TÜRK LOYDU

Chapter 52 – Diving Systems

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This latest edition incorporates all rule changes. The latest revisions are shown with a vertical line. The section title is framed if the section is revised completely. Changes after the publication of the rule are written in red colour.

Unless otherwise specified, these Rules apply to ships for which the date of contract for construction as defined in TL- PR 29 is on or after 1st of January 2020. New rules or amendments entering into force after the date of contract for construction are to be applied if required by those rules. See Rule Change Notices on TL website for details.

"General Terms and Conditions" of the respective latest edition will be applicable (see Rules for Classification and Surveys).

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Diving Systems

AMENDMENTS

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SECTION 1

CLASSIFICATION and CERTIFICATION of DIVING SYSTEMS and DIVING SIMULATORS

Page

A. Scope of Application

1. General

These Rules are valid for the construction of diving systems, diving simulators, diver pressure chambers and the systems necessary for operation, which shall be classified (see B. - F.) or Certified (see G.) by **TL.**

These Rules can be used in analogous way for manned pressure chambers for other applications, like e.g. compressed air and caisson works.

2. Diving systems

For the purpose of these Rules, systems for supporting diver operations which are permanently installed on a diver support ship, a similar floating structure or an offshore plant respectively which are assembled for the actual duty of a mission and are installed for a limited period, are diving systems.

Diver launching systems are also belonging to these systems.

3. Diving simulators

As diving simulators a pressure chamber system is understood, in which training of divers or Manned and unmanned tests can be performed in dry or wet environment, at conditions which are adequate to an underwater mission. Normally diving simulators are installed in buildings or similar objects.

4. Diver pressure chambers

For the purpose of these Rules, pressure chambers or pressure chamber systems, in which divers are treated and transported under pressure, are diver pressure chambers.

B. Classification and Characters of Classification

1. Classification

1.1 Opportunity for Classification

1.1.1 Diving systems may be classified and have then to be subjected to periodic surveys by **TL** according to the duration of Class.

1.1.2 Diving simulators, diver pressure chambers, diver launching systems and single elements of diving systems are in general not subject to Classification, but will be certified by **TL.** The requirements for their Certification are defined in G.

If a diving simulator shall be classified on request of a manufacturer or operator, the Rules for Classification of diving systems shall be applied in analogous way.

1.1.3 Diving systems, which shall not be classified by **TL,** but which shall be constructed and tested according to the Rules and under survey of **TL,** may receive an adequate System Certificate from **TL**, see G.

1.2 Basis for classification

The following Rules for Classification and Construction constitute the basis for the Classification of diving systems.

For requirements not defined in these Rules, the other Rules for Construction of **TL** have to be applied.
The term "Rules for Construction" includes Rules for Materials and Welding as well as other Rules for Construction issued by **TL.**

1.3 Scope of classification

Classification covers the structure, machinery and electrical equipment of diving systems.

1.4 Class certificate

The Certificate of Classification for diving systems is issued by the **TL** Head Office. It is to be kept at the diving system.

1.5 Class register

Diving systems classified by **TL** are entered in the Register Book with a note of the relevant Character of Classification and are, as far as applicable, included in the list of ships with diving System Certificates.

1.6 Operational records

For diving systems operational records are to be kept in which details of operations (diving operations, maintenance, damages, repairs, etc.) are to be entered. The record is to be submitted to the **TL** Surveyor on request.

2. Characters of Classification

2.1 The Character of Classification for diving systems is:

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2.2 Diving systems built under the survey and in accordance with the Rules of **TL** using materials and components tested by **TL** in conformity with its Rules receive the notation **+** in front of the Character of Classification.

2.3 Diving systems built under the survey and in accordance with the rules of another recognized classification society receive, on being awarded **TL** classification, the notation **[+]** in front of the Character of Classification.

2.4 For diving systems of non-standard design, **TL** reserve the right to subject the systems to additional tests, to order a special survey schedule and to make special entries in the Class Certificate and the Register Book.

3. Duration of Class

3.1 The period of Class of permanently installed diving systems is always identical to that of the machinery plant of the diver support ship, floating structure or the offshore plant. The Class will be maintained as long as the diving system is subjected to all prescribed surveys, and any modifications and repairs found to be necessary are carried out to the satisfaction of **TL.**

3.2 If the diving system is not subjected to the prescribed surveys at their due dates, the Class will be suspended.

3.3 If the diving system has suffered damage affecting its Class or if such damage may be assumed, a survey is to be performed before diving operations begin. **TL** is to be notified of such damage.

3.4 Where it is found that the diving system no longer complies with the requirements of the Rules on the basis of which the Class was assigned, or if the operator fails to carry out repairs or alterations considered necessary by **TL** within a specified period to be agreed upon, the Class of the diving system will expire.

3.5 If the repairs or modifications required by **TL** have been carried out and the system is subjected to a Reclassification Survey, the original Character of Classification may be reinstated. This survey is to be carried out in accordance with the requirements for a Class Renewal Survey.

3.6 For diving systems which are out of operation for some time or their diver support ship, floating structure or offshore plant is laid up, the period of Class remains unchanged. On request, surveys which fall due may be postponed until the diving system is replaced into service. The total scope of the surveys required thereafter shall be determined by **TL** for each case individually.

3.7 If for some reason the Class has expired or has been withdrawn by **TL**, this will be indicated in the Register Book. The Certificates of Classification shall be returned to **TL**

C. Classification of Diving Systems Built or Converted under the Survey of and in Accordance with the Rules of TL

1. General

1.1 Application for the classification of a diving system is to be submitted to **TL** in writing by the manufacturer or operator.

1.2 In general, particulars of the diving system are to be submitted to **TL** in triplicate. in case of electronic transmission as single issue for examination.

1.3 Any deviation from the approved drawings and documents are subject to the approval of **TL** before work is commenced.

1.4 The surveyor is to be advised in sufficiently early time for tests to be performed under the supervision of **TL**.

1.5 On the completion and successful testing of the diving system, TL will issue the Classification Certificate.

2. Supervision during construction

2.1 Materials for new constructions, replacements and repaired parts have to be tested as defined in the **TL** Rules for Materials.

2.2 Parts of the diving system requiring approval will be checked during manufacture for conformity with the approved documents.

2.3 The separate components of the diving system are to be tested at the manufacturer test bed for mechanical strength and, where appropriate, for functional efficiency. Where components are novel in design or have not yet sufficiently proved their efficiency on board ship or in diving systems, **TL** may demand more extensive tests.

2.4 The Surveyors of **TL** will supervise the installation or the assembly of the diving system on the ship, floating structure or the offshore plant, will examine the workmanship and will carry out the required tightness and functional tests.

2.5 Upon completion, the entire diving system will be subjected to a test under working conditions in accordance with Section 2, G.

2.6 To enable the Surveyor to fulfil his duties, he is to be given free access to the ship, the floating structure or the offshore plant and the workshops where parts requiring approval are manufactured, assembled or tested. Assistance by providing the necessary staff and equipment has to be granted by the shipyard or manufacturer. The compliance with the requirements for workmanship according to H. is to be checked by the Surveyor.

D. Classification of Diving Systems not Built under the Survey of TL

1. General

1.1 Applications for the Classification of diving systems not built under the survey of **TL** are to be submitted to **TL** in writing.

1.2 With the application for classification documents relating to the diving system are to be submitted for examination the scope of which shall be as stated in the Rules for Construction. The documentation relating to functional tests is to be submitted and, where necessary, individual tests are to be repeated.

1.3 Existing Class and period of Class, as well as any requirements which have been made conditional upon the existing Class are to be reported to **TL**.

1.4 Where the diving system has existing Class awarded by a recognized classification society, it may in exceptional cases be sufficient to forward one set of the necessary documents.

2. Procedure of admission to Class

2.1 For admission to Class the diving system is to be surveyed in accordance with the provisions for a Class Renewal Survey.

2.2 If the diving system holds the Class of another recognized Classification Society, the survey of individual parts may be deferred pending the next due date a survey of these parts within the scope of an Annual Survey may be declared as sufficient.

