web site.

http://www.unece.org/trans/danger/publi/adr/adr2009/09ContentsE.html

- Links to certain notified bodies under the directive can be found on the web site: http://portailgroupe.afnor.fr/public_espacenormalisation/AFNORCLAPT/orgnotifDESPT.pdf

Remark that bodies notified for the Pressure Equipment Directive need an additional notification to work in the TPED field.

- Transportable CLAP Files web site:
http://portailgroupe.afnor.fr/public_espacenormalisation/AFNORCLAPT/fiches.htm

4.2.1.3.2 Scope (in the frame of ITER cryogenic system)

Transportable vessels, cylinders, tubes, cryogenic vessels, and tanks.

4.2.1.3.3 Exclusions

Non-exhaustive list of exclusions:

- Vessels for non-hazardous gases under 2 bar
- Gas cartridges,
- Refrigerators with less than 12 kg of refrigerant.

4.2.1.3.4 Classification for conformity assessments

The statutory texts define three categories for pressure equipment, based on its pressure volume product (P.V) in bar.liters and hence its stored energy.

Assessment and conformity procedures are different for each category, ranging from occasional auditing of test procedures for the lowest (category I) hazard up to full ISO9001 quality management and/or notified body type examination for category 3 equipment. The assessment procedures are arranged in a modular structure and manufacturers have the choice of which modules to select (within pre-determined combinations) in order to best suit their application and manufacturing procedures.

T.P.E Category	**P.V bar.litre**	**Conformity assessment module**	**Conformity assessment description**
1	< 300	A1	Design under the control of the manufacturer. Internal manufacturing checks with occasional NB monitoring of final assessment
		B + C1	EC type examination + internal production control with occasional unexpected audit of final assessment
2	300-1500	H	Full QA design, manufacture and final assessment
		B + E	EC type examination + QA system approval for production and final assessment
		B + C1	EC type examination + internal production control with occasional unexpected audit of final assessment
3	>1500	G + D	Unit verification by NB + QA system approval for production and final assessment
		H1 + D	Full quality assurance with design examination and special surveillance of final test
		B + D	EC type examination + QA system approval for production and final assessment
		B + F	EC type examination + Notified body verification of production and final assessment for each product

Table 3: **Conformity module assessments and categories**

4.2.1.3.5 Codes and standards

French Decrees do not contain design or safety requirements in and of themselves, they refer rather to the requirements set forth in Chapter 6.2 of Annex A of ADR, addressing all aspects of equipment design and production, including dimensions, materials, welding and test methods. A list of standards, giving presumption of conformity with the requirements of ADR, is set forth.
In any case, the application of these standards by the manufacturers, while not compulsory, will considerably simplify compliance with the essential requirements of the directive.
For materials and conception

- Standard 45: EN 1797-I : 1998 Cryogenic vessels - Gas/material compatibility
- Standard 46: EN 1251 1 + 2 : 2000 Cryogenic vessels: transportable insulated vessels of not more than 1000 liters volume: Fundamental requirements + Design, fabrication, inspection and testing.
- Standard 47: EN 15530-1 + 2:2002 Cryogenic vessels-Large transportable vacuum insulated vessels: Fundamental requirements + Design, fabrication, inspection and testing.

Materials not referenced in harmonized standards shall be certified either by use of a European Approval of Material (EAM) or via particular material appraisal (PMA).
For operation and periodic inspections

- Standard 48: EN 1251-3: 2000 Cryogenic vessels: transportable insulated vessels of not more than 1000 liters volume: Operational requirements
- Standard 49: EN 15530-3:2002 Cryogenic vessels-Large transportable vacuum insulated vessels: Operational requirements

4.2.1.3.6 Administration requirements

4.2.1.3.6.1 Documentation

In addition, to ensure that the equipment complies with the performance requirements of the directive, manufacturers must also complete a specified declaration of conformity and they must compile and maintain a technical file of information about how the equipment was designed and manufactured and supply it to the Notified body.
The documents requested are listed in the Paragraph 1.8.7.7 of ADR.
Depending on category and conformity module assessment they shall include:

- Documents for EC-type examination,

- Documents for internal fabrication control,
- Documents for final assessments and tests,
- Documents for periodical inspections.

4.2.1.3.6.2 Marking

The manufacturer shall affix the PI mark and the stamp of the expert who carried out the tests and inspections in an indelible manner.
In addition, each pressure vessel must be provided with an identification plate with the following indications:

- The manufacturer's name or mark,
- The year of manufacturing
- The serial number
- The approval number (if the design type of the receptacle is approved)
- The type of fluid to be use
- The maximum and minimum working temperature (°C)
- The volume of the vessel (liters)
- The tare of the receptacle without fittings and accessories
- The design pressure (bar gauge.)
- The test pressure (bar gauge)
- For compressed gases filled by pressure, the maximum filling pressure at 15 °C allowed for the receptacle
- The water capacity in liters
- The mass of the vessel full (kg) for each fluid used
- The date (year) of the initial inspection

4.2.1.3.7 Important remarks

Safety-related valves are required to be pi-marked. Other valves require no special markings.
It is permissible to incorporate pi-marked pressure equipment into a CE marked pressure system without further assessment but it is not permissible to use CE-marked cylinders for transporting compressed gases. They must be re-assessed according to the TPED and pi-marked.
The reason for this is that the Conformity Assessment Procedures for the TPED are more stringent and always require notified body certification whereas pressure vessels in the lower categories of the Pressure Equipment Directive can be self-assessed and certified by the manufacturer.
A double marking proves that the pressure equipment complies with both directives, and can be used in both contexts without further assessment.
As open (non-closed) cryogenic receptacles are used for the transport of Class 2 refrigerated liquefied

gases, they are covered by the RID/ADR. They are not subject to all Chapter 6.2 of the RID/ADR which relates to the design, the construction, the inspection and testing relevant to cryogenic receptacles.
They shall only fulfill the requirements of 6.2.1.2 (Materials of receptacles).
Consequently, open (non-closed) cryogenic receptacles are not subject to conformity assessment and are not pi-marked.

4.2.1.3.8 Technical requirements for liquid transportable containers

Technology differs depending on the nature of the fluid. LHe transport and storage require an enhanced thermal insulation based on implementations of vacuum and multi-layer insulation efficiencies.
The transport and storage of LN2, LO2 and LAR are generally carried out in the same type of containers, including a safe pressurizing device.
Generally speaking, the following technical specifications shall be formulated for the supply of transportable cryogenic containers:

4.2.1.3.8.1 Technical specifications

- Total capacity in l,
- Useful capacity in l,
- Working pressure in bar,
- Weight (tare) in kg,
- Full weight in kg and depending on the fluid,
- Total height in mm,
- Diameter in mm,
- Filling time (container cold) in minutes,
- Liquid withdrawal in l/h,
- Loss rate in %/day,
- Number and type of couplings for withdrawal,
- Type of coupling for pressurization.

4.2.1.3.8.2 Handling specifications

The following specifications shall be chosen in consideration of the future work environment:

- Forklift pockets for handling by forklift truck,
- Frame integration,
- Rolling devices.

In any case, in addition to these specific devices, the mobile storage shall be equipped with

attachments suitable for crane handling.

4.2.2 *Rotating machines*

4.2.2.1 Cold centrifugal compressors

4.2.2.1.1 Technology

The choice of the cold compressors is in the responsibility of the supplier. However, technology with references for operation with helium at cryogenic temperature is mandatory. The main technologies recommended for cryogenics are centrifugal compressors with oil free bearings (active magnetic bearings, dynamic/static gas bearings or hybrid ball bearings using ceramic balls).
Cold compressors must be defined using reduced variable for the design parameters. The pressure field (compressor) must represent the pressure ratio as a function of the reduced flow for different reduced iso-speeds. The stall and choke lines must be shown.
Definition of the reduced variables:

- Design parameters of cold compressors

  Each cold compressor must be defined with the following design parameters:
  Tin_0 : The inlet temperature for design conditions,
  Pin_0 : The inlet pressure for design conditions,
  N_0 : The impeller speed for design conditions,
  m_0 : The mass-flow for design conditions

- Pressure field of cold compressors

For each cold compressor, a pressure field must be given using the following reduced variables:

Reduced flow: $$mr = \frac{m}{m_0}\sqrt{\frac{Tin \times Pin_0}{Tin_0 \times Pin}}$$

Reduced speed: $$Nr = \frac{N}{N_0}\sqrt{\frac{Tin_0}{Tin}}$$

Pressure ratio: $$\tau = \frac{Pout}{Pin}$$

Where

Tin : The inlet temperature of the cold compressor
Pin : The inlet pressure of the cold compressor
$Pout$: The inlet pressure of the cold compressor

N : The speed of the cold compressor
m : The mass-flow of the cold compressor

4.2.2.1.2 Drive and control

The mass-flow rate of helium should be easily adjustable via rotation speed regulation (Variable Frequency Drive). Rotational speed of the centrifugal compressor should include a 10% speed margin at least with respect to the maximum value encountered in the different operating modes.
If electrical motors and/or electrical circuits under helium atmosphere are used, a low-voltage power supply must be used in order to prevent dielectric breakdown. The motor must be proven to have a good electrical isolation in a helium atmosphere. The compressors include auxiliary systems such as motors, controls, power supplies and protection devices against loss of utilities. The Mean Time Between Maintenance (MTBM) for the cold compressors must be at least 12,000 hours.

4.2.2.1.3 Maintenance-Replacement

The system supplied must allow easy maintenance and exchange of cold compressors. It shall include all the elements needed to isolate and warm up a cold compressor and to purge the replacement compressor in situ without breaking the vacuum and warming up the cold box. Heating by circulation of gas is preferred to electrical heating for this application. The intervention time for the cold compressor exchange including the warm-up must be less than 4 hours.

4.2.2.2 Turbines expanders

4.2.2.2.1 Technology

For turbine expanders, the supplier must have references for these components with helium for helium turbines and with nitrogen for nitrogen turbines.
For helium turbines, only turbines with gas-lubricated or magnetic bearings must be accepted. The power extracted by the turbine brake must be transferred to water-cooled heat exchangers. These exchangers must have a high resistance to corrosion. Acceptable materials are stainless steel and copper compatible with the water quality. The water side must provide easy access for cleaning. All welds on joints separating helium and water must be done on the water side.
For nitrogen, turbine booster compressor technology could be used to decrease energy consumption and enhanced efficiency.

4.2.2.2.2 Maintenance - Replacement

In order to allow easy exchange of turbine cartridges, the system must include all the elements needed to isolate and warm up a turbine, and to purge the replacement turbine in situ without warming up the

heat exchanger blocks. Heating by circulation of gas is preferred to electrical heating for this application. Duration of the replacement of one turbine cartridge should not exceed 4 hours.

4.2.2.3 Supercritical helium circulators

4.2.2.3.1 Technology

The choice of the SHe circulators is the responsibility of the supplier. However, technology with references for operation with supercritical helium is mandatory. The bearing technologies used for circulators are oil free such as magnetic, gas or ball bearings. The stall and choke lines must be shown in the compressor map in addition to the pressure ratio as a function of the flow for several iso-speeds.

4.2.2.3.2 Drive and control

Mass flow rate of supercritical helium produced by any circulator shall be easily adjustable via rotation speed regulation using Variable Frequency Drive. Rotational speed of the SHe circulator should include at least 10% speed margin with respect to the maximum value encountered in the different operating modes.
If electrical motors and/or electrical circuits under helium atmosphere are used, a low voltage power supply must be used in order to prevent dielectric breakdown. The circulators must be delivered including all auxiliary systems such as motors, controls, power supplies and protection devices against loss of utilities… The MTBM for the circulators must be at least 12,000 hours.

4.2.2.3.3 Maintenance - Replacement

The system supplied must allow easy maintenance and exchange of circulators. It shall include all the elements needed to isolate and warm up a SHe circulator, and to purge the replacement circulator in situ without breaking the vacuum and warming up the cold boxes. Heating by circulation of gas is preferred to electrical heating for this application. The intervention time for SHe circulator exchange including the warm-up must be less than 4 hours.

4.2.2.3.4 Tests

Helium leak test $<10^{-7}$ Pa.m^3/s ambient
$<10^{-9}$ Pa.m^3/s to cold box vacuum

4.2.2.4 Warm compressors

4.2.2.4.1 Introduction

The purpose of compressors is to provide the flow of gas at required pressures to achieve the

performance of the refrigerator according to the cryogenic process.
The compressor types used for cryogenic facilities can be divided into two groups:

- Dynamic compressors are based on the principle of imparting velocity to a gas stream and then converting this velocity energy into pressure energy.
- Positive displacement compressors confine a certain inlet volume of gas in a given space and subsequently elevate this trapped amount of gas to some higher pressure level.

The majority of compressors in either the dynamic (axial/centrifugal) or positive displacement (reciprocating, Roots blower and screw-type) categories incorporate moving components.
Diagram of compressor types

The main types of gas compressors are illustrated below.

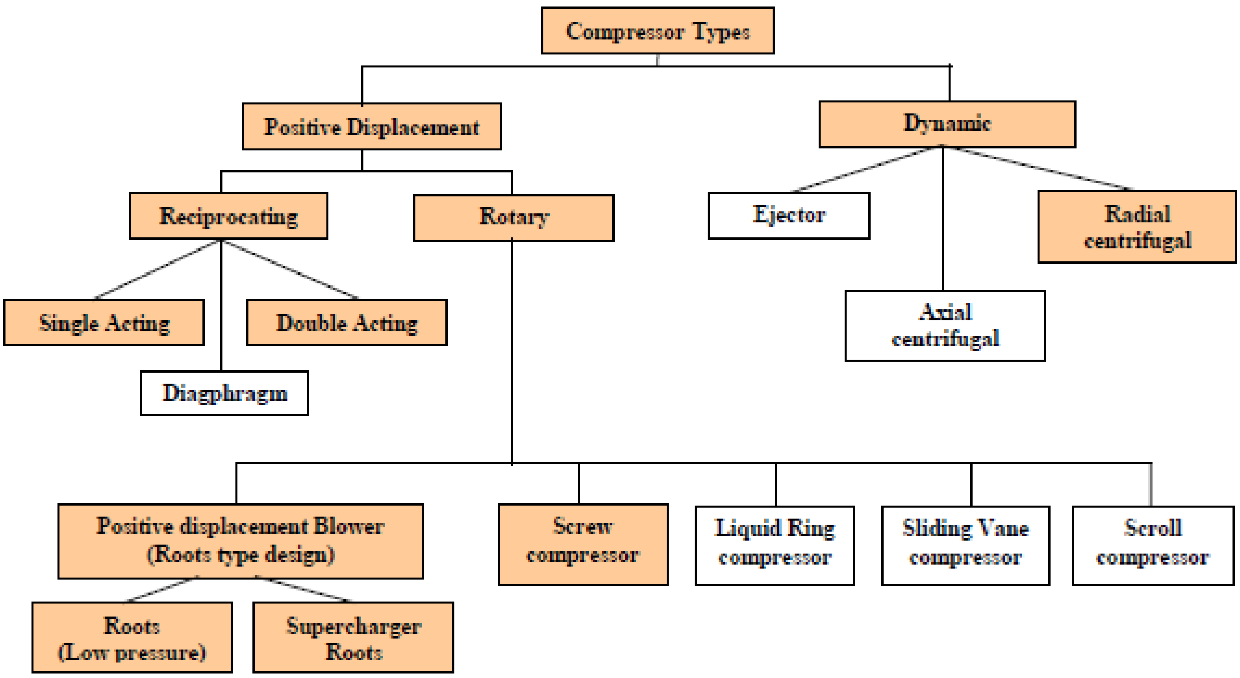


Figure 7: Compressor type diagram

4.2.2.4.2 Using warm compressors for the cryogenic facilities

The compressor types quoted below in pink (Screw compressors, Warm Centrifugal compressors, Blowers, Reciprocating compressors ...) are referenced for operation with cryogenic gas.

They can be chosen in order to comply with the specific cryogenic process.

4.2.2.4.3 Compressor selection factors

- Flow capacity (minimum, nominal, peak),
- Suction pressure (Inlet),
- Operating pressure (Discharge),
- Drive (Motor Power),
- Gas quality,
- Noise level,
- Vibration level,
- Duty hours per year without maintenance.

4.2.2.4.4 Choice of compressor types

The choice of the compressor type shall take into account:

- The number of compression stages
- The cooling method (air, water, oil)
- The drive method (motor, engine, steam, other)
- The lubrication (specific oil)
- Packaged or custom-built
- The optimization of the investment and operation costs
- The isothermal efficiency

4.2.2.4.5 Noise level

Compressor noise level

According to the choice of compressor types, the manufacturer shall take into account the noise issues:

- Reciprocating compressors generate sound at a low frequency due to the low speed of compressor components.
- Screw compressors generate sound at a high frequency due to the high speed of the compressor components.

Typical noise levels at 1 meter from an electrically driven compressor will be approximately:

- 95 to 100 dBA for reciprocating machines.
- 100 to 105 dBA for screw and centrifugal machines

Remark

If the compressor noise exceeds the value specified above, the contractor shall deliver and install for each compressor unit a specific device such as sound-adsorbing cage.

Noise standards

The manufacturers shall provide documents including values for the noise level for each compressor and each electrical motor drive according to the international standard for machine noise.

The equipment must refer to:

- Standard 50: ISO 3740 Acoustics - Determination of sound power levels of noise sources - Guidelines for the use of basic standards

4.2.2.4.6 Vibrations

The supplier must consider the problem of vibrations induced by the compressor motor to the other equipment such as piping or the other compressor motor units.

Compressor vibration level

According to the choice of compressor types, the manufacturer shall take into account the vibration issues:

- Reciprocating compressors vibrate at a low frequency with high amplitude,
- High-speed screw compressors vibrate at a high frequency with low amplitude.

Design recommendations

The noise generation by high speed screw compressors can be reduced via six basic design criteria.

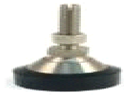
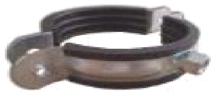
Type	Principle	Exemple
Insulation plate	The screw compressor is mounted on concrete block and an insulation plate is inserted between the block and the ground	
Compressor mounting feet	Feet are mounted between the compressor and the ground	
Compressor mounting frame	The mounting frames are used to prevent compressor/piping movement and sound radiation	
Compressor discharge gas muffler	Discharge gas mufflers are used to reduce gas pulsations caused by the compressor.	
Compressor line support	The lines are clamped using vibration absorbing pipe clamps	

Table 4: Vibration adsorption and attenuation

4.2.2.4.6.1 Vibration requirements

The maximum allowable vibration levels for the compressor station are as follows:

- At the top of the compressor skid foundations <1.0 mm/s RMS (10-1000Hz)
- On the motors <4.5 mm/s RMS (10-1000Hz)
- On the compressors <11 mm/s RMS (10-1000Hz)
- On piping or equipment around the compressors <30 mm/s RMS (10-1000Hz)

The vibration levels shall be measured during the acceptance tests.

4.2.2.4.6.2 Vibration standards

4.2.2.4.6.2.1 Torsional analysis

For motor-driven units and units including gears, the compressor provider shall ensure that a torsional vibration analysis of the complete coupled train complies with the ISO 10440-1 requirements.

- Standard 51: ISO 10440 Petroleum, petrochemical and natural gas industries - Rotary-type positive displacement compressors - Part 1 : process compressors

4.2.2.4.6.2.2 Vibration and balance

Major parts of the rotating element, such as the shaft and timing gears, shall be individually, dynamically balanced to

- Standard 52: ISO 1940-1 Mechanical vibration - Balance quality requirements for rotors in a constant (rigid) state - Part 1: specification and verification of balance tolerances
- Standard 53: ANSI S2.19 Balance Quality Requirements of Rigid Motors

4.2.2.4.6.2.3 Vibration standards

The equipment must comply with the following:

- Standard 54: ISO 2954 Mechanical Vibration of Rotating Reciprocating Machinery – Requirements for Instruments for Measuring Vibration Severity
- Standard 55: ISO 2372 Mechanical vibration of machines with operating speed from 10 to 200 rev/s

Therefore, the contractor shall provide a list of measuring points on the compressor and the associated piping which will indicate the maximum values of vibrations.

4.2.2.4.7 Leaks

4.2.2.4.7.1 Helium leakage

The maximum acceptable He leak rates of the compressor station, including interconnecting piping, are as follows:

Individual leakage:

- From the helium and oil circuits to atmosphere (at max working pressure) 10^{-5} mbar.l/s
- From the helium and oil circuits to the water circuits (at max working pressure) 10^{-8}mbar.l/s
- Leakage through valve seat 10^{-4} mbar.l/s
- Leak rate from helium guard system in case of using sub-atmospheric circuits 10^{-5} mbar.l/s

Global leakage for the total Warm Compression Station:

- Overall helium leakage from the running compressors $0.1m^3$/days NTP

4.2.2.4.7.2 Oil leakage

Oil leaks from the compressor station will not be accepted, with the exception of those inevitable at shaft seals of compressors and oil pumps.

Every shaft seal shall be equipped with a transparent vessel collecting the lost oil and easy visualization of the oil level.

Oil leaks through shaft seals must not exceed 5 ml/h per compressor or oil pump.

4.2.2.4.7.3 Air leakage

The maximum acceptable air leak rates of the compressor station, including interconnecting piping, are as follows:

Overall air leakage into VLP stage below vacuum (evacuation for purging) 10^{-3} mbar.l/s

4.2.2.4.8 Motor drives

The motor drive shall be sized in order to take into account all the operating conditions specified by IO.

The driver shall be sized to:

- Accept any specified process variations (temperature, pressure, fluids properties),
- Comply with plant start-up conditions,
- Comply with the speed-torque requirements of the driven compressor.

Motor characteristics

Motor drives mains characteristics and accessories:

- Electrical characteristics, including motor efficiency,
- Starting conditions, including the expected voltage drop on starting,
- Type of enclosure,
- Cooling system
- Sound pressure level,
- Type of insulation,
- Required service factor,
- Ambient temperature and elevation above sea level,
- Transmission losses,
- Temperatures detectors, vibration sensors and heaters specified,
- Vibration acceptance criteria,

- Use in variable-frequency drive applications.

Motor standards

Motor drives shall comply with internationally recognized standards:

- Standard 56: API 541 Form-Wound Squirrel Cage Induction Motors – 250 Horsepower and Larger
- Standard 57: API 546 Brushless Synchronous Machines
- Standard 58: Area classification, based on API RP 500 Recommended practice for classification of locations for electrical installations at petroleum facilities classified as Class I, Division 1 and Division 2

The above-mentioned standards shall be in accordance with:

- Standard 59: IEEE 841 Petroleum and Chemical Industry—Premium- Efficiency, Severe-Duty, Totally Enclosed Fan-Cooled (TEFC) Squirrel Cage Induction Motors—Up to and Including 370 Kw

4.2.2.4.9 Screw compressors

4.2.2.4.9.1 Description

Screw compressors are positive displacement rotary devices. Compression is achieved by successive volumes of suction gas being enclosed in a confined space between the two rotors and the casing.
Due to the rotation of the shafts the pressure of the trapped gas increases until it reaches and exits the compressor discharge.
All supercharger types benefit from the use of an intercooler to reduce heat produced during pumping and compression.

Figure 8: Cutaway drawing of a screw compressor

4.2.2.4.9.2 Advantages and Disadvantages

Advantages	**Disadvantages**
Simple design	Necessity to use bypass and slide valve
Compact size	Efficiency depending on operating conditions
Low vibration	Instabilities of pressure due to the use of slide valve
Low to Medium investment cost	Single stage designs have lower efficiency
Low to Medium maintenance cost	Necessity to use oil separator and ORS
Two-stage designs provide a good efficiency	Necessity to use oil and air for sealing and cooling
Easy installation	
Few moving parts	

Twin screw compressors are gaining in applications primarily over reciprocating piston compressors because of their "quiet" operation.

They have many benefits including improved reliability and efficiency.

4.2.2.4.9.3 Main application

- Used for constant-volume and variable-pressure application,
- Most popular compressor design in helium Warm Compression Stations,
- Used principally as cycle compressors for helium cryogenic plant,
- Using of two stages allows the creation of a Medium Pressure (MP) stream.

4.2.2.4.10 Compound Screw compressors

4.2.2.4.10.1 Description

Compound screw compressors are developed to offer a two-stage compression system that allows:

- Using one single-drive motor,
- Saving space (minimizing footprint),
- Minimizing the initial cost (single motor),
- High compression ratio.

A wide range of different rotor sizes are available for the low- and high-pressure stages in order to maximize compressor efficiency.

Compound screw compressors combine all advantages of a typical separate two-stage into one package.

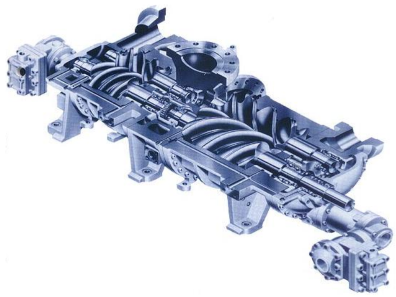


Figure 9: Cutaway drawing of a compound screw compressor

4.2.2.4.10.2 Advantages and Disadvantages

Advantages	Disadvantages
Compact size than two stages	Efficiency lower than two-stage screw compressors
Lower investment cost than two stages	
One motor drive	No management of the Medium Pressure
One Compressor	Unable to maintain a rescue operating mode in case of failure (motor, compressor) compared with two stages
One control panel	
One oil cooler	
One oil-retention system	More vulnerable: gear box, misalignment,
Reduced number of vibrations	
Reduce pipes, valves and fittings compared to two stages	
Higher compression ratio than a single stage	

4.2.2.4.10.3 Screw compressor oil flooded standards

Screw compressor shall conform to:

- Standard 60: ISO 10440-1 Petroleum, petrochemical and natural industries, rotary-type positive displacement compressor – Part 1 : Process compressor
- Standard 61: API 619 standards Rotary-Type Positive-Displacement Compressors

4.2.2.4.11 Warm centrifugal compressors

4.2.2.4.11.1 Description

Centrifugal compressors make up the dynamic compression family of machines.

The gas is accelerated at high speed through one or more impellers and the kinetic energy is converted into static pressure.
The centrifugal compressor increases the fluid density.
Centrifugal compressor can be designed for single-stage and multi-stage
There are two main casing types:

- Horizontally split casing
- Vertically split casing (barrel-type compressor)

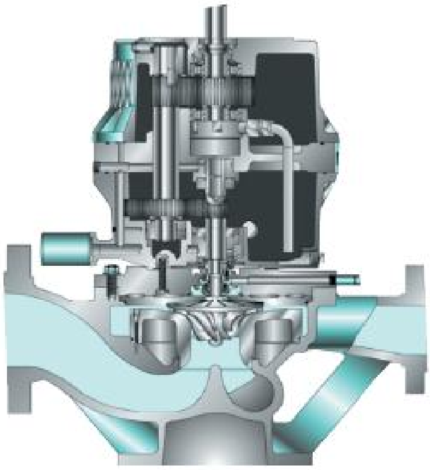


Figure 10: Cutaway drawing of centrifugal compressor

4.2.2.4.11.2 Advantages and Disadvantages

Advantages	**Disadvantages**
High efficiency	High investment cost
Can reach high pressures	Sophisticated monitoring and control systems
Relative initial cost improves as size increases	Limited capacity control modulation
Does not require special foundations	High rotational speeds requiring special bearings
Oil-free	Specialized maintenance considerations
	Low compression ratio

4.2.2.4.11.3 Main application

Centrifugal compressors are used for systems requiring very large flow

4.2.2.4.11.4 Warm centrifugal compressor standards

Warm centrifugal compressor shall comply with:

- Standard 62: API 617 standards, Axial and Centrifugal Compressors and Expander-compressors for petroleum, chemical and gas services

4.2.2.4.12 Blowers

4.2.2.4.12.1 Description

The Roots type supercharger or Roots blower is a positive displacement pump which operates by pumping gas with a pair of meshing lobes.

Gas is trapped in pockets surrounding the lobes and carried from the intake side to the exhaust.
The supercharger is driven directly from the engine's crankshaft via a belt or spur gears.

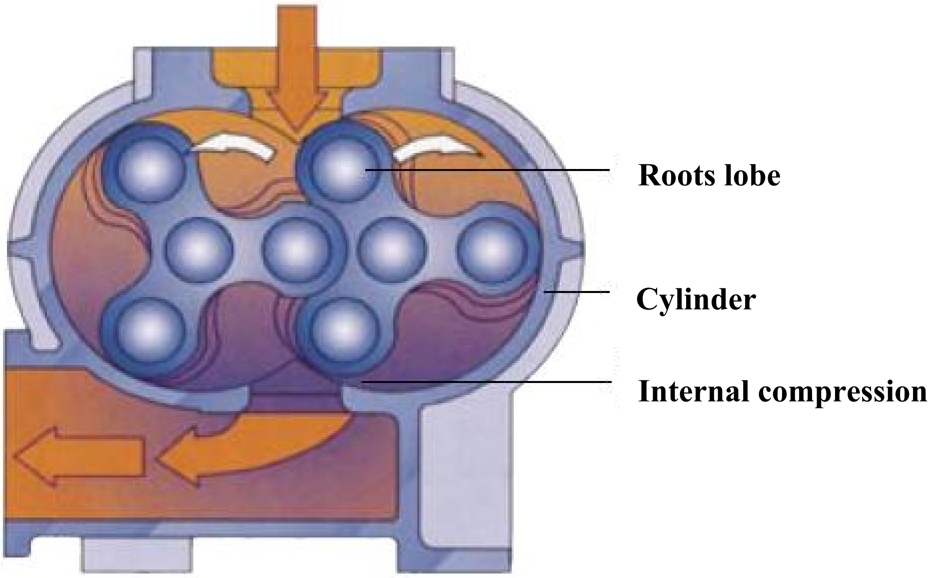


Figure 11: Roots layout

4.2.2.4.12.2 Advantages and Disadvantages

Advantages	Disadvantages
Good efficiency	Discharge pressure is limited
High volume flow rates are possible	Low pressure ratio
	Efficiency decreases with time (due to the increase of mechanical friction losses)

4.2.2.4.12.3 Main application

Roots blowers shall be used in applications where a large volume of helium must be moved across a relatively small pressure differential.

This includes low vacuum applications, with the Roots blower acting alone, or used as part of a high

vacuum system, in combination with other pumps.

4.2.2.4.12.4 Blower compressor Standards

Blower compressor shall comply with

- Standard 63: ISO 10440-1 Petroleum, petrochemical and natural industries, rotary-type positive displacement compressor – Part 1 : Process compressor
- Standard 64: API 619 Rotary-type positive displacement compressors for petroleum and gas industry services

4.2.2.4.13 Reciprocating compressors

4.2.2.4.13.1 Description

Reciprocating compressors are positive displacement compressors that use pistons driven by a crankshaft to deliver gases at high pressure.

- They are supplied in either single-stage or multi-stage types
- The maximum allowable discharge-gas temperature determines the maximum compression ratio
- Typical compression ratios are about 3 per stage to limit discharge temperature to 149°C to 177°C.
- Intercoolers are provided between stages for the multistage machines.
- Some reciprocating compressors have as many as six stages in order to provide a total compression ration over 300

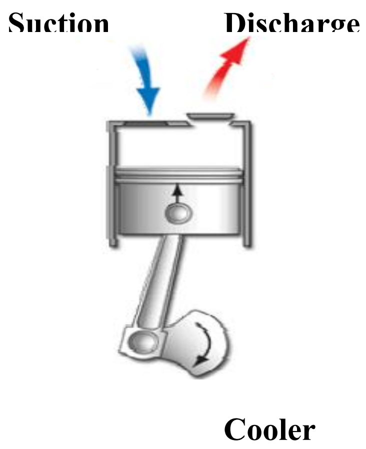


Figure 12: One stage of compression

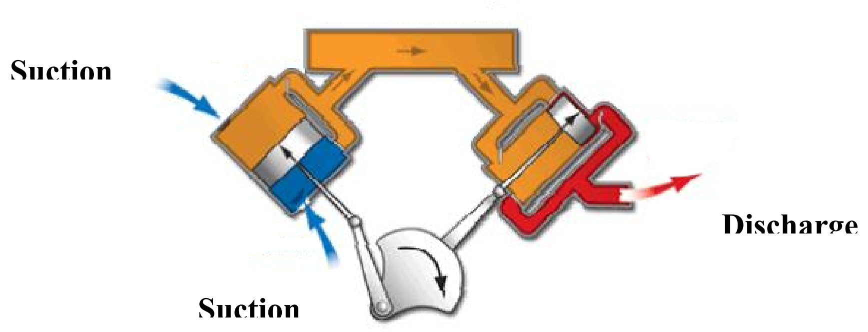


Figure 13: Two stages of compression

4.2.2.4.13.2 Comparison and advantages

Advantages	Disadvantages
Simple Design,	Higher maintenance cost
High efficiency	
Lower initial cost	Many moving parts (valves, piston, connecting rod)
Easy to install	Potential vibration problems
Oil free in the non-lube design	Requires specialized and frequent maintenance
Two-stage models offer the highest efficiency	Foundation may be required depending on size
Special machines can reach extremely high pressure	

4.2.2.4.13.3 Main application

Reciprocating compressors are used when high-pressure head is required at low flow such as helium storage.

4.2.2.4.13.4 Reciprocating compressor Standards

Reciprocating compressor shall comply with:

- Standard 65: API 618 Reciprocating compressors

Compressor technical specifications

Table 5 gives comparison of compressors in terms of range, application and efficiency.

Table 6 gathers information on compressors in terms of noise, vibration, requested utilities and infrastructure.

4.2.2.4.13.5 Compressors costs and maintenance

Table 7 gives comparison of investments and maintenance costs for each type of compressor.

4.2.2.4.13.6 Compressors Power and Drive

Table 8 shows the more classic drive types to associate with each compressor.