2.3 A Classification Certificate will be issued on the basis of satisfactory Surveyor's Reports on the admission to Class. Once a diving system has been classed with **TL**, the same regulations will apply as for diving systems built under survey of **TL**.

E. Surveys for Maintenance of Class

1. Kinds of surveys

Diving systems classed with **TL** are to be subjected to the following surveys, if their Class is to be maintained:

1.1 Annual survey, see 3.1.

1.2 Intermediate survey, see 3.2.

The intermediate survey falls due nominally 2,5 years after commissioning and each class renewal and may be carried out on the occasion of the second or third Annual Survey.

1.3 Class Renewal Survey after five years, see 3.3.

1.4 Damage survey, where the diving system has been damaged or where the hull or parts of the machinery plant have suffered damage liable to affect the diving system, see 3.4.

1.5 Extraordinary Survey, before the start of diving operations with a modified diving system or after new assembly or change of location of a diving system, see 3.5.

1.6 **TL** reserve the right to demand for extraordinary surveys in justified cases. Such surveys may be taken into account for the prescribed regular surveys.

1.7 Apparatus and components are to be arranged accessible for surveys. If it is either impracticable or excessively costly to prepare units and components for internal survey on the installation location, surveys may also, on application by the operator, be performed in the manufacturer's works or other authorized workshop.

2. Explanatory notes on surveys

2.1 The locally responsible Surveyor of **TL** is to be given timely notice when regular surveys become due or when it is intended to carry out repairs or alterations, so that the work can be supervised.

2.2 The records of each survey, as well as special requirements upon which the maintenance of Class has been made conditional, will be entered in the Classification Certificate. In addition to the Character of Classification and the month and year of Classification, the Register Book shall also state the month and year of the last Annual Survey or the last Class Renewal Survey.

2.3 The reports prepared by the Surveyors are checked by **TL**. The results of surveys carried out are published in the Register Book, upon acceptance.

2.4 Where defects are repaired provisionally only, or where the Surveyor does not consider immediate repairs or replacements necessary, the class of the diving system may be confirmed for a certain limited period by making an entry in the Certificate of Classification. The withdrawal of such restrictions will be entered in the Certificate of Classification.

2.5 Where parts are damaged or worn to such an extent that they no longer comply with the requirements of **TL**, they are to be repaired or replaced.

2.6 If a diving system has to be surveyed in a location where, or near which, there is no Agent or Surveyor of **TL**, the locally responsible Consul, a competent Office or Authority, or the Average Commissioner of the relevant Insurance Company concerned is to be requested to cause a survey by an expert. The commission of the expert is to be confirmed by the Consul, the Office of Authority, or the Average Commissioner.

The called-in expert shall be requested to forward to **TL** forthwith a report on the condition and on the repairs as well as on the decision arrived at. A copy of the report is to be retained at the diving system. The decision of the expert is subject to the approval of **TL**, who will decide on whether the diving system has to be surveyed again.

3. Performance of surveys

The surveys are to be performed according to the following criteria. If the operational systems of the diving system should be different from the standard case, the scope of the surveys may be adjusted accordingly in coordination with **TL**.

3.1 Annual survey

The Annual Survey of the diving system shall include at least the following tests and checks:

3.1.1 Examination of the documents relating to the diving system and scrutiny of the operational records.

3.1.2 The entire compression chamber system including all fixtures, penetrations, window frames, doors and covers, seals, locking systems etc. is to be inspected for visible damages, cracks, deformation, corrosion and fouling etc.

3.1.3 Check of measures for corrosion protection (e.g. anodes).

3.1.4 All other pressure vessels and apparatus under external and internal overpressure, valves, fittings and safety equipment are to be subjected to external inspection.

3.1.5 The entire machinery plant including electrical installations and gas supply system for the pressure chamber system and all redundant systems are to be subjected to external inspection.

3.1.6 Check that insulation measurements have been performed on the electrical equipment.

3.1.7 Review of safety systems including response pressure of the safety valves and the set points of the safety and warning devices.

3.1.8 Functional test of all alarm systems.

3.1.9 Switching from the main to the emergency electricity supply is to be tested.

3.1.10 The accuracy of all essential instrument readings is to be checked (e.g. depth gauge, gas analyzer, etc.).

3.1.11 All emergency systems are to undergo a functional test (e.g. the autonomous gas supply of the diving chamber)

3.1.12 Functional test of the life support systems.

3.1.13 Tightness tests of the life support systems.

3.1.14 Review of the function of the fire surveillance and extinguishing systems.

3.1.15 All hose lines for the gas supply and gas filling as well as the hoses of the diver's heating and the umbilicals are to be checked for visible damages and tightness.

3.1.16 Acryl glass panes are to be subjected to a visual check for cracks, scratches, changes of structure (crazing). As far as possible at installed condition, the contact area and window sealing are to be checked.

3.1.17 Umbilical and lifting cable are to be checked for visible damages, cracks, deformations and corrosion.

3.1.18 Function of the main and emergency communication systems are to be checked.

3.1.19 If compressors for breezing air are used the quality of the compressed air is to be proven, e.g. according to EN 12021.

3.1.20 The mating arrangement will be checked for visible damages, cracks, deformations and corrosion attacks and, as far as possible, subjected to a functional test.

3.1.21 The launch and recovery system including all load transmitting devices is to be checked for visible damages, cracks, deformations and corrosion and shall undergo a functional test including a brake test (power failure).

3.1.22 The systems for safe stowage and safe deck transport aboard the diver support ship are to be reviewed.

3.1.23 The supply systems which are necessary for the safe operation of the diving system and their control aboard the diver support ship are to be checked.

3.1.24 The functional efficiency of the total system is to be checked by means of a trial dive.

3.2 Intermediate Survey

An Intermediate Survey is an Annual Survey according to 3.1 extended by the following scope:

3.2.1 Performance of a tightness test on the compression chamber system at maximum permissible working pressure using air.

3.2.2 For diving chambers, compression chamber penetrations and closings are to be checked by an under pressure test with at least 0,2 bar below atmospheric pressure.

3.2.3 Verification of the set pressures and reset pressures of compression chamber relief valves and of safety and warning systems.

3.2.4 Functional tests on mechanical and electrical equipment.

3.2.5 Functional test and purity check on all breathing gas compressors.

3.2.6 Functional test on mating and de-mating of the hyperbaric rescue system.

3.3 Class Renewal Survey

In addition to the surveys defined in 3.2 the following tests and examinations are to be carried out for Class Renewal Surveys:

3.3.1 Visual check of all fastenings, bearing and coupling elements of all machinery and devices.

3.3.2 Check of the shell cladding and buoyancy aids (pressure resistant foam). If necessary the cladding has to be removed.

3.3.3 Pressure chambers and locks are to be subjected to functional tests and a tightness test with maximum allowable working pressure and the actual operating medium.

3.3.4 Check of the structural areas which are not easily accessible with the aid of a non-destructive test procedure.

3.3.5 Dimensional checks and non-destructive wall thickness tests are to be performed on the pressure chambers and especially the diving chamber. Where necessary, buoyancy aids, cladding and layers of thermal insulation are to be removed for this purpose.

3.3.6 With the diving chamber the jettisoning of emergency ballast and floating tests are to be performed.

3.3.7 Internal visual check of vessels and apparatus under pressure. If these cannot be satisfactorily inspected internally or their satisfactory condition cannot be fully verified by internal inspection, another non-destructive test method is to be used and/or a hydraulic pressure test is to be performed. Where necessary, buoyancy aids, claddings and layers of thermal insulation are to be removed for this purpose.

3.3.8 The examinations according to 3.1.16 are to be performed for dismantled acrylic glass panes. (Duration of employment normally 10 years)

3.3.9 Check that accessories, especially hose assemblies and compensators are changed according to the maintenance plan.

3.3.10 After 10 years all pressure chambers are to be subjected to a hydrostatic internal pressure test and eventually also to an external pressure check.

3.3.11 For the launch and recovery system including all load transmitting devices a dynamic test with 1,25 times **SWL** including a brake test (power failure) is to be performed.

3.3.12 Where surveys are performed on a diving system or parts thereof during the period of Class the scope of which corresponds to a Class Renewal Survey, then the regular Class Renewal Survey for the parts concerned may at the operator's request be postponed accordingly.

3.4 Damage Survey

3.4.1 If a diving system has suffered damage affecting its Class or if such damage may be assumed, or if the diver support ship has received damage affecting the diving system, a Damage Survey is to be carried out.

3.4.2 Following damage, the diving system is to be presented for survey in such a way that a satisfactory inspection can be carried out. The extent of the Damage Survey will be determined by **TL** in each individual case.

3.5 Extraordinary Survey

3.5.1 When any modification is made in respect of design, mode of operation or equipment, and after major maintenance works especially repairs of pressure vessels, the diving system is to be subjected to an Extraordinary Survey.

3.5.2 In addition, mobile diving systems are to undergo an Extraordinary Survey equivalent in scope to an Annual Survey after each re-assembly and whenever there is a change of location.

A further check shall be made to ensure that the diving system is properly assembled, secured and supported at the location of installation.

3.5.3 For diving systems which are designed for change of location and if their assembly guarantees an easy installation, an Extraordinary Survey can be waived.

F. Surveys other than for Classification

1. Survey by special agreement

Where surveys are required by official ordinances, international agreements or other provisions, **TL** will undertake them on application, or by official order in accordance with the relevant provisions.

2. Surveys relating to the safety of equipment

2.1 For all components with an important safety aspect (e.g. pressure vessels and apparatus etc.), **TL** will, on application, examine the drawings, carry out all the necessary surveys, acceptance tests and pressure tests and issue the relevant Certificates.

2.2 On application, **TL** will also perform the periodic surveys required for pressure vessels and apparatus.

2.3 When any modification is made in respect of design, mode of operation, equipment or location of installation **TL** will perform a survey of the safety measures of the total diving system. A relevant Certificate for the tests will be issued (compare G.).

G. Certification

1. General

1.1 The application for Certification of a diving system, a diving simulator, a diver compression chamber, a diver launching system or parts thereof is to be required from **TL** by the manufacturer or operator in written form.

1.2 After the contract has been signed by parties, documents for these systems are to be submitted to **TL** generally in triplicate respectively in case of electronic transmission as single issue for approval. The scope of the documents to be submitted depends on the type and equipment of the system and follows from Section 2, E., Section 3, A.6. or Section 4, A.3.

1.3 Surveys which have to be performed by **TL** are to be noticed to **TL** in due time.

2. Certification according to TL Rules

2.1 Opportunity for Certification

Diving systems, diving simulators, diver pressure chambers, diver launching systems or parts thereof, which are constructed and tested according to the Rules and surveys of **TL** may receive a System Certificate.

2.2 Scope of Certification

The Certification comprises the complete plant including its machinery and electrical equipment as well as the installation at the location.

2.3 System Certificate

2.3.1 After completion and successful testing of the plant a System Certificate will be issued by **TL**

2.3.2 **TL** certifies with the Certificate the technical condition of the plant at the time of the tests and approvals. In addition it will be confirmed that no safety reservations are opposing the operation of the plant.

2.3.3 The validity of the System Certificate is 5 years at the utmost and can be prolonged after a renewed test. For maintaining the Certificate the system is in general to be subjected to an Annual Survey. The scope has to be agreed with **TL** in each single case.

The System Certificate expires if substantial changes are performed at the system respectively if the system has been severely damaged and the change or the repair has not been agreed and approved by **TL**.

3. Certification according to other rules

3.1 For diving systems, diver pressure chambers, wet bells and parts thereof, which are not built according to the Rules of **TL**, the applied rules have to be defined in a binding way in the application for Certification.

3.2 Systems which have been constructed and tested under survey of **TL** according to other recognized rules may receive a Certificate by **TL**

H. Workmanship

1. General

1.1 Requirements to be complied with by the manufacturer and supplier

1.1.1 Each workshop of a manufacturer/supplier has to be provided with suitable equipment and facilities to enable proper handling of the respective materials, manufacturing processes, structural components, etc. **TL** reserve the right to inspect the plant accordingly and ask for related requirements or to restrict the scope of manufacture to the potential available at the plant.

For safety relevant components and elements it is to be defined by **TL** if the manufacturer/supplier needs an approval by **TL** Components and elements are regarded as safety relevant, if a direct danger for persons or the environment may be caused by them.

1.1.2 The manufacturing plants are to have at their disposal sufficiently qualified personnel. The supervisory and control personnel is to be named to **TL** the areas of responsibility are to be defined. **TL** reserve the right to require proof of qualification.

1.2 Quality control

1.2.1 The manufacturer/supplier has to apply a quality management system, like e.g. ISO 9001 or equivalent.

1.2.2 As far as required and expedient, all components both during manufacture and on completion are to be checked for completeness, correct dimensions and faultless workmanship according to the Standard of good engineering practice.

1.2.3 Upon inspection and eventual corrections by the manufacturing plant, the structural components are to be presented to the **TL** Surveyor for inspection, in suitable sections, normally in uncoated condition and enabling proper access for inspection.

1.2.4 The **TL** Surveyor may reject components that have not been adequately pre-checked and may demand their resubmission upon successful checks by the manufacturer and, if necessary, corrective actions.

2. Details in manufacturing documents

2.1 All significant details concerning quality and functional ability of the component concerned shall be entered in the manufacturing documents (workshop drawings, etc.). This includes besides scantlings - where relevant - such items as surface conditions (e.g. finishing of flame cut edges and weld seams), special methods of manufacture involved as well as inspection and acceptance requirements and where relevant permissible tolerances.

As far as a standard (works or national standard, etc.) shall be used it has to be harmonized with **TL**

2.2 If, due to missing or insufficient details in the manufacturing documents, the quality or functional ability of the component cannot be guaranteed or is doubtful, **TL** may require appropriate improvements. This is valid analogously for supplementary or additional parts (e.g. reinforcements), even if these were not required at the time of plan approval or if - as a result of insufficient detailing - could not be required.

SECTION 2

RULES for CONSTRUCTION of DIVING SYSTEMS

Page

A. General Principles

1. Diving systems and their components are to be designed for the conditions under which they shall be operated according to the specification.

2. Diving systems are to be designed to enable a safe transfer of persons under pressure from the decompression chamber to the underwater working place (and vice versa) as well as an entrance and exit of divers under pressure without risk.

3. Diving systems are to be so designed and constructed that a safe operation, a sufficient maintenance

B. Rules and Regulations to be Considered

1. TL Rules

1.1 The following Rules are valid as additional requirements for Classification and construction of diving systems in addition to the Rules for Classification and Construction of **TL**:

- Classification and Surveys
- Chapters 1, 4, 4-1 and 5
- Chapter 2 and 3.

1.2 Designs differing from the Rules of Construction may be permitted provided that they have been checked by **TL** for their suitability and are recognized as equivalent.

1.3 Diving systems or parts thereof whose development is based on new principles and which have not yet been sufficiently tested in practical operation require special approval by **TL.**

1.4 In the cases mentioned in 1.2 and 1.3, **TL** is entitled to require the submission of additional documentation and the performance of special tests.

1.5 **TL** reserve the right to impose demands additional to those contained in the Rules in respect of all types of systems when such action is necessitated by new knowledge or practical experience, or to sanction deviations from the Rules in specially justified cases.

2. National regulations

National regulations existing alongside **TL**'s Rules are naffected.

3. International Conventions and Codes

Diving systems conforming to these Rules also comply with the requirements according to:

- IMO Resolution A.536(13): "Code of Safety for Diving Systems", 1983
- IMO Resolution A.583(14): "Amendments to the Code of Safety for Diving Systems, 1985
- IMO Resolution A.831(19): "Code of Safety for Diving Systems", 1995
- IMO Draft Resolution MSC.185(79): "Adoption of Amendments to the Code of Safety for Diving Systems", 2004
- IMO Resolution A.692(17): "Guidelines and Specifications for Hyperbaric Evacuation Systems 1991.
- The International Code of Safety for Diving Operations, 2023 (2023 Diving Code) (MSC.548(107)

C. Definitions

1. General

For the purpose of these Rules the terms used have the meanings defined in the following unless expressly provided otherwise:

1.1 Mating Device

The equipment necessary for the connection and disconnection of a diving bell or an HBSC to a surface compression chamber**.**

1.2 Breathing gas/breathing gas mixture

All gases/mixtures which are used for breathing during diving operations.