Type of Compressors		Global efficiency	Volume flow range (m3/h)	Minimum Suction Pressure (Inlet) (MPa)	Maximum Discharge Pressure (MPa)	Maximum pressure ratio	Full load consumption (Wh/Nm3)
Rotary Screw Compessors Oil flooded	**Single stage**	0,5 up 0,6	100 up 25 000	0,01	2,8	15	110 up 200
	Compound	0,4 up 0,45	100 up 15 000	0,01	2,8	25	110 up 200
Blower (Roots type design)	**ROOTS (Low Pressure)**	0,6 up 0,7	1000 up 200 000	0,01	0,1 max	2	120 up 141
	High Presssure		60 up 6 000	0,01	2,5 max	2	120 up 141
Reciprocating Compressors	**Lube**	0,7 up 0,85	100 up 15 000	0,1 * * For Sub-atmospheric applications, precautions from leaking into cylinders through piston rod packing	30 (with 6 stages)	3 per stage	100 up 150
	Non-Lube		100 up 15 000		10	3 per stage	110 up 160
Warm Centrifugal Compressors (Radial)	**Single stage**	0,6 up 0,8	200 up 400 000	0,1 * * For subatmospheric inlet conditions, special seal and buffering are necessary	20	3	100 up 130

Table 5: Compressor technical features

Type of Compressors		Flow rate control	Noise (dB)	Vibration	Leakage	Cooling system	Oil	Foundation
Rotary Screw Compessors Oil flooded	Single stage	Slide valve (15 -100%) step less Bypass Speed control (30 - 100%)	100 up 105	Low	Low	Oil / Water Helium / Water	Oil injection Oil lubricated	Low
	Compound	Slide valve (15 -100%) step less Bypass Speed control (30 - 100%)		Low	Low	Oil / Water Helium / Water	Oil injection Oil lubricated	Low
Blower (Roots type design)	ROOTS (Low Pressure)	Speed Control Bypass	75 up 95	Medium	High (helium leak when Roots is stopped)	Helium / Water	Oil - free	Medium
	High Presssure	Speed Control Bypass	70 up 90	Medium	High (helium leak when Roots is stopped)	Oil / Water Helium / Water	Oil injection Oil lubricated	Medium
Reciprocating Compressors	Lube	Suction valve inloaders (step and stepless) Clearance pockets Bypass	95 up 100	High	Low	Helium / Water	Oil lubricated	High
	Non-Lube	Suction valve inloaders (step and stepless) Clearance pockets Bypass			Low	Helium / Water	Oil - free	
Warm Centrifugal Compressors (Radial)	Single stage	Inlet guide vane Speed control (70-100%) Bypass	100 up 105	High rotational speed implies special bearings	Low	Helium / Water	Oil - free	Low

Table 6: Compressor technical features

Type of Compressors		Maintenance			Investement Cost	Operation Cost
		Level	Overhaul period (hours)	Elements to replace		
Rotary Screw Compessors Oil flooded	**Single stage**	Low	35 up 50 000	Oil seals Thrust bearings	Low	Low
	Compound	Low			Low than two stages	Low
Blower	**ROOTS (Low Pressure)**	Low	10 up 20 000	Oil seals Thrust bearings	Low	Low
	High Presssure	Low	10 up 20 000	Oil seals Thrust bearings	Low	Low
Reciprocating Compressors	**Lube**	High	Valves -> 10 000 h Piston rings -> 20 000 h Bottom rings -> 20 000 h Bearings and liner replacements -> 40 000 h		Low	High
	Non-Lube					
Warm Centrifugal Compressors (Radial)	**Single stage**	Low	Specialized maintenance		High	Low

Table 7: Compressor costs and maintenance

Type of Compressors		Drive	Electrical Voltage
Rotary Screw Compessors Oil flooded	Single stage	Direct Variable Speed Drive	400V AC up 6,6kV
	Compound	Direct Variable Speed Drive	400V AC up 6,6kV
Blower	ROOTS (Low Pressure)	Direct Variable Speed Drive	400V AC up 6,6kV
	High Presssure	Direct Variable Speed Drive	400V AC up 6,6kV
Reciprocating Compressors	Lube	Direct	400V AC up 6,6kV
	Non-Lube		400V AC up 6,6kV
Warm Centrifugal Compressors (Radial)	Single stage	Direct Variable Speed Drive	400V AC up 6,6kV

Table 8: Compressor Power and Drive

4.2.3 *Oil systems*

The use of oil-flooded machines requires lube oil circulation throughout the system. The oil systems ensure several functions:

Inside the machine

- Lubrication of bearings,
- Lubrication of the mechanical parts where the compression occurs,
- Reduction of the compression heat in the machine,
- Shaft or rotor lobe sealing,
- Circulation around the engines

Outside the machine

- Separation of oil and gas after compression,
- Cooling of the oil before return inside the engines,
- Control of ancillary oil systems (slide valves, ...)

The architecture of a typical oil system shall be composed of the following components:

- A circulation unit,
- Oil retention vessels,
- Oil Coolers,
- A set of ancillary components, valves, check-valves, filters, indicators.

4.2.3.1 Oil requirements

4.2.3.1.1 Lube-oil and seal-oil systems standards

Lube-oil and seal-oil system components shall conform to:

- ➢ Standard 66: ISO 10438-1 Petroleum, petrochemical and natural gas industries-lubrication, shaft-sealing and control-oil systems and auxiliaries – Part 1: General requirements
- ➢ Standard 67: ISO 10438-2 Petroleum, petrochemical and natural gas industries-lubrication, shaft-sealing and control-oil systems and auxiliaries – Part 2: Special-purpose oil systems
- ➢ Standard 68: API 614-99 standards (chapters 1 and 2) are equivalent to ISO 10438-1 and ISO 10438-2

The oil system shall utilize a lubricant compatible with the process gas in terms of the following:

- Dilution,
- Degassing,
- Corrosion,
- Viscosity changes,
- Moisture adsorption,
- Oil affecting the process

4.2.3.1.2 Oil type

The use of synthetic polyglycol oil is widely spread in cryogenic Warm Compression Stations due to:

- High lubricating properties
- Good viscosity/temperature ratio
- Low vapor pressure at the operating temperature (essential for cryogenic application)

As required oil, BP BREOX B35® could be used for screw compressor lubrication and BP BREOX IL 150 SW could be use for reciprocating compressors. The Physical properties of these oils are described in Appendix 9.7A and Appendix 9.7B.

4.2.3.1.3 Technical advice

- As the polyglycol oil is hygroscopic, contact with the atmosphere shall be avoided,
- Before the filling, a pre-treatment shall be carried out in order to reduce the water and light hydrocarbon produced during the synthesis of the oil,
- This treatment shall also be able to eliminate all solid particles larger than 25 µm and keep content in the oil to less than 2500 ppm by volume,
- The amount of oil must be defined with 5% reserve,
- The spare oil must be kept inside the building and not exposed to freezing temperatures,
- During long shut-down periods, the increase of viscosity of any oil left in piping or aerial coolers must be taken into account.

4.2.3.2 Oil circulating system

Depending on the compressor manufacturer and the operating conditions, two main methods are used for oil circulation:

- Forced circulation by means of ancillary pumps,
- Use of differential pressures

4.2.3.2.1 Oil pumps

Two main possibilities exist concerning ancillary pumps: they can be either mechanically built up with the compressor or autonomous, generally driven by an electrical motor.
The built-up version presents a potential economic aspect but much more current applications are composed with autonomous units, allowing the addition of redundant pumps in order to

counteract any failed ones. In this case the switching between pumps and their disassembly for repair can be carried out during the operation. Redundancy is essential since oil pumps show lower reliability than other compressor auxiliaries.

4.2.3.2.2 Pump standards

Pumps shall conform to:

- Standard 69: ISO 10438-3 Petroleum, petrochemical and natural gas industries-lubrication, shaft-sealing and control-oil systems and auxiliaries – Part 3: General purpose oil systems
- Standard 70: API 614-99 standards (chapters 3) are equivalent to ISO 10438-3

4.2.3.2.3 Oil circulation using differential pressure

The differential pressure from discharge to suction is set to move the oil around the system. The Figure 14 shows a typical oil and cooler of screw compressors of a cryogenic system.

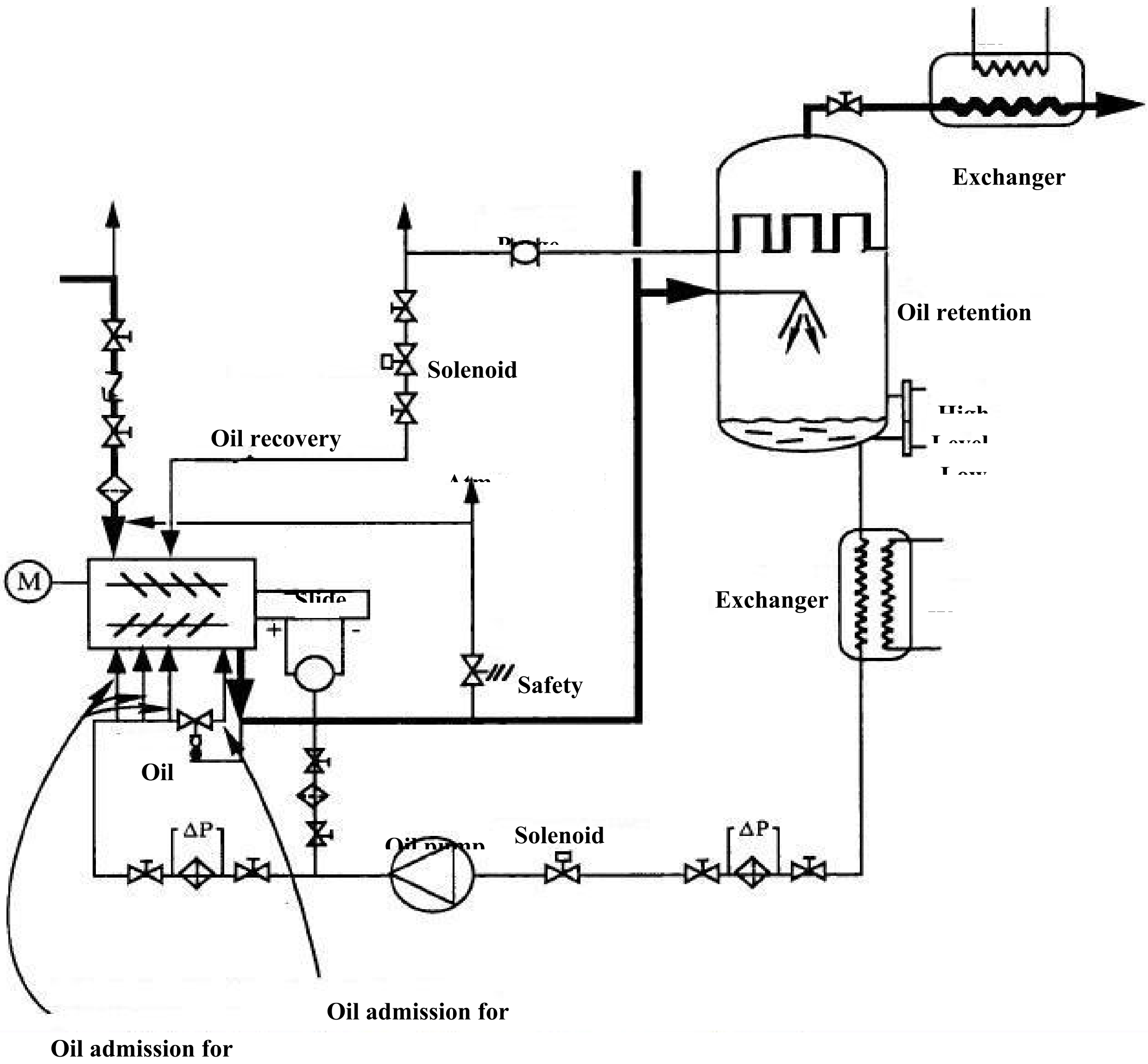


Figure 14: Typical oil and cooler of screw compressors of a cryogenic system

4.2.3.3 Oil balancing, purge and fill-up systems

During the operation, part of the oil not trapped by the oil retention vessel at middle pressure involves a decrease in oil level. Consequently, a balancing of oil shall be carried out from the high pressure retention vessel to the middle pressure retention vessel.

Each compressor and oil removal system shall be equipped by a purge and conditioning system, enabling the following actions:

- Creating the vacuum in each portion of the circuit,
- Pressurizing each portion of the circuit with clean Helium gas,

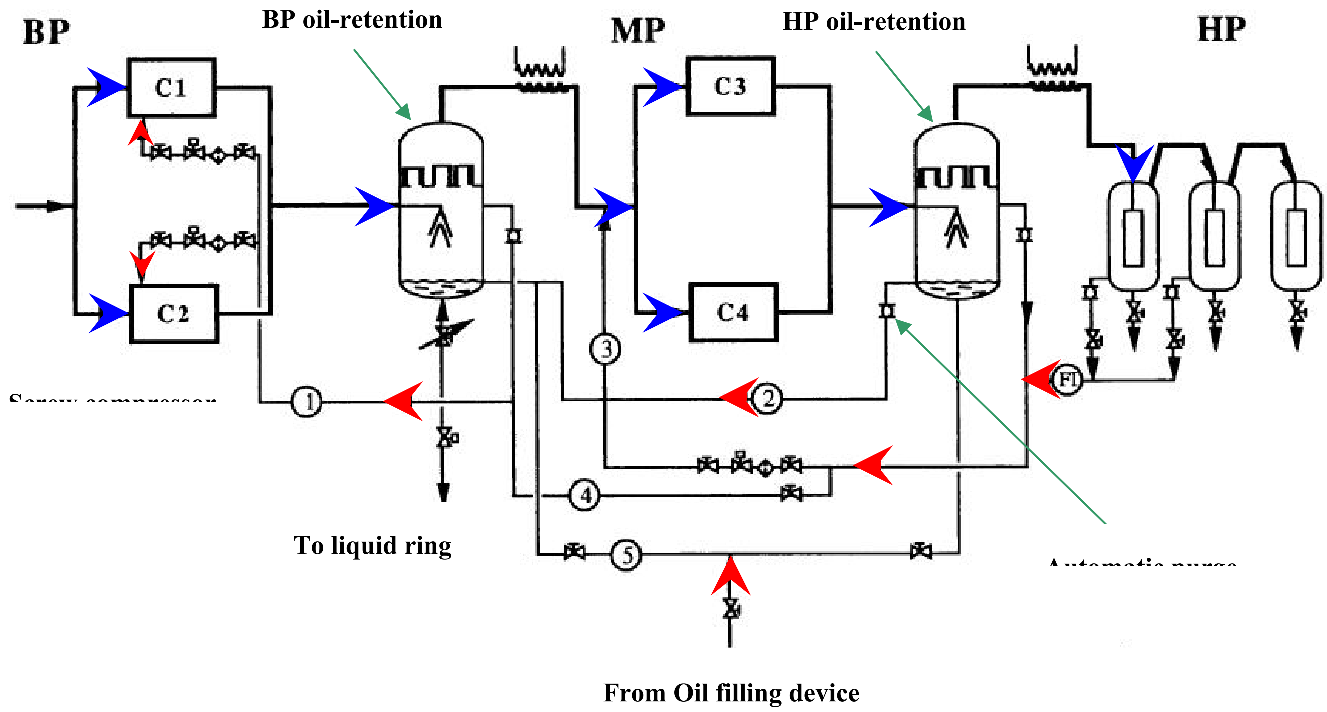
The above-mentioned actions shall be carried out via a panel of manual valves.
These connection valves must be set up so as to avoid the intake of oil into the purge system.
The helium returns such as Low Pressure or Medium Pressure shall be equipped with check valves.
Each retention vessel shall be equipped by a fill-up system. This oil fill-up system shall consist of:

- An oil barrel (providing the oil)
- An oil vessel buffer supplied by the oil barrel and fill-up or emptying of the oil retention vessel
- Valve to control the oil vessel buffer pressure

Figure 15 represents an example of oil balancing, purge and fill-up systems used by a cycle screw compressor of a cryogenic system.

Oil and helium

Oil balancing, purge and fill-up



BP oil-retention vessel purge to intermediate C1, C2

Balancing between HP and BP oil-retention vessels

HP oil-retention vessel purge and coalescer 1 and 2 toward suction pressure C3 and C4

HP oil-retention vessel purge and coalescer 1 and 2 toward suction pressure C1 and C2 during the specific operating mode

Oil manual transfer line BP <-> HP and oil filling from oil tank

Figure 15: Example of oil balancing, purge and fill-up systems

4.2.3.4 Primary oil-retention vessel

Primary oil-retention vessels remove the oil from the gas and must feature separation by gravity at the outlet of each stage of compression.

These vessels are also used as reservoirs for the lube oil.

Oil-retention reservoirs must be incorporated in the base frames of the compressor skids equipped by retention tanks to handle the full oil content of the skid in case of pipe rupture. These retention skids shall be equipped with oil detectors.

In addition, spillages are very likely to occur, also far from the retention skids. The compressor building's large floor surface must also self-retain the oil in case of very large spillage.

Figure 16 shows a primary oil-retention vessel used for the screw compressors of the cryogenic system.

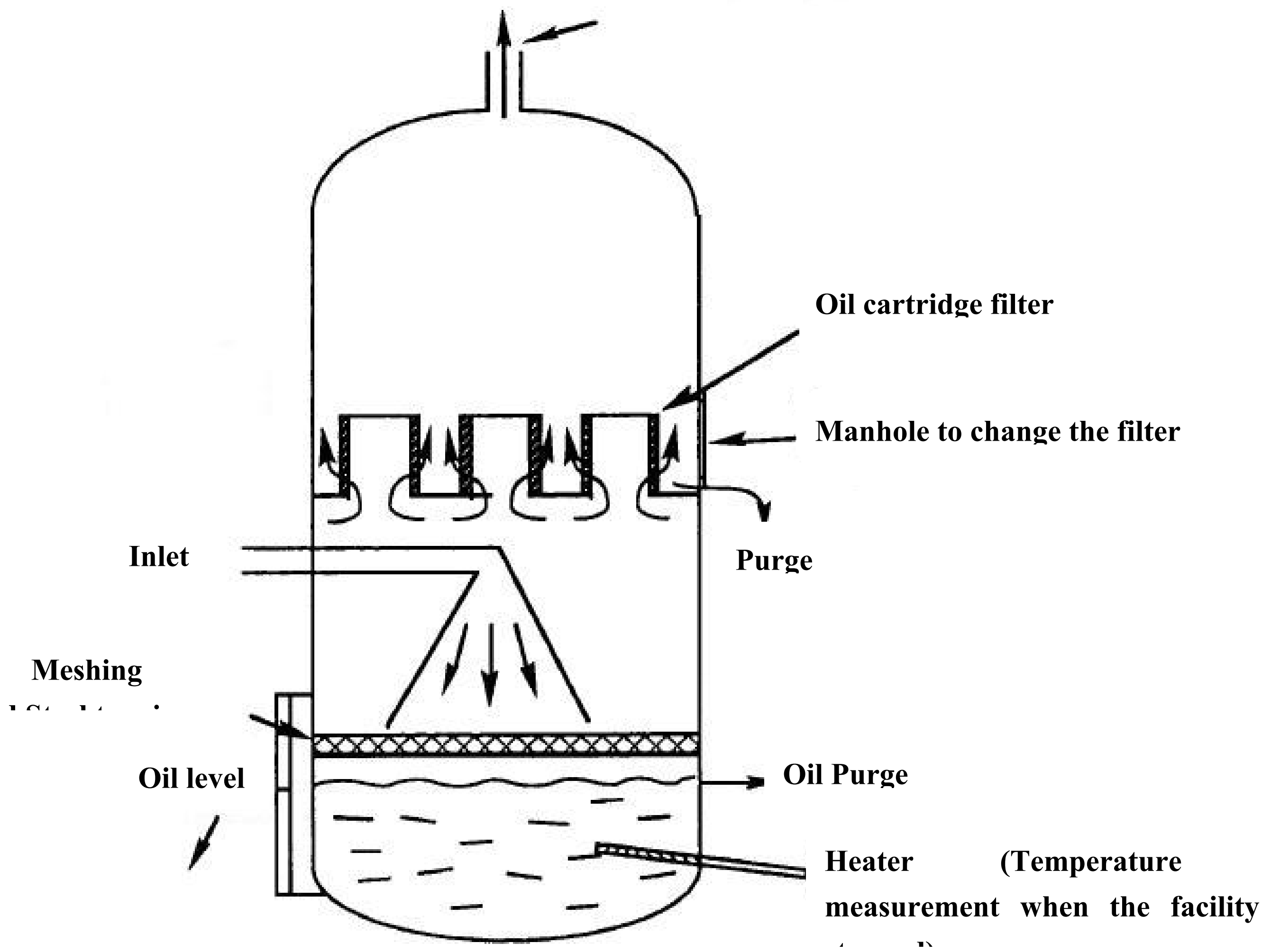


Figure 16: A typical primary oil-retention vessel

4.2.3.5 Oil cooling

Oil can be cooled by the means of different methods:

- Either a direct cooling method which consists of using an after air cooled heat exchanger,
- Either an indirect method, using an after water cooled heat exchanger. This exchanger is integrated in a forced closed loop using a water pump. This method aims to keep the loop inside the buildings.

The oil cooler is an air-cooled or water-cooled heat exchanger that is sized to adapt the capacity of the compressor being cooled.
The lube oil will flow from the bottom of the separator, through the oil cooler where it is cooled from discharge temperature down to 60°C.
The cooler should be designed to handle the worst operating conditions.
The discharge temperature shall be maintained at least 10 K higher than the dew point of the process-gas components and water vapor.

4.2.3.5.1 Oil-Cooler Standards

Oil-coolers shall comply with:

- Standard 71: ISO 10438-1 Petroleum, petrochemical and natural gas industries-lubrication, shaft-sealing and control-oil systems and auxiliaries – Part 1: General requirements
- Standard 72: ISO 10438-3 Petroleum, petrochemical and natural gas industries-lubrication, shaft-sealing and control-oil systems and auxiliaries – Part 3: General purpose oil systems
- Standard 73: API 614-99 standards (chapters 1 and 3) are equivalent to ISO 10438-1 and ISO 10438-3

4.2.3.6 Ancillary components

It is extremely important that the oil injected into the compressor remains as clean as possible, using several filters implanted in the circuits.
Conditioning circuits and specific measurements are also necessary for easy operation of oil systems.

4.2.3.6.1 Pumps oil filter

The oil pumps providing oil bearings, shaft seals and slide valves shall possess redundant oil filters mounted parallel to the suction side of the oil pumps.

These filters shall be exchangeable during operation.

4.2.3.6.2 Slide valves oil filter

A fine oil filter shall be set up at the suction of the slide control valves.

4.2.3.6.3 Bearings and shaft seals oil filter

A fine oil filter shall set up at the injection line of the compressor bearings and shaft seals.

4.2.3.6.4 Injection compressor

A wire mesh filter shall be integrated in the oil-supply line for each screw compressor.

4.2.3.6.5 Oil filter standards

Oil filters shall conform to the requirements of ISO 1438-2 and to the following:

- Oil filters for bearings, seals and control-oil systems shall provide a minimum particle removal efficiency of 99.5% for 10µm particles ($\beta \geq 200$)
- API 614-99 standards (chapters 2) are equivalent to ISO 10438-2.

4.2.3.7 Oil measurements

Oil measurement shall be necessary for the operation and protection of the equipment.

4.2.3.7.1 Operation oil measurement

The different oil facilities shall be equipped with:

Oil level measurement

- In each oil retention vessel
- In each oil retention tank (On/Off indication)
- In the third coalescer (On/Off indication)

Oil pressure

- Oil-injection pressure on each compressor skid
-

Oil differential pressure

- Differential across each oil filter

Temperature measurement

- Outlets of the coolers

4.2.3.7.2 Local measuring point

- Operation-hour counter for each oil pump
- Oil level in the oil retention vessels
- Pressure in the oil retention vessels
- Oil-injection pressure for each compressor skid

4.2.3.7.3 Oil measurement standards

Oil instrumentation shall conform to the purchaser's specifications which refer to ISO 10438.

4.2.4 *Final Oil Removal System*

Oil is present in the form of aerosols and vapor in the compressed gases downstream of oil-flooded screw compressors. To remove this oil and reduce the contents to finite levels it is possible to use successive coalescing oil separators followed by a charcoal adsorber.

4.2.4.1 Process description

The Final Oil Removal System (FORS) shall be capable of removing the last particles of oil from helium in order to avoid sending any impurities in Cold Boxes.
The basic architecture of a FORS will consist of:

- At least 3 coalescers in series which retain small droplets of oil (mechanical trapping),
- A charcoal oil adsorber set up downstream of the coalescers, to trap by adsorption the vapor generated by the lubricant and volatile oil residues such as CH_4 in the main lubricant,
- A final filter (2 microns) installed at the outlet of charcoal adsorber, in order to stop particles of the charcoal adsorbent which could be carried over by the gas flow.

Figure 17 represents an example of a Final Oil Removal System used by the cycle screw compressors of a cryogenic system.

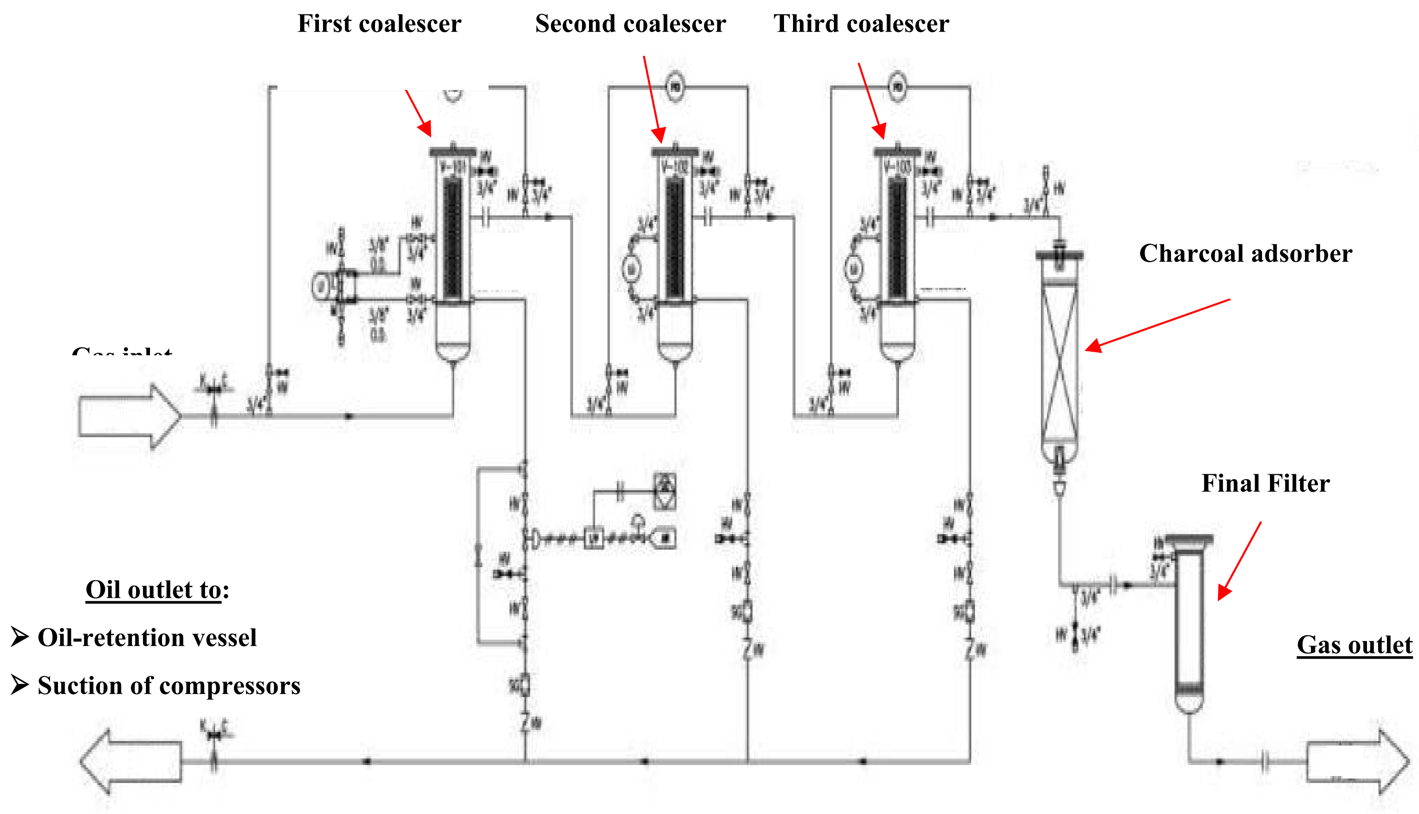


Figure 17: Example of final oil removal system for WCS of cryogenic system

4.2.4.2 Coalescers

The engineering design of coalescers shall allow treating a low gas velocity in order to optimize the efficient coalescing.

The third coalescer ensures the function of guard unit. A device shall detect oil presence at the third coalescer outlet which leads to the shutdown of the Warm Compression Station.

Figure 18 provides a schema of a coalescer located in a Warm Compression Station.

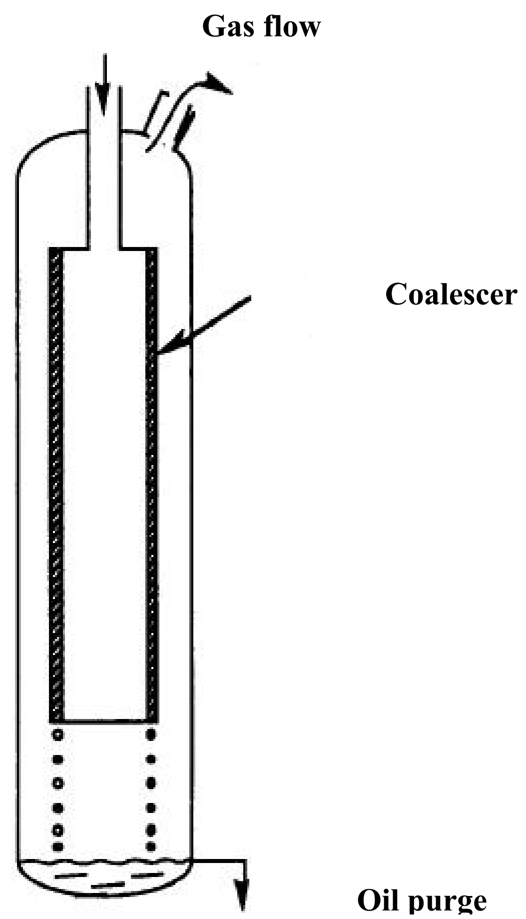


Figure 18: Typical coalescer for WCS

4.2.4.3 Charcoal adsorber

After the coalescers, the charcoal adsorber will retain any oil vapor.

4.2.4.3.1 Charcoal adsorber design

The charcoal adsorber must be designed for the maximum HP compressor helium flow with a 20% flow reserve.

The design of the charcoal adsorber must take into account the operation time without exceeding the guaranteed outlet impurity level specified in the ITER technical specification.

Access for changing the adsorbent must be planned.

4.2.4.3.2 Charcoal adsorber requirements

The charcoal in form of smooth pellets or the equivalent shall be required.

The adsorbent must be changed every 15,000 hours according to ITER operation and

regenerated and dried by circulation of gas nitrogen at a hot temperature before starting normal operation.
The charcoal oil adsorber shall be equipped with valves allowing the purge and filling. The direction flow of the gas through the charcoal bed must be from top to bottom.
Technical requirements defined in chapter 2.2.5.3 below are also applicable to the charcoal adsorber.

4.2.5 *Dryers*

4.2.5.1 Definition

The dryer works on the principle of adsorption technology: an adsorber substance removes moisture from the gas flow at ambient temperature. Porous and high surface area adsorbents are set to work in order to adsorb selectively the water vapor molecules on their surface. After a specified operating time, the humidity has to be removed from the adsorber bed. To allow a continuous operation, a twin tower adsorber is necessary. While one tower is adsorbing for a period of time, the other tower is reactivating.

The Dryer shall include the following components:

- Two adsorber beds,
- Filters,
- Purge and regeneration equipment, including the vacuum pumps for purge,
- Pipework and valves, including the equipment needed for pressure relief, purging of all circuits and the regeneration of the adsorbers,
- Measuring and actuating devices required for process control,
- All safety devices necessary to avoid damage to equipment and operating personnel,
- Eventually the corresponding electrical cabinets.
-

All the equipment of the dryer listed above shall be completely assembled on one common skid.

4.2.5.2 Dryer operations

Transitions between the operating phases will be managed by dedicated measurements. Tightness of circuits shall be controlled during each phase to prevent air inlet and nitrogen helium mixture.

4.2.5.2.1 Normal operation

During normal operation, the dryer shall continuously retain the moisture impurities from the

gas flow.
The conditions of normal operation (temperature and pressure) will be given in the technical specifications.

Dryer performance will be described in the technical specifications:

- Maximum mass flow,
- Maximum pressure drop,
- Maximum water impurity at the entrance of the dryer,
- Maximum water impurity at the outlet of the dryer,
- Autonomy of one dryer.

4.2.5.2.2 Regeneration

The regeneration is basically divided into four phases:

- Depressurization from nominal pressure to regeneration pressure,
- Heating: the regeneration of the dryers shall be done by circulating warm nitrogen through the adsorber bed in counter-current to the normal operation flow,
- Purging shall be done by filling and evacuating the adsorber with dry and clean helium,
- Cooling shall be done with dry and clean helium circulating in co-current to the normal operation flow,

The conditions of regeneration (temperature and pressure during each phase) will be given in the technical specifications.

Dryer performance will be described in the technical specifications:

- Duration of regeneration,
- Number of purging cycles,
- Gas consumption.