1.3 Launch, recovery and transfer system

The plant and equipment necessary for launching, recovering and transfer of the diving bell between the work location and the decompression chamber.

Launch, recovery and transfer systems may be applied also for hyperbaric evacuation systems, compare R. and for wet bells, compare S.

1.4 Decompression chamber

A pressure vessel for occupancy of divers before or after missions aboard of a support ship with means of controlling and monitoring the internal pressure within the chamber.

Decompression chambers are also known as deck decompression chambers (DDC) or surface compression chambers

1.5 Pressure vessel

A container which is exposed to internal or external over pressure.

1.6 Gas cylinders

Bottles for storage and transport of gases under pressure.

1.7 Pressure chamber

Pressure vessel for human occupancy (PVHO) at higher than atmospheric pressure, normally equipped with means of controlling and monitoring.

1.8 Gas storage

In the open or in spaces fixed installed containers with pressurized gas, where the breathing and working gases for the operation are stored.

1.9 Hyperbaric evacuation system

An emergency system whereby divers under pressure can be safely evacuated from the support ship to a location where decompression can be carried out.

1.10 Life support system

Systems for gas supply, purification, exchanging and conditioning of the atmosphere in the pressure chamber as well as for the supply of water and food and for the removal of waste. It comprises in addition the surveillance system and equipment required to provide a safe environment for the diving crew in the diving bell and the pressure chamber system under all possible pressures and conditions to which they may be exposed during diving operations.

1.11 Diving system

System for the support of diving operations especially in greater depths with following main components: decompression chamber, diving bell, hyperbaric evacuation system, Launch, recovery and transfer system and installations for storage and filling of gases.

A further type of diving system is a diver launch system, which consists of a wet bell or diver basket and the belonging launch and recovery system.

1.12 Diving pressure

The respective overpressure, corresponding to the relevant diving depth, to which a diving bell or a diver is exposed during underwater operations [bar].

1.13 Support ship

Surface vessel (Diving Support Vessel - DSV) or floating structure for support and supply of diving operations. Within these Rules the diver support ship may also be a stationary supply station (e.g. on the coast or on a stationary offshore plant).

1.14 Diving bell

A submersible pressure vessel for human occupancy (PVHO), including its ancillary equipment, for transfer of divers under pressure between the work location and the decompression chamber.

1.15 Diver basket

A simple basket for the transport of divers to the underwater working location.

1.16 Lifting cable

Cable for lifting and lowering a diving bell/wet bell.

1.17 Transportable diving system

Diving system which is designed, to be assembled and operated for a limited time period at different installation locations.

1.18 Umbilical

Connection between support ship and diving bell respectively between diver and the adjacent supply arrangement, which might contain monitoring, communication and power supply cables, breathing gas and hot water hoses. The lifting cable for lifting and lowering the diving bell/wet bell may be part of the umbilical.

1.19 Wet bell

A diver deployment and recovery device as a minimum fitted with a gas filled dome, a main supply umbilical from the surface (providing breathing gas and other service to a manifold inside the device), and diver excursion umbilicals terminated at the device.

1.20 Living compartment

Part of the decompression chambers which is used as habitation of the divers before and after the diving missions and which is adequately equipped.

1.21 Hyperbaric survival craft (HBSC)

A pressure vessel for human occupancy (PVHO) and associated support plant and equipment whereby divers under pressure can be safely evacuated from a diving unit until recovered to a position where planned decompression can be completed.

1.22 Pressure vessel for human occupancy (PVHO)

A container intended to be occupied by one or more persons that is capable of withstanding an internal or external pressure differential exceeding 0.14 bar (2 psi).

2. Main dimensions and main parameters

2.1 Length over all L

The length over all L is the external length between the most forward and most aft point of a chamber including all fixed installed components of equipment, measured in longitudinal direction [m].

2.2 Breadth over all B

The breadth over all B is the maximum breadth of a chamber including all fixed installed components of equipment, measured vertical to the length L in horizontal direction [m].

2.3 Total height H

The total height H is the total height from the baseline to the upper edge of the chamber including all fixed installed components of equipment, measured in vertical direction [m].

2.4 Diameter D of a chamber

The diameter D of a chamber is the diameter of the cylinder or the sphere related to the inner side of the wall [m].

2.5 Volumes of the pressure chambers

2.5.1 Total volume V

The total volume of the diving system V is the sum of the volumes of all single chambers including the volumes of all access passages [ℓ].

2.5.2 Single volume V_i

The single volume Vi is the volume of a chamber [ℓ].

2.5.3 Displacement volume of the diving bell Δ↓The displacement volume of the completely submersed diving bell is Δ↓ [m^3].

2.6 Payload NL of the diving bell

The maximum additional load of the diving bell consisting of divers, devices, equipment, materials is the payload NL [kg]. Normally for equipped divers at least a weight of 150 kg is to be considered.

2.7 Total weight G

The total weight of the diving system ready for operation is G [t].

2.8 Diving depths and diving pressures

2.8.1 Nominal diving pressure

The nominal diving pressure NDP [bar] is the pressure which corresponds to the nominal diving depth NDD [m] for unrestricted diving operation of the diving system.

2.8.2 Test diving pressure

The test diving pressure TDP [bar] is the pressure for testing the components of the diving system subjected to external pressure for strength, tightness and ability to function. It corresponds to a test diving depth TDD [m].

2.8.3 Collapse diving pressure

The collapse diving pressure CDP [bar] is the pressure for the components of the diving system subjected to external pressure for which the component will be destroyed without consideration of the creeping behaviour and the creep rupture strength of the material.

It corresponds to a collapse diving depth CDD [m].

3. Components of diving systems

As far as present, the following components form part of the diving system and are to be designed, constructed and tested in accordance with these Rules:

- Decompression chambers
- Diving bells
- Wet bells
- Diver baskets
- Permanently installed gas containers
- Pressure vessels
- Pipes, valves, fittings and hoses
- Umbilicals
- Breathing gas systems
- Life support systems
- Diver heating systems
- Sanitary systems
- Communication systems
- Electrical systems and equipment
- Automation, communication and locating equipment
- Gas analyzing systems
- Fire prevention, fire detection and extinguishing equipment
- Compressors
- Gas mixers
- Helium reclaim system
- Launching, recovery, transfer and mating
- Hyperbaric evacuation system.

D. Environmental Conditions

1. General

As a minimum requirement, the design, selection and arrangement of all machinery, instruments and equipment of diving systems are required to conform to the environmental conditions stated below. For diving systems which are operating in defined areas only, deviating environmental conditions may be approved.

2. Inclined positions

If not specified otherwise, a functioning without disturbances has to be guaranteed for the inclinations defined in Table 2.1. For hyperbaric evacuation systems deviating values may be approved.

3. Water

For the design of diving systems and their components the temperature range of the water as well as the range of salt content and therefore of the density is to be defined. If not agreed otherwise, the values of Table 2.2 are to be used. A value of 0,101 bar/m is valid when converting diving depth to pressure.

4. Seaways

The seaways up to which the diving system is allowed to operate are to be agreed with **TL**. If not agreed otherwise, diving systems are to be designed for sea states with a significant wave height of at least 2 m, allowance being made for accelerations of 2 g downwards and 1 g upwards in the vertical and 1 g each in the longitudinal and transverse directions (g = 9,81 m/s^2).

5. Tide and currents

For the design of the diving system the different factors influencing currents according to the operation area and their possible combinations are to be considered.

6. Climate

Values for the climate conditions inside and outside the pressure chambers are to be taken from Table 2.2.

Equipment and instruments in pressure chambers have to function satisfactorily up to the maximum allowable working pressure.

7. Vibrations and shaking

Machinery shall not cause any vibration or shaking which imposes unacceptable stresses on other machines, equipment or the diving system. The amplitudes and accelerations defined in the **TL** Rules Machinery Installations,Chapter4, Section 1, C. are to be complied with.

8. Explosion endangered zones

Explosion endangered zones are locations in which:

- An explosive gas-air mixture is continuously present or present for long periods (zone 0);
- An explosive gas-air mixture is likely to ocur in normal operation (zone 1);
- An explosive gas-air mixture is not likely to occur and if it does, will persist for only a short time (zone 2).

Concerning the operation of diving systems in explosion endangered zones I.3. is to be observed.

9. Further environmental conditions

For the design of diving systems also the environmental conditions happening during an eventual air transport (e.g. underpressure/temperature) are to be considered.

E. Documents for Approval

1. General

1.1 Before the start of manufacture, plans and drawings of all components subject to compulsory inspection, to the extent specified below, are to be submitted in triplicate.

1.2 The drawings have to contain all the data necessary to check the design and the loading of the equipment. Wherever necessary, calculations relating to components and descriptions of the system are to be submitted.

1.3 Once the documents submitted have been approved by **TL**, they become binding for the execution. Any subsequent modifications require **TL**'s consent before they are implemented.

2. Total system

The following documents are to be submitted.

2.1 Description of the system together with the essential design data, such e.g.:

- Diving procedure
- Nominal diving depth NDD
- Main dimensions and parameters acc. to C.2.
- Maximum operating time
- Maximum number of divers in each diving bell or decompression chamber
- Maximum number of divers in the system

Table 2.1 Inclined positions

Components	Angle of inclination [°]			
	Athwartship		Fore and aft	
	Static	Dynamic	Static	Dynamic
Compression chambers and other deck installations on ships on semi-submersibles	 ±15 ±15 **(1)**	 ±22,5 ±22,5 **(1)**	 ±5 ±15 **(1)**	 ±10 ±22,5 **(1)**
Diving chambers	±22,5	±45	-	-
(1) in each direction				

Table 2.2 Environmental conditions

Area	**Temperature**	**Humidity**	**Miscellaneous**
Air in chambers	+5 ÷ +55°C	%100	Air with salt content
Air outside chambers **(1) (2)**	-10 ÷ +55°C	%100	
Water outside chambers	-2 ÷ +32°C	-	Salt water: − 3,5 % salinity − density of 1028 kg/m³
Control spaces	+5÷ +55°C	%80	-
(1) *For installation on the open deck, temporary flooding with salt water and salt fog as well as icing is to be considered* **(2)** *For installation in closed spaces deviating values may be approved*			

2.2 General arrangement drawings of the diving system and if applicable block diagrams.

2.3 Installation drawings.

2.4 Foundation drawings showing fixed and free points.

2.5 Drawings of supply and disposal systems (water, electricity, etc.).

2.6 Drawings of consoles showing controls and instrument displays.

2.7 Failure Modes and Effects Analysis (FMEA according to F.), if required.

2.8 Test schedule.

3. Vessels and apparatus under pressure

3.1 Drawings are to be submitted of vessels and apparatus under pressure giving full details for appraising the safety of the equipment.

Especially is to be included:

- Purpose of application
- Capacities of individual compartments
- Media contained, operating pressures and temperatures
- Proposed materials, thermal insulation materials, paints, buoyancy material
- Welding specifications
- Heat treatment
- Manufacturing tolerances
- Non-destructive tests

3.2 Drawings are also to be submitted of individual items of vessel equipment such as:

- Windows, window flanges, retaining rings
- Door leaves and frames
- Bayonet locks
- Coupling clamps
- Integral opening reinforcements
- Supply locks
- Internal facilities

4. Gas supply

4.1 Piping diagrams, block diagrams and descriptions are to be furnished for the entire gas supply system, including a list of valves and fittings.

4.2 Details of the umbilical structure for the supply of the diving bell, wet bell and divers.

4.3 Description of proposed cleaning procedure for breathing gas system.

4.4 Details of the gas analysis, including an equipment list.

4.5 Description of compressors and their drives with definition of essential design and operating data.

5. Life support systems

It is to be submitted:

5.1 Piping diagrams, block diagrams and descriptions of systems and equipment.

5.2 Calculations of the cooling and heating requirements.

5.3 Description and drawings of the water supply and disposal system.

5.4 Description and design details of the diver heating system.

6. Electrical equipment

It is to be submitted:

6.1 A general arrangement drawing of the electrical equipment containing at least the following information:

- Voltage rating of systems
- Power or current ratings of electrical consumers
- Switchgear, indicating settings for short-circuit and overload protection; fuses with details of current ratings
- Cable types and cross-sections.

6.2 The power balance of the main and emergency power supply systems for diving systems with their own power generating plant.

6.3 Drawings of switchgear and distribution equipment.

6.4 Complete documentation for electric motor drives with details of control, measuring and monitoring systems.

6.5 Battery installation drawing with details of battery types, chargers and battery room ventilation.

6.6 Details of electrical penetrations through pressure chamber walls.

6.7 Drawings and descriptions of all electrical components installed in pressure chambers.

7. Automation, communications and locating equipment

It is to be submitted:

7.1 General arrangement drawings/block diagrams of control equipment, including lists of measuring points.

7.2 Equipment list covering sensors, indicating instruments, etc.

7.3 Drawings and descriptions of electronic components such as instrument amplifiers, computers and peripheral units.

7.4 General arrangement drawings and equipment lists for communications systems and signalling equipment.

7.5 Arrangement drawing and description of the video system.

7.6 Description of the central control position.

8. Fire protection

It is to be submitted:

8.1 A description of the preventive fire protection measures.

8.2 Details of the fire loads in the system.

8.3 Drawings and descriptions of:

- Fire detection system
- Fire alarm equipment.
- Fire extinguishing system(s)

9. Launching, recovery, transfer and mating systems

9.1 Launch and recovery systems

It is to be submitted:

- Description of the system with details of operating conditions and technical data including lifting and lowering speed
- Data about installation and connection conditions including control stand
- Design drawings of:
  - launch and recovery systems
  - coil-up/coil-off mechanism for umbilical
  - substructures of handling gear and winches
  - detailed drawings of exchangeable single parts and fittings or definition of the standards where they are based on
  - machinery equipment such as winches, drives etc.
  - piping and instrumentation diagrams of the hydraulic or pneumatic systems
  - control scheme and description of safety systems
  - information about nominal data and type of protection of electrical installations
  - data for lifting and guide cables/ umbilicals

9.2 Installations for stowage and deck transport

It is to be submitted:

- Plans with description of the transport, the stowage and the lashing measures including parts lists with the lashing material used
- Description of the electrical measures
- Description of the fire protection measures
- Description of the explosion protection

9.3 Mating equipment

It is to be submitted:

- Description of system with data about operating conditions
- Data concerning installation and connecting conditions including control station
- Design drawings of the mating equipment

- Control scheme and description of the safety equipment

10. Hyperbaric evacuation system

It is to be submitted:

10.1 Description of system and operating instruction

10.2 Arrangement drawing

10.3 Construction drawing of evacuation system

10.4 Drawing of the launch and recovery system, including description of the power supply

10.5 Emergency plan with definition of the procedures for all possible emergency cases

11. Wet bells

It is to be submitted:

11.1 System description

11.2 Arrangement plan

11.3 Construction drawings for e.g. wet bell, diver basket, launch and recovery systems, control platform, gas supply, umbilical, electrical equipment.

F. Failure Modes and Effects Analysis (FMEA)

1. General

1.1 The Failure Modes and Effects Analysis (FMEA) has the purpose to identify possible failures in subsystems and in components, which are part of a diving system and to describe the effects on the total system and its subsystems or components.

1.2 For diving systems an analysis concerning the function and availability of the diving system after occurrence of a single failure has to be submitted if requested by **TL.**

1.3 The FMEA shall be executed in an early stadium accompanying the design to be able to realize system modification at due time. A tabular form, e.g. according to IEC 60812 or IMCA D 039 is to be used.