4.2.5.3 Technical requirements

All dryer equipment shall be suitable for the full range of the relevant operating conditions.
All items likely to require maintenance repair or replacement shall be easily and quickly accessible and shall not require other items to be cut out.

4.2.5.3.1 Adsorbers

The equal flow distribution must be guaranteed during normal operation and regeneration. Thus, devices located inside the adsorber bed shall not lead to irregularities in the adsorber filling and the creation of favored gas passages.

During the regeneration phase, the coefficient of expansion of the adsorbent material compared to the vessel material may produce a local movement. To avoid abrasion of the adsorbent, the design of the bed support must take into account this point.

The adsorber vessels are to be constructed in order to ensure ease of replacement of the adsorbent.

4.2.5.3.2 Adsorbent material

As adsorbent material, a molecular sieve of alkali alumino-silicate (Zeolite) is required. The adsorbent specifications (granulometry, pore size …) will be set in the technical specifications.

The adsorbent material shall be vibrated during and after the filling process in order to guarantee even distribution of the filling.

4.2.5.3.3 Filters

To prevent adsorbent particles from being carried out by the flow, a filter downstream of each adsorber bed is required. The wire mesh of this filter will be described in the technical specifications. The contractor shall decide on the number and position of any additional filters required, particularly in order to ensure valve seat protection against dust.

All filters shall be accessible for cleaning without the necessity to cut or weld. All filters shall be designed such that no dust collected can fall into the connected piping during replacement.

4.2.5.3.4 Electrical heaters

At least one electrical heater is required for heating the GN2 during the heating phase of the regeneration. The capacity of the heater(s) shall be defined in accordance with the different modes.

Heater requirements are developed in chapter 4.2.11.

4.2.5.3.5 Valves

Refer to chapter 4.2.14.

4.2.5.3.6 Safety valves

Refer to chapter 4.2.12.1.

4.2.5.3.7 Dryer interfaces

The interfaces with the refrigerator, with the gaseous nitrogen supply and the environmental conditions will be described in the technical specifications.

4.2.5.3.8 Vibration level

The vibration level generated by the dryer to the supporting structure will be set in the technical specifications.

4.2.5.3.9 Mechanical design

The design of the equipment and the choice of components shall be adapted to the operating conditions of the dryer.
Mechanical components subject to fluid pressure shall comply with the requirements of Pressure Equipment Directive (PED) described in chapter 4.1.1.

4.2.5.3.10 Cleaning and surface treatment

Refer to chapter 4.1.6

4.2.5.3.11 Leak rates

Maximum values admissible:

- Total leak rate from helium circuits: 10^{-6} Pa m^3/s (10^{-5} mbar l/s) (in normal operating conditions),
- Single leak rate from helium circuits: 10^{-9} Pa m^3/s (10^{-8} mbar l/s) (at max. working pressure and room temperature),

Valves (at the maximum pressure difference in operation):

- Individual leak rate across seat: 10^{-5} Pa m^3/s (10^{-4} mbar l/s)
- Individual leak rate across to atmosphere: 10^{-5} Pa m^3/s (10^{-4} mbar l/s)

4.2.5.3.12 Measuring points

The following measuring points shall be installed on the dryer. They are necessary for

operation and basic diagnostics in case of malfunction and shall be exploitable by the process control system:

4.2.5.3.12.1 Pressure measurements

- Main supply helium pressure,
- Helium pressure in each adsorber unit,
- Helium differential pressure over each filter,
- Helium differential pressure between helium inlet and outlet,
- Vacuum pressure at the vacuum pump suction.

4.2.5.3.12.2 Temperature measurements

- Gas temperature at the outlet of each adsorber,
- Gas temperature at the inlet of each adsorber (for regeneration control),
- Gas temperature for regeneration gas supply at the outlet of each adsorber.

4.2.5.3.12.3 Impurity measurements

- Measurement of moisture of helium supply,
- Measurement of moisture at 2/3 in flow direction of each dryer bed inside the adsorbent,
- Measurement of moisture with high precision of dry helium at the outlet of the adsorbent,
- Measurement of nitrogen of dry helium at the outlet of the adsorbent.

Any additional measurement considered necessary by the Bidder for operation, protection, control and interlocks not listed above shall be completed.
Instrumentation requirements are developed in chapter 4.2.16.

4.2.5.3.13 Process control

Process control shall allow the following functions:

- Fully automatic operation during start-up, regeneration and normal operation and for the transition from one mode to another,
- Safe shut-down and automatic restart in case of utility failure,
- Starting of regeneration of an adsorber bed initiated by a moisture level signal measured at 2/3 of the adsorber bed,
- Initiation of the regeneration of an adsorber bed depending on a maximum time of operation,

- Initiation of the regeneration phases of an adsorber bed by a manual operator command.

4.2.6 *Helium External Purification*

4.2.6.1 Definition

The function of an external purifier is to supply users with clean helium (free of moisture, eventually CO2, nitrogen and oxygen). *For instance, backup of helium in the cycle*.
In a cryogenic installation, helium gas can be polluted in three ways:

- in case of storage in a porous recovery gas bag
- a delivery of "impure" gas
- an accidental entry of air, and to a lesser extent air intakes by back streaming

To purify the helium flow, it is first sent into dryers in order to remove moisture. Then gaseous helium is directed through 80 K adsorbers immersed in a bath of liquid nitrogen, to trap the possible nitrogen and oxygen traces present in the gas. A heat exchanger, placed between the dryers and the cold adsorbers, uses cold nitrogen vapor to pre-cool the gas leaving the dryers and entering the cold adsorbers.
The external purification shall include the following components:

- Dryers; two separate adsorber bed bottles if continuous operation is required,
- A 300 K/80 K heat exchanger,
- 80 K adsorbers; switchable ones if continuous operation is required,
- A cryostat for the cold adsorbers; usually, the cold adsorbers are cooled in a liquid nitrogen bath,
- Filters,
- Purge and regeneration equipment,
- Pipework and valves,
- Measuring and actuating devices,
- Safety devices,
- The corresponding cabinets,
- The process control system and the control logic,

All the equipment of the external purifier must be integrated in one common skid.

4.2.6.2 External purification operations

4.2.6.2.1 Normal operation

The description of normal operation and parameters to specify are given in chapter 4.2.5.2.1 for dryers and in chapter 4.2.10.2.1 for cold adsorbers. For cold adsorbers, the maximum nitrogen consumption for the liquid bath shall be added.

4.2.6.2.2 Regeneration

Refer to chapter 4.2.5.2.2 for dryers.
The regeneration of the cold adsorbers immersed in LN2 liquid bath is basically divided into 3 phases:

- Switch to the other cold unit or bypass of the sole cold unit
- Draining of the pot circuits and draining of the LN_2 from the bath
- Heating: circulation in counter-current to the normal operation flow, of warm gaseous nitrogen (80 °C) through the pots and the heat exchanger

* In case of non-switchable cold adsorbers, a bypass of cold adsorbers can be useful during their regeneration. In this manner, the external purifier can still provide gas without moisture.

4.2.6.2.3 Cooling

Refer to chapter 4.2.5.2.2 for dryer cooling.
Cooling of the cold adsorbers shall be done in two steps:

- Evacuation of nitrogen content in the adsorbers by circulating in co-current with 300 K dry helium (already purified) and/or vacuum pumping of the pot with a primary pump
- Re-cooling the adsorbers by refilling of the LN_2 bath

4.2.6.2.4 Technical requirements

All equipment of the external purifier shall be suitable for the full range of the relevant operating conditions.
All items likely to require maintenance repair or replacement shall be easily and quickly

accessible and shall not require other items to be cut out.
Refer to chapter 4.2.5.3 for dryers.
Refer to chapter 4.2.10.3 for cold adsorbers.
Refer to chapter 4.1.1 for LN2 bath cryostat.

4.2.6.2.5 Heat exchanger

The heat exchanger can be of the counter-current type using the cold and pure helium coming from cold adsorbers and immersed in the cold nitrogen vapor to pre-cool the helium to purify. To improve efficiency, it is recommended to integrate the pre-cooling heat exchanger in the cryostat of the cold adsorbers.
Refer to chapter 4.2.9 for heat exchanger types and requirements.

4.2.6.2.6 Bypasses

A global bypass (dryers and cold adsorbers) must be installed on the external purifier.
The dryers must be equipped with a bypass.
In the case of non-switchable cold adsorbers, a bypass of cold adsorbers can be useful during their regeneration. By this way, the external purifier can still provide gas without moisture.

4.2.6.2.7 Tests

Refer to chapter 5.5.4.3 for dryers and cold adsorbers.
Refer to chapter 5.4 for LN2 bath cryostat.

4.2.7 *Gas filters*

4.2.7.1 Cold filters

All the cold rotating machines (cold compressor, super critical helium circulator and turbines) must be protected at their inlet with a mechanical filter of adequate size. It must be possible to warm up this filter without warming up the other circuit of the cold box.
The RAMI and/or hazard analysis of the cold box shall state if the filter must be housed in a separated vacuum jacket than the rest of the cold box.
Moreover, it is highly recommended to insert filters on the inlet pipes of the front end boxes (CVB and CTB) if no bypass valves exist between the supply and return lines.
Finally, filters must be located at the outlet of each cold adsorber.

4.2.7.2 Warm filters

A filter must be located at the inlet of each warm rotating machine (compressor and oil

pumps), at the outlet of each dryer and at the outlet of each oil adsorber.
The RAMI and/or hazard analysis of the equipment the filter belonging to, shall define if redundancy is required or not for each filters.

4.2.8 *Gas analyzers*

The function of gas analyzer is to achieve local control, periodic or continuous, of the quality of helium used in the cryogenic installation. The goal is to protect the system against the accumulation of elements that can condense in the cold box and create damages as a blockage of cold valves and filters, deterioration of heat exchangers performance or the breaking of a turbine.
These analyses control the efficiency of purification devices such as coalescers, dryers, warm and cold adsorbers and also detect an eventual gas inleak. According to the threshold set, the gas analyzer sets up alarms which can result in various actions:

- switches and regenerates a dryer or a cold adsorber
- reduces the speed or the mass-flow of a turbine
- stops certain components.

Figure 19 gives the functional schema of a gas analysis: the gas to be analyzed is taken in the process then transferred to the analysis unit through the sampling line after conditioning.

Figure 19: Functional schema of a gas analysis

4.2.8.1 Helium purity measurement

In helium, all gas components of air can be found. The use of oil in the screw compressors can result in the presence of hydrocarbons in helium.
Two types of analysis are available: single gas or multi-gas analyses.
Different configurations are possible:

- a selective gas analyzer can be used directly on the process pipe (single gas analysis)
- a non selective gas analyzer can be used downstream a gas separation unit (multi-gas analysis)

- a combination of selective and non selective gas analyzers in series can be used downstream from a separation unit (multi-gas analysis).

Gas analyzers must be able to detect gas components at very low concentrations.

Table 9 shows the main gas components which can be present in helium and the associated detection type.

Gas	Detection type	
	Single gas analyse	Multi-gas analyse
Oxygen (O_2)	Oxygen analyser	Gas separation unit (gas chromatography) + detector
Nitrogen (N_2)	Nitrogen analyser	
Hydrogen (H_2)		
Organic components (C_nH_m)	Flame Ionization Detector (FID)	
Carbon monoxide (CO)		
Moisture (H_2O)	Hygrometer	

Table 9: Gas components and associated detection type

4.2.8.2 Position of impurity measurement

Refer to chapter 4.2.16.4.7.3.
Sampling line
A sampling line is a line to condition and carry the gas sample to be analyzed from the sample point to the analysis unit.
The sampling line is generally equipped with:

- sample tap
- pressure reducer
- filters
- valves
- mass flow regulator
- flow-meter
- circuit for inert-gas purging
- an eventual heating of the sampling line
- an additional bypass loop

To make a representative measurement, the composition of the gas sample must not be modified between the sample point and the analysis unit. Phenomena which contribute to variations of gas sample composition are the following:

- Addition of components:
    - gas pollution by poor sealing of the sampling line
    - degassing of the walls of the sampling line
    - permeability of materials
- Loss of components:
    - selective adsorption and retention by walls of the sampling line
    - condensation
    -

In the design of a sampling line, the following points shall be taken into account:

- Turbulent flow is recommended because it creates a well-mixed fluid (avoid laminar flow)
- Reduction of residence time of sample gas in the sampling line
- Minimization the risk of leak

4.2.8.2.1 General recommendations

The sampling line should be as short in length and as small in diameter as possible to decrease the residence time, the surface area and to promote turbulent flow.
To minimize the risk of leak, it is recommended to limit the number of connections (elbows, tees, valves…). For connections, it is recommended to use Two-Ferrule Mechanical Grip Design fittings for ppm measurement or Metal Gasket Face Seal Fittings for ppb measurement.
“Dead volume” in tubing should be avoided, as they cannot easily be flushed.
Valves shall be of gas-chromatography quality

Normative references

- Standard 74: EN ISO 10715 Natural gas – Sampling guidelines
- Standard 75: EN ISO 8573-3 Annex C Compressed air – Part 3: Test methods for measurement of humidity

4.2.8.2.2 Materials used in sampling

It is recommended that stainless steel be used for all surfaces with which the gas will come into contact. Rubber tubing or connections are not recommended because of their high permeability.

The adsorption effect can be modified and often reduced by surface treatment. For detection of very low humidity concentrations, polished or electro-polished stainless steel is recommended.

For humidity measurements, hygroscopic materials shall be avoided.

4.2.8.2.3 Filters

A fine-dust removal filter shall be placed in each sampling line upstream of the analysis unit in order to protect it.

To remove oil aerosol, a coalescer filter and a charcoal filter shall be placed in series downstream of the components (valves, flow-meter, analysis unit) of the sampling line. The flow-meter of the sampling line will monitor an eventual clogging of these filters.

4.2.8.2.4 Safety valve

A safety valve shall be placed on or downstream of the pressure reducer to protect analysis unit from an uncontrolled increase in pressure in case of pressure reducer failure.

4.2.8.2.5 Bypass loop

The function of a by-pass loop, also known as a “fast loop”, is to achieve in the sampling line a higher mass-flow in order to reduce the residence time and minimize the impact of adsorption, degassing effects, gas pollution. Closest to the analysis unit, the total mass flow is shared between the by-pass loop and the line to the analysis unit (Figure 20).

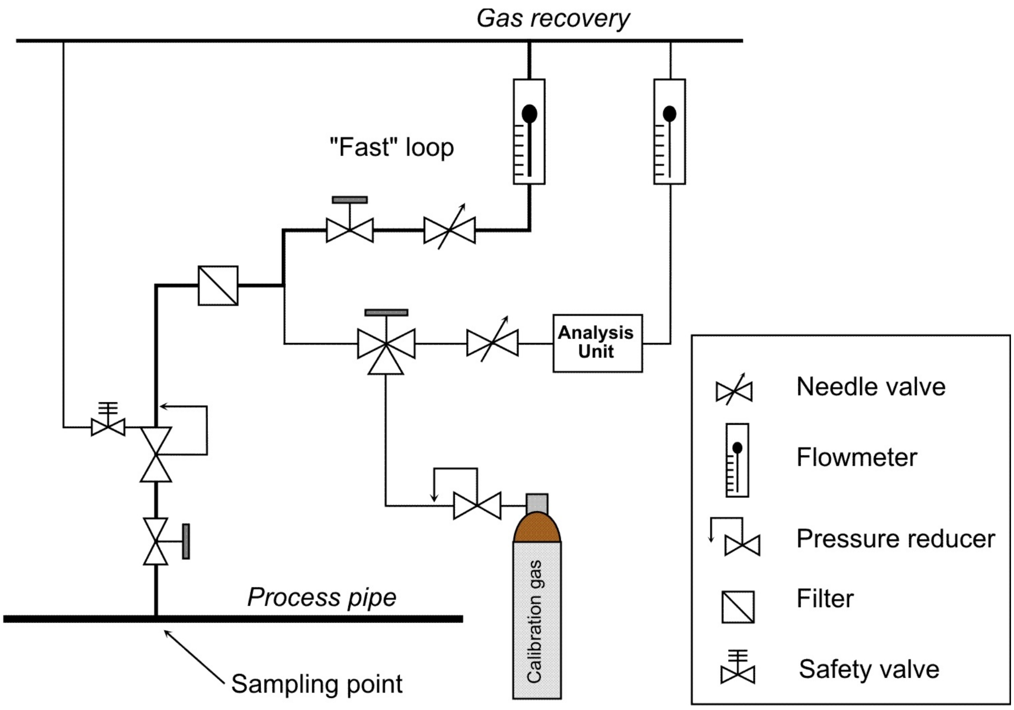


Figure 20: Schematic diagram of a sampling line with "fast" loop

4.2.8.2.6 Leak tightness

The maximum leak rate admissible from helium circuits of a sampling line is fixed at 10^{-9} Pa m^3/s (10^{-8} mbar l/s).
For valves, flow-meters, filters, refer to dedicated chapters.
The maximum total leak rate admissible from a sampling line is fixed at 10^{-6} Pa m^3/s (10^{-5} mbar l/s).

4.2.8.3 Hygrometer

A hygrometer is a single gas detector which measure humidity of a gas.
Table 10 gathers the most used hygrometers in cryogenics.

Hygrometer type		measuring principle	measure parameter	range	Response time	
Variable impedance hygrometers	Resistive	Variation of the resistivity of a hygroscopic polymer according to adsorbed humidity	Relative humidity	5% to 95%	fast	+ Very fast response time Can be portable - Sensitive to temperature Difficult to use at high temperature
	Capacitive with dielectric polymer	Variation of the capacitance of a polymer dielectric according to adsorbed humidity	Relative humidity	5% to 100%	very fast	+ Insensitive to temperature Can be portable - Difficult to use at high temperature and high relative humidity
	Capacitive with aluminum oxide dielectric	Variation of the capacitance of a dielectric according to adsorbed humidity	dew or frost temperature	-80 °C to 0 °C	middle to fast	+ Insensitive to temperature High operating pressure
Electrolytic hygrometer		Electrolysis of water adsorbed by phosphorus pentoxide (P2O5)	ppmv (dew temperature)	1 to 10000 ppm (-75 to 5 °C)	slow to middle	+ Direct measurement measure Suitable for low level of humidity - Calibration for a fixed mass flow at a given temperature and pressure Interfering gases: ammoniac, alcohol vapor, hydrocarbon
Cooled mirror dew point hygrometer		Measurement of the dew or frost temperature by condensation on a cooled mirror	dew or frost temperature	-90 °C to 100 °C	middle to fast	- Sensitive to others condensable vapours For negative temperatures, difficult to appreciate the difference between ice and water Drift of detection system due to impurities or defects on the surface of the mirror

Table 10: Principle and characteristics of hygrometers

Reference of standards

- Standard 76: EN ISO 8573-3: Compressed air – Part 3: Test methods for measurement of humidity

4.2.8.4 Oxygen analyzer

An oxygen analyzer is a single gas detector which measure oxygen concentration in a gas. Table 11 shows the most commonly used oxygen analyzers in cryogenics. In some installations, the oxygen measurement is used to detect a possible air intake.

<table>
<tr><th>Oxygen analyser</th><th>Measuring principle</th><th>Range</th><th>Response time</th><th colspan="2"></th></tr>
<tr><td>High temperature electrochemical sensors: http://www.aoi-corp.com/additional_information/oxygen_sensor_types/ - #Zirconium Oxide Oxygen Sensors (EN 61207-2)</td><td>Application of NERNST law. The sensor is heated between 700 °C and 850 °C placed in a oven</td><td>0.1 ppm to 100 %</td><td>fast</td><td colspan="2">Do not tolerate hydrocarbons of any species, hydrogen, and carbon monoxide</td></tr>
<tr><td rowspan="2">Electrochemical methods with liquid or gelled electrolyte</td><td rowspan="2">Two dissimilar electrodes immersed in an aqueous electrolyte - reduction/oxidation reaction generates an electrical current proportional to the oxygen concentration in the sample gas</td><td rowspan="2">0-10 ppm to 0-25%</td><td rowspan="2">fast</td><td>Changing sensor (no stock possible) due to consumption of anode</td><td rowspan="2">Constant operating pressure
Susceptible to over pressurization
Do not tolerate gas species such as hydrogen sulphide, hydrogen chloride, sulphur dioxide</td></tr>
<tr><td>Extended life with the non-depleting anode</td></tr>
</table>

Table 11: Principle and characteristics of oxygen analysers

Normative references

- Standard 77: EN 61207-1 Expression of performance of gas analyzers. Part 1: general
- Standard 78: EN 61207-2 Expression of performance of gas analyzers. Part 2: oxygen in gas (utilizing high-temperature electrochemical sensors).

4.2.8.5 Hydrocarbon detector

A FID detector is used directly on the process pipe. Refer to chapter 4.2.8.5.4.

4.2.8.5.1 Gas-chromatographic method

The gas-chromatographic method is a separation technique in analytical chemistry which can be coupled with a detector for qualitative and/or quantitative analysis of gaseous components.
The gas sample to be analyzed is introduced at the entrance of a packed column in a gas chromatograph, and transported through it by using a carrier gas. The different molecules of the mixture will separate and leave the column one after the other after a certain period of time which depends on the affinity of the column material with the different molecules. Finally, the different molecules are analyzed by a detector (Figure 21).
A chromatograph consists of:

- a system of carrier gas supply, usually from a bottle
- an injection system, for instance a rotary valve, introduces instantly a calibrated volume of gas sample into the continuous flow of the carrier gas at the entrance of the column
- a column placed in a temperature-controlled chamber
- a detector

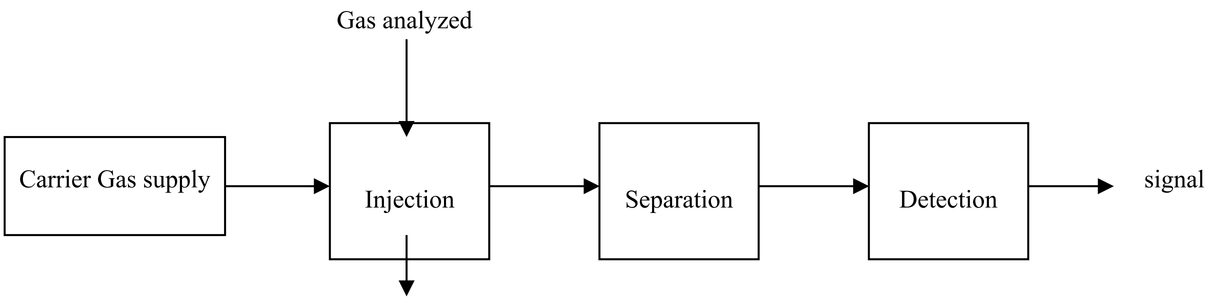


Figure 21: Functional diagram of a gas chromatograph

A chromatograph produces a non-continuous measurement because it analyses successive gas samples with a recovery of reference conditions between two gas samples.

4.2.8.5.2 Carrier gas

The carrier gas must pass through all the circuits of the chromatograph unit. Thus carrier gas supply consists of:

- at least two switchable gas bottles
- pressure reducer which controls the outlet pressure

Several carrier gases are available (hydrogen, nitrogen, helium, argon). Helium is commonly used for a helium cryoplant.
Because it is mixed with the sample gas to be analyzed, the carrier gas shall be a high purity gas. Different levels of purity are available; commonly helium "6.0" is used.

4.2.8.5.3 Column

The column is a stainless steel tube packed (maximum 2 m) or an open tubular (15 to 100 m). The packed column is filled with silica grains. The open tubular column is a silica tube whose diameter is smaller than the packed column.
The temperature-dependence of molecular adsorption and rate of progression along the column requires a careful control of the column temperature within a few tenths of a degree for precise work.

4.2.8.5.4 Detector

Detectors commonly used in gas chromatography to analyze impurities in helium are the following:

- Thermal Conductivity Detector (TCD): electrical detector, based on the principle of the Wheatstone bridge: the passage of components will vary the voltage, this variation is due to difference in conductivity of each component,
- Flame Ionization Detector (FID): it consists of a hydrogen/air flame and a collector plate. The effluent from the GC column passes through the flame, which breaks down organic molecules and produces ions. The ions are collected on a biased electrode and produce an electrical current,
- Discharge Ionization Detector (DID): it is an ion detector which uses a high-voltage electric discharge to produce ions. The ions produce an electrical current, which is the signal output of the detector.

Table 12 shows the main characteristics of these detectors

Detector	Detected components molecules	Detectability	Linear range *	
TCD	universal	10-1000 ppm	10^5-10^6	Non-destructive analysis sensitive to temperature
FID	most organic components (CH_4, C_nH_m)	0.1 ppm	10^5-10^7	Destructive analyse Insensitive to H_20, CO_2, noble gas
DID	universal	50 ppb	10^6	Non-destructive analysis Require correct implementation for reliable results
* Linear range is the ratio of the maximum detectable quantity on minimum detectable quantity				

Table 12: Main characteristics of detectors

Normative references

- Standard 79: EN ISO 6975 Natural gas – Extended analysis – Gas-chromatographic method
- Standard 80: EN ISO 6974-3 Natural gas - Determination of composition with defined uncertainty by gas chromatography - Part 3: determination of hydrogen, helium, inert gases and hydrocarbons up to C8 using two packed columns
- Standard 81: EN ISO 6974-4 Natural gas - Determination of composition with defined uncertainty by gas chromatography - Part 4: determination of nitrogen, carbon dioxide and C1 up to C5 and C6+ hydrocarbons for a laboratory and on-line measuring system using two columns

4.2.9 *Heat exchangers*

The heat exchangers are an essential component in cryogenics to obtain low temperatures. References are required for the suppliers. They are used both for the warm compression station and in the cold boxes, although the technologies chosen are generally different. At cryogenic temperature, aluminum plate-fin heat exchangers are mainly used. Even if for small power, pipe heat exchangers could be used and remain less expensive.

For all heat exchangers, the type and origin of materials and transition pieces must be given. Stainless steel heat exchangers must be of all-welded construction.

At warm temperature, shell and tube are generally used to cool the oil compressor circuits using water flow.

All heat exchangers must undergo the control and conditioning procedure described below:

- Total leakage from all heat exchangers of the cold box (at max. working pressure and room temperature) : 10-7 Pa.m3/s (10-6 mbar l/s)

- Total leakage for the heat exchangers (at max. working pressure and room temperature) : 10-7 Pa.m3/s (10-6 mbar l/s)
- Around junctions, connections, welding, brazing, leak rate must be less than 10-9 Pa.m3/s (10-8 mbar.l/s). (Pumping in the closed circuit and external gaseous helium local surrounding)

Controls Tests by the supplier should be done by certified technicians using calibrated equipment. These operations will be at the charge of the supplier. Helium leak tests and control of pressure held must be performed:
Heat exchangers will be dried, dusted off and closed with end caps under neutral gas pressurization. The Manufacturer shall be responsible for the packing and delivery including the incurred costs. The packing shall provide protection against bad weather, shocks, and transport risks.

Documentation

- Drawing of the heat exchangers with connecting pipes and calculation data sheets
- The complete report concerning the fabrication of the heat exchanger unit and the materials used (inspection and test procedure, test report)
- Manual (installation, operating instructions)

4.2.9.1 Brazed aluminium plate-fin HX

General design

The brazed aluminum plate-fin heat exchanger is a type of heat exchanger design that uses plates and finned chambers to transfer heat between fluids. It is often categorized as a compact heat exchanger due to a high heat transfer surface area to volume ratio.
A plate-fin heat exchanger is composed of a piling of plates and brazed fins. This type of heat exchanger must be vacuum brazed.
These components must be designed and manufactured in accordance with the ALPEMA standards defined by the manufacturers' association (http://www.alpema.org).

Cryogenic requirements

All heat exchangers operating below 20 K should be arranged vertically with the warm end up. Heat exchangers operating above 20 K may be oriented horizontally.
Water in the first heat exchanger of the cryoplant cold box should be removable without polluting the rest of the system. Therefore a provision on the first heat exchanger is required in order to warm it up and regenerate it for removal of frozen water.

For aluminum brazed heat exchangers, transition pieces are necessary between pipes in stainless steel and aluminum heat exchanger. Manufacturers of these transition parts must be referenced for helium cryogenic plants. For the welding of the heat exchangers with pipes, specific rules must be respected due to the

aluminum-stainless steel junctions.

For aluminum plate-fin heat exchangers, the pinch values, (Twarm – Tcold) must not be less than:

- 1 % of the warm-flow temperature for the warm-end heat exchanger
- 1.3 % of the warm-flow temperature for exchangers down to 40 K
- 1.5 % of the warm-flow temperature for exchangers below 40 K.

4.2.9.2 Shell & tube HX

General design

As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes, and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The set of tubes is called a tube bundle, and may be composed by several types of tubes: plain, longitudinally finned, etc.
These components must be designed and manufactured in accordance with the TEMA standards defined by the manufacturers' association (http://www.tema.org) or equivalent.

Specific requirements

Shell and tube heat exchanger are frequently used for the warm compressor oil cooling circuits. The oil or helium is in the shell stream and the water must flow inside the tubes. The tubes and end plates must be in stainless steel (316L) or equivalent. All joints separating water from oil or helium are to be fusion-welded, with the welds on the water side. Access to the inner surface of the tubes for inspection and cleaning must be easy. On the gas side, the coolers must be equipped with purge valves for rinsing. At the water side, valves to drain the water and empty air pockets must be installed.

4.2.9.3 Air-cooled HX

General design
Air-cooled heat exchangers are devices for rejecting heat from a fluid directly to ambient air, commonly used in industrial applications where a reliable source of water is not available as a cooling medium. Even if water is available, in some cases, air-cooled exchangers are preferred for economic or operational reasons: dedicated cooling water circuits, pumps, water cooling systems and water conditioning systems reduce reliability and complexity and capital requirements, as well as operating and maintenance costs.

Specific requirements
The mechanical design of the exchanger must accommodate the process conditions including pressure and temperature and, possibly, risk of corrosion, fouling and condensation.
One or more heat exchanger bundles of tubes (smooth and finned) and an air moving device such as a fan are generally used.

Atmospheric heaters
Ambient temperature -20°C to +30°C
Design pressure 25 bar

The design, mechanical-thermal calculations, mechanical drawings and electrical drawings shall be submitted to IO for approval prior to manufacture.
Mechanical components exposed to fluid pressure shall comply with the European Pressure Vessel Code.
All materials used for the manufacture of atmospheric heaters shall be suitable for the use for which they are intended. The specification for the materials of the main components will be subject to approval by IO. All materials used at low temperature to be joined by welding shall be low-carbon austenitic stainless steel, or the equivalent. Materials known to become brittle at low temperature shall not be used for components that may become cold in normal or emergency situation. All metals used shall be corrosion-proof even under prolonged exposure to condensing water.

Recommended materials:
Aluminum atmospheric heater (finned pipes)

4.2.9.4 Plate heat HX

General design
A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. Major advantages are compactness versus a conventional heat exchanger (since the fluids are exposed to a much larger surface area because the fluids spread out over the plates,) and flexibility (easy modification of the number of plates or types of plates, cleaning, etc.). Gaskets between the plates are generally used, but for small heat exchangers, they could be brazed.
The operation temperature is usually between 270 K and 450 K.

Specific requirements
Stainless steel must be used for the plates and the materials for sealing gasket must be compatible with the fluids and their pressure and temperature (oil + helium and water).
Tubes and seals must be compatible with the pressure, temperature and type of fluid cooled.

4.2.9.5 Pipe or double-pipe HX

General design
Pipe or double-pipe heat exchangers in stainless steel or copper materials could be used. This is not compact heat exchanger technology but is generally inexpensive. Pipe heat exchangers could be used in liquid baths (helium or nitrogen) and double-pipe heat exchangers could allow the exchange of energy between two fluid flows.

4.2.10 *Cold Adsorbers*

4.2.10.1 Definition

80 K and 20 K adsorbers are required to purify helium respectively from nitrogen and from neon and hydrogen. The cold adsorber work on the principle of adsorption-technology: an adsorber substance removes “impurities” from the gas flow at low temperature. Porous and high-area adsorbents are set to work in order to adsorb selectively the molecules on their surface. When the adsorbent is saturated, impurities have to be removed from the adsorber bed. Regarding the operation time between two regenerations, two switchable adsorbers are necessary for the 80 K stage to allow a continuous operation, whereas a single adsorber at 20 K is sufficient.

In addition, the cold adsorber systems shall include the following components:

- Filters,
- Purge and regeneration equipment, including vacuum pumps for purge,
- Pipe work and valves, including the equipment needed for pressure relief, purging of all circuits and regeneration and cool-down of the adsorbers,
- All necessary injection lines of impurity contents at the inlet of the adsorbers in order to pass performance tests,
- Measuring and actuating devices required for process control,
- All safety devices necessary to avoid damage to equipment and operating personnel.

4.2.10.2 Adsorber operations

Transitions between the operating phases shall be managed by dedicated measurements.

4.2.10.2.1 Normal operation

During normal operation, the adsorber shall continuously retain the “impurities” from the gas flow.

The conditions of normal operation (temperature and pressure) will be given in the technical specifications.

The performance of the adsorber will be described in the technical specifications:

- Maximum nitrogen or hydrogen and neon impurities at the outlet of the adsorber,
- Maximum mass flow,
- Autonomy of one adsorber at maximum mass flow and maximum nitrogen or hydrogen and neon impurities at the entrance,
- Maximum pressure drop.

4.2.10.2.2 Regeneration

The regeneration at 300 K of the cold adsorbers is basically divided into four phases:

- Depressurization from nominal pressure to regeneration pressure. To prevent ice formation, cold exhaust gas shall be warmed up by an electrical heater or by mixing with warm helium,
- Heating; the regeneration of the adsorber shall be done by circulating warm (300 K) helium through the adsorber bed in counter-current to the normal operation flow. A potential heater upstream from the adsorber can be added to maintain helium gas temperature at 300 K,
- Purging shall be done by filling with dry helium and evacuating the adsorber by a primary pump,
- Filling and pressurizing the adsorber with helium at nominal pressure.