2. Description of the subsystems relevant for the analysis

2.1 The FMEA shall represent an independent document and be understandable without consulting further documentation. This means that all relevant subsystems are to be described concerning the structure of their basic functions, the installed redundancies and especially the interfaces of the subsystems to each other.

2.2 The description shall provide the operating personnel with a good overview of the system structure and the functionalities of the relevant subsystems. For all subsystems typical failure modes and their effects on the overall function of the system shall be indicated. Further on the corrective actions to manage these failures and their effects are to be provided.

2.3 For diving systems the following subsystems are relevant for maintaining the overall function:

- Equipment and interior arrangement of the decompression chambers and diving bells
- Equipment of the wet bell, as far as existing
- Piping systems including pumps, fittings and hoses
- Umbilicals
- Compressor plant
- Life support systems for maintaining of the chamber atmosphere
- Generation and distribution of electrical power
- Emergency power supply
- Electrical protective systems
- Automation, communication, navigation and locating equipment including central control position

- Fire protection
- Launch and recovery system
- Coil-up/coil-off mechanism for umbilicals
- Transfer and mating equipment
- Hyperbaric evacuation system

The system descriptions are to be completed by block diagrams according to 3.

3. Block diagrams of the relevant subsystems

For each relevant subsystem a block diagram is to be established. This block diagram shall contain the essential information of the system required for the failure analysis, which is normally:

- Definition of the subsystems
- All essential components of the subsystems
- Interfaces between the components of the subsystems
- Interfaces to or from other subsystems (typical for heat exchangers, hydraulic and compressed air drives and controls, etc.)
- Arrangements for control of the total system
- Supplies from outside the total system
- Further aspects depending on the actual design of the total system

At interfaces the different types of power, media and data may be transferred.

4. Analysis of the different relevant subsystems

Each relevant subsystem is to be analyzed with regard to the following essential aspects, in course of which further aspects may occur during the execution of the analysis, compare worksheet in 5.:

- Malfunctions of components
- Failure of components in a subsystem
- Interface failures between the subsystems, a subsystem and its components as well as between components themselves. The interface analysis is very important, as according to experience many failures are created due to lack of knowledge of which data, medium and power are transferred or how failures are spread via the interfaces to other subsystems/ components.
- Malfunctions of subsystems
- Failure of subsystems
- Faulty operation of subsystems or components, only with certain probability
- Failures because of external influences which may lead to simultaneous failure of redundant subsystems, e.g. changed environmental conditions and their control, voltage and amperage fluctuations in power supply, contamination of supply media, etc.
- Hidden failures

  Check for hidden failures and the practicality of Alarms arrangement of periodic testing, where alarms are not practical

5. Tabular worksheet

The analysis shall be carried out in tabular form with a worksheet according to the following example or e.g. according to IEC 60812 or IMCA D 039.

The analysis has to consider all operational modes.

6. Assumptions and defined limits for the analysis

During the analysis the assumptions are to be defined which influence the result of the analysis. Typical assumptions are e.g.:

- The operating personnel is qualified and trained to safely operate the diving system.

- The power supply of energy and as far as necessary with other consumables from outside the diving system is secured in redundant way.

- The adjustments and switching operations prescribed in the operation manual are followed by the operating personnel, etc.

7. Treatment of changes

In case of changes at the diving system respectively at the supporting systems the FMEA is to be adjusted adequately.

8. Conclusions

The FMEA shall contain a summary of the results of the analysis for the relevant diving system. In addition it should contain a listing of the main failures which may occur for the operation of the diving system and especially for keeping the desired atmosphere in the decompression chambers and diving bells. For the operating personnel training measures for incontestable handling of the system in the event of such failures are to be proposed.

A periodic check of the FMEA including practical trials is recommended.

9. FMEA Test program

9.1 According to the FMEA a test program is to be established. The purpose of this program is to verify the assumptions and the expected operation behaviour of the diving system as defined in the analysis.

9.2 The program has to consider typical failure modes in the relevant systems and components including the failures for the worst thinkable case. All operational modes of the diving system are to be reflected.

9.3 The test program is to be agreed with **TL** and needs to specify in detail how the test shall be carried out respectively how simulation is done**.**

G. Tests and Trials

1. General

1.1 Diving systems and their ancillary equipment are subject to constructional and material tests as well as to pressure and tightness tests and trials. As a minimum requirement, this shall include verification of compliance with the approved documents, inspection of workmanship, the verification of materials and checking of dimensional tolerances. All the tests prescribed in the following paragraphs are to be performed and documented, wherever applicable. About the presence of **TL** Surveyors at these tests and trials **TL** will decide in each individual case.

1.2 For series-manufactured parts, test procedures other than those prescribed may be agreed with **TL** provided that they are recognized as equivalent by **TL.**

Table 2.3 Example of a tabular worksheet

ID number	Subsystem components	Type of failure	Failure cause	Failure detection	Consequences for subsystem/ components	Consequences for total system	Failure correction	Remarks
1								
2								
3								

1.3 **TL** reserve the right to extend the scope of the tests where necessary and also to subject to test those parts for which testing is not expressly prescribed in the Rules.

1.4 The material test Certificates for the applied materials, reports on non-destructive testing of welds and, if applicable, the results of inspections of workmanship and evidence of heat treatments performed are to be presented.

1.5 Gas storage, pressure chambers and life support systems including piping system are to be subjected to a tightness test with the adequate breathing gas or a gas mixture with similar properties at maximum allowable working pressure. As maximum permissible leakage rate 1 % pressure drop within 24 hours for the whole pressure chamber system is valid.

1.6 After the pressure chambers and ancillary equipment have been installed on board, the diving system together with its ancillary plant is to be subjected to functional test. All items of safety equipment are to be tested except where a sufficient trial has already been performed on the manufacturer's premises in the presence of **TL.**

1.7 During sea trials the launch, recovery, transfer and mating systems are to be subjected to a test in which the diving bell loaded to its maximum weight is lowered to the nominal diving depth **NDD**. Thereafter, the diving bell is to be inspected for leaks and the electrical installation including the communication system is to be tested.

1.8 Parts subject to replacement are to be replaced with tested parts. The same also applies to spare parts.

2. Vessels and apparatus under pressure

2.1 On completion, pressure vessels and apparatus are to be subjected to a constructional test. The constructional test includes verification that the vessel conforms to the approved drawings and that the workmanship is satisfactory. All components have to be accessible to allow adequate inspection.

2.2 A hydraulic pressure test is to be performed prior to insulation and preservation treatment of the vessels. Each pressure chamber compartment is to be tested individually. The walls may exhibit no permanent deformation or leakage.

2.3 For vessel and apparatus, the test pressure shall normally be equivalent to 1,5 times the internal maximum allowable working pressure.

2.4 Vessels and apparatus at the diving bell which are exposed to an external pressure are also required to undergo an external pressure test. The test pressure has to be at least adequate to the test diving pressure **TDP** of the diving bell.

2.5 Vessels and pressure-proof housings, which are applied internally in pressure chambers and may be subjected to external overpressure, are to be tested at least with 1,5 times the maximum allowable working pressure of the chamber (see Table 2.8a).

2.6 Where the compression strength of vessels and apparatus under pressure cannot be proven sufficiently by calculation, an alternative check is to be agreed with **TL.**

3. Diving bell and decompression chamber windows

3.1 Each pressure chamber window has to undergo a hydraulic pressure test which may be performed after installation together with the pressure chamber or in a testing device. The test pressure shall normally be equivalent to 1,5 times the internal maximum allowable working pressure or the test diving pressure **TDP**. For the pressure test it has to be observed that the test pressure is not higher than 1,5 times the design pressure of the window.

3.2 After the pressure test windows may exhibit no scratches, cracks or permanent deformations.

4. Compressors

4.1 Compressor components subjected to pressure are to undergo a hydraulic pressure test at a test pressure equal to 1,5 times the delivery pressure of the compressor stage concerned.

4.2 On completion, compressors are to be subjected to a tightness test at their maximum allowable working pressure. In addition, a function and performance test is to be carried out in which the final moisture content and any possible contamination of the compressed gas are to be determined. The control, monitoring and safety devices are to be checked.

5. Piping systems

5.1 On completion of manufacture but before insulation or painting, all piping systems under internal pressure are to undergo a hydraulic pressure test at 1,5 times the design pressure. Piping systems under external diving pressure are to be tested in addition with nominal diving pressure NDP (depending on the load case from outside or inside).

5.2 Wherever possible, all butt welds in piping systems for life support systems are to be subjected to 100 % X-ray test.

5.3 Piping systems for breathing gas and oxygen are to be subjected to a purity test.

6. Hoses, hoses assemblies umbilicals

6.1 All aspects for tests and trials of umbilicals are defined in Annex E, D.

6.2 As far as the requirements for umbilicals are applicable for hoses, these have to be applied.

7. Electrical equipment

7.1 Electrical machines, components, cables and lines are to be tested in the manufacturer's works in accordance with the **TL** Electric Rules.

7.2 All electrical systems and equipment are to be inspected and tested before the diving system is put into service.

7.3 Electrical protective devices are to be checked; in addition, an insulation test is to be performed on the electrical equipment in the pressure chambers.

7.4 All electrical equipment which is exposed to diving pressure shall be checked additionally for insulation after the first diving.

8. Automation, communications and locating equipment

8.1 Indicating and monitoring instruments are to be tested for the accuracy of their readings and their limit value settings.

8.2 Automatic control systems are to be checked for satisfactory performance under service conditions.

8.3 Normal and emergency communications equipment is to be subjected to a functional test. The effectiveness of the helium speech unscrambler is to be demonstrated down to nominal diving depth NDD.

8.4 Proof is required of the autonomy of the safety systems.

9. Life support systems

9.1 Within a functional test the satisfactory functioning of the life support systems under normal and emergency conditions is to be proven.

9.2 The arrangement of the analyzing devices is to be inspected, and the accuracy of their readings and their limit value settings is to be checked.

10. Fire protection

10.1 The fire behaviour of the chamber equipment is to be checked by reference to the relevant test Certificates and symbols.

10.2 A check is to be made as to whether the electrical heating systems and heaters are fitted with protection against overheating.

10.3 Fire alarm, detection and extinguishing appliances are to be subjected to a functional test.

11. Launch, recovery, transfer and mating systems

11.1 Launch and recovery systems

Before putting into operation of the launch and recovery system as well as the coil-up/coil-off mechanism for umbilicals an acceptance test with the following single tests is to be performed:

- Check that for all single parts the required proofs are existing

- The breaking strength of the used ropes is to be proven by a total rupture test and to be certified.

- Static test of the system at the manufacturer with a test load equal to 2,2 times the safe working load SWL

- Dynamic test (brake test) aboard with 1,25 times the safe working load SWL

- For an A-frame operated by two hydraulic cylinders an additional test with SWL and use of only one cylinder is to be performed.

- Check of minimum lifting speed

- Test that the procedure of transfer and launch or recovery of the diving bell/wet bell is performed in normal and emergency operation safely and without jerk. The test in normal operation is to be performed down to nominal diving depth NDD.

- Check of devices for jettisoning the lifting cable/ umbilicals

- Test of function including safety and alarm systems

11.2 Stowage and deck transport systems

Before use of the stowage and transport systems an acceptance test with the following single test is to be performed:

- Check that proofs are available for all exchangeable single parts

- Check, that proofs are available for the rupture strength of the used ropes

- Check that the transport of the diving bell or the wet bell in normal and emergency operation is safe and without jerk

- functional test including check of the safety devices

11.3 Mating system

- The mating procedure is to be tested. For power drives the main drive as well as the auxiliary drive are to be checked for correct function.

- It is to be checked that release of the mating system and transfer of the diving bell can only take place when the connecting trunk is not under pressure.

12. Hyperbaric evacuation system

By a functional test it is to be demonstrated that the hyperbaric rescue system is able to convey divers under pressure from aboard to a safe position and that they can be monitored and supplied during this mission.

13. Diving bells

13.1 Static test of the lifting points for the lifting cable with 2,2 times the permissible total weight (dead weight + payload) of the diving bell.

13.2 The fixing point of the umbilical at the diving bell is to be tested statically with 2,2 times the maximum permissible tension load of the umbilical.

13.3 For the following systems additional functional tests are to be performed:

- Main and emergency power supply
- Control and monitoring systems
- Arrangements for recovery of a diver who had an accident

13.4 The weight and buoyancy of diving bells are to be measured and their stability in normal and emergency operation is to be checked. The release of ballast weights and the operation of the device for the emergency release of the lifting cable and the umbilical are to be demonstrated in shallow water.

14. Wet bells

14.1 Static test of the lifting points for the lifting cable with a test load equal to 2,2 times the permissible total weight (dead weight + payload) of the wet bell.

14.2 The fixing point of the umbilical at the wet bell is to be tested statically with 2,2 times the maximum permissible tension load of the umbilical.

14.3 For the following systems additional functional tests are to be performed:

- Main and emergency power supply
- Control and monitoring systems
- Arrangements for recovery of a diver who had an accident
- Communication equipment

14.4 Lowering of the wet bell down to nominal diving depth **NDD**.

H. Marking

1. Pressure chambers

All pressure chambers, like e.g. diving bells and decompression chambers are to be fitted in a prominent position with a permanently mounted name plate containing at least the following data:

- name or company designation of manufacturer
- year of construction and serial number
- maximum allowable working pressure or nominal diving pressure [bar]
- test pressure [bar]
- capacity [ℓ] (indication for each chamber compartment)
- dead weight of diving bell [kg]
- payload NL of diving bell [kg]
- maximum permissible number of divers
- date of test
- test stamp

2. Wet bells

All wet bells and diver baskets are to be fitted in a prominent position with a permanently mounted name plate containing at least the following data:

- Name or company designation of manufacturer
- Year of construction and serial number
- Nominal diving depth **NDD**
- Dead weight of wet bell [kg]
- Payload **NL** [kg]
- Maximum permissible number of divers

- Date of test

- Test stamp

3. Valves, fittings, indicating and warning devices

All essential valves, fittings, operating elements, indicators and warning devices are to be provided with a permanent and seawater resistant identification. The identifying marks are to be clear and unmistakable.

In pressure chambers at least flame resistant materials are to be used for the marks.

4. Pressure vessels and gas cylinders

4.1 All other pressure vessels and gas cylinders are to be prominently and permanently marked with the following details:

- Name or company designation of manufacturer

- Year of construction and serial number (pressure vessels)

- Serial number (gas cylinders)

- Type of gas

- Maximum allowable working pressure [bar]

- Test pressure [bar]

- Maximum allowable working temperature (for > 50 °C and < -10 °C)

- Capacity [ℓ]

- Empty weight (of gas cylinders) [kg]

- Date of test

- Test stamp

4.2 Permanently installed pressure vessels, gas cylinders and gas piping systems are, in addition, to be marked with a permanent colour code in accordance with Table 2.4 and with the chemical symbol designating the type of gas concerned. The marking of pressure vessels and gas cylinders has to be visible from the valve side.

Systems for other media are also to be marked in suitable way.

The distances of the markings are to be chosen for pipe systems according to function and safety.

5. Launch and recovery systems

The launch and recovery systems as well as the coilup/ coil-off mechanism for the umbilicals are to be marked with a fixed type plate at a good visible position which contains at least the following data:

- Manufacturer

- Serial number and year of construction

- Safe working load SWL [t]

- Load radius [m]

- Date of test and test stamp, for cranes at the bottom end of the right-hand jib member and next to the point where the member joins to the crane housing

Table 2.4 Marking of gas systems

Type of gas	Chemical symbol	Colour code
Oxygen	O_2	White
Nitrogen	N_2	Black
Air	-	White and black
Helium	He	Brown
Oxygen/Helium mixed gas	Heliox	White and brown
Oxygen/Nitrogen mixed gas (Nitrox)	Nitrox	White and brown
Oxygen/Helium/Nitrogen mixed gas	Trimix	White and brown
*The designation of gases for special purposes is to be agreed with **TL.***		

6. Compressors

Concerning the marking of compressors see L.5.