The conditions of regeneration (temperature, pressure, duration of each phase) and required performance will be given in the technical specifications:

- Duration of regeneration,
- Number of purging cycles,
- Gas consumption.

4.2.10.2.3 Cooling

Cooling shall be done with dry helium circulating in co-current to the normal operation flow.
The technical specifications will give:

- The maximum mass flow allowed during cooling,
- The maximum duration of cooling.

4.2.10.2.4 Standby

For adsorbers at 80 K, a standby phase is useful between the end of the regeneration and the return to normal operation. During this phase, the adsorber can be kept at nominal pressure and temperature to allow a rapid switch to normal operation.
Technical specifications will give details on this potential phase.

4.2.10.3 Technical requirements

All adsorber equipment shall be suitable for the full range of the relevant operating conditions.
All items likely to require maintenance, repair or replacement shall be easily and quickly accessible and shall not require other items to be cut out.

4.2.10.3.1 Adsorbers

The equal flow distribution must be guaranteed during normal operation, regeneration and cool-down. In this manner, devices located inside the adsorber bed shall not lead to irregularities in the adsorber filling and the creation of preferred gas passages.

The design of the adsorbers must be such that any movement of the adsorbent and any emission of dust, both upstream and downstream, are prevented.
The adsorber vessels must be designed in order to facilitate the replacement of the adsorbent inside the vacuum vessel.
The adsorbers shall possess all necessary connections and manual valves to ensure isolation, evacuation and purging.

4.2.10.3.2 Adsorbent material

An activated charcoal is required for adsorbers. It must be chemically and mechanically stable under all operating conditions.
The adsorbent specifications (granulometry etc.) will be set in the technical specifications.

4.2.10.3.3 Filters

To prevent adsorbent dust being carried by the flow, a wire mesh filter downstream from each adsorber bed is required. A wire mesh upstream from each gas analyzer is mandatory. The wire mesh of these filters will be set in the technical specifications.
The contractor shall decide on the number and position of any additional filters required, particularly in order to ensure valve seat protection against dust.
All filters shall be accessible for cleaning without the need to cut or weld. Access openings must be installed to allow access to the filters without the need to enter the vacuum vessel. All filters shall be designed such that no dust collected can fall into the connected piping during replacement.

4.2.10.3.4 Electrical heaters

An electrical heater is required to control adsorber inlet temperature during the heating phase of the regeneration. To prevent ice formation, an electrical heater is recommended to warm up the cold return gas.
The capacity of the heaters shall be defined in accordance with the different operating modes.
Heater requirements are developed in chapter 4.2.11.

4.2.10.3.5 Bypasses

All adsorbers must be equipped with a bypass to reroute the helium flow during all operation conditions of the refrigerator.
For 20 K adsorber, this bypass allows the regeneration at low temperature.

4.2.10.3.6 Valves

Refer to chapter 4.2.14.

4.2.10.3.7 Safety valves

Refer to chapter 4.2.12.1.

4.2.10.3.8 Dryer interfaces

The interfaces with the external piping and with the environmental conditions will be described in the technical specifications.

4.2.10.3.9 Hot surfaces

All surfaces which might, due to the process design, have a temperature of greater than or equal to 320 K shall be protected against contact by personnel by the means of adapted insulation.

4.2.10.3.10 Mechanical design

The design of the equipment and the choice of components shall be adapted to the operating conditions of the adsorber.
Mechanical components subject to fluid pressure shall comply with the requirements of Pressure Equipment Directive (PED) described in chapter 4.1.1.

4.2.10.3.11 Cleaning and surface treatment

Refer to chapter 4.1.6

4.2.10.3.12 Leak rates

Maximum values admissible:

- Total leak rate from helium circuits: 10^{-6} Pa m^3/s (10^{-5} mbar l/s) (in normal operating conditions),
- Single leak rate from helium circuits: 10^{-9} Pa m^3/s (10^{-8} mbar l/s) (at max. working pressure and room temperature),

Valves (at the maximum pressure difference in operation):

- Individual leak rate across seat: 10^{-5} Pa m^3/s (10^{-4} mbar l/s)
- Individual leak rate to atmosphere: 10^{-6} Pa m^3/s (10^{-5} mbar l/s)

4.2.10.3.13 Measuring points

The following measuring points shall be installed on the adsorbers. They are necessary for operation and basic diagnostics in case of malfunction and shall be exploitable by the process control system:

4.2.10.3.13.1 Pressure measurements

- Helium pressure in each adsorber bed,
- Helium differential pressure over each filter,
- Helium differential pressure between helium inlet and outlet,
- Vacuum pressure at the vacuum pump suction.
-

4.2.10.3.13.2 Temperature measurements

- Gas temperature at the inlet of each adsorber,
- Gas temperature at the outlet of each adsorber,
- Temperature in each adsorber bed,

4.2.10.3.13.3 Impurity measurements

- For each 80 K adsorber, measurement of nitrogen at 2/3 in flow direction inside the adsorbent,
- For 20 K adsorber, measurement of neon and hydrogen at 2/3 in flow direction inside the adsorbent.

Any additional measurement considered necessary by the Bidder for operation, protection, control and interlocks not listed above shall be completed.
Instrumentation requirements are developed in chapter 4.2.16.

4.2.10.3.14 Process control

The process control shall allow the following functions:

- Fully automatic operation during start-up, regeneration and normal operation and for the transition from one mode to another,
- Safe shut-down and automatic restart in case of utility failure,
- Starting of regeneration of an adsorber bed initiated by an moisture impurity level signal measured at 2/3 of the adsorber bed,
- Switching of the adsorber operation after a maximum continuous operation time independently from the impurity level signal,
- Initiation of the regeneration phase of an adsorber bed by a manual operator command.

4.2.10.4 Tests

4.2.10.4.1 Manufacturing tests

For components subject to Pressure Equipment Directive (PED), tests are described in chapter 5.4.

4.2.10.4.2 Reception tests on ITER site

The operating conditions during the reception tests will be given in the technical specifications. The following main points shall be validated:

- Performance of the adsorber beds in terms of helium purification (nitrogen extraction for 80 K adsorbers, N2 and H2 extraction for 20 K adsorber),
- Duration of operation time,
- Duration of the regeneration,
- Maximum pressure drop specified,
- Fully automatic operations of the adsorbers.

The detailed procedures of tests will be detailed in the technical specifications.

4.2.11 *Heaters*

4.2.11.1 Introduction

Heaters represent important devices for cryogenic system operation and reception acceptance tests.
There are two classes of heaters applied in cryogenics: electrical and ambient air heaters.
Ambient air gas heaters or liquid evaporators can be used only in temporary or intermittent operation allowing defrosting. They have an important application when they must remain operational in case of power failure and regardless of environmental conditions. They can be considered as a special case of heat exchangers as considered in 2.2.9.
This chapter describes only the electrical heaters.
The electrical heaters shall be selected according to the specificities of the cryogenic system, regarding their application and their environment.
Even if custom manufactures are proposed for specific uses, most of adapted heaters for cryogenic purpose can be found off the shelf.
All heaters shall be chosen in order to guarantee a maximum of safety, reliability and performance.

4.2.11.2 Heating system components

A heating system shall consist of (see Figure 22):

- The Heater itself,
- A Temperature Protection device acting on the power or the control unit,
- A Control unit associated to a measurement,
- A Power unit (Switchgear).

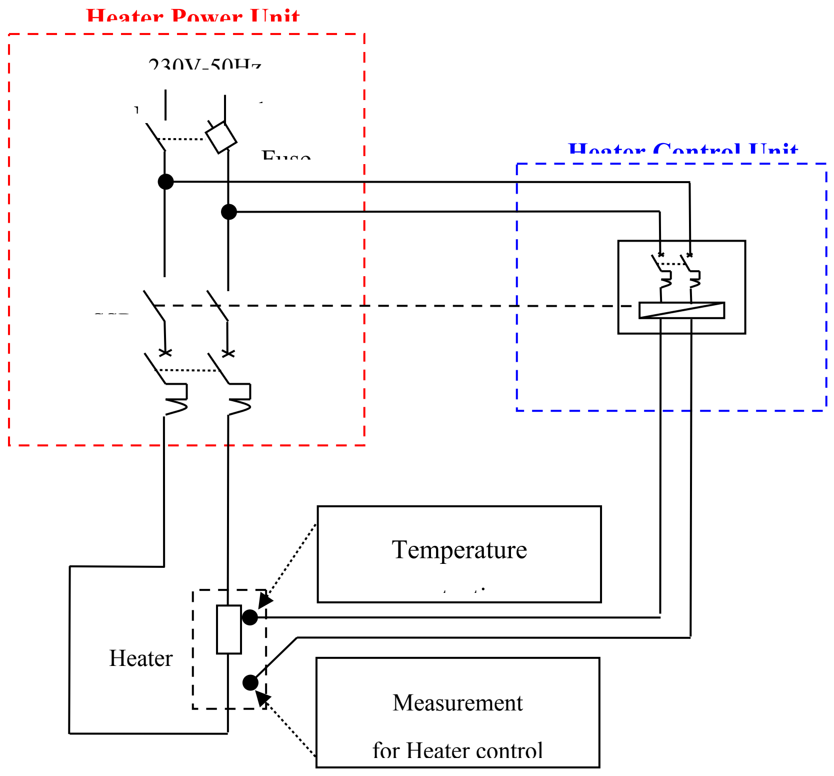


Figure 22: Heating system diagram

4.2.11.3 Applications

The heater elements shall comply with requirements based on to their possible different uses. The main implementations of heaters encountered in cryogenic systems are:

- Immersion in liquid baths,
- Implantation inside or around pipes and vessels,
- Implantation inside massive supports.

Principal applications are:

- The control of pressure, temperature or level in piping and vessels,
- The simulation of heat loads,
- The warming of cold vapors,
- The prevention of ice and frost formation,
- The warm-up phases of cryogenic systems,

- The heating phases of adsorber and dryer regeneration,
- The temperature control of specific devices, such as oil separators.

4.2.11.4 Industrial heaters

4.2.11.4.1 Classic heating wire

The basic element is the 80/20 Nickel-Chrome wire. Above 1350°C, pure Nickel can be required.
This resistive element is then assembled in various types of heaters depending on the foreseen application.

4.2.11.4.2 Standard Heaters

The following paragraph describes technical aspects of main industrial heaters used in cryogenics. In addition to general functional requirements listed below, the specific technical requirements related to each type are listed in Table 13. Then Table 14 shows the various applications of these types.

4.2.11.4.2.1 General Requirements

According to the operating parameters, general specifications of heaters shall at least include:

- Type of application:
  - Liquid heating, by circulation or immersion,
  - Gas heating,
  - Solid heating.
- Operating conditions
  - Mass flow, volume,
  - Maximum power,
  - Maximum and minimum temperature of operation,
  - Maximum pressure of operation, compliance with ATEX directive chapter 7.5.
- Electrical requirements
  - Electrical supply level,
  - Electrical connection type,
  - Electrical insulation.
- Exposure to environment constraints (vacuum, magnetic, nuclear, moisture, vibrations, seismic).

4.2.11.4.2.2 Specific requirements

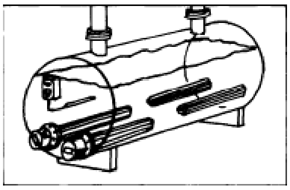
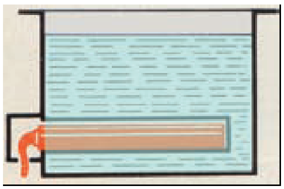
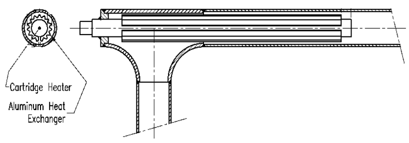
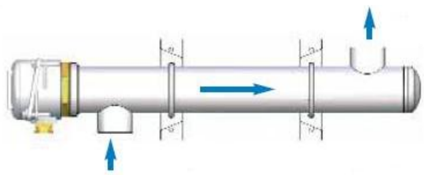
Heater type	Description	Usual characteristics	Specific requirements
Tubular	80/20 nickel-chrome resistance wire Stainless steel sheath Magnesium oxide insulation Formable into a large variety of shapes	Temperature up to 800 °C Ø 6 to 22 mm Density load heat flux up to 12 W/cm^2 Power up to 20 kW Electrical supply 230 V and 400 VAC	Heating element: tube diameter and length, heating and non-heating length, specific sheath materials, forming shape Mounting method: screw, flange or welded version, bulkhead fitting
Ceramic core	Comprise coils of nickel chrome resistive wires inside a cylindrical ceramic core	Temperature up to 450 °C Ø 47 and 58 mm Density load heat flux up to 10 W/cm^2 Power up to 6 kW Electrical supply 24 V to 400 VAC	Heating element: heating and non-heating length, overall diameter and length Mounting method: screw or flange version, bulkhead fitting
Cartridge	80/20 nickel-chrome resistance wire spiral wound around a magnesia former Stainless steel sheath Non formable Electrical connection on single side	Temperature up to 450 °C Density load heat flux up to 80 W/cm^2 Power up to 5 kW Electrical supply 24 V to 400 VAC	Heating element: diameter, heating and non-heating length, specific heath materials Possible temperature integral protection device: thermocouple type and location Mounting method: insertion in a thimble trap (H7 bore fit) with specific thermal grease, screw or flange version

Immersion	with pin shaped tubular element(s) assembled in cluster and immersed directly in the medium with removable heating elements inserted in thimble traps	Temperature: refer to corresponding heating element Density heat flux: refer to corresponding heating element Power up to 40 kW Electrical supply 230 V and 400 VAC	Heating element : refer to tubular, or ceramic core or cartridge heaters Cluster characteristics: diameter, number of pins, pin fixing (welded, brazed), immersion length, heating and non heating length Possible temperature protection device: type (thermostat, thermocouple, PT100), location, fixing (welded on the heating element, inside a thimble trap) Mounting method: screw or flange version, bulkhead fitting
Circulation	Screw plug or flanged immersion heater mounted in a thermally insulated heating chamber These heaters can be connected hydraulically in series or in parallel in order to obtain high power	Temperature refer to corresponding heating element Density heat flux refer to corresponding heating element Power up to 40 kW Electrical supply 230 V and 400 VAC	Heating element: ref immersion heater Flanges: size, location, orientation of inlet, outlet flanges and drain pipe Temperature protection device: type (thermostat, thermocouple, PT100), location, welded on the heating element Mounting method: overall dimensions, position, orientation of mounting lugs and saddles, mobile skid version with wheels equipped with a control panel
Mica band	Resistance wire or tape wound onto a mica sheet Stainless steel cover protection	Temperature up to 350 °C Ø 20 to 610 mm Density load heat flux up to 8 W/cm^2 Power up to 500 W Electrical supply 12 V to 400 VAC	Heating element: diameter, width, one or two piece, specific material for cover protection Clamping system: separate strap, clamping flange, clamping pad... Possible temperature protection

			device: thermocouple type, location, fixing
Flexible	Circuit printed on a silicone or polyimide (kapton) film	Temperature up to 200 °C Density load heat flux up to 0.8 W/cm^2 Power up to 1 kW Electrical supply 12 V to 240 VAC	Heating element: size, insulation type Temperature protection device: type (thin-film RTD, thermocouple, thermostat), location Mounting method: pressure-sensitive adhesive, epoxy and cement, clamping

Table 13: Specific requirements of industrial heaters

4.2.11.4.2.3 Heater implementation

Immersion in liquid baths	Immersion heater  Cartridge inserted in a thimble trap 
Implantation inside pipes	Cartridge inserted in a thimble trap   Circulation heater  Mobile heater 

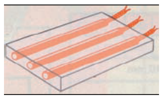
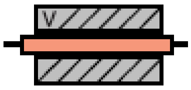
Implantation around pipes/vessels (continued next page)	Mica band heater  Flexible heater 
Implantation inside massive supports	Cartridge or ceramic core heater inserted in drilled hole  Tubular heater 

Table 14: Heater applications

4.2.11.4.2.4 Design and manufacturing

Depending on the operation conditions and the type of application, heater components are considered as pressure equipment and must be designed and manufactured to fulfill the Essential Safety Requirements of the Pressure Equipment Directive.

Examples:

- Circulation or mobile heaters constituted by tubular heating elements inserted in a metallic envelop and setting to work fluids with pressure above 0.5 bar gauge are considered as pressure vessels,
- Heating elements inserted in thimble trap and immersed in vessel or pipe with pressure exceeding 0.5 bar gauge are considered as pressure accessories.

4.2.11.4.2.5 Materials

All materials shall be corrosion-proof.
Flanges and sheaths shall comply with general material requirements as specify in the dedicated chapters.
All heater components, connection wires and associated cable shall be free of halogen, sulphur and asbestos substances.
Mechanical and thermal properties of selected materials shall be provided to IO.

4.2.11.4.2.6 Codes and standards

All heater components shall comply with IEC codes and standards and with requirements for earthing and electromagnetic compatibility (EMC) according to the Electrical Design Handbook (Iter IDM reference 2DSPT6), part 4: Earthing, EMC and Lightning Protection.

4.2.11.5 Protection temperature sensor

In order to avoid overheating of the system, each electrical heater must possess a specific protection temperature sensor acting on the power or the control unit.
These elements can be integrated in the heater or placed in an area where the heating power provided is the most representative.
These temperature sensors shall not be used to control the heater temperature, only for the components protection in case of overheating.
Lists of thermocouples which are more adapted for use in magnetic and irradiative environment will be found in chapter 4.2.16.3.3.
For the cartridge heaters or similar heaters which operate at low temperature, a complementary security system such as pressure drop control shall be installed in order to avoid overheating in case of the circulation loop stops in order to avoid overheating.

4.2.11.6 Heater control unit

Most of control units consisting in thyristor modules are convenient to drive the thermal loads with various processes:

- Phase angle firing,
- Pulse modulation.

For small power or particular accuracy of power measurement requirements, DC units shall be required.
Furthermore the time response of the system shall be taken into account notably in case of circulation loop stopping.
The effective power output of the control unit shall be measured and transmitted to the CCS (Cryogenic Control System).

4.2.11.7 Heater power unit

The heater power unit shall ensure:

- The protection of persons against direct electrical contact via a high sensitive Residual Current Device (RCD),
- The thermal-magnetic protection of components carried out by switchgear (circuit-breaker or fuses).

4.2.11.8 Associated measurement

Each heater system shall be associated to a sensor (level, temperature, pressure …) used for regulation, located judiciously in order to track the representative effect of the delivered thermal load.
The choice of this sensor shall comply with the rule applicable to cryogenic system (more information concerning design, implementation chapter 4.2.16).

4.2.11.9 Heater reception acceptance tests on site

Moreover the mandatory tests as geometry, leak tightness, pressure tests described in the chapter 5.2, the heater elements shall withstand specific tests on site shown in Table 15.

Test	Acceptance criteria
Partial discharge test (only on heating element)	No discharge
Isolation resistance	> 1 GΩm at 500V
Control of heating wire resistance	±5% of nominal resistance
Burn up test: full power during 10 minutes	Check correct functionality of the heater and correct temperature readout

Table 15: Specific tests of heaters on site

4.2.12 *Safety systems*

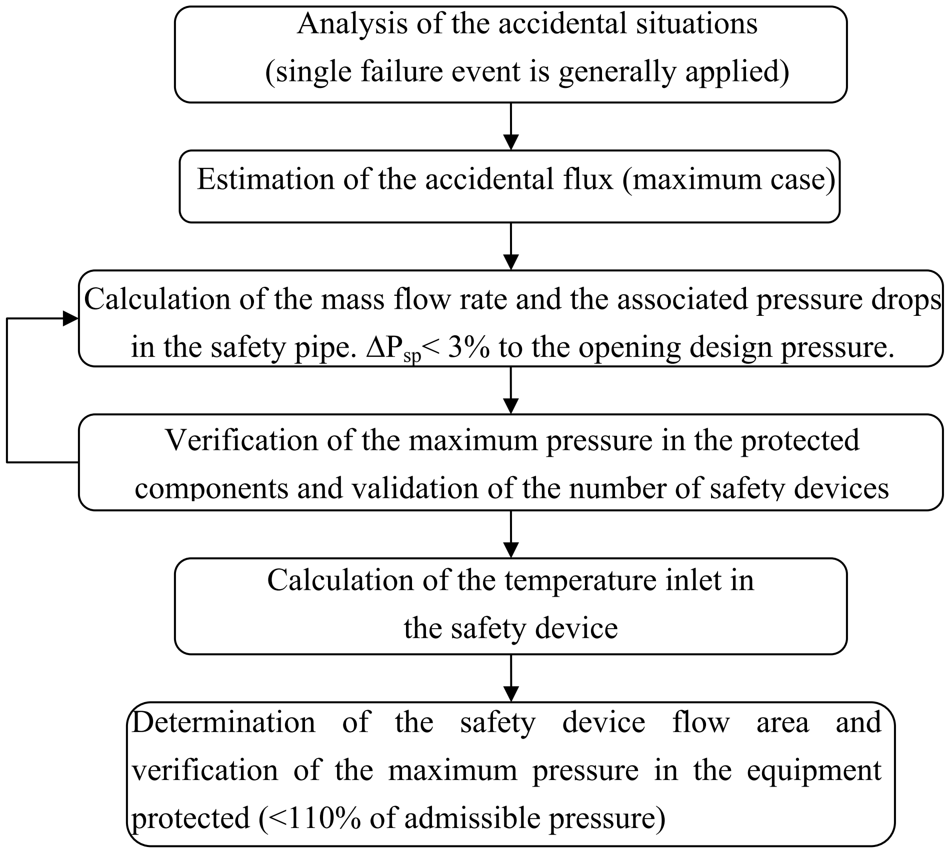
A safety system (pressure limiting system) is a component installed to protect materials (pipes, vessels) and persons to an accidental situation (breaking of the insulation vacuum, damage of a pipe …). It has to be designed using the following standards:

- Standard 82: ISO 4126 Part 1 to 7 Safety devices for protection against excessive pressure

- Standard 83: EN 13648 Part 1 to 3 Cryogenic vessels - Safety devices for protection against excessive pressure
- Standard 84: ISO 21013, ISO 7005-1:1992 for Metallic flanges

The choice and calculation of safety components must be approved by IO before installation on cryogenic equipment (see the ITER Cryogenic Safety Handbook (ITER IDM ref. 2V3VMN)).

The design procedure for all safety devices is generally the following:



This paragraph describes the components used to protect the cryogenic system (circuits, vessels and vacuum vessels) from overpressure due to accidents.

4.2.12.1 Safety valves

Safety relief valves shall be installed, where necessary, according to applicable regulation. This concerns especially cold volumes, which can be isolated by valves, as well as all insulation vacuum volumes. The valves must be sized so as to ensure discharge into the atmosphere or another volume the maximum plausible flow due to a fault (e.g. pipe rupture or breaking the insulation vacuum) at a pressure not exceeding the design value.

All safety valves must be accessible and removable for periodical calibration. The surrounding pipe work is therefore to be designed so as to allow the dismounting of safety valves by disconnecting flanges.
As an additional measure to control leakage of safety valves, all local manifolds collecting exhaust from the safety valves and connected to the atmosphere via a non-return valve shall be equipped with a small rubber balloon. The balloon shall be installed on the end of the tube connecting the manifold to the atmosphere. Standard balloons should be used.
Safety valves may or may not be vented into a helium volume for recovery.
The safety valves blowing a mix of helium and oil shall vent into a chimney that separates oil from helium. Helium shall next be vented outside the building and oil recovered in an oil pit.

4.2.12.2 Controlled safety valves

This paragraph describes the components used to protect:
- the cryogenic system from overpressure due to accidents
- the helium circuits or superconducting magnets against over-pressure resulting from an accident such as a resistive transition (Quench).

4.2.12.3 Safety valves

Safety relief valves shall be installed, where necessary, according to applicable regulation. This concerns especially cold volumes, which can be isolated by valves, as well as all insulation vacuum volumes. The valves must be sized so as to ensure discharge into the atmosphere or another volume the maximum plausible flow due to a fault (e.g. pipe rupture or breaking the insulation vacuum) at a pressure not exceeding the design value. The design pressure as well as the discharge temperature for each individual case are to be determined in line with technical specifications.
Safety valves from helium volumes shall vent into common recovery headers. The headers have to be connected to the helium gas tanks. A system to detect leakage of safety valves, e.g. a flow meter for small flow or some He detection device, is to be connected to each header. If connection of safety valves to atmosphere cannot be avoided, the corresponding line shall be closed via a suitable non-return valve in order to prevent air in-leak.
As an additional measure to control leakage of safety valves, all local manifolds collecting exhaust from the safety valves and connected to the atmosphere via a non-return valve shall be equipped with a small rubber balloon. The balloon shall be installed on the end of the tube connecting the manifold to the atmosphere. The balloons used shall preferably be of a standard type. Otherwise, reserve balloons shall be provided.
All safety valves must be accessible and removable for periodical calibration. The surrounding pipe work is therefore to be designed so as to allow the dismounting of safety

valves by disconnecting flanges.

The safety valves located on pipe containing oil and helium shall vent into a chimney that separate oil from helium. Helium shall next be vented outside the building and oil recovered in an oil pit.

4.2.12.4 Reference documents and standards

- Standard 85: EN 13458-3: Static Vacuum insulated vessels
- Standard 86: EIGA publications 24/08/E: Vacuum Insulated Cryogenic Storage, Tank Systems, Pressure Protection Devices.

This document provides a code of practices for pressure protection devices and other referenced standards that are applicable.

4.2.13 *Safety Important Components (SIC)*

The document « classification et méthodologie des SIC_FR.doc » reference **ITER_D8347SF3 v1.1** from ITER gives the principles and criteria implemented for the classification of the Safety Important Components (SIC). A preliminary list of SIC is attached in appendix A. In this list the cryogenic transfer lines and the cryoplants do not have to ensure a safety function.

4.2.14 *Valves*

4.2.14.1 Valve description

The main components of a valve and their application are shown in Table 16. Figure 23 gives an example of a valve.

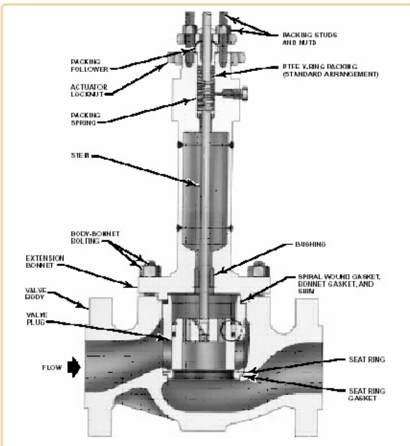


Figure 23: Example of Globe valve

	function	comments
Body	envelope which contains the fluid going through the valve	Main body shapes: - straight - angle - multi-channel
Bonnet	- cover on the valve body - casing through which the stem passes - supports the actuator	can be equipped with a leak test plug
Seat	Sealing surface which ensures the closure of the valve. It can be integrated or be a separate component.	Main materials of sealing surface: PTFE, vespel, PCTFE
Valve plug	Mobile component of the valve whose position in the fluid stream can change the flow.	Main valve plug shapes: Plug (V shape, needle), Butterfly, Ball
Stem	connected to the actuator transmits motion of the operating device to the shutter	
Packing	ensures the sealing of the stem and the bonnet	Different types: - Single or double O-ring system - Gland packing - Bellow
Actuator	utilizes a source of power to produce motion of the stem to operate the valve	The source of power can be: - Manual - Pneumatic - Electric

Table 16: Main valve components and their application

4.2.14.2 Valve characteristics

4.2.14.2.1 Flow coefficients

The use of flow coefficients offers a standard method of comparing valve capacities and sizing valves for specific applications.
The flow coefficient Cv is the volume (in US gallons) of water at 60°F that will flow per minute through a valve with a pressure drop of 1 psi across the valve.
The flow coefficient Kv is the volume (in m3) of water at 15°C that will flow per hour through a valve with a pressure drop of 1 bar across the valve.
The relation between Cv and Kv is:

$$Cv = 1.16\ Kv$$

4.2.14.2.2 Relation flow-travel (equal %, linear, on/off)

All control valves have an inherent flow characteristic that defines the relationship between 'valve opening' and flow rate under constant pressure conditions.
The design of the obturator/seat affects how the control valve capacity changes as the valve moves through its complete travel. Figure 24 gives, for globe valves, the different shapes of

valve plug and seat arrangement corresponding to the different inherent flow characteristics.

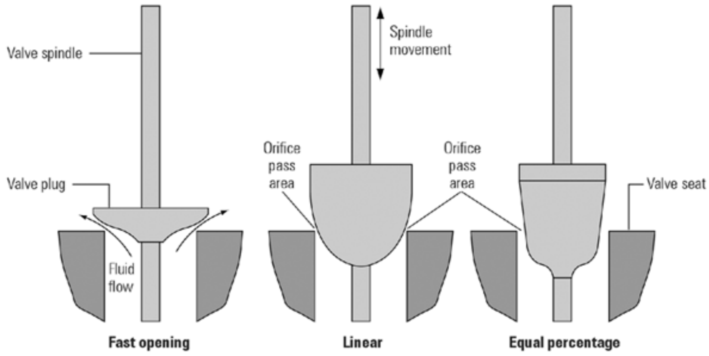


Figure 24: Different plug shapes and their inherent flow characteristics

The inherent flow characteristics of typical globe valves and rotary valves are compared in the Figure 25. These curves are based on constant pressure drop across the valve. The 3 main types available for globe valves are usually designated:

- Linear**,** flow capacity increases linearly with valve travel.
- Equal percentage**,** flow capacity increases exponentially with valve travel. Equal increments of valve travel produce equal percentage changes in the existing C_v.
- Fast opening (On/Off), a very small variation of valve travel produces a large change in flow capacity.

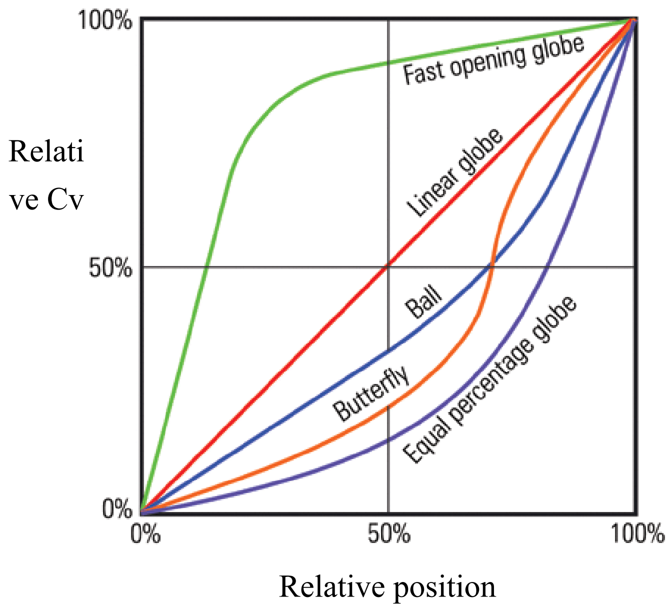


Figure 25: Inherent flow characteristics

4.2.14.2.3 Range ability

Valve range ability is defined as the ratio of the maximum to minimum controllable flow coefficient though the valve (NF EN 60534-2 standard). Small range ability correlates to a valve that has a small range of controllable flow rates. Valves that exhibit quick opening characteristics have low range ability values. Larger range ability values correlate to valves that have a wider range of controllable flows. Linear and equal percentage valves fall into this category. The Table 17 gives the indicative range ability of most usual valves.

Valve type	Range ability
Globe	20:1 to 50:1
Butterfly	20:1
Ball standard	20:1
Eccentric rotary plug	100:1
Segmented Ball	300:1

Table 17: Representative range ability of usual valves

4.2.14.3 General requirements

The general specifications of valves shall at least include:

- Operating conditions
    - Maximum flow
    - Maximum pressure
    - Minimum pressure drop
    - Operating temperature

- Valve characteristics
    - Flow-travel relation (linear, equal percentage, on/off)
    - Safety position (normally closed/normally open)
    - Form
    - Actuator
- Material accepted
- Leak tightness (seat tightness, from body to vacuum, from body to atmosphere)
- Environmental conditions (magnetic field, radiation)
- Mechanical interface with vacuum, with process

- Accessories (positioner, position (end switches, read back)
- RAMI

Table 18 summarizes the specifications already set by IO (ITER_D_2VV4PL v1.0).

Operating conditions: Nominal Pressure Temperature range	 5 MPa 4.5 K to 470 K
Valve type: Flow-travel relation Actuator	 “fast closing” and “slow opening” type (turbine inlet valve) Pneumatic (air supply 7 bar g, oil and water free) Solenoid for on/off valves (220/240 Vac or 24 Vdc) Rilsan (not for ionization, radiation environment), cooper or Stainless Steel for I/A tubing
Material Body Static O-ring Seat/Seal	 Stainless steel (AISI 316L) Viton Vespel, PTFE, PCTFE, PEEK
Leak tightness	2.10^{-9} Pa.m^3/s (from body to vacuum) 10^{-5} Pa.m^3/s (from body to atmosphere) 10^{-4} Pa.m^3/s across the seat (Room temperature, upstream / design pressure, downstream / vacuum pressure)
Mechanical interface with vacuum with process	 Flange accepted only for warm valves Welded on the cold boxes Welded on the piping
Accessories: Positioner Position	 Electro pneumatic Remote control (Hart protocol, Netbus, other fieldbuses…) Refer to the Namur guidelines or IEC 60534-6-1 standard End switches Read back (4-20mA)
Reliability Maintainability	Integrated into cryogenic system for 20 years Operation during 10,000 stroke cycles and 20 thermal cycles without replacing any component MTBF provided by the manufacturer Technical documentation and spare parts during 10 years

Table 18: Valve specifications already set by ITER

4.2.14.4 Warm valves

Table 19 shows the most common valve types.

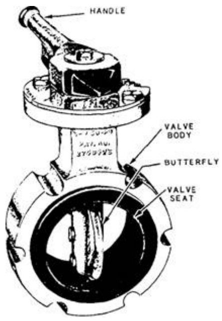
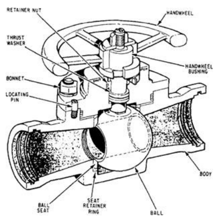
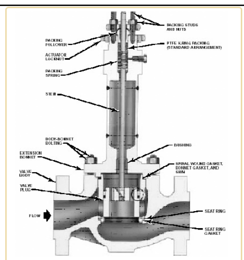
Valve type	DN	Kv	Scheme	Comments	Recommended applications
Butterfly valve	40 to 1000	≈ 60 to 100000		* low pressure drop * suitable for frequent maneuvering * high capacity * low cost and maintenance * good flow control - no full passage - high torque required for control - unsuitable for high differential pressure	
Ball valve	8 to 150	≈ 3 to 3500		* small pressure drop * quick and easy maneuvering * compact * high capacity * low cost and maintenance - Unsuitable for control	Discussions with ITER
Globe/Angle valve	15 to 300	≈ 0.1 to 1300		* accurate flow control * adjustable relation flow-travel - high pressure drop - expensive	

Table 19: Main warm valves

4.2.14.5 Cold valves

According to heat loads requirements and number of low temperature cycles, valves used at low temperature can be classified in three categories:

- Standard valves
- Standard valves with some enhancements to operate at low temperature
- Cryogenic valves specially designed for cryogenics

4.2.14.5.1 Additional requirements

In addition to general requirements, the technical specifications of cryogenic valves shall include:

- Operating conditions (gas, JT, liquid, superfluid)
- Maximum heat losses leaks (insulating extension, vacuum insulation, thermalization)
- Assembly (interface with vacuum and process)

4.2.14.5.2 Cryogenic valves

Table 20 shows the main cryogenic valves.

Valve type	DN	Kv	Scheme
Cryogenic ball valve	8 to 150	≈ 6 to 1030	
Cryogenic Butterfly valve	50 to 1200	≈ 100 to 85000	
Cryogenic Globe/Angle valve	2 to 200	≈ 0.007 to 850	

Table 20: Main cryogenic valves

Standards

In European standard, a valve is a component which can change the flow rate by opening or

closing the passage of fluid. This category includes the control valves. Indeed, a control valve is a valve operated mechanically. It consists of a valve connected to an actuator which makes the obturator position variable in response to a control signal.
The main European standards for valves are the following:

TERMINOLOGY

- Standard 87: NF EN 736-1 (1995-06) Valves - Terminology - Part 1: definition of types of valves
- Standard 88: NF EN 736-2 (1997-11) Valves - Terminology - Part 2: definition of components of valves
- Standard 89: EN 736-3 (2008-05) Valves - Terminology - Part 3: definition of terms

GENERAL DESIGN

- Standard 90: EN 1503-1(2000-12) Valves - Materials for bodies, bonnets and covers - Part 1: steels specified in European Standards
- Standard 91: EN 1503-2(2000-12) Valves - Materials for bodies, bonnets and covers - Part 2: steels other than those specified in European Standards
- Standard 92: EN 12516-1(2005-10) Industrial valves - Shell design strength - Part 1: tabulation method for steel valve shells (2 - 2007-03-01)
- Standard 93: EN 12516-2 (2004-12) Industrial valves - Shell design strength - Part 2: calculation methods for steel valve shells
- Standard 94: EN 12516-3(2003-06) Valves - Shell design strength - Part 3: experimental method
- Standard 95: EN 12570(2001-08) Industrial valves - Method for sizing the operating element

TESTS

- Standard 96: EN 12266-1 (2003-06) Industrial valves - Testing of valves - Part 1: pressure tests, test procedures and acceptance criteria - Mandatory requirements
- Standard 97: EN 12266-2 (2003-06) Industrial valves - Testing of valves - Part 2: tests, test procedures and acceptance criteria - Supplementary criteria

MARKING

- Standard 98: EN 19 (2002-06) Industrial valves - Marking of metallic valves

DEDICATED STANDARD (refer to standards above)

- Standard 99: EN 1983 (2006-08) Industrial valves - Steel ball valves
- Standard 100: EN 593 (2009-08) Industrial valves - Metallic butterfly valves

- Standard 101: EN 1984 (2000-03) Industrial valves - Steel gate valves
- Standard 102: EN 1626 (2008-12) Cryogenic vessels - Valves for cryogenic service
- Standard 102 for cryogenic valves, gives additional requirements for materials, design and defines cryogenic tests and leak tests.
- For industrial control valves, an additional set of European standards must be followed.

TERMINOLOGY

- Standard 103: EN 60534-1 (2005-06) Industrial process control valves - Part 1: control valve terminology and general considerations

DESIGN

- Standard 104: EN 60534-2-1 (1999-09) Industrial process control valves - Part 2-1: flow capacity. Sizing equations for fluid flow under installed conditions

TESTS

- Standard 105: EN 60534-2-3 (1998-05) Industrial process control valves - Part 2-3: flow capacity. Test procedures.
- Standard 106: EN 60534-2-4 (2009-10) Industrial-process control valves - Part 2-4: flow capacity - Inherent flow characteristics and range ability
- Standard 107: EN 60534-2-5 (2004-01) Industrial process control valves - Part 2-5: flow capacity - Sizing equations for fluid flow through multistage control valves with interstage recovery
- Standard 108: EN 60534-3-1 (2001-06) Industrial process control valves - Part 3-1: dimensions - Face-to-face dimensions for flanged, two-way, globe-type, straight pattern and centre-to-face dimensions for flanged, two-way, globe-type, angle pattern control valves
- Standard 109: EN 60534-3-2 (2001-10) Industrial process control valves - Part 3-2: dimensions - Face-to-face dimensions for rotary control valves except butterfly valves
- Standard 110: EN 60534-3-3 (1999-02) Industrial process control valves. Part 3-3: dimensions. End-to-end dimensions for butt-weld, two-way, globe-type, straight pattern control valves**.**
- Standard 111: EN 60534-4 (2006-11) Industrial process control valves - Part 4: inspection and routine testing
- Standard 112: EN 60534-9(2008-05-01) Industrial process control valves - Part 9: test procedure for response measurements from step inputs

MARKING

- Standard 113: EN 60534-5 Industrial process control valves - Part 5: marking

NOISE LEVEL

- Standard 114: EN 60534-8-1 (2006-02) Industrial process control valves - Part 8-1: noise considerations - Laboratory measurement of noise generated by aerodynamic flow through control valves
- Standard 115: EN 60534-8-2 (1993-06) Industrial process control valves - Part 8: noise considerations. Section 2: laboratory measurement of noise generated by hydrodynamic flow through control valves.
- Standard 116: EN 60534-8-3 (2001-02) Industrial process control valves - Part 8-3: noise considerations - Control valves aerodynamic noise prediction method
- Standard 117: EN 60534-8-4 (2006-03) Industrial process control valves - Part 8-4 : noise considerations - Prediction of noise generated by hydrodynamic flow

A second standard exists. It refers to standards on valves and industrial control valves:

- Standard 118: EN 1349 “Industrial process control valves” (2009-12)

4.2.14.6 Tightness class - Seat leakage

This specifies the maximum seat leak rate admissible for each tightness class (I to VI). The test procedures (fluid of test, pressure drop across the valve) are also described (EN 60534-4).

Table 21 summarizes the maximum seat leakage according to the tightness class.

Tightness class	Maximum leakage
I	No special requirement
II	5.10^{-3} * nominal capacity
III	10^{-3}* nominal capacity
IV	10^{-4}* nominal capacity
V	Leak rate depends on the seat diameter and pressure drop
VI	Leak rate depends on the seat diameter and pressure drop

Table 21 : Maximum seat leakage according to tightness class

4.2.14.7 Safety Integrity Level (SIL)

Industrial valves can be compatible with:

- Standard 119: EN 61508-5 Functional safety of electrical/electronic/programmable

electronic safety-related systems - Part 5: examples of methods for the determination of safety integrity levels

For valves lightly loaded, the SIL is a measure of the valve performance in terms of probability of failure on demand (PFD). It is the risk that a valve will fail when it is operated For valves used in continuous ("continuous mode"), the SIL is expressed in terms of probability of failure by hour (PFH).

There are four discrete integrity levels associated with SIL: SIL 1, SIL 2, SIL 3, and SIL 4 (Table 22). The manufacturer specifies the maximum SIL for which the valve can be used.

To maintain SIL level of the valve, periodic tests, described in EN 61508, must be performed.

Safety Integrity Level (SIL)	Probability of failure on Demand (PFD)	Probability of failure by Hour (PFH)
SIL 4	10^{-5} to 10^{-4}	10^{-9} to 10^{-8}
SIL 3	10^{-4} to 10^{-3}	10^{-8} to 10^{-7}
SIL 2	10^{-3} to 10^{-2}	10^{-7} to 10^{-6}
SIL 1	10^{-2} to 10^{-1}	10^{-6} to 10^{-5}

Table 22: Scale of SIL levels

4.2.15 *Actuators and positioners*

4.2.15.1 General rules

From a general point of view the valve is composed of the valve body, and the actuator which acts on the valve in order to change its position. It is recommended to use a positioner or pressure converter which commands the actuator and then the valve. The positioner regulates the position of the valve and converts information coming from automation for the actuator (Figure 26).

Due to the specific environmental constraints of the ITER tokamak, it is necessary to install remote electronic devices (chapter 7.7). If a pneumatic positioner is used, its orientation has to be controlled, as well as the effect of the magnetic field on the nozzle-diaphragm spring. For remote positioners, diameter and length of pipe, air pressure supply (pressure amplifier) and the behavior of the valve have to be taken into account.

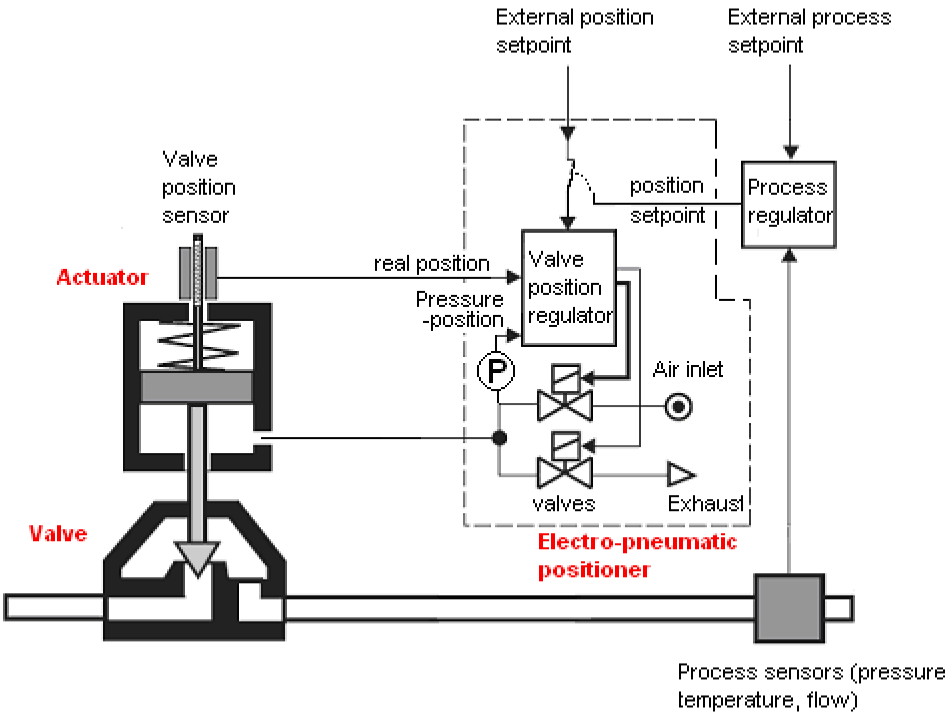


Figure 26: General schema of a valve with positioner

4.2.15.2 Normative references

ACTUATOR

- Standard 120 : EN 15714-1 (2009-12) Industrial valves - Actuators - Part 1: terminology and definitions
- Standard 121: EN 15714-2 (2009-12) Industrial valves - Actuators - Part 2: electric actuators for industrial valves - Basic requirements
- Standard 122: EN 15714-3 (2009-12) Industrial valves - Actuators - Part 3: pneumatic part-turn actuators for industrial valves - Basic requirements
- Standard 123: EN 15714-4 (2009-12-01) Industrial valves - Actuators - Part 4: hydraulic part-turn actuators for industrial valves - Basic requirements

POSITIONER

- Standard 124: EN 60534-6-1 (1998-01) Industrial process control valves - Part 6: mounting details for attachment of positioners to control valves. Section 1: positioner mounting on linear actuators.
- Standard 125: EN 60534-6-2 (2001-07) Industrial process control valves - Part 6-2: mounting details for attachment of positioners to control valves - Positioner mounting on rotary actuators

- Standard 126: EN 60534-9 Industrial process control valves - Part 9: test procedure for response measurements from step inputs
- Standard 127: EN 61514 Industrial-process control systems - Methods of evaluating the performance of valve positioners with pneumatic outputs
- Standard 128: EN 61514-2 Industrial-process control systems - Part 2 : methods of evaluating the performance of intelligent valve positioners with pneumatic outputs

4.2.15.3 Control valves actuators

Two types of pneumatic actuators are available: simple (membrane) or double effect. Selection of actuator is made in line with the selection of the valve itself. If necessary the purchase of the actuator could be decoupled from the valve body in synergy between each supplier.
The simple effect actuator (Figure 26) is the simpler design with a back pressure spring which allows a safety position in case of lack of air. This design simplifies also the interface between actuator and positioner by using only pipe in order to command the jack (push or pull). Its main drawback is the response time with remote positioner when the valve is push or pull by the spring. This time is mainly defined by the spring strength and the volume of air to be exhaust.
The double effect actuator (Figure 27) is more complex than the previous one but allows better response time. This type of valve could be used for bi-stable valve in order to maintain the position even in case of blackout or lack of air pressure.
The position measurement valve can be carried out by resistive, capacitive or inductive measurement (chapter 4.2.16). Due to the ITER environment, we recommend using a resistive measurement. Some electro-pneumatic positioners allow using pressure output as a position measurement. In this case, the positioner becomes an automation data/pressure converter.

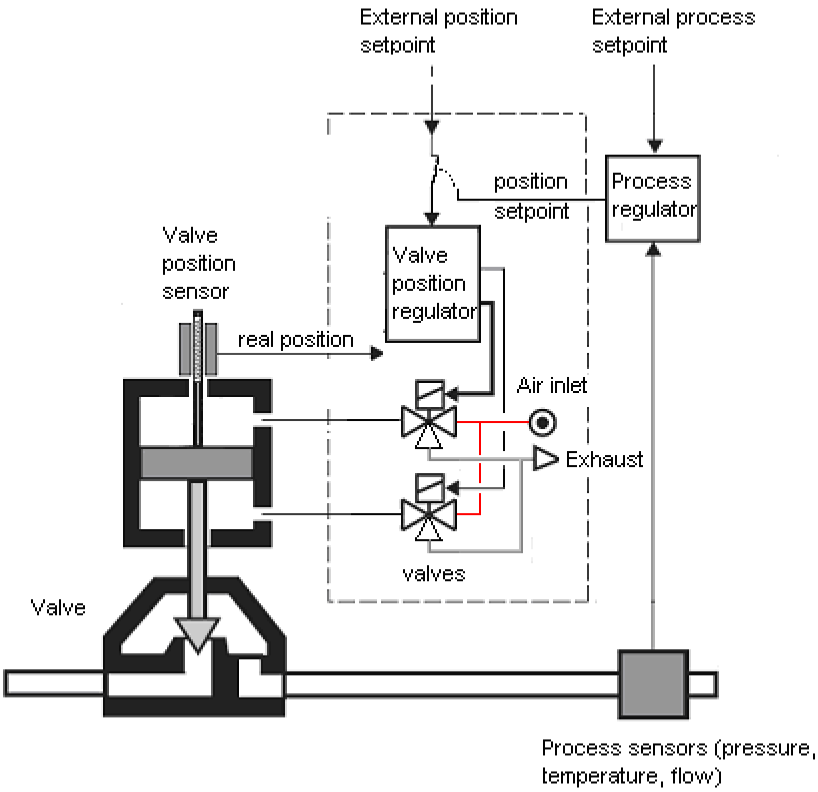


Figure 27: Schema of control valve with double effect actuator and its command

4.2.15.4 On/Off valves actuators

Simple effect or double effect jacks are used for On/Off valve actuator. For simple effect valve, the back spring has to be defined to pull or push back the valve to its safety position. Selection of actuator is made in line with the selection of the valve itself. They are usually used as insulation valves.

4.2.15.5 Remote positioners - Close positioners

For remote positioner (Figure 26) there are two loops of regulation control:

- the valve position: with the electro-pneumatic positioner including set point coming from automation system, measurement of position on the actuator and output pressure delivers to the actuator,
- a physics value: with automation system including calculated set point by PLC, physics measurement (P, T L F) by gauge on the vessel around and output value delivers to the positioner.

For remote converter (PLC data/Pressure) only the first loop is working. Usually the relative output pressure range is 0.2bar-0% and 1 bar-100% but the size of actuator could involve the selection of a non-standard range.

Due to the rooting pipe distance between valve actuator and their positioner or converter,

response time has to be checked especially when air in the membrane is depressurized by back pressure spring (Figure 26). In order to avoid this issue, the use of double effect actuator is recommended. In this case position measurement of the valve can be carried out only by a position sensor (Figure 27).
Finally we can underline that both types of command can be installed with 100 m length of pipe. The designer will keep in mind that the selection of the section of pipe, its materials and the air pressure supply (pressure amplifier) will impact the response time of the valve.
Another option can be considered as a split positioner solution: the electrical component of the positioner is separated from the pneumatic one. In such case, the electrical part of the positioner is located in an area protected from ionization/radiation and single neutron effect. This option is recommended to prevent use of long pipes with pressurized air that are replaced by cables.

4.2.16 *Instrumentation sensors (cryogenic field)*

4.2.16.1 Introduction

The instrumentation design must respect some general rules applicable for the whole of the cryogenic system.
However, due to its configuration and its environment, the description of the instrumentation of the cryogenic's system of ITER has to be divided into 3 parts:

- The Warm Compressor Station (WCS) with instrumentation at room temperature, specific analysis of purity of helium and usual industrial environment.
- Cold boxes with instrumentation from room temperature to 4 K, specific analysis of purity of helium and usual industrial environment.
- Cryogenic distribution from room temperature to 4 K in a specific magnetic and nuclear environment.

This document specifies requirements and constraints for each part of the cryogenic system. For cryogenic devices external to the cryogenic system, one will have to find equivalent constraints to match her/his requirements.

4.2.16.2 General rules and concept of measurement

All the instrumentation must comply with International Organization for Standard (ISO). List of ISO rules:

- Standard 129: ISO 1000 International system for units
- Standard 130: ISO 1179 Steel compression couplings for tubes
- Standard 131: ISO 2714 Positive displacement Meters
- Standard 132: ISO 2715 Turbine meters
- Standard 133: ISO 2954 Mechanical vibration of machines 10 to 200 rev/s

- Standard 134: ISO 3461 Symbolic representation, for process measurement control functions and instrumentation
- Standard 135: ISO 5167 Specification for square-edged orifice plates nozzles and Venturi tubes inserted in circular cross section conduits running full
- Standard 136: ISO 5168 Methods of measurement of fluid flow: estimation of uncertainty of a flow rate measurement
- Standard 137: ISO 8310 Temperature measurement system
- Standard 138: ISO 9000 Quantity system principals and applications
- Standard 139: ISO 9001 Quantity systems
- Standard 140: ISO 3511 Symbolic representation, for process measurement, control functions and instrumentation
- Standard 141: ISO 6718 Specification for bursting, disc and bursting disc devices
- Standard 142: ISO 3740 to 3746 Guide to selection of methods of measuring noise
- Standard 143: ISO 3864 Safety signs and colors
- Standard 144: ISO 14713 Protecting coating of iron steel structures
- Standard 145: ISO 8423 PVC insulated cables. For electric power and, lighting
- Standard 146: ISO 2714/2715 Positive displacement Meters

All electrical equipment must comply with the rules which are based on IEC standards and codes (http://www.stdswebport.org ask for password and login from ITER organization), Color code (if one exists), Electrical Safety code (ITER.D.26QSAJ.v2.0; ITER.D.26QS2N.v1.0; ITER.D.26QUC3.v1.0) and ITER Safety Instruction. (UID:2YQM6T ; UID:2547C4)
For the global cryogenic system environment requirements, range of sensors and general accuracy are given in the Table 23.

Service Area		Environmental Requirement		
Storage area	(**S**)	Atmospheric:-10°C to +50°C		
Compressor building	(**C**)	Ambient: 15°C to 45°C, vibration frequency: up to 1000 Hz		
Cold Box Building	(**B**)	Ambient: 15°C to 45°C		
Tokamak building	(**T**)	Ambient: 20°C to 45°C, Magnetic field <0.033 T, Radiation hardness < 2.10^{-3} Gy/h (during POS) [4]		
Measurement Loops	**S**	**C**	**B**	**T**
Temperature	4.5 K to 330 K	80 K to 400 K	4.5 K to 300 K	3.7 K to 470 K
Absolute pressure	1 bar to 50 bar	1 bar to 25 bar	1 bar to 25 bar	1 bar to 25 bar
Differential pressure		0 to 3 bar	0 to 1.5 bar	0 to 2 bar
Measurement Loops	**S**	**C**	**B**	**T**
Vacuum pressure		1 Pa to 10^5 Pa	10^{-5} Pa to 10^5 Pa	10^{-5} Pa to 10^5 Pa
Flow rate		0 to 4 kg/s	0 to 2 kg/s	0 to 3 kg/s
Level	0–100% (LN2, LHe)	0–100% (Oil)	0–100% (LN2, LHe)	0–100% (LHe)
Vibration speed		2–8 mm/s (for compressor)		
Rotating speed		Up to 50 Hz	Up to 4000 Hz	Up to 200 Hz
Position	0–100%	0–100%	0–100%	0–100%
Electrical power	0–100%	0–100%	0–100%	0–100%
General accuracy requirement for measurement instrumentation: 0.1 % to 0.5 % Full Scale				

Table 23: Cryogenic system main requirements

4.2.16.2.1 Operation

Instrumentation and control equipment have to be selected for automatic continuous operation over long periods, for remote control and maintenance operation. The components must not

only withstand without damage the normal working conditions, but also all foreseeable failure situations of the refrigerator (e.g. over-pressure and unusual temperatures). Specifically, access and replacement of instrumentation around cryogenic distribution located in the Tokamak building are issues which have to be taken into account.

4.2.16.2.2 Sensors

The designer has to specify sensors and actuators necessary for the implantation of the required control loop in the Process Control System. He/she has to take into account the operational requirement of cryogenic system. Location of sensors is essential in order to give ease of operation and quick diagnosis in case of failure.

For usual industrial environment, we advise to select only reliable, standard proven and easy-to-maintain components.

It is advised, in order to allow tracking of the measured value, to have additional analogous instruments for flow, pressure and temperature switches.

As a general rule, for company selection, continuity in sensor production is an argument of selection. In addition the ability of the supplier to have a trade net allowing the rapid finding of components on shelf has to be taken into account.

4.2.16.2.3 Signal conditioning, cubicles and cables

Outside of the Tokamak building, minimizing the wiring, facilitating the maintenance and the commissioning of equipment are main targets for the designer. Accessibility of sensors and transmitters with an adjustable range also has to be considered.

In specific Tokomak building environmental conditions the use of electronics could lead to shield cubicle and maybe remote handling. It is advisable to avoid such a design. However, cubicles have to be installed at the shorter distance to avoid the loss of measurement accuracy (ratio signal/noise) especially for sensors with low level signals and high accuracy (4 K temperature at +/-5mK).

Up to an irradiative level of 2.5 Gy in the Tokomak building, it is highly recommended to remote all installation of electronics. Even with transducer, a particular environment could lead to a short list of suppliers and to R&D works.

Due to the variable magnetic field, grounding has to respect rules avoiding electric loop with earthing usually at the conditioning signal device side [(Electrical Design Handbook (Iter IDM reference 2DSPT6)]. If the value of this magnetic field is going to exceed 0.04T, it is recommended to protect or avoid conditioner implementation.

Homogeneity of protocol for sub-system sensor communication has to be requested [(Plant Control Design Handbook (PCDH) (ITER IDM ref. 27LH2V)]. Disconnection of one of the

local cabinets or analogical data should not stop the connections with the other.
Cable insulation, support, guides and rooting routing tray of all cables must be compatible with fire rules.

4.2.16.2.4 Power supply interface

Design of the power supply has to consider their variable magnetic field environment [(Electrical Design Handbook (Iter IDM reference 2DSPT6)].

4.2.16.2.5 Labeling and documentation.

Labeling of sub-system has to be respected.
The selected supplier must comply with the final documentation (chapter 8)

4.2.16.3 Sensor: installations and rules

4.2.16.3.1 Pressure measurements

4.2.16.3.1.1 General rule

For pressure gauge a mechanical mounting should be defined allowing replacement without pollution of helium circuit or vacuum and for the Tokamak building avoiding an electrical loop through the pipe, conditioner and the grounding. The electro-Magnetic Capacity (EMC) shall be known.
For instruments arranged on a common panel, all calibration lines shall be connected to a calibration header. All instruments connected to a calibration header must withstand the maximum calibration pressure in this header without de-calibration or damage. In case no pressure transducer or transmitters are compatible with ITER environment, the mechanical mounting of the pressure sensors have to be carried out remotely by means of capillary lines. Length and diameter of these lines have to be evaluated according to time response of the sensors.

4.2.16.3.1.2 Pressure gauge above atmosphere

Due to the fact that such transducers are a small part of the market, a shorter list of suppliers has such a type of gauge in their catalogue. Short series manufacturing could be launched, however as a result price will be higher.
With the exception of true differential measurements, absolute pressure gauges (transmitter or transducer) have to be used and absolute pressures displayed. All gauges must withstand, without de-calibration or damage, all pressures from vacuum to the maximum working pressure, given by the setting of the relevant safety valve. Connections of differential pressure gauge shall respect:

- Standard 147: IEC61518 Mating dimensions between differential pressure (type) measuring instruments and flanged-on shut-off devices up to 413 bar (41,3 MPa)

For cold pressure measurement a particularly care should be taken to avoid thermo-acoustic effect which could cause unstable reading and large drift of measurement (chapter 4.1.4).

4.2.16.3.1.3 Vacuum pressure gauge

This gauge should be able to withstand gas inrush (see ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM).

4.2.16.3.2 Flow measurements

4.2.16.3.2.1 General rules

For all sensors, the designer shall be attentive to the size and fitting of flow meters for their implementation. Their mechanical connection should also take into account environmental conditions and replacement without pollution of helium circuits or leak. The electro-Magnetic Capacity (EMC) shall be known.

To withstand the Tokamak building environment, it is advised to check sensor ability. Transducers only are allowed. As parts of flow measurement, pressure and temperature have to be able to withstand the Tokamak environment (chapter 4.2.16.3.1 and 4.2.16.3.3).

4.2.16.3.2.2 Specific rules

Venturi flow measurement (Figure 28): pressure pick-ups should be located in a straight pipe of between 4 or 8 times the inlet pipe diameter (D) for the inlet (stream stability).

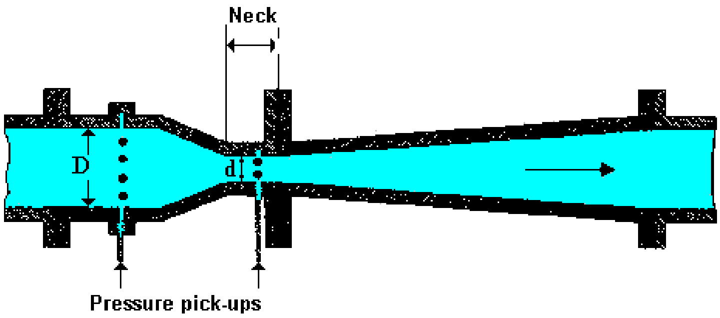


Figure 28: Venturi cross section

For ultrasonic flow, measurements have to be installed in a straight pipe of at least 5 to 10 times the diameter of pipe before and after a singularity (stream stability). Depending on this ratio, suppliers will determine accuracy of such equipment in their environment.

For Coriolis flow measurement, supplier will calculate the pressure drop induced by such flow meter. Obviously characteristics of the fluid are required.

4.2.16.3.3 Temperature measurements

4.2.16.3.3.1 General rules

From the electrical feed-through at 300 K to the sensor a thermal anchoring of wires has to be performed in order to limit the amount of heat brought by them. This anchoring shall be carried out at 80 K and/or downstream close to the spot measurement.
Moreover in order to limit sensor self heating, the value of supply current shall not exceed 5 µA for 4 K RTD (Resistive Temperature Device) measurement and 1mA for 80 K RTD measurement.

4.2.16.3.3.2 Sensor mounting

Particular care must be taken for the implementation of sensors. The mounting process including thermal anchoring for sensor and wires (Figure 29 and Figure 30) and value of current supply are essential parameters which will guarantee the quality of measurement.
In terms of accuracy, the "finger of glove" mounting has to be preferred instead sticking anchoring. Due to its low degassing and low thermal resistance, it is advised to used Apiezon grease or equivalent for the thermal coupling (Figure 31). Epoxy Stycast glue could be used but involves in case of failure more issues; moreover its use is forbidden in gas containing tritium due to the property of epoxy to catch it. If the requirement is harsher forbidding epoxy glue, apiezon grease for example, a solution with MI cable help to sort out these issues (Figure 32).
As some unsticking could appear during the life of the Tokamak due to differential contraction, it is recommended to prefer canisters set up in package with calibrated hole than bear ship for thermal sensor installed in difficult access place. The package used to mount the sensor could be soldered, screwed or bolted on the pipe for the thermal anchoring. The canister sensor or end of cable jacket will be mounted with Apiezon grease.

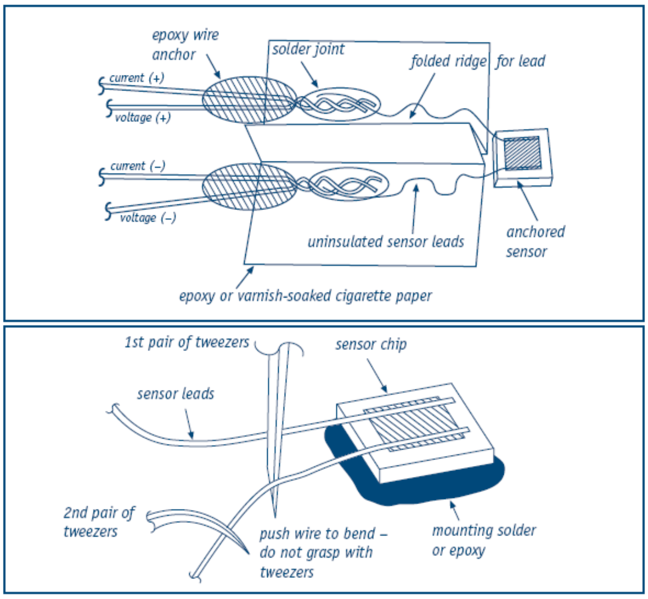


Figure 29: Sensor bare-ship or on substrate and wires attachment

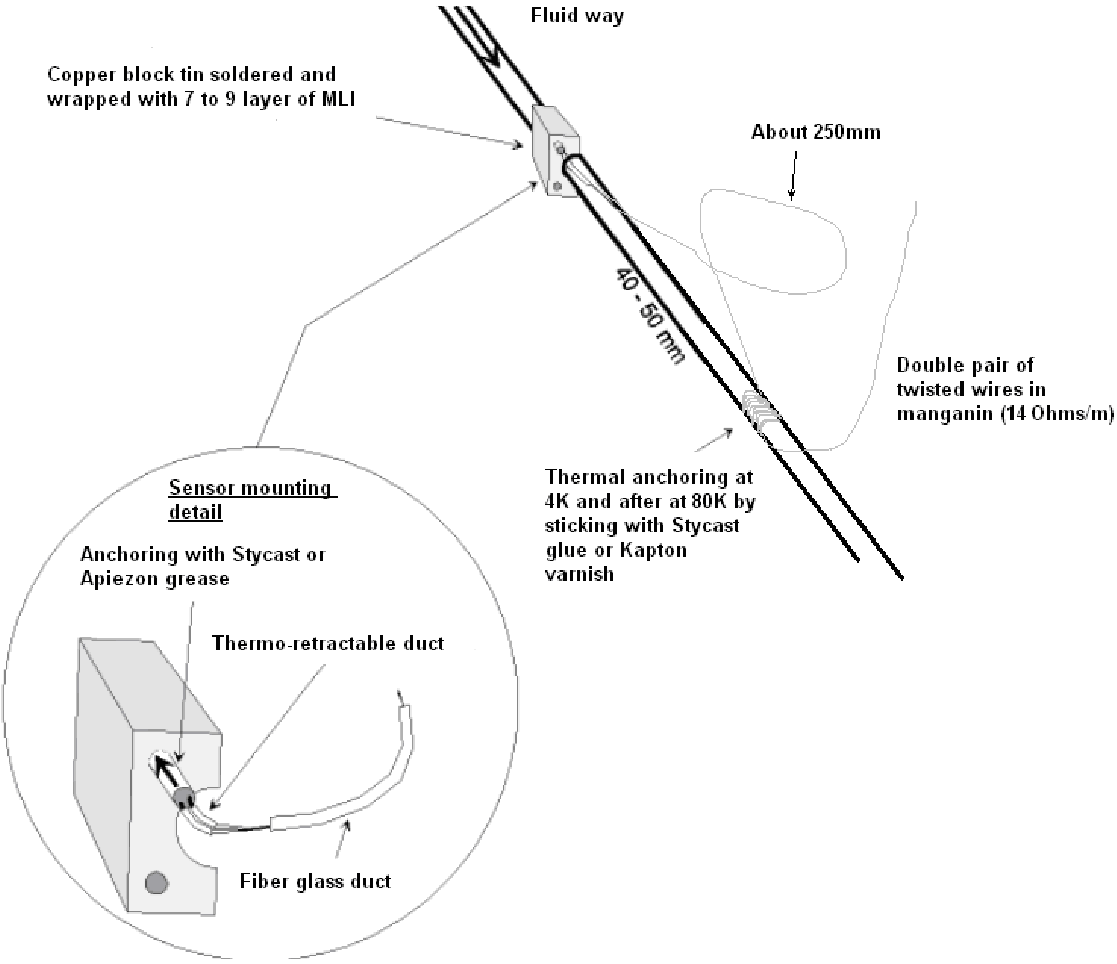


Figure 30: Sensor in canister and wires thermal anchoring

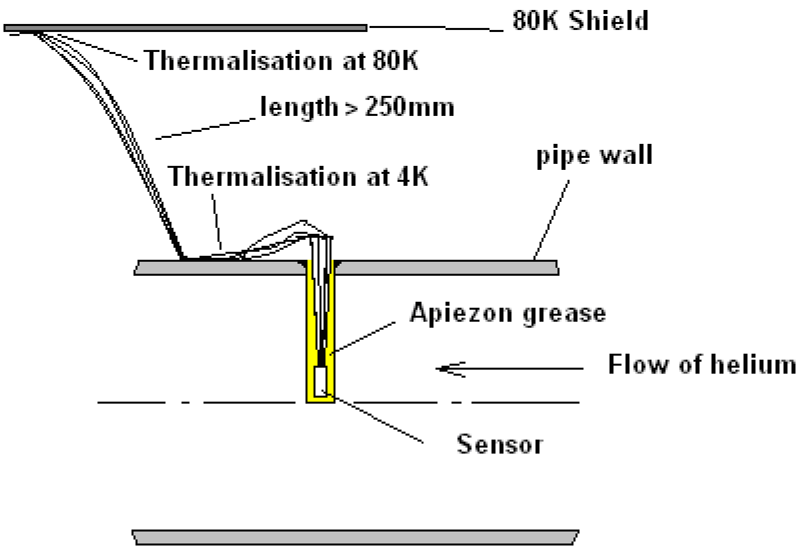


Figure 31: Finger glove mounting

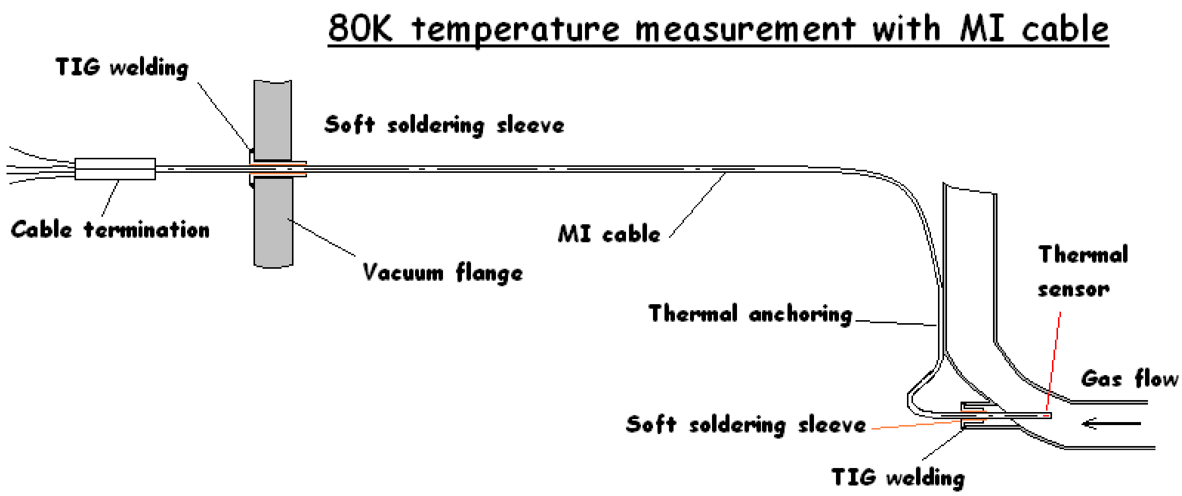


Figure 32: Finger glove mounting with MI cable

4.2.16.3.3.3 Wires and cables

In order to avoid electro-magnetic noise a four wires configuration with two twisted pairs is recommended. By this way one pair of wires is dedicated to current supply and the other to the voltage measurement minimizing the variable offset of the wire resistance (R versus T° property of material).

In order to minimize thermal flow coming from measurement means, a thermal anchoring of wires at 80K and at 4K downstream measuring point is recommended for 4 K measurement. For the same purpose a length around 250mm is advised between these two thermal

anchorings. Use of wires with lower thermal conductivity (>2 W/mK at 4 K) than copper (Manganin, Phosphor bronze) is advised.
Finally for soldering of wires with leads of sensors 90/10/ Pb/Sn solder is recommended. (liquidus point of 575 K and solidus point at 458 K). For its low out-gassing Indium soldering could be preferred to PbSn; however one will have to keep in mind its melting point at 430 K.
To summarize, during the wire selection, one will have to keep in mind: thermal conductivity, resistance (Ω/m); number of leads (feed through); Insulating thermal rating (400 K?); Insulation breakdown voltage (>400 V).

4.2.16.3.4 Level measurements

In cryogenic field the main level measurements are: supra superconducting wire; delta p; ultrasonic waves; thermometers inside the bath and positioning at different level, weigh scale.
The superconducting wire method [which is the method most commonly used to measure a cryogen level] is composed of a NbTi wire installed in the center of a stainless steel pipe. Air tightness is insured by a toric joint compressed in a conic shape around the pipe of the superconducting gauge in order to seal the cryostat volume. Due to the different mountings proposed by supplier, particular care has to be taken to avoid leakage and/or helium circuit pollution (helium guard chap 2.14.2). For a horizontal helium tank or bath, attention should be paid to cold helium fluid behavior around superconducting wire.

4.2.16.3.5 Rotation speed measurements

With respect of the above-mentioned parameters, installation instructions of supplier have to be followed.

4.2.16.3.6 Vibration measurements

Systems are available on the market and are completely automatic. They are very flexible and can be used for very complicated machines with a great number of units in a limited space. The configurations are also flexible with the possibility of using a large variety of data collection and acquisition hardware systems
Installation instructions given by supplier have to be followed.

4.2.16.3.7 Position measurements

At least 6 ways are available for position measurement: resistance, inductance, capacitance, step motor, sonic and optics.

Depending on the environment, resistance, inductance or capacitance are used with or without mechanical amplification for valves or pressure sensors for example. The broader range for optics is from a few µm to a few 100 m, pressure sensors from a few 100 bars to 0.01 bar with a membrane, gas bag ballast position. Step motors are also used but need vibration filtering due to their extreme sensitivity.
The position measurement sensor is supplied with the devices on which the position needs to be measured. Consequently no installation instructions are needed. If not, a specific mechanical adaptation of the sensor has to be performed on the devices.

4.2.16.3.8 Impurity measurements in helium

4.2.16.3.8.1 General rules

Purchasing an analyzer involves ordering valves, piping for the connection of the gas-analysis instruments and the analysis instruments as a whole in order to get the requested accuracy. In this frame, piping as far as possible should avoid bends and must be heated to stay clear from trapping surfaces. The valves must be of gas-chromatography quality.

4.2.16.3.8.2 Location of pick-ups

a) Warm Compressors Station. (WCS)
Three impurity measurement pick-up points could be implemented in the compressor room:

- Up and downstream of dryers or downstream of charcoal pot for humidity measurement.
- Up and downstream from charcoal pot for Hydrocarbon measurement.
- Downstream of the Warm Compressors Station (WCS) for Oxygen or Nitrogen measurement.

b) Main Cold box:
Two impurity measurement pick-up points should be implemented in the cold box:

- Downstream of turbines for humidity measurement.
- At the HP inlet of the cold box and at 2/3 of the bed of adsorbers (80K and 20K) for air components measurement (N_2; O2; H_2; CO; CH)

c) Main Cold box:
The entire helium buffer shall be sufficiently equipped with tubing to allow the connection of portable analyzer, to allow periodic verification of impurity level of all the helium storage.

4.2.16.3.9 Conditioning signal device

4.2.16.3.9.1 General rules

Due to the low magnetic environment (<0.033 T see Table 2) and in order to minimize the

wiring and to facilitate the maintenance and commissioning of equipment, input cabinets connected via Fieldbus with sequence control should be installed as close as possible to vessels or on skids. Sensors and transmitters with an adjustable range should be accessible either in the local electrical cabinet or via field bus or by electrical loop. Homogeneity of protocol for sensor communication is requested. Signal conditioning devices of transducers should be grouped by types in this electrical cabinet. For the compression bench this cabinet could be installed per skid. For cold boxes these cabinets should include transmitters by type around each vessel.
The earth connections of all electrical equipment must be connected together and led to the earth connector of the mains by building [(see ITER Electrical Design Handbook (Iter IDM reference 2DSPT6)].
As all the equipment must be pre-assembled and all checks not requiring helium flow carried out by the supplier, suitable intermediate connectors must be used for the cables between the equipment and the cabinet to allow easy connection and separation.
Analogical data will be transported from transmitters or signal conditioning devices to sequence control through a Field bus. The Field bus cables between the main electrical and the local cabinets must be dismountable using connectors. Disconnection of one of the local cabinets or analogical data should not stop the connections with the other.
For cabling see: ITER I&C SIGNAL PROCESSING
Part I: signal cabling, earthing and cubicle wiring configurations chapter 4 and 5.

4.2.16.3.9.2 Mechanical & Electrical mounting

a) DIN Rail Mount
As the name implies, a DIN rail mount signal conditioning signal device mounts on a DIN rail bracket. DIN rail conditioners are very popular in industrial applications since they provide a rugged mounting format for either a few or a large number of signal conditioning signal devices.
b) Backplane Mount Conditioners
Certain signal conditioning signal devices can also be mounted on a common backplane. The backplane style provides the advantage of all output signals being accessible through a single common connector. The backplane style signal conditioning signal devices are often used with data acquisition systems since a single cable can connect multiple conditioners to a data acquisition device.
c) Digital Conditioning signal devices
The output of a digital conditioning signal device is converted to a digital format such as RS232, RS485 or even Ethernet. Digital signals have several advantages over analogous signals. They provide a high degree of immunity from electrical noise, they can also support

extended transmission distances and are easily connected to a computer. With an Ethernet output, the input signal can be read across an entire network or even across the internet if so configured.

4.2.16.4 Sensors: transmitters and measuring instruments

4.2.16.4.1 Pressure measurements

4.2.16.4.1.1 Absolute pressure measurements:

For measurements around cold boxes or the WCS, standard transmitters could be used.

For control loops, the accuracy including hysteresis and non-linearity has to be greater than or equal to ±0.2 % of the calibrated span. The long-term drift has to be less than or equal to ±0.4 % per year at maximum span.

If for other measurements, transmitters with a span and an offset adjustable by at least to ±10% are used. Their accuracies including hysteresis and non-linearity have to be greater than or equal to ±0.5 % of the maximum span. The long-term drift has to be less than or equal to ±1.0% per year at maximum span.

The unit to be displayed shall be in bars except for sub-atmospheric pressure sensor for each the unit to be displayed can be in mbar.

4.2.16.4.1.2 Differential pressure measurements

Differential pressure must have a bypass valve. For measurements around cold boxes or the WCS, standard transmitters could be used.

The accuracy including hysteresis and non-linearity has to be greater than or equal to ± 0.25 % of the calibrated span. The long-term drift has to be less than or equal to ± 0.5 % per year at maximum span.

4.2.16.4.1.3 Vacuum pressure measurements:

See ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM), Local pressure gauges

4.2.16.4.1.4 Filling with oil

Filling with oil is necessary for dampering in case of mechanical vibrations. Accuracy class 1 % is sufficient. Absolute pressure must be displayed. For manometer, the following applies:

- Standard 148: EN 837 Part 1 to 3 Pressure gauges

4.2.16.4.1.5 Signal conditioning devices for pressure transducers

All pressure transducers must be cabled to an accurate conditioning signal device. The conditioning signal device must provide adjustment for offset and span. A total accuracy in % of the span has to be defined. Especially in WCS the working range of room temperature has to be checked.

Type of sensor	Range	Accuracy including non-linearity, hysteresis, non-repeatability	Compensate operation range of temperature	Full scale output.	Mechanical shock Over pressure and burst pressure	Comments
Fully active four arms Wheatstone bridge	From 0 to 200Bar	0.5% of the full range	Depending of selection,usual 273K to 325K	From 100mV to 5V.	Must be check with supplier	Industrial proven pressure gauge
Capacitance manometer	1 mBar to 1Bar	0.25% of the reading	Depending of selection,usual 283K to 325K	From 0 to 10V	Must be check with supplier	Industrial proven pressure
Piezo manometer	0.1mbar to 10Bar	<1% of the reading	273K to 325K correction 0.02% of the full scale	From 0 to 10V	Must be check with supplier	Industrial proven pressure gauge

Table 24: List of pressure gauges above atmospheric pressure.

Table 25: List of Flow Meters

Type of sensor	Cryogenic system application	Accuracy	Range ability, Ratio of full span to smallest flow measured with accuracy Principle	Advantages	Drawbacks	Documents
Orifice	Room temperature	2-4% of the full scale	3.5:1 $\dot{m} = \rho \dot{Q} = \alpha \varepsilon \frac{\pi}{4} d^2 \sqrt{2 \Delta P \rho} \propto \sqrt{\Delta P}$ α : flow coefficient ε : expansion coefficient d : Venturi neck diameter ΔP: Pressure difference between up-stream and Venturi neck.	Low cost Extensive industrial practice.	Pressure drop.	ISO/TR 15377:2007
Venturi	Room and cryogenic temperatures	0.5 to 3% of the full scale.	3.5:1 Same than orifice	Lower pressure drop than orifice.	High cost.	ISO5167-4:2003 ISO/TR 15377:2007
Flow nozzle	Room temperature	2% of the full scale.	3.5:1 Same than orifice	Intermediate pressure drop	Higher cost than orifice. Limited pipe size.	ISO/TR 15377:2007
Turbine	Room and cryogenic temperatures	0.25 to 2% of the measurement at room temperature	20:1 ω=V*tan α α : blade angle compared with shaft axis	Wide range ability, good accuracy Slow drift due to bearing friction.	High cost, has to prove reliability and accuracy at cryogenic temperature.	ISO9951:1993
Vortex	Room temperature	1% of the measurement	10:1 F=St U /D U speed of fluid D outlet diameter	Wide range ability, size, insensitive to variations in density, temperature, pressure and viscosity.	Expensive, need R&D for helium or nitrogen gas	

			St number of Strouhal		application.	
Coriolis	Room and cryogenic temperatures	0.25% of measurement.	Drop pressure Minimum density of fluid $\vec{F} = m\vec{\gamma} = 2m\vec{\omega} \wedge \vec{v}_R$ V_R speed of fluid ω angular speed of sensor F resulting strength	Accuracy.	High cost, size, Pressure drop	ISO10790:1999
Time of flight	Room and cryogenic temperature	10% of measurement.	Medium $V=L/ t_m$ L distance between sensors and hot wire t_m average time of heat propagation	Low/medium cost, size Pressure drop	Low accuracy	
Hot wire	Room and cryogenic temperature	10% of measurement	Low $W = \dot{m}\Delta H = \dot{m}\int_{T_1}^{T_2} C_p \delta T \approx \dot{m} C_p$	Low/medium cost Pressure drop	Low accuracy	ISO/NP14511:2001
Ultra sonic	Room and cryogenic temperature	1.5% of measurement	Medium $\bar{v} = \frac{C^2 \Delta t}{2L \cos\theta} = \frac{L \Delta t}{2t_m^2 \cos\theta}$ L distance between sensors C speed of sound Θ angle between sensor axis and fluid axis t_m time of sound propagation	Pressure drop, work at 80K	High cost, minimum speed of fluid, stabilization of down and up stream.	ISO/NP12242; ISO/NP17089-2

Table 25: List of flow meters

4.2.16.4.2 Flow measurements

As displayed in Table 25, there are many ways to carry out a flow measurements. Note that a pressure drop added by flow measurement can be an issue. Installed in parallel with a light pressure drop, a divert flow measurement can be a solution to avoid such issue.

- Standard 149: ISO/TR 15377:2007 Measurement of fluid flow by means of pressure-differential devices - Guidelines for the specification of orifice plates, nozzles and Venturi tubes beyond the scope of ISO 5167
- Standard 150: ISO 5167-4:2003 Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full
- Standard 151: ISO 9951:1993 Measurement of gas flow in closed conduits. Turbine meters
- Standard 152: ISO 10790:1999 Measurement of fluid flow in closed conduits. Guidance to the selection, installation and use of Coriolis meters (mass flow, density and volume flow measurements)
- Standard 153: ISO/NP 14511:2001 Measurement of fluid flow in closed conduits - Thermal mass flow meters
- Standard 154: ISO/NP 12242 Rolling bearings - Instrument precision bearings - Part 2 : boundary dimensions, tolerances and characteristics of inch series bearings

4.2.16.4.2.1 Flow rate of helium and nitrogen gas at room temperature

Due to their hardiness, performance and low-price orifices, nozzles or Venturi nozzles with differential pressure transmitter are usually selected.However they should have in addition temperature and pressure measurement for the calibration of the mass-flow. If selected, flow measurements must be positioned to measure clean helium gas (without clogging element).

4.2.16.4.2.2 Flow rate of cryogenic fluid

Selection of flow measurement of cryogenic fluid is a balance between cost, accuracy, range ability and pressure drop. However presently all sensors have to prove through R&D outside laboratory their ability to work down to 4 K in industrial conditions. For single phase flow the most industrially used are Venturi nozzles.

4.2.16.4.3 Temperature measurements

The unit to be displayed shall be in Kelvin, except for temperature sensor above ambient temperature for which the unit to be displayed can be in ºC.

Selection of these industrial sensors is a balance between price, range ability, accuracy,

reproducibility, thermal response time and capacity to withstand specific environment. Table 27 gives a list of sensors used generally in the cryogenic field.

4.2.16.4.3.1 Room temperatures pipe work outside the cold box

Depending on required accuracy, these temperatures could be measured directly in the fluid stream or on the external surface of the pipe. Due to the calibration work price of such sensors, selection will depend also on the required accuracy.

4.2.16.4.3.2 Cryogenic temperatures

Due to their use for control purposes these sensors need high-precision measurements. Consequently the measured values used shall be as far as possible introduced into the fluid stream. It could be envisaged to have dismountable sensors without breaking the insulation vacuum in particular for those sensors having operational vital functions in control loops, However this possibility is more expensive and very often redundancy is preferred. It is suggested that those temperature sensors that have an operational function and that are not dismountable without breaking the vacuum should be doubled including all wiring up to an external connector for easy and rapid exchange in case of failure.

Whatever the mounting selected, the supplier has to prove that the installed measurement chain is able to satisfy the accuracy requirements:

Particular care is required in the implementation of these sensors. The drawings of the fixations and details of the thermal anchoring must be given.

For specific utilizations, fiber optic measurement could be envisaged. The ability of the AsGa sensors to withstand the Tokamak building environment has to be checked (R&D).

- Standard 155: IEC 751
- Standard 156: EN 60751 (EU)
- Standard 157: SAMA-RC-4 (USA)
- Standard 158: CEI 584

Table 26: Usual sensors used in cryogenic thermometry

Type of sensor	**Range**	**Accuracy**	**Reproducibility, thermal response time.**	**Current supply, Dissipation**	**Level of signal,**	**Reference documents**	**Comments**
PT-100	14K to 850K	From +/-10mK at 30K to +/-46mK at 500K	+/-5mK at 77K, from 2s at 77K to20s at 273K	1mA , at 273K, 100µW at 273K	100mV	Conform to IEC751 standards down to 70K EN60751 (EU) SAMA-RC-4 (USA)	Low magnetic field dependence above 40K
Silicon diode	1.4K to 500K	From Standard curve +/-0.25K from 2K to 100K	+/-10mK at4.2K;100ms at 77K	10µA, 10µW at 77K	1.02V at 77K	Standard curve.	Sensitive to magnetic field and radiation
Thermocouple (T;K;E,J)	3K to 700K (T); 3K to 1400K (K); 3K to 1250K (E);	>1% at low temperature 0.1% above 300K	Depending of selection		3 to 62µV/K (T), 4mV/K(K);8 mV/K(E) around 20K	Standard curve. CEI 584	Sensitivity to magnetic field and radiation
Fiber optic sensor	10K to 500K	+/-0.2K for calibrated area (10°) and +/-0.8K for the remains	<500ms		Optic diode AsGa	Short range calibration curve (10K) done by supplier with conditioning signal device	Need of 1 feed through, allow long distance conditioning (500m)
Type of sensor	Range	Accuracy	Reproducibility, thermal response time.	Current supply, Dissipation	Level of signal,	Reference documents	Comments
Cernox	100mK to 420K	From +/-5mK at 1K to +/-65mK at 400K	+/-3mK at 4.2K; from1.5ms to0.4s at 4.2K	1-5µA; 10^{-7} W at 4.2K	1-5mV	Calibration curve given by supplier	Recommended for use in radiation and in magnetic field
Carbon ceramic	100mK to 500K	Few mK	+/- 1mK at 4.2K	5-10 µA; 10^{-7}W at	30mV	Calibration curve given by supplier	Recommended for use in

(TVO)				4.2K			radiation and more sensitive than Cernox of magnetic field
Carbon glass	1.4K to 100K	From +/-4mK at 1K to +/-105mK at 300K	+/-0.75mK at 4.2K	1-5µA; 10^{-7} W at 4.2K	1-5mV	Calibration curve given by supplier	Low sensitive to magnetic field and irradiation

Table 26: Usual sensors used in cryogenic thermometry

4.2.16.4.3.3 Conditioners for cryogenic sensors

In order to ensure accuracy, all temperature sensors must be cabled with 4 wires to an accurate conditioner, using a low measuring current (self heating). The conditioning signal device must provide adjustment for offset and span. Located at a long routing distance, the way that this low-level signal is transported and analyzed is certainly an issue (R&D).

4.2.16.4.3.4 Cryogenic sensor packaging & installation:

As some unsticking could appear during the life of the Tokamak due to differential contraction, it is recommended to prefer canisters set up in a package with a calibrated hole rather than a bare chip for a thermal sensor installed in place of difficult access. The package used to mount the sensor could be welded, soldered or bolted on the pipe for the thermal anchoring. The sensor canister will be mounted with Apiezon grease. This kind of mounting would allow disassembly.

If there are packages or sensors attached to a pipe, particular care must be taken to clean the pipe surface. Thermal anchoring will be carried out downstream at closest temperature of spot measurement and at 80 K on a nearby thermal shield. The anchoring will take into account possible movement of cables during operation due to Lorentz force and thermal contraction. This movement should not break the insulation of cables or their insulation.

4.2.16.4.4 Level measurements

4.2.16.4.4.1 Liquid Helium level

Measurements of static head by differential pressure transmitter or by superconducting gauge are usual. A calibration curve for conversion from height or length to liquid volume has to be provided.

4.2.16.4.4.2 LN2 level

Measurement of the liquid nitrogen is usually done using capacitive sensors for small volumes or measurements of static head by differential pressure transmitter or ultrasonic sensor for tanks.

4.2.16.4.4.3 Oil level

Capacitive, ultrasonic or buoyancy-based sensors are industrial components. Not to be installed in the Tokamak building.

4.2.16.4.4.4 Oil level switch:

The oil level switch has to be adjustable. Not to be installed in the Tokamak building.

Type of sensor	Measurement range,	Use	Installation procedure	Advantage and *drawback*	comments
Float position detection	0- few meters	Liquid at room temperature or higher	Need clean liquid	Reliability, *subject to errors due to changes in liquid density*	Separator or coalescer use.
ΔP measurement	No limit	Liquid at room and cryogenic T°	Need of valves for insulation purpose.	P measurement easy to insulated for maintenance or test, *subject to errors due to changes in liquid density*	Nitrogen and helium tank use.
Ultrasonic measurement Liquid at room T° & Nitrogen liquid	0- few meters	Liquid at room T° & Nitrogen liquid	Need of calibration with empty vessel	Transducer does not come into contact with the process material (leak probability), *Turbulences at the surface affect accuracy,*	Nitrogen tank and balloon use.
Superconducting wire measurement Helium liquid	0- few meters	Helium liquid	Leak of helium gas risk.	Calibration of gauge with helium condition has to be done *Turbulences at the surface affect accuracy*	Helium tank or dewar use.
RF admittance	0-few meters	From high T° to cryogenic T°, from vacuum to high pressure	Single penetration of tank.	There are no moving parts to wear, plug, or jam, *moisture range or movement of probe affect accuracy*	Working either with nitrogen liquid or oil or water.

Table 27: List of level measurement

4.2.16.4.5 Rotation speed measurements

Type of sensor	Range of measurement	Accuracy	Input signal of conditioner, mounting	Output signal of conditioner	Document
Tachometer	1 rpm to 10000rpm	< 0.01% of the full range	Mechanical mounting at the tip of shaft.	See supplier catalogue	EMC - Electromagnetic Compatibility: complies to CE per EMC Directive 89/336/EEC. Immunity per EN 50082-2, 1995 Emission per EN 50081-2, 1995.
Passive inductive sensors	1 rpm to 100000rpm	< 0.001% of the full range	Single pulse/revolution,	See supplier catalogue	
Active Hall sensors	0 to 20000 teeth/Sec	See supplier catalogue	Single pulse per tooth, air gap between sensor and shaft 0.01 to 0.04mm.	See supplier catalogue	
Magneto resistive sensors					
Fibber optic			Emission and reception of light. Perpendicular of the shaft		Use for turbine speed rotation measurement

Table 28: List of rotation speed measurement

4.2.16.4.6 Vibration measurements

4.2.16.4.6.1 Diagnosed machine units

- line of rotor and axis,
- elements of bearing,
- fluid film bearings,
- gear boxes and other mechanical drives,
- blade machines,
- ventilators,
- turbines, etc.

4.2.16.4.6.2 Detected defects

- imbalance,
- defects of the joints,
- non-uniform radial tension,
- cavities, cracks on the bearing,
- defects of several surfaces of friction,
- slip of race,
- defects of lubrication.
- wavering axis,
- deviation of alignment,
- defects of the blades (use, slit, resonance),
- static, dynamic eccentricity of space of air,
- power supply failures of energy, etc...

4.2.16.4.6.3 Maintenance planning:

Systems can provide recommendations for the maintenance, repairs and or other corrective actions to be made after the detection of dangerous defects or those installation defects that decrease the machine service life. The planning of the following measurements is automatic, and takes into account the diagnosed condition of the machine and its condition forecast.

4.2.16.4.6.4 Diagnostic Results Analysis and Presentation

The diagnostics can be accomplished by measuring and analyzing the envelope spectra of high-frequency vibration generated by the friction forces between the moving elements inside the machine units and auto spectra of low-frequency vibration.

The diagnostic process is usually illustrated by graphs and texts with symptoms for each defect. For vibration measurement, it applies:

- Standard 159: ISO 5347-17:1993 Methods for the calibration of vibration and shock pick-ups

4.2.16.4.7 Position measurements

4.2.16.4.7.1 General rules

At least 6 ways are available for position measurements: Resistance, inductance, capacitance, step encoder, ultrasonic optic. For resistance, inductance, capacitance measurement can be amplified by small connecting rods which improve the sensitivity.

For their selection and installation some parameters are important:

- Non-sensitivity to external conditions (magnetic fields, mechanical shock…).
- With or without magnet.
- Any metallic target: steel, copper, brass, aluminium, nickel, iron.
- Temperature range.
- Sensor assemblies (room available, distance sensor conditioner and so on).
-

4.2.16.4.7.2 Signal conditioning device

A signal conditioning signal device is a device that converts one type of electronic signal into another type of signal. Its primary use is to convert a signal that may be difficult to read by conventional instrumentation into a more easily and compatible with PLC input read format. In performing this conversion a number of functions may take place. They include:

- Amplification

When a signal is amplified, the overall magnitude of the signal is increased. Converting a 0-10 mV signal to a 0 -10V signal is an example of amplification.

- Electrical Isolation

Electrical isolation breaks the galvanic path between the input and output signal. That is, there is no physical wiring between the input and output. The input is normally transferred to the output by converting it to an optical or magnetic signal then it is reconstructed on the output. By breaking the galvanic path between input and output, unwanted signals on the input line are prevented from passing through to the output. Isolation is required when a measurement must be made on a surface with a voltage potential far above ground. In ITER isolation is also used to prevent ground loops.

- Linearization

Converting a non-linear input signal to a linear output signal. This is common for 4 K sensor or thermocouple signals.

- Cold Junction Compensation

Used for thermocouples. The thermocouple signal is adjusted for fluctuations in room temperature.

- Excitation

Many sensors require some form of excitation for them to operate. Level gauges and RTDs are two common examples.

4.2.16.4.7.3 Impurity measurements in helium

In order to guarantee the cleanliness of helium, impurity measurement devices are set up around trapping devices in the Warm Compressors Station and in the Cold Box.

H_2O, O_2: and N_2

The analysis instrument has to include:

- Instruments suitable to detect moisture (H_2O) in helium with a measuring range of 0-100ppm by volume, accuracy better than or equal to ±1 ppm by volume and a long-term drift greater than or equal to ±1ppm by volume by year.
- Instruments suitable to detect air (O_2 or N_2) in helium with a measuring range of 0-100 ppm by volume, accuracy better than or equal to ±0.1 ppm by volume and a long-term drift greater than or equal to ±1ppm by volume by year.

Hydrocarbons:

This measurement does not need to be installed permanently. The technique of measurement used in the petroleum area can be applied (Flame Ionized Detector). Due to its utilities usefulness mainly during commissioning and its price, rental could be envisaged. The upper limit for the concentration of hydrocarbons, measured downstream from the dust filter after the charcoal adsorber, is around 10^{-2} ppm by weight.

A method for measuring has to be given.

N_2;O_2; H_2; CO; CH:

- Instruments suitable to detect nitrogen (N_2), oxygen (O_2), methane (CH_4), carbon oxide (CO), hydrogen (H_2) in helium with a measuring range of 0-100ppm by volume, accuracy greater than or equal to ±0.1 ppm by volume and a long-term drift greater than or equal to ±1 ppm by volume by year.
- The cold box must be equipped with all required valves or flanges for measuring the content of H_2O; N_2, O_2; H_2; CO and CH in the helium. Either a continuous measurement or a discontinuous method, applicable in particular for the acceptance test and commissioning, has to be foreseen.

In order to guarantee values, a method for measuring it has to be proposed.

4.2.17 *Multi-layer insulation*

Most of the surfaces of components kept lower than 80 K must be covered by MLI.

The MLI layers are typically composed of aluminized Mylar foils separated by an insulating spacer.

The heat transfer across MLI is dominated by the radiation and solid conduction through the layers. Experimental curves presenting the sum of the two thermal effects versus layer density show a minimum around n=20 layers/cm, depending on the super-insulation type.

Consequently, a good design principle is to have a MLI density of 20 layers/cm.

When choosing a MLI to work between 77 K and 4 K, the choice should be made on a case-by-case

basis, depending on the operational vacuum conditions, the geometry and orientation, the ease of installation and the quantity.
MLI has also a significant effect of heat flux reduction in case of sudden vacuum degradation and shall lead to a reduction in pressure safety valve sizes.

4.2.17.1 Main requirements of materials

- MLI layer shall be doubly aluminized polyester film (Mylar type) with net or tulle as spacer.
- The overall thickness of the film shall be 10 to 25 µm with 400 Å aluminium coating.
- The following properties of the film shall be indicated and guaranteed by the manufacturer:
    - Density;
    - Tensile strength,
    - Water adsorption rate,
    - Out-gassing rate.

Each production roll of reflective film shall be checked with respect to:

- The following values shall be guaranteed by the manufacturer or checked during manufacturing:
    - Thickness,
    - Electrical resistivity of the aluminium coating,
    - Adhesion of the aluminium coating to the film.
- The following properties of the spacer shall be indicated and guaranteed by the manufacturer:
    - Density,
    - Tensile strength,
    - Water adsorption rate,
    - Out-gassing rate.
- MLI will be either single layer or blanket with 10 layers or more,
- The MLI layer shall be of perforated type for vacuum behavior;
- In case of blanket use, the external layer on both sides of all blankets shall be composed of reinforced reflective film.
- To ensure the optimum performance of the blankets, the composite layers shall have a low packing factor, defined as the ratio of the number of composite layers to the total thickness of the blanket (a typical packing factor is 3).

4.2.17.2 Handling and transport

Immediately after manufacturing, each MLI blanket shall be individually wrapped in a clean clear polythene plastic bag. The box foreseen for the transport shall be equipped with a humidity indicator, to prove that the relative humidity during storage and transportation will not exceed 65 %.

4.2.17.3 Installation

Experience shows that the correct installation of the blankets is as important as the choice of the materials. In particular, care shall be taken to avoid gaps in the MLI layers together and over-packing the MLI.
Wherever possible, and particularly for cryolines, MLI wrapping will be done automatically by a dedicated orbital wrapping machine.
To hold the different blankets in place or to join them, specific MLI tape with low out-gassing properties shall be used.
The location of the junctions shall be chosen to facilitate this operation (straight sections).
Wherever it is not possible to use a machine, the wrapping will be done manually.
Experienced and qualified personnel using protection gloves can apply the layers manually as blankets.
The layers must cover the entire cold surfaces and shall not be compressed.
For ease of installation of the blankets, they can be equipped with Velcro® fasteners, stitched to the edges of the blankets. However, the fasteners must not reduce locally the packing factor of the blanket by more than 50 %.
Consequently, the junctions and the slit closures of MLI blankets shall be performed in order of preference, by the means of:

- Velcro® fasteners,
- Specific MLI adhesive tape
- Hand stitching.

After installation, each blanket shall be visually inspected to verify if any part is detached.

4.2.17.4 Particular provisions

- The vacuum level in vessels or cryolines is expected to be greater than 5.10-5 mbar in warm condition for an optimal efficiency of the MLI,
- The design of the insulation must allow easy access to dismountable equipment inside the vacuum vessel,
- Pumping ports have to be designed to avoid the intake of any loose sheets of super insulation.

5. Tests

All tests shall be carried out according to the IO Quality Assurance Program (QAP).
Commercially available pressure equipment must be tested individually or in assemblies and according the standards or code selected to meet the ESR on pressure equipment.
Pressure assemblies set up on the ITER site shall also meet the ESR on pressure equipment. The weld processes, the pressure tests and the leak detection tests shall comply as much as possible with European or international standards.
IO shall define the extent of its participation in the inspection of testing, and within this framework, IO

reserves the right to be present, or to be represented by an organization of its choice, to witness any tests carried out on the contractor's or its sub-contractor premises.

5.1 Welding tests

5.1.1 *Weld inspections*

The type of weld inspection carried out at the contractor manufacturer's site shall be as set forth in the selected code or standard.

The types of inspection are the following:

- 100 % visual inspection
- Radiography inspection

The degree of X-ray of welded executed at the contractor's or sub-contractor's works shall be as set forth in the selected code or standard.

If:

- Standard 160: ISO 5817 Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections

is followed, 100% radiographic examination of all welds is mandatory.

(In case of problems, the contractor shall carry out additional X-rays, up to 100%)

- Ultrasonic inspection,
- Magnetic-particle inspection,
- Liquid-penetrant inspection,

5.1.2 *Welding test inspectors*

Qualified personnel shall carry out weld inspections.

The inspectors appointed for testing shall be qualified according to:

- Standard 161: EN 473: 1993 Qualification and certification of NDT personnel – General principles
- Standard 162: ISO 9712 Non-destructive testing – Qualification and certification of personnel

5.1.3 *Welding test procedures*

- Standard 163: EN 571-1 1997: Non destructive testing-Penetrant testing,
- Standard 164: EN 583-4: Non destructive testing-Ultrasonic examination,
- Standard 165: EN 875: 1995: Destructive tests on welds in metallic materials-Impact test,
- Standard 166: EN 970: 1997 Non destructive examination of fusion welds-Visual examination,
- Standard 167: EN 895: 1995 Destructive tests on welds in metallic materials -Transverse tensile tests,
- Standard 168: EN 910: 1996 Destructive tests on welds in metallic materials -Bend tests,

- Standard 169: EN 1289:1998: Non destructive testing-Penetrant testing of welds-Acceptance level,
- Standard 170: EN 1290:1998: Non destructive testing-Magnetic particle testing of welds,
- Standard 171: EN 1291:1998: Non destructive testing-Magnetic particle testing of welds-Acceptance level,
- Standard 172: EN 1435 Non-destructive examination of welds. Radiographic examination of welded joints,
- Standard 173: EN 1712:1997: Non destructive testing of welds-Ultrasonic testing of welded joints-Acceptance level,
- Standard 174: EN 1713:1998: Non destructive testing of welds-Ultrasonic testing –Characterization of indication in welds,
- Standard 175: EN 1714:1997: Non destructive examination of welds, Ultrasonic examination of welded joints,
- Standard 176: EN 12062 Non destructive testing of welds-General rules for metallic materials,
- Standard 177: EN 12517-1:2006: Non destructive testing of welds-Radiographic testing of welded joints-Acceptance levels,
- Standard 178: EN 13068-3: 2001 Non destructive testing- Radioscopic testing,
- Standard 179: ISO 1106-1: 1984 Recommended practice for radiographic examination of fusion welded joints**.**

5.2 Pressure tests

All pressure equipment shall be submitted to a pressure test in order to prove its resilience and to demonstrate its leak tightness.

This test can either be carried out via a hydrostatic pressure test, or by a pneumatic test.

Note that, due to hazards induced by pneumatic tests, this type of testing shall exclusively be carried out in specific facilities and according to procedures ensuring safety for all participants.

The level of pressure to apply to the equipment during this test shall not be less than the greater of:

- 1.43(PS + 1) bar in case of hydrostatic pressure test,
- 1.25 (PS + 1) bar in case of pneumatic pressure test.

5.2.1 *Normative references*

- Standard 180: EN 13445-5: 2009 -Unfired pressure vessels-Inspection and testing.

This standard gives the detailed requirements of the pressure tests.

- Standard 181: EN 13458-2: 2003 -cryogenic vessels –Inspection and testing

This standard gives information about the pressure tests of inner vessels of cryogenic components.

5.3 Leak tests

5.3.1 *Normative references*

- Standard 182: EN 473: 1993 Qualification and certification of NDT personnel – General principles,
- Standard 183: EN 1330-8 : Non destructive testing-Terminology,
- Standard 184: EN 1779:1999: Non destructive testing-leak testing- Criteria for method and technique selection,
- Standard 185: EN 13185:2001: Non destructive testing-leak testing-tracer gas method,
- Standard 186: prEN 13192:2001 Non destructive testing-Leak test-Calibration of gaseous reference leaks,
- Standard 187: pr EN 13625:2001 Non destructive testing-Leak test-Guide to the selection of instrumentation for the measurement of gas leakage,
- Standard 188: ISO 3530 Mass spectrometer leak detector calibration.

5.3.2 *Leak test procedures*

The contractor shall provide to IO a leak testing procedure which will include the:

- Description of the component to be tested
- Leak tightness requirements of the component to be tested
- Test equipment specification
- Preparation of the component to be tested
- Test procedure and documentation
- Name and qualification of the person(s) performing the test

5.4 Manufacture tests

5.4.1 *Definitions*

The mechanical assembly consists of all operations to build a single component (heat exchanger, vessel …).
The assembly is all operations which consist of connecting single components to achieve main components like cold boxes, ACB, cryolines.

5.4.2 *Mechanical assembly tests*

The contractor shall perform a series of individual tests to confirm the conformity of single components before assembly.
The following tests shall be carried out:

- Welding tests (refer to chapter 5.1)

Additional tests shall be requested on sub-assemblies where location of leaks and repair becomes

difficult due to limited access.

- Pressure tests (refer to chapter 5.2)

In addition to the presence of notified body, all pressure tests of components shall be witnessed by IO representative.

- Leak tests (refer to chapter 5.3)
- Specific leak tests: leak tests of the cold components (ex. transfer lines) shall be carried out after sprayed liquid nitrogen on welds.

5.4.3 *Tests of assembled components*

Once the components assembled, the following test shall be performed according to the corresponding procedures:

- Welding tests,
- Pressure tests,
- Leak tests,
- Cleanliness inspections: these operations are developed in chapter 4.1.6.

5.4.4 *Electrical and wiring tests*

The continuity and the respect of the electrical schema have to be checked.
Labelling for all buttons, lights, and measurement indicators has to be controlled. Labelling of wires has also to be checked.
The earthing and the design of each cubicle have to respect the Electrical Design Handbook (Iter IDM reference 2DSPT6) for grounding and lightning protection.
Electrical connections will be done without electric attendance in respect of rotation phases order especially with 3 phases motor supply. The rotation direction of phase has to be check before switching on 3 phases electrical motor.
The respect of the mechanical schema has to be checked:

- General dimensions,
- Location of buttons, lights, measurement indicators and so on,
- Implantation of cable feed-through,
- Location of path for cable routing at interfaces with gutter or electrical cable trough,
- If pulse air or air conditioning pipe are connected mechanical dimensions have to be measured.

5.4.5 *Functional tests*

The functional tests correspond to the last step carried out at the manufacturer premises for specific

components.
Major components such as cycle compressors, turbine expanders, cold circulators, cold compressors shall undergo test programs on the manufacturer test benches for a range of power up to maximum value, in order to verify the component characteristics.
These tests programs shall be defined by the contractor in agreement with IO, which shall check them for the acceptance before delivery. An example of checklist is given in ISO 10440 and EN 10204 (Metallic products – Types of inspection documents).
These tests shall confirm the plant performances indicated in the technical specifications, and shall be thereafter compared at the IO site during the performance and capacity tests.

5.4.5.1 Test of the helium cold machinery and the helium screw compressors

The test program for the different kinds of compressors (screw or centrifugal) shall be defined by the manufacturer in agreement with IO.
Test protocols listing the measured values for each compressor have to be supplied to IO for acceptance before delivery of the compressors to the IO site.

5.4.5.2 Tests of the compressor motors

Each motor must be tested individually at the premises of the manufacturer.
Before the tests, the supplier has to provide IO with a test program and a list of values to be measured including at least:

- Power consumption,
- Factor power (cos φ),
- Temperatures,
- Noise level,
- Vibrations.

The measured values for each motor have to be submitted to IO prior delivery.

5.4.5.3 Tests of the cold helium machinery

Factory using dedicated test benches at manufacturer' premises of cold machinery like turbines, cold circulators and cold compressors must be performed at design rotation speed and ambient temperature.
The test criteria are vibrations, rotor stability and noise.
The test program shall be defined by the manufacturer in agreement with IO.

5.4.6 *Manufacturing test documentation*

Refer to Chapter 8 Documentation.

5.5 Tests on ITER site

The tests on ITER site shall consist in a first phase of reception, erection and installation of the components.
Main components will then be connected to each other in order to achieve the sub-systems of the cryoplant.
These sub-systems which form “assemblies”, must again meet the requirements of the Pressure Equipment Directive, concerning welding and pressure tests. Leak tests shall also be carried out.
After completion, the commissioning shall be split into two parts, the preliminary tests and the running tests.
Then the reception tests shall allow performance and capacity tests in order to confirm the plant performances and the meeting of the requirements indicated in the technical specifications.
The supplier shall provide a list of values used during the functional tests at the manufacturer’s premise: flows, power consumption, pressures, temperatures, vibrations.
These values shall be used and reproduced during the Acceptance Tests on ITER site

5.5.1 *Reception and Erection*

5.5.1.1 Incoming inspection

All components shall undergo incoming inspection including the following controls:

- Inventory control of components,
- Check of all component dimensions upon receipt in order to verify conformance with required parameters and tolerances,
- Removal of temporary caps and protection in order to perform visual examination of the conditions of surfaces, welds and finishes,
- Check the pressure settings of 0.15 MPa for all volumes equipped with manometers during transport,
- Analysis of accelerometer readings taken during transport.

In the event a component does not fulfil the required specifications, the contractor shall commit to changing the component.
After this successful stage, the responsibility of the transporter or conveyer can be released.
All temporary caps and protection shall be put back in place in order to preserve the conditions of surfaces and finishes during the next phase. These protections can be also necessary in case of short-term storage before installation.

5.5.1.2 Erection, lifting and handling

The lifting and handling operations are described in Packing and Delivery chapter 6.

5.5.1.3 Final position inspection

The contractor shall carry out a final position inspection which consists of verifying all components:

- Check of damages having occurred during lifting, handling, or erection
- Check of internal contamination with dust and water having occurred during storage or erection,
- Verification of instrumentation, vacuum system integrity,
- Verification of alignment and position.
- Removal of special fixations and supports for internal vessels used only during transport to prevent damages due to vibrations and positions different from the final ones.

5.5.2 *Installation*

5.5.2.1 Assembly of components

This phase will consist of connecting the different components by the means of piping and permanent joining processes in compliance with installation procedures and according to welding standards.
After these assemblies, the following tests shall be performed:

- Tests of welds,
- Pressure tests,
- Leak detection on circuits in comparison with the atmosphere and with the vacuum vessel.

5.5.2.2 Final acceptance of assembly

The acceptance of the contractor's work shall be declared following the successful inspections and verifications.

5.5.3 *Commissioning*

The commissioning shall consist first by the preliminary tests and then by the running tests commissioning.
The first part called ''preliminary tests'' will consist of testing, controlling and checking the components.
The second part called "running tests' will consist of preparing machine start-up.
All tests shall be carried out under the responsibility of the supplier its taff, in the presence of the ITER representative.

5.5.3.1 Preliminary tests or Warm tests to perform at ITER site

During this phase, the contractor shall carry out conditioning and testing of components in order to make them available for operation.
The preliminary tests shall include the following operations:

- Conditioning of the circuits,

- Checking of electrical circuits and connections to /from instrumentation and control system (refer to chapter 5.4.4),
- Checking of safety components and particularly the safety valves,
- Control of the measuring circuits and verification of all control settings,
- Checking of the functioning of all control valves
- Checking of water and air circuits,
- Checking of vacuum pumping.

Remark:
The tests shall be carried out and financed by the contractor and witnessed by ITER

5.5.3.2 Running tests of rotating machines at ITER site

After the execution of preliminary tests, the running tests of the helium cycle compressor and helium pump shall be carried out by the manufacturer and shall include the following operations:

- The suitable oil filling for the machines,
- The suitable helium filling of the circuits,
- The start-up of the machines,
- The dust removal of the circuits with positioning of temporary filters in particular points,
- The leak control of circuits in comparison with the atmosphere, when the machines are running.

Main precautions for the running tests:

- The helium gas shall be available at sufficient pressure and amount in the storage for the tests,
- The machines shall preferably not operate simultaneously (consequently the power supplies and water loop could be reduced),
- All necessary site utilities, including local data acquisition tools and networks, shall be available.

5.5.4 *Reception tests*

The reception tests shall be carried out after the commissioning.
The reception tests of the Cryoplant including the Warm Compressor Stations and the Cold Boxes will consist of performance and capacity tests, in order to confirm the plant performance and the requirement indicated in the technical specifications.
In order to perform reception tests, a sufficient quantity of helium gas must be stored in the storage tanks or by other means, in order to complete the tests.
The purity of this helium shall be guaranteed by IO and defined in the technical specifications.

5.5.4.1 Performance tests for the warm compression station

The performance of the Warm Compressor Station will satisfy the requirements of refrigerator

according to all or the more stringent steady states and transient operation modes.
The cold boxes should not be operated during the tests of the compressor station.
The performance warm tests of the compressors will consist of:

- Check of mechanical characteristics,
- Check of vibrations, noise and oil injection,
- Check of the performance of the oil removal system,
- Check of the cooling water system,
- Check of control software and interlocks,
- Measurement of main characteristics: helium flow rate, pressures, temperatures and individual power consumption.

5.5.4.2 Capacity tests for the warm compression station

The capacity tests of the Warm Compression Station will only be undertaken when all the tests described in chapter 5.5.4.2 have been successfully completed and all specified documents have been supplied.
The capacity warm test will consist of a defined duration (XX hours) of operation at full-load, in steady-state conditions.
These tests will include the following permanent measurements:

- Flow rate through the test bypass valves downstream the oil adsorber,
- HP, MP and LP pressures for screw compressors,
- Inter stage pressures for multistage centrifugal compressors,
- Suction and delivery temperatures of helium at various compression stages,
- Oil temperatures at compressor injections,
- Cooling water temperature at inlet and outlet of all different compressor units,
- Corresponding cooling water flows,
- Individual electrical motor currents and powers,
- Electrical motor temperatures.

5.5.4.3 Tests of dryers and cold adsorbers

The performance of helium purification of these components, as defined in chapters 4.2.5 and 4.2.10 shall be demonstrated.
The tests shall also demonstrate the compliance of the durations of the regeneration phases and their efficiency in accordance with the technical specifications.

5.5.4.4 Performance cold tests

After successful reception tests including performance and capacity warm test of the cryoplant, a performance cold test shall be carried out.
The performance cold test of the cryolines shall include a liquid nitrogen test of sub-assemblies to

check their mechanical integrity and vacuum behavior.
The performance cold tests of the cold boxes shall include:

- Check of mechanical characteristics,
- Check of vibrations and noise,
- Check of control software and interlocks for all modes of operation and simulated failures.

5.5.4.5 Cold Capacity tests

The cold capacity tests shall be performed only when the cold performance tests quoted in chapter 5.5.4.4 are successful.
The capacity tests shall be carried out for all steady-state operation modes, unless there is a special agreement with IO.
Nevertheless, a capacity test shall be performed for the most stringent operating modes such as “peak power mode’’, “nominal mode”, “baking”, during the specified period agreed on in the test program.
During these tests, all the components of the cryoplant such as warm and cold machineries, transfer lines, sub-cooler shall be in operation. Test should be carried out sequentially starting with the refrigerator cold boxes (nitrogen and helium) followed by the entire system. This would allow the required factorization of the cooling capacities measured at the various temperature and distribution levels of the system.
The simulation of the cryogenic loads could be done by:

- A test cryostat connected at the interfaces between the various refrigerator cold boxes (helium and nitrogen) and the cryodistribution system, different test cryostats will be needed for the helium and the nitrogen systems,
- A test-cryostat connected at different levels of the cryodistribution.
- Heaters located permanently inside the main distribution valve box and the various cryodistribution components such as ACBs, cryostats.

If specified in the technical specifications, the liquefaction rates shall be verified for each steady state mode.

5.5.4.6 Test in transition modes (Cold)

The fully automatic transitions between operation modes shall be tested.
Cooling and warming temperature rates shall be in compliance with the technical specifications.

5.6 Acceptance and Guarantee

5.6.1 *Provisional Acceptance Certificate*

On successful completion of the reception tests and delivery of all specified documents, ITER will issue a provisional acceptance certificate.
The contractor shall guarantee all equipment it has supplied for the period laid down in the tender

documents, starting from the date of the certificate.
The contractor shall also guarantee that all equipment delivered will continue to conform to the requirements laid down in these documents and will maintain the performance defined therein.
The supply of complete documentation will be a condition for the provisional Acceptance Certificate. Refer to chapter 8.

5.6.2 *Final Acceptance*

At the end of the guarantee period ITER shall provide a Final Acceptance Certificate.

6. Packing, transport and storage phases

The Contractor shall include in its tender all the transport, off-loading and installation of the supply at ITER Site.
The Contractor shall be responsible for all administrative and customs formalities, including transport insurance. Importation formalities must be completed prior to the delivery to ITER Site.
After factory tests, final cleaning and inspection, the Contractor is responsible for the packing, loading, transport, shipment, and off-loading at the ITER Site.
He shall ensure that the equipment is delivered to the ITER site without damage or any possible deterioration in performance due to transport conditions.
In case of damages during transport, they shall be repaired at the cost of the contractor.

6.1 General requirements

Each element shall be delivered together with its test certification documents individually packed after manufacture.
A copy of the travelling data information shall be included in each individual package.
The packaging shall protect against damage, dust, hydrocarbon contaminants and condensation. All components shall be packed in boxes designed to prevent damage or distortion during transport. The cases will be of structure sufficient for safe and efficient handling on carriage or by crane. All volumes shall be filled with dry gaseous nitrogen at a pressure of 0.15 MPa and kept above atmospheric during all transport phases. If necessary, specific components shall be entirely enclosed in sealed polyethylene inflated with dry air for shipping.
All openings are to be blanked off by identified caps to avoid ingress of dirt and moisture. All machined surfaces shall be protected. The use of adhesive tape for the protection and packing of components shall be limited so as to avoid the risk of contamination from the tape.
Where used, adhesive tape shall be fully removable leaving no residues.
The following information will have to be clearly visible on the boxes, both in English and French:

- Total weight of the element,
- Handling instructions with location of specific interfaces or points for transport and lifting,

- Position of storage.

When necessary, accelerometers will be joined in the packing of sensitive components in order to control the acceleration/deceleration forces undergone during transport.
The contractor shall be refer to the rules of the IO Safety Code (for example Fire permits)

6.2 Requirements for small components

Small elements shall be sealed into polyethylene bags (halogen free) with a desiccant substance. The Contractor shall form sets of bags, then pack them in boxes designed to prevent damage or distortion during transport.

6.3 Requirements for cryolines

The contractor shall submit to IO:

- A plan of the conditioning foreseen for the delivery of the cryolines sections,
- A study of the proposal transport scheme, including a provisional plan.

Clearly identified temporary covers approved by IO shall close all pipes.
The cryoline sections shall be transported with vessel under vacuum or filled with dry GN2 as all inner pipes; in any case, the corresponding pressure levels shall be monitored during all transport phases and controlled during the incoming inspection.
The transfer lines must be packed into stiff boxes to ensure sufficient protection against damage and contamination specially ingress of dirt and moisture into the fluid and vacuum pipes. The minimum curvature radius applied to the transfer lines during transport will be subject to approval by IO.
This packing shall allow ground storage without supplementary supports and without risks for the personnel and for the lines.
A particular conditioning plan shall be established concerning the packing and the delivery of any long semi-flexible cryoline. These specifications shall include:

- The protection foreseen during transport and storage,
- The expected directions of rolling up,
- The description of handling tools associated, necessary for unfolding the lines: axis wheel, brake, cables,
- An instruction notice for these associated tools.

6.4 Requirements for storage vessels

All the cryogen storages shall be transported with vessel under vacuum or filled with dry GN2 as all inner vessels; in any case, the corresponding pressure levels shall be monitored during all transport

phases and controlled during the incoming inspection.
The Contractor shall be responsible for the installation of the cryogen storage vessels on the IO site.

6.5 Delivery on ITER site

All deliveries shall be announced to the IO site management, at least 2 days in advance.
Prior to delivery, the contractor shall inform IO of the necessary services to provide in order to ensure a safe and practical delivery of components, such as electricity and compressed air.
Generally speaking, the contractor will provide its own tools and special handling devices.
All equipment for lifting and handling delivered together with the supply shall comply with the requirements of IO Safety Code for lifting equipment.
All handling of the contractor's material used by IO personnel will be done under the responsibility of the contractor and shall be supervised by him.
Note that the personnel of the contractor might be allowed to operate the cranes only after successfully passing a test organized by IO

6.6 Long-term storage of cryogenic components

If cryogenic components are delivered ahead of installation to the ITER cryogenic system, these components shall be stored in safe conditions preventing any possibility of contamination or degradation. With this aim, the original packaging of the components shall be re-usable after opening.

7. Environment, operation and maintenance considerations

7.1 Reliability, Availability, Maintainability and Inspectability considerations

7.1.1 *Introduction*

Reliability, Availability, Maintainability and Inspectability (RAMI) aspects can heavily impact cost, schedule and future operation of the cryogenic system.
These aspects must be carefully evaluated and incorporated into the design phases of the project.
Methodologies and previous studies for assessing the RAMI analysis on the cryogenic system are hereafter summarized.
These studies are based on suitable methods and tools and according to QA and standards.

7.1.2 *Definition of RAMI*

Availability represents the average proportion of time when a repairable system operates over a long period.
The availability characteristics of a system are determined by:

- The reliability (failure rate)
- The maintainability (ease of maintenance)

A system with high reliability can be unavailable most of the time if the repair time of its components is very long.
High availability requires reduction of both rate and duration of critical equipment failures.

7.1.3 *RAMI at the design phase*

During the preliminary design, RAMI shall help the designers in achieving an optimum design, adjusting the reliability and maintainability requirements among the subsystems and components. One of the most important points during this stage is to identify critical facility subsystem failures that impact the cryogenic system operation. In this frame, the EFDA-F4E task TW6-TDS-RAMSUP was launched in 2008. The corresponding report addresses the following points:

- Functional breakdown analysis of the cryogenic system,
- RAMI analysis by modelling of the previous functional analysis,
- Proposition of a detailed system failure analysis,
- A proposal of actions to improve availability,
- Summary and conclusions for the RAMI analysis;

The proposal of actions is shown in Table 29, extracted from deliverable 3-1 of the EFDA-F4E task.

Function	Action
Warm compressing	Vibration diagnostic implementation associated to alarms checked by the local control to enable a preventive and anticipated maintenance.
	Reduce the maintenance interval of bearing maintenance (typically from 40 000 h to 30 000 h)
	Introduce an electronic device for progressive starting up.
	Spare on site and fast intervention logistics (specific contract)
Water cooling	Full redundancy (every function at nominal performance) on every cryogenic subsystem: warm compressing, main cooling, vacuum pumping mainly
Compressed air	Full redundancy of air compressors and dryers for the actuators associated to buffer tanks spread out over the cryogenic system for the actuators of every function.
Power supply	Full redundancy of main power supply for TS cooling, rough vacuum pumping and UPS for instrumentation and control (I&C) for every function of the cryogenic system.
Measuring and actuating	Full redundancy of critical sensors. (critical sensors to be assessed)
	Perform a specific study for sensor and actuator maintenance scenario, include the recommendations into the system design (access, capability to be replaced, ...)
	Perform a specific study to assess the reliability of sensors and actuators in close tokamak environment, include the recommendations into the system design (location, protection, ...)
	Spare on site and specific contract for sensors/actuators maintenance and calibration
Cryodistribution and main cooling	Reduce the potential effect on power refrigerating unit by enlarge the power margin or a specific design of the last cooling stage, ratio to be assessed.
	Increase the thermal buffer capacity of the ACB LHe bath and the SHe cooling loop by enlarging the LHe and SHe volume, ratio to be assessed.
Vacuum pumping	Overcapacity of rough pumping or redundancy.
	Policy of minimizing the vacuum seals and bellows.
	Capacity to analyse gaseous exhaust from rough pumping during warm up for air detection (ratio and flow) in order to assess the air leak in the cryogenic vacuum vessels.

Table 29: Actions proposed to improve reliability of the cryogenic system (September 2008)

The conclusion of the report suggests more in-depth work and an update of the study throughout the detailed design of the system. Indeed, this work must be enlarged to take into account some aspects not included in the RAMSUP task, because not well described in ITER DDD3.4.

7.2 Standardization

The cryogenic control system must be built following the requirements of the Plant Control Design Handbook (PCDH) (ITER IDM ref. 27LH2V). The PCDH and its associated documents, presented in Figure 33, constitute the referring documents concerning the control system. These documents define methodology, standards, specifications and interfaces applicable to ITER Cryogenic plant system instrumentation & control (ITER references in Table 30). The document describing PCDH structure is document associated with PCDH and it will evolve with the same rules of the core PCDH.

The latest version of each document must be used during all the plant system I&C Life Cycle.

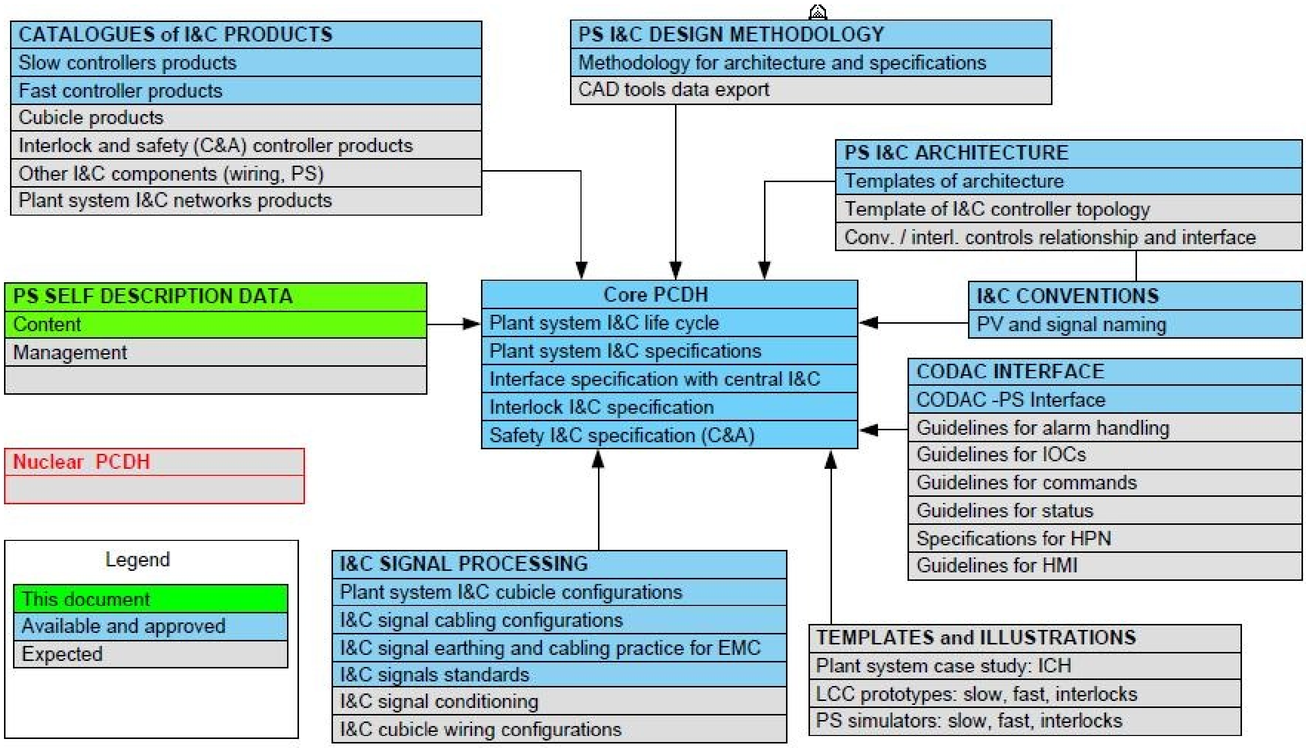


Figure 33: PCDH structure

Plant control design handbook	ITER_D_27LH2V	V5.2
Plant control design handbook for nuclear control systems	ITER_D_2YNEFU	V1.1
Iter instrumentation and control-primer	ITER_D_32J454	V1.1
Plant system I&C architecture	ITER_D_32GEBH	V1.1
The CODAC-Plant system interface	ITER_D_34V362	V1.2
Self description schema documentation	ITER_D_34QXCP	V1.1
I&C signal processing PART1 Cubicle and wiring configurations	ITER_D_3299VT	V3.1
Methodology for plant system I&C design	ITER_D_353AZY	V2.0
I&C signal process variable naming convention	ITER_D_2UT8SH	V5.1
I&C signal process variable naming convention signal class and signal type identifiers	ITER_D_358U9U	V2.1
Guideline for fast controller, I/O bus systems and communication method between interconnected systems	ITER_D_333K4C	V1.2
Codac catalogue of I&C products-fast controllers	ITER_D_345X28	V1.2
ITER PLC(slow controller) catalogue	ITER_D_333J63	V1.1

Table 30: ITER reference of PCDH documents

Some outstanding topics could appear for specific points. Some of them are identified and listed in the associated Plant Control Design Handbook (PCDH) (ITER IDM ref. 27LH2V) document. If not, these

topics must be clearly identified and the associated technical choices must be itemized.

A specific section (chapter 4.2.16) in the cryogenic handbook is dedicated to the cryogenic specific instrumentation which cannot be found in the PCDH.
Due to the specificity of the cryogenic system, the following recommendations should be noted:

- Spare space must be available for the future extension: The PLC cabinet layout shall include spare space for the I/O required for a future plant growth with at least xx% additional operating capacity. As a minimum, this shall include some space for at least xx I/O boards and the associated interface terminals.
- Following the PS I&C architecture and the I&C signal processing document, specific attention must be dedicated to the controllers topology and the I&C cubicle configuration due to the different location of the cryogenic system (cryodistribution in nuclear and magnetic environment). Such a design must also take into account some specific configurations of sensors and actuators (cold boxes). Refer to chapter 4.2.16.
- When field-buses are foreseen (cold box for example), specific attention must be dedicated to the maintenance aspect. In every case, the replacement of a numerical sensor (disconnection of the loop) must never corrupt the overall network.
- During the commissioning and operation phases a local HMI in the WCS seems to be essential to operate the system.

7.3 Spare parts

The following amounts of spare parts are recommended for the main sub-systems of the cryogenic system.

WARM COMPRESSION STATION	
Equipment	**Spare part amount**
Compressor maintenance kit for 40 000 h (including bearings and coupling sets)	One kit for two same type compressors
Compressor maintenance kit for 10 000 h	One kit for one same type compressor
Oil for compressor	30% of total inventory
Compressor motor	30% of each type amount, or one at least

Table 31: Spare parts for WCS

COLD BOX	
Equipment	**Spare part amount**
Adsorbers	50% of inventory of charcoal or resins, and filters amount.
Turbo expanders	One maintenance kit for each expander (joints and filters), One expander for each type
Cold compressors Compressor + motor + electronics	One maintenance kit for each compressor, One compressor of each type, 30% of each motor type amount, 50% of electronic converter amount or one at least.
Circulating pumps Pump + motor + electronics	One maintenance kit for each pump, One pump of each type, 30% of each motor type amount, 50% of electronic converter amount or one at least.
Warm sensors (pressure, flow, speed,…) Local indicators (manometers, numeric display,…)	10% of each type amount, or one at least
Cold sensors (temperature, level)	5% of each type amount, or one at least
Signal conditioning for sensors	10% of each type amount, or one at least
Instrumentation power supplies	10% of each type amount, or two at least
Electric actuators (contactors, switches, output interfaces)	10% of each type amount for actuators or one least
Electric safety devices (breakers-fuse)	10% of each type amount for actuators or one at least 30% of fuse amount
Programmable Logic Controller boards I/O interfaces SCADA	To be defined by CODAC

Table 32: Spare parts for cold box

ANALYSIS DEVICES	
Equipment	**Spare part amount**
Helium analysis devices	One maintenance kit for each device
Helium leak detectors (static or movable)	One maintenance kit for each device

Table 33: Spare parts for analysis device

OTHER COMPONENTS	
Equipment	**Spare part amount**
Valve maintenance kit including motor, detendors	One maintenance kit 20% of each type amount, One motor for 10% of each amount or one at least.
Relief valves or relief disk	10% of each type amount or two at least.
Elbows, hoses and specific junctions	10% of each type amount or one at least

Table 34: Others Spare parts

7.4 Management of regulatory in-service inspections and regulatory tests

Depending on their classification, Pressure Equipment is subject to In-Service Inspections and periodic controls. This chapter presents the regulatory texts, describes the operations performed during the inspections, and indicates various possibilities ig managing these In-Service Inspections, through compliance with specific provisions validated by the French government.
Aspects of the modification and repairing of pressure equipment are then presented.

7.4.1 *Pressure Equipment operation*

7.4.1.1 Applicable regulation

[1] French decree 99-1046 dated December 13, 1999 related to the manufacture of pressure equipment (Transposition of the European Directive 97/23/EC Pressure Equipment Directive into French law).
[2] French order dated 15 March 2000 Operation installation and in-service inspection of Pressure Equipment.
[3] BSEI Notes and decisions
BSEI : « Bureau Sécurité des Equipements Industriels de la Direction Générale des Entreprises, du ministère de l'écologie, du développement et de l'aménagement durable ».
[4] DGAP files: question/answer document, concerning interpretation of requirements of French order dated 15 March 2000.

The Decree 99-1046 of December 13, 1999 has established rules for the control of pressure equipment. This decree was supplemented by the French order of March 15, 2000 relating to Operation, installation and in-service inspection of such pressure equipment. This order is then modified by the Decree of October13, 2000 and by the decree of March 30, 2005.
The BSEI Note No. 06-080 of 06 March 2006 clarifies the conditions of application of the French order dated 15 march 2000.
The BSEI decisions 08-067 and 09-200 give legitimacy to technical professional handbooks that may concern cryogenic components.
The BSEI decision 09-219 concerns also cryogenic components.
These texts are a statutory basis but are not sufficient and often require additional information or interpretation.
The DGAP (department of Gas and Pressure Equipment) has established a system of questions/answers (similar to CLAP files) for in service control in order to complete the regulatory texts. The answers are the results of discussions between the concerned authorities (administration DREAL, regulatory bodies and professional organizations) and are presented to the Central Board of Pressure Vessel.
They are then widely spread by the DGAP, and these files are available on the following website:
www.industrie.gouv.fr/sdsi/dgap/regl-esp.html

7.4.1.2 Scope and definitions

The description of the in-service verifications hereafter relate to equipment of a cryogenic system (equipment which contain a fluid of group 2). They are split into requirements concerning vessels and requirements for piping.
<u>Operator</u>: Means the owner of the equipment or his representative, except in case of a contractual link between the user and the owner. In this case the operator is the user, which is in charge of the start-up, the maintenance and the operation of the equipment.
<u>Authorized body</u>: Notified body authorized to perform periodic requalification

7.4.1.2.1 Requirements for vessels

Vessels containing gas of group 2 are subject to the In Service requirements when the following conditions are met:

- PS > 4 bar
- And PS*V > 200 bar.l
- Excepted if V ≤ 1 litre and PS ≤ 1000 bar
-

<u>In-Service declaration for vessel</u>
Moreover, when PS * V> 10,000 bar.l, the first obligation is to declare the equipment to the regulatory

authority (see example of template of **In-Service declaration** in Appendix 9.8).
For this equipment, a tracking file must be opened, in which all in-service operations must be recorded.

7.4.1.2.2 Requirement for piping

Pipes containing gas of group 2 are subject to the In-Service requirements when the following conditions are met:

- PS > 0,5 bar
- And PS*DN > 3500 bar.l
- And DN > 100

In-Service declaration for piping
Moreover, when PS > 4 bar and PS*DN > 5000 bar.l and DN > 250 the first obligation is to declare the equipment to the regulatory authority (see template of In-Service declaration in Appendix 9.8).
For this equipment a tracking file must be opened in which all in-service operations must be recorded.

7.4.1.3 Periodic inspection

7.4.1.3.1 Periodic inspection of vessels

A qualified person (or an authorized body) designed by the operator must carry out the inspection.
The maximum time interval between each inspection is 40 months. Typical inspection operations are listed in Appendix 9.9.
The inspection includes:

- Verification of external side,
- Verification the internal side,
- Verification the safety devices,
- Any further investigation deemed necessary (modification, repairing).

The result of the periodic inspection must be mentioned in a report established, dated, and signed by the inspector.
In case of any remark made in the report, the operator must countersign and date the report.
Moreover, in case of any anomaly linked to security, the operator must:

- Stop the operation of the equipment
- Take all provisions in order to recover an acceptable level of security.

7.4.1.3.2 Periodic inspection of piping

For pipes, the operator must establish a verification program in the year following the commissioning. This program defines the interval between each inspection and the specific areas to examine.

The result of the periodic inspection must be mentioned in a report established by the inspector, and the operator must take into account all remarks made in this report.

7.4.1.4 Periodic requalification

7.4.1.4.1 Periodic requalification of vessels

An expert from an authorized body must pronounce the requalification.
The maximum time interval between each requalification for a vessel containing group 2 gases is 120 months. The starting date is the date of the mandatory pressure test performed during the final assessment of the pressure vessel.
The requalification includes:

- The verification of the presence and the update of the technical and administrative documentation,
- An inspection of the both sides of the wall,
- The examination of the safety devices (*),
- Any further investigation deemed necessary (modification, repairing).

The result of the requalification must be mentioned in a report including a certificate and the signature of the expert. A horse head marking validates all the operations of the requalification.
(*) When PS*V > 3000 bar.l, the safety devices must be recalibrated or replaced.

7.4.1.4.2 Periodic requalification of piping

This operation concerns only pipes which are submitted to the In-Service declaration. For this operation the pipe control program must be approved by an authorized body.
The requalification must be pronounced by an expert from an authorized body.
The maximum interval between each requalification for piping containing group 2 gases is 120 months.
The requalification includes:

- The verification of the presence and the update of the technical and administrative documentation,
- An inspection of the specific zones defined in the control program,
- Any further investigation deemed necessary (modification, repairing).

Hydraulic pressure tests are not required.
The result of the requalification must be mentioned on a report. There is no marking required.

7.4.1.5 Technical professional handbooks

7.4.1.5.1 Technical Professional handbook n° 152.01, Appendix 9.11

"Specific provisions applicable to pressure equipment with single-wall constituent of non-refrigerating

(*) facilities operating at low temperatures"
(*) i.e. in which fluids are renewed in normal operation
This document, only available in French, was written and issued by the French Association of Compressed Gas (AFGC).
The validity and the legitimacy of this handbook are introduced by the BSEI decision n°08-067.

7.4.1.5.1.1 Scope

The pressure equipment of the cryogenic system which is subject to the French order dated 15 March 2000 enters into the scope of this handbook, as constituents of Facilities of liquefaction or purification by cryogenics of oxygen, nitrogen, rare gases or hydrogen.

7.4.1.5.1.2 Benefit

For benefit of the following special conditions:

- Exemption of internal and external visits during the periodical inspection or the requalification inspections,
- Exemption of hydraulic pressure test during the periodical requalification.

7.4.1.5.1.3 Specific provisions for design and manufacture

For steel equipment the following design and manufacturing requirement must be observed:
The welding (or joint) coefficient must be ≥ 0,85
However there is no requirement for the welding coefficient if the equipment (particularly heat exchangers),

- Is a constituent of a liquefaction plant,
- Cannot withstand the initial hydraulic pressure test,
- Has been manufactured with non-destructive tests for the soldered joints.

For equipment manufactured in other materials or with steel other than austenitic stainless steel, quatre particular conditions must be satisfied: Appendix 9.11.

7.4.1.5.1.4 Specific in-service rules

Management of periodical inspection
Internal inspection: Not required
External inspection:

- For equipment which is part of a cold box or constituent of a cryogenic purification unit, the inspection is not required
- For other equipment, the inspection is replaced by an examination of the aspect and integrity of the coating of the thermal insulation, Appendix 9.11.

Management of periodical requalification
Internal inspection: Not required

External inspection:

The control program of piping as described in § ***5.4.1.3.2*** must be applied.

The vessels entering in the scope of this handbook are submitted to the following checking:

- Verification of the entirety of the equipment documentation,
- External aspect control as requested for periodical inspection, completed by removal of heat insulation on specific zones,
- Verification of safety accessories according to article 26 of the French order of March 15, 2000.

Pressure test: Not required

General provisions

Any dismounting or destruction of the coating of the heat insulation should be used to perform an inspection of the wall by an authorized body.

The requirements of this handbook must be respected in case of repair or modification of the equipment to keep the subsequent benefit of exemption of visits and hydraulic tests.

7.4.1.5.2 Technical professional Handbook n°152.02, Appendix 9.12

"Specific provisions applicable to vessels with double-wall used for production or storage of liquefied gases at low temperature "

This document, only available in French language, was written and emitted by the French Association of Compressed Gas (AFGC).

The validity and the legitimacy of this handbook are introduced by the BSEI decision n°09-200.

7.4.1.5.2.1 Scope

The vessels classified as pressure equipment of the cryogenic system which are subject to the French order dated 15 March 2000 enter into the scope of this handbook, when the following conditions are met:

- These vessels are used for production or accumulation at low temperatures of Nitrogen, Helium and most of the group 2 gases,
- The Thermal insulation of the vessels is performed by maintaining the vacuum in wall interspaces, possibly complemented by an insulator in these spaces.

7.4.1.5.2.2 Benefit

For benefit of the following special conditions:

- Exemption of internal and external inspections required by the French order dated 15 March 2000,

- Exemption of hydraulic test required at time of the periodical requalification.

7.4.1.5.2.3 Specific provisions for design and manufacture

In addition to compliance with essential safety requirements of Annex I of Decree 99-1046, the pressure equipment must be manufactured in compliance with the requirements of:

- Standard 189: NF EN 13458 -1
- Standard 190: NF EN 13458-2
- Standard 191: NF EN 13458-3 (Annex ZA)

The technical documentation supplied by the manufacturer shall contain a statement of compliance with these standards.

7.4.1.5.2.4 Specific in-service rules

Management of periodical inspection

The periodical inspection, as defined in Art. 11 of the French order of March 15, 2000, is replaced by the following operations:

An external visual inspection, in order to detect any thermal short circuit

- Functional verification of valves,
- Leak tightness in operating conditions,
- Assessment of operation or environment changes
- Examination of security accessories as defined in appendix 2 of the referenced handbook
- Check of the realization of previous similar controls of periodical inspection as defined in Appendix 9.9.

These operations must be carried out at least every 40 months by an authorized body or by a qualified service of the operator.

Management of periodical requalification

The verifications and controls are the same as for periodical inspection except for the last point. An authorized body must carry out the examination of security accessories.

Security accessories examination, see appendix 2 of referenced Handbook

The examination will concern the identification, the certification and the compliance to the equipment.

During the visual examination, the following points must be checked:

- General aspect;
- Mounting and orientation,
- Tightness
- Location of release pipe
- Free exhaust of release pipe.

The general aspect and entirety of bursting disks are also to be checked.

7.4.1.6 BSEI decision 09-219, Appendix 9.10

"Exemption from internal inspection for pressure equipment containing particular gas or gas mixtures".

Document only available in French, issued by the « Bureau Sécurité des Equipements Industriels de la Direction Générale des Entreprises, du ministère de l'écologie, du développement et de l'aménagement durable ».

7.4.1.6.1.1 Scope

The pressure equipment of the cryogenic system which is subject to the French order dated 15 March 2000 enters into the scope of this decision, when the following conditions are met together:

- The internal pressure of the vessel is permanently maintained above 0.5 bar gauge,
- The gas in the vessels must have very low impurity rates, Appendix 9.10.

All elements certifying the permanent respect of the previous provisions must be established in a technical file and produced to the In-Service Inspector.

7.4.1.6.1.2 Benefit

Exemption of internal inspection required by the French Decree dated 15 March 2000.

7.4.1.7 Summary of In-Service Inspection management for Cryogenic components

Table 35 shows most of the cryogenic components and summarizes their regulatory In-service follow-up, assuming they are subject to In-Service Inspections.

QP means Qualified Person from operator service,

AB means Authorized Body

Type of component	Every year	Every 3 years	Management of the periodic inspection	Every 10 years	Management of the periodic requalification
Vessels Heat exchangers, storages, tanks, bathes, buffers, coalescers dryers, adsorbers		Periodic inspection QP or AB	Exemption of the internal side verification when compliance with: TPH 152.01 TPH 152.02 BSEI 09-219	Periodic requalification AB	Exemption of the Pressure test when compliance with: TPH 152.01 TPH 152.02
Piping Cryolines, warm piping.		Periodic inspection QP or AB	Control program approved by an AB	Periodic requalification AB	Control program approved by an AB
Safety devices Safety valves, bursting disks	Visual inspection recommended QP	Periodic inspection QP or AB		Periodic requalification AB	Control of replacement or recalibration AB
Pressure accessories Valves, heaters, flanges		Periodic inspection QP or AB		Periodic requalification AB	Tested with the associated vessel

Table 35: Regulatory In service follow-up of cryogenic components

7.4.2 *Intervention on Pressure Equipment*

In accordance with point VII of article 17 of the French decree 99-1046 dated December 13, 1999, the repair or the modification of pressure equipment must conform to the rules applicable for new equipment.

The important modifications led to a new conformity evaluation of the equipment.

Pressure equipment cannot be repaired or modified if the whole technical documentation of the equipment, including the conformity declaration, is not completed.

For pressure equipment submitted to an In-Service declaration, the operation tracking file must be available.

A synoptic of intervention management is presented in Figure 34.

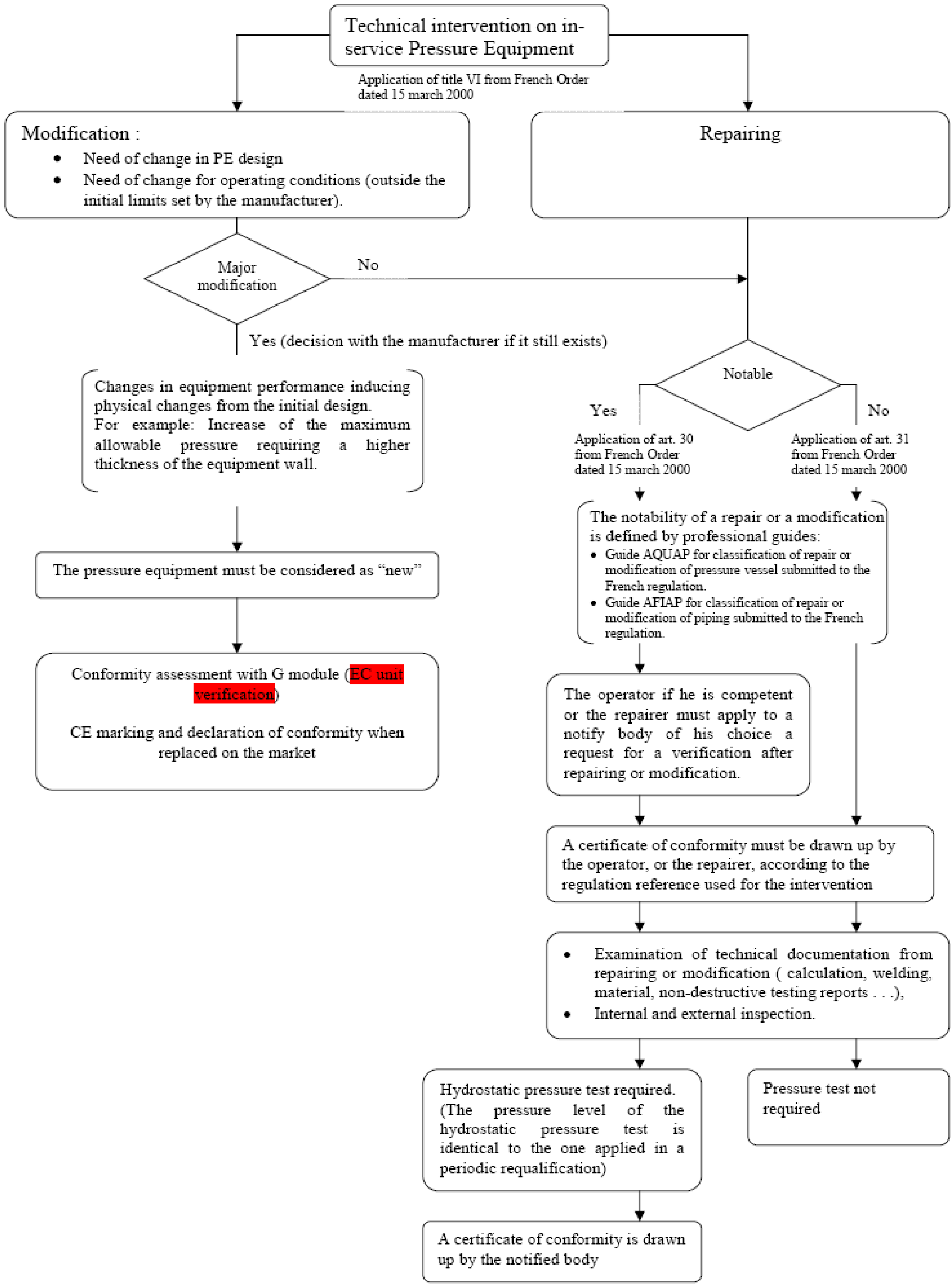


Figure 34: Synopsis of intervention management

7.5 Constraints linked to ATEX directive (explosive atmosphere)

7.5.1 *Statutory texts*

The European Community adopted two directives on explosive atmospheres known as "ATEX".

The EU directive 1999/92/CE dated December 16, 1999, specifies the minimum requirements for the protection of workers potentially at risk from explosive atmospheres.

This directive was transposed into French law by decrees 2002-1553 and 2002-1554 of December 24, 2002. Two orders of July 8, 2003 supplement the two decrees while transposing the appendices of the directive. They concern:

- The definition of the sites where explosive atmospheres can be formed.
- Regulations aiming at improving the health and safety of the workers exposed to the explosion risks.
- The selection criteria of the apparatuses and the protective systems used on the sites where the explosive atmospheres can arise.
- The warning signs of dangerous sites.

A third order, dated July 28, 2003, sets the conditions of installation for the electrical materials on the sites where explosive atmospheres might exist.

The EU directive 94/9/CE is issued in order to harmonize the laws of the European states for the apparatuses and the protective systems intended to be used in explosive atmospheres. This document is addressed to manufacturers and gives the essential requirements which the apparatuses and the protective systems must meet, as well as the procedures of conformity assessments.

It was transposed into French law by decrees 96-1010 of November 19, 1996 and 2002-695 of April 30, 2002, supplemented by orders of March 3, 1997 and August 21, 2000. They concern:

- The bearing of the CE marking,
- The bearing of the Ex proof marking and additional marking,
- The conformity declaration,
- The classification of the equipment

7.5.2 *Explosion protection documentation*

According to the statutory texts, this documentation shall demonstrate:

- That the explosion risks have been determined and assessed,
- That adequate measures are taken meet the statutory requirements,
- Those areas where regulations are applicable,
- That measures have been taken for the safe use of equipment by workers.
- The content of the training for concerned employees,

- Procedures to be applied and written instructions to be established before work is carried out in the concerned areas.

The explosion protection documentation and related risk assessment shall cover not only normal operating, but also maintenance, start-up and shut-down.
The explosion protection documentation shall include:

- The name of establishment, the name of the safety manager of the plant,
- A description of the process parameters relevant to the risk of explosive atmosphere,
- The list of the substances which induce this risk,
- A list of relevant procedure and work instructions,
- A list of the electrical and mechanical equipment and their classification for use in ATEX areas.
- Manufacturer certificates,
- EU conformity declarations.

7.6 Safe operation of cryogenic activated carbon gas purifiers

Over the past ten years, several incidents concerning cryogenic activated carbon purifiers and adsorbers were reported, some having caused powerful explosions.
Detailed descriptions of these incidents and guidance for the safe operation of such cryogenic gas purifiers are contained in a document issued by the European Industrial Gases Association (EIGA): **"Hazards associated with the use of activated carbon cryogenic gas purifiers".**
Note that said document is not a standard. It only contains information or suggestions based on technical information and experience currently available.
The following link leads to this document:
http://www.eiga.org/fileadmin/docs_pubs/Doc%2043%2007%20E.pdf

7.7 Environmental constraints

At ITER the designers have to cope with three types of environmental constraints:

- Magnetic field level and variation thereof.
- Irradiative environment.
- Thermal cycling with high temperature (baking at 500K).

7.7.1 *Magnetic field tolerance and recommendation*

The characteristics of sensors have to be checked with accuracy in order to guarantee their capability to withstand the harsher environment where they will be installed. If this capacity is not observed, we recommend consulting other ITER groups with similar issues or other companies with a similar problem.
Up to 40 mT no electronic devices could withstand such magnetic field values. This

intolerance is mainly due to the over-consumption of device supply. Consequently all electronic devices deep within a magnetic field of up to 40 mT have to be sent to a less harsh environment. As a result the issue of transporting a low-level signal for a long distance could appear especially for the thermal sensors at 4 K.

7.7.2 *Ionizing radiation tolerance and recommendation*

The characteristics of sensors have to be checked carefully in order to guarantee their capability to withstand the harsher environment where they will be installed. If this capacity is not observed, we recommend consulting other ITER groups with similar issues or other companies with a similar problem.
Up to 2.5 Gy (life of the device) many companies such as EDF or Areva recommend not to install electronics. Consequently all electronic devices deep within irradiative environments up to 2.5 Gy have to be sent in a less harsh environment. As a result the issue of transporting a low-level signal for a long distance could appear especially for the thermal sensors at 4 K.

7.7.3 *Thermal cycling tolerance and recommendation*

The characteristics of sensors have to be checked with accuracy in order to guarantee their capability to withstand the high temperature where they will be installed. Particular care has to be taken for 4K measurements. If this capacity is not observed, we recommend consultation with other ITER groups with similar issues or other companies with a similar problem.
Due to mechanical constraints that thermal cycling undergoes regarding the chain of measurement inside the cryostat:

- Choice of materials for thermal anchoring. For example in the presence of tritium, epoxy glass is forbidden [ITER Vacuum Handbook (Issue 2.3, IDM Ref: ITER_D2EZ9UM), annex 3].
- Choice of materials to solder the wires of sensors. Special attention should be paid to liquidus and solidus points.

7.7.4 *Chemical retention and recommendation*

A hazardous substance is any chemical or biological agent which is hazardous for the health (very toxic, toxic, harmful, corrosive, asphyxiant, etc.) or for the environment. It can be in any physical state (gas, liquid, solid).
It can affect the body by:

- inhalation,
- ingestion,
- contact with the skin, eyes mucous membranes
- penetration through the skin,

or affect the environment:

- pollution of the ground by streaming or overflow,
- pollution of the atmosphere by rejection.

In a cryogenic system, the main chemical risks are:

- Inhalation of lubricants or condensates in vapor phase from compressors or vacuum pumps,
- Inhalation of dust during the change of active charcoal or molecular sieve,

CIRCULAR DRT n°12 of May 24, 2006 relating to the general rules of prevention of the chemical risk and particular rules to made regarding the risks of exposure to carcinogenic, mutagen or toxic for the reproduction agents,

- ➢ Standard 192: ISO 12100-1: Safety of machinery - basic concepts - general principles for design - Part 1: basic terminology, methodology, chapter 4.8,
- ➢ Standard 193: ISO 12100-2: Safety of machinery - basic concepts - general principles for design - Part. 2 Technical principles, chapter 5.4.4,
- ➢ Standard 194: EN 626-1: Safety of machinery – Reduction of risk to health from hazardous substances emitted by machinery – Part 1: Principles and specifications for machinery manufacturers,
- ➢ Standard 195: EN 626-2: Safety of machinery – Reduction of risk to health from hazardous substances emitted by machinery – Part 2: Methodology leading to verification procedures,
    - Anoxia with helium or nitrogen gas

Refer to the ITER Cryogenic Safety Handbook (ITER IDM ref. 2V3VMN) – chapter 6.5 Oxygen Deficiency Hazards (ODH)

- Environmental pollution with lubricants or condensates in liquid, mist, vapor phase,

Standard decree - Heading n° 361: Refrigeration or compression (Installations of)

Council Directive 2006/42/CE on Machinery, annex I, 1.5.13 Emissions of hazardous materials and substances,

- ➢ Standard 196: EN 1012-1: Compressors and vacuum pumps - Safety requirements - Part 1: compressors, chapters 4.5 and 5.5,
- ➢ Standard 197: EN 1012-2: Compressors and vacuum pumps - Safety requirements - Part 2: vacuum pumps, chapters 4.6 and 5.6.1.

7.7.5 *Condensate management*

7.7.5.1 Waste oils

It is prohibited:

- to dispose of waste oils into nature (ground, water)
- to burn them

- to mix them with another substance (water, brake fluid…)

Waste oils shall be:

- stored in a tight container
- delivered to an approved collector

Council Directive 75/439/EEC of 16 June 1975 on the disposal of waste oils

7.7.5.2 Condensate on cryolines

Cryolines likely to frost, as quench line, shall be equipped with gutters to recover condensates. Gutters shall direct condensates towards industrial water network.

7.8 Guideline for hazard analysis of the system

FMAE Analysis of Failures Modes and their Effects

Failure Mode Effects Analysis (FMEA) is a logical technique used to identify and eliminate possible causes of failure. The technique requires a sequential, disciplined approach to assess systems, products or processes, in order to establish the modes of failure and the effects of failure on the system, product or process. This is to ensure that all possible failure modes have been fully identified and ranked in order of their importance. The FMEA discipline requires the documentation of any evaluation with regard to the failure mode, effect and criticality. The analysis work can be applied at any stage; design, manufacture, test, installation or use, but is best performed at the early (development or design) stage. In a simple system the study may be performed on the total system or product, but with more complex systems it may be necessary to break the product down into various sub-systems or sub-assemblies.

- ➢ Standard 198: EN 60812 Analysis techniques for system reliability - Procedure for failure mode and effects analysis (FMEA)

European standard EN 60812 describes Failure Modes, Effects and Critically Analysis (FMECA), and gives guidance as to how they may be applied by:

- Providing the procedural steps necessary to perform an analysis,
- Identifying appropriate terms, assumptions, critically measures, failures modes,
- Defining basic principles,
- Providing examples of the necessary worksheets or other tabular forms.

7.8.1 *Fault Tree Analysis*

A combination of analyses is often recommended by specific standards of safety, which often require an analysis of the individual failures and an analysis of the multiple failures. The first requirement being filled by FMDE, the second can be satisfied by the Fault Tree Analysis. Moreover, it exists as a consistency check between the 2 analyses.

The Fault Tree Analysis (FTA) technique is described in:

- Standard 199: EN 61025 Fault tree analysis (FTA)

The aim of the FTA is to analyze the conditions and factors causing an undesired, so-called top event. The fault tree itself is a graphical representation of these causes as a tree where the top event is stated as the root node. The other nodes represent either events that are direct or indirect causes of the top event or gates. Gates link two or more cause events causing one fault event in the suitable manner.
This European Standard describes FTA and provides guidance on its application as follows:

- Definition of basic principles, including describing and explaining the associated mathematical modeling, and the relationships of FTA to other reliability modeling techniques,
- Description of the steps involved in performing the FTA,
- Identification of appropriate assumptions, events and failure modes
- Identification and description of commonly used symbols

7.8.2 *The HAZOP (hazard and operability) study*

7.8.2.1 Definitions

Hazard: any operation that could possibly cause a catastrophic release of toxic, flammable or explosive chemicals or any action that could result in injury to personnel.
Operability: any operation inside the design envelope that would cause a shutdown that could possibly lead to a violation of environmental, health or safety regulations or negatively impact profitability

7.8.2.2 HAZOP Concept

The HAZOP process is based on the principle that a team approach to hazard analysis will identify more problems than when individuals working separately combine results. Hazard & Operability Study is undertaken to review the design and operation of the hazardous facility. In this study, a team comprising of Plant personnel and individuals with varying backgrounds and expertise, is constituted. This team identifies all causes of deviation from usual safe operations that can lead to any safety hazard or operability issue. The HAZOP team explores all the possible causes of the problem and its consequences. This is done after application of relevant guidewords, considering process parameters and extensive brainstorming sessions within the team.
Maintenance operations are important area to study because they often create hazards as well as operability problems.

It is also possible to unroll the HAZOP by planning a key word initially then systematically to affect the identified parameters to it. A table of synthesis proves often useful to guide the reflection and to collect the results of the discussions held within the work group. The key words, coupled the important parameters for the process, make it possible to generate in a systematic way the drifts to be considered.

- Standard 200 : CEI 61882 Hazard and operability studies (HAZOP studies) - Application guide

Standard CEI 61882 proposes examples of key words of which the use is particularly current.
The HAZOP is a particularly effective tool for the thermo hydraulic systems. This method presents, just like FMAE, a systematic and methodical character. Considering, moreover, simply the drifts of parameters of operation of the system, it avoids all the possible modes of failures for each component of the system. On the other hand, the HAZOP study presents difficulties to analyze the events resulting from the simultaneous combination of several failures.

8. Documentation

As a general rule, all documents must be made available in three copies and in a computer-readable form.
All technical documents shall be presented in English.
Dimensions shall be indicated using the SI system, except pressure which may be indicated as bar.
All changes to valid documents shall be marked clearly to indicate the revision status

8.1 Preliminary documentation

- Preliminary documents used for technical discussions can be established with specific software, but must be convertible to a common electronic format readable and printable.
- The technical description of appliances integrated in complete systems, giving the manufacturer’s name, the types and references of the equipment, with data about maintenance and operation.

8.2 Documentation to be submitted for approval prior any fabrication

The Pressure Equipment regulations provide for the supply of specific documentation in the design and conception phases; in this case, refer to *Documentation linked to pressure equipment regulations*
For other components, the following documents are requested:

- Foreseen production schedule,
- Assembly drawings of all components indicating the dimensions and the weights and with part lists of the materials used,
- Lists of valves with valve size calculations and choices,
- List of instrumentation,
- Thermal data sheets for all heat exchangers,
- Electrical drawings including layout and wiring.
-

Drawings

Drawings as part of the required documentation must comply with ISO drawing standards.
IO will specify the delivery form of the drawings.
IO will also specify the software to use:

- For installation drawings,
- For process and instrumentation diagrams,

Block diagrams, Process Flow Diagrams and Piping and Instrumentation Diagrams and component lists must be carried out according to:

- ➢ Standard 201: ISO 3511 Process measurement control functions and instrumentation -- Symbolic representation

The documentation concerning electrical equipment and wiring must be presented as specified in the ITER Electrical Design Handbook (ITER IDM reference 2DSPT6).

8.3 Documentation linked to Pressure Equipment regulation

The pressure equipment entering within the scope of Decree 99-1046 shall be subject to a final examination (Appendix I, §3.2.1).
In addition to visual examination, the final verification includes examination of the technical records which must cover design and fabrication. All documentation shall be prepared in accordance with the relevant standards and codes and must comply with the selected conformity module.

The required technical documentation shall be available as follows:

D E S I G N	*For the Pressure equipment relevant to A - A1 - D1 - E1 - G - H evaluation modules, the following documents must be provided for the final examination* • General description of the pressure equipment, • List of codes or harmonized standards applied and solutions adopted, • Design drawings, manufacturing drawings (if necessary), diagram of components, subassemblies or circuits, description and explanation for an understanding of the said drawings and diagrams (if necessary), • Identification marking drawings (identity plate), • List of materials used, • Results of design calculation made , • Forming procedures, • Heat treatment procedures, • Non-Destructive Test procedures, • Permanent assemblies procedures, • Operating instructions.
F A B R I C A T I O N	• Evidence of qualification of Non-Destructive Test personnel relevant to the equipment category; • Evidence of qualification of permanent joining personnel relevant to the equipment category, • Data dealing with heat treatment (e.g. diagram of temperatures); • Inspection documents for base materials and consumables, • Procedures to ensure the traceability of the material, • Non-Destructive Test reports, including radiographic slides, • Test reports of destructive tests (e.g. test coupons), • Reports on defects or deviations arising during manufacture, • Data related to the preparation of component parts (e.g. forming chamfering), • Evidence of qualification of permanent joining procedures, • Conceptual design and manufacturing drawings, diagrams of components, sub-assemblies circuits, etc., • Results of design calculation or test results in case of experimental design.

These documents shall be available for final inspection whether said inspection is carried out by the manufacturer or the notified body.

8.4 Quality and safety documentation

8.4.1 *Quality documentation*

Documents to be submitted for approval regularly during the period between notification of the contracts and provisional acceptance: Refer to ITER quality documents.

8.4.2 *Safety documentation*

Refer to the ITER Cryogenic Safety Handbook (ITER IDM ref. 2V3VMN):

8.5 Documents to be submitted for approval prior to transport

- Certified production schedule,
- Detailed planning for the transport.

8.6 Documents to be submitted for approval prior to any test of equipment

- Detailed specifications,
- Data sheets and instruction manuals of components,
- Process logic diagrams and programs if written by contractors,
- Detailed tests programs and detailed tests procedures,
- Uncertainty calculations related to measurement equipment during tests,
- Detailed maintenance plan.

8.7 Documents to be submitted before provisional acceptance

- Complete set of the final design mechanical-thermal calculations,
- Reports on all tests carried out on ITER site
- Total mechanical documentation with mention “as built”,
- Total electrical documentation with mention “as built”,
- Operating instruction manuals including particular settings,
- Maintenance manuals,
- List of spare parts.

The supply of the complete documentation will be a condition for provisional acceptance.

9. List of appendices

9.1 Tables of classification of Pressure Equipment

9.2 Conformity Modules

9.3 List of harmonized standards

9.4 Example of a hazard analysis template

9.5 Welding

9.6 Template of Essential Safety Requirements

9.7 Oil properties

9.8 Template of In-Service declaration (French language only)

9.9 General rules for In-Service inspections

9.10 BSEI decision 09-219

9.11 Technical professional book n° 152-01

9.12 Technical professional book n° 152-02

9.13 List of figures

9.14 List of tables