7. Hyperbaric evacuation system

Concerning the marking of hyperbaric evacuation systems see R.2.5.

I. Principles for the Design and Construction of Diving Systems

1. General principles

1.1 Wherever expedient and feasible, diving systems are to be designed and constructed in such a way that failure of any single component cannot give rise to a dangerous situation.

1.2 Diving systems and their components are to be designed and constructed that during missions and operation of the pressure chamber sufficient possibilities for monitoring are given. This can be achieved e.g. by video systems or acoustic devices.

1.3 All parts of a diving system are to be designed, constructed and mounted in such a way as to facilitate cleaning and disinfection.

2. Conditions in chambers

2.1 Diving systems are to be so equipped that a breathable atmosphere can be maintained in decompression chambers and diving bells throughout the entire operating period of the divers.

2.2 The partial pressure of the CO_2 in the chamber atmosphere has to be kept permanently below 0,005 bar assuming a CO_2 production rate of 0,05 Nm^3/h per diver. In diving bells it has to be possible to keep the partial pressure of CO_2 below 0,015 bar as a minimum requirement. Under emergency conditions the partial pressure of CO_2 has to be kept below 0,02 bar for at least 24 h.

2.3 Diving systems using mixed gas and designed for operating periods of more than 12 hours are to be capable, under steady conditions, of keeping the temperature in the decompression chamber constant to ± 1 °C in the 27 - 36 °C temperature range while maintaining a relative humidity of at least 50 %.

2.4 Decompression chambers are to be designed and equipped in such a way that a homogeneous atmosphere (CO_2 and O_2 concentrations, temperature and humidity) can be maintained in the chamber.

2.5 In the steady state, a permanent noise level (over 8 hours) in the pressure chambers exceeding 65 dB(A) is not permitted

3. Arrangement

3.1 Diving systems on support ships may only be located and operated in areas not subject to an explosion hazard. In exceptional cases, installation subject to special conditions may be permitted in the lowest explosion protection zone.

3.2 As far as possible, the area in which the diving system is installed is to be kept free of fire loads. In addition, only those electrical cables needed to operate the diving system should be routed through this area.

3.3 It is not permitted to locate diving systems and breathing gas storage facilities may not be located in engine rooms unless the engine plant is connected to the diving system.

3.4 Diving systems and breathing gas storage facilities are to be located in spaces which can be adequately ventilated and provided with suitable electric lighting.

3.5 Where parts of the diving system are located on the open deck, these are to be protected against damage due to other shipboard activities**.**

4. Chamber equipment and fittings

4.1 The equipment and fittings of decompression chambers and diving bells are to be suitable for operation in hyperbaric atmospheres. Under these conditions they shall not give off any toxic or strongly irritant gases. The same also applies to protective coatings and paints used inside the chambers.

4.2 Only incombustible or at least flame retardant materials should be used in the chambers.

4.3 Diving bells where the emergency surfacing is initiated by jettisoning of ballast, are to be equipped with devices to jettison the lifting cable/ umbilicals and the ballast weights. The devices for jettisoning of ballast are to be so designed that two mutually independent actions in the interior of the chamber are required to initiate the release.

4.4 After jettisoning of the ballast weights the diving bell with full payload NL and flooded trunk has to have a positive buoyancy of 3 % of the displacement at nominal diving depth NDD. Hereby the bell shall have sufficient stability to stay in upright floating condition. As far as applicable the definitions for buoyancy and stability according the **TL** Rules for Submersibles, Section 3 are to be observed

5. Corrosion protection

5.1 Diving systems and all their accessories are to be effectively protected against corrosion.

5.2 Anti-corrosion coatings exposed to the conditions within the chambers have to conform to the requirements stated in 4. In addition, they shall not tend to blister or flake under hyperbaric conditions

J. Vessels and Apparatus under Pressure

1. Decompression chambers and diving bells

1.1 General

1.1.1 The following Rules are applicable to decompression chambers and diving bells which are used in diving systems and in which persons stay in breathable atmosphere at pressures higher than atmosphericpressure.

1.1.2 The documents to be submitted to **TL** for approval are listed in E.3.

1.1.3 The necessary tests and markings are stated in G.2. and H.1.

1.2 Design principles

1.2.1 Pressure chambers

1.2.1.1 Each pressure chamber or compartment is to be so equipped that it is fully protected against inadmissible working overpressure and inadmissible pressure drops.

1.2.1.2 Pressure chambers are to be so designed that at least two persons can simultaneously pass in or out through the locks without exposing the other divers in the system to a pressure change.

1.2.1.3 In diving systems where divers are required to remain under pressure for a continuous period of more than 12 hours, the living compartment of the decompression chamber is to be so designed and equipped that persons are able to stand upright in it and each diver is provided with a bunk on which he is able to stretch out comfortably. A toilet and shower are also to be provided. The toilet and shower are to be accommodated in a separate compartment. Toilet facilities capable of discharging the waste to outside and further waste water systems are to be equipped with suitable interlocks to prevent pressure losses in the chamber system.

1.2.1.4 The living area of decompression chambers and other compartments envisaged for decompression are to be provided with a lock through which provisions, medicines and equipment items can be passed in and out without exposing the occupants of the chamber to a pressure change.

1.2.1.5 Locks are to be designed to prevent accidental opening under pressure; if necessary, suitable interlocks are to be fitted.

1.2.1.6 Each pressure chamber compartment is to be provided with view ports enabling all occupants to be observed from outside.

1.2.1.7 Wherever necessary, pressure chamber Windows are to be protected against mechanical damage from inside and outside.

1.2.2 Diving bells

1.2.2.1 Each diving bell is to be so equipped that it is fully protected against inadmissible internal working overpressure and inadmissible pressure drops.

1.2.2.2 Each diving bell is to be provided with an extra lifting point designed to take the entire weight of the bell including ballast and equipment as well as the payload NL.

1.2.2.3 Close to the lifting point, the diving bell is to be provided with spare connections for hot water (¾" NPT female thread) and breathing gas (½" NPT female thread).

The manifold should also incorporate connectors for the following:
ate connectors for the following:

- internal pressure;
- sampling of internal gas;
- communication; and
- electrical power.

The manifold is to be clearly marked and effectively protected.

1.2.2.4 Diving bells are to be designed to allow entry and exit even in an emergency.

1.2.2.5 Diving bells are to be equipped with a device for the recovery of an unconscious diver out from the diving bell.

1.2.2.6 The dimensional design of diving bell shall be such as to provide adequate space for the proposed number of divers and their equipment.

1.2.2.7 Seating is to be provided for each diver in the diving bell.

1.2.2.8 Diving bells are to be provided with view ports so that divers working outside the chamber can be observed from within the chamber. The Windows are to be protected against mechanical damage from inside and outside.

1.2.2.9 Each diving bell is to be adequately illuminated.

1.2.3 Doors, accesses and penetrations

1.2.3.1 Two measures are to be provided, that the doors and hatches are closed and secured before diving, one measure has to be visually apparent.

1.2.3.2 Doors and mating devices for diving bells, which are not tightening by pressure, are to be so equipped with a closing mechanism that opening under pressure is excluded. The closing mechanism is to be designed that the correct closing position can be clearly apparent before pressure is applied.

1.2.3.3 Means are to be fitted to enable doors to be opened from both sides. A banging of doors and access hatches is to be avoided safely by mechanical measures.

Door trunks are to be fitted with pressure compensating valves.

1.2.3.4 Doors and hatches for persons are required to have a clear opening, at least 500 mm in diameter. For diving bell lockin/lockout hatches the clear diameter shall be at least 600 mm.

1.2.3.5 The length of the hatch trunk should not exceed the hatch diameter.

1.2.3.6 Penetrations through chamber walls for umbilicals/supply lines and other pipelines, hoses and cables are to be protected, as far as possible, by chamber extensions and coverings against mechanical damage.

1.2.3.7 Doors and access openings are to be laid out for at least collapse diving pressure CDP.

1.2.4 Pressure proof bulkheads

Pressure proof bulkheads for subdivision of the internal space of decompression chambers are to be designed for maximum allowable working pressure.

1.3 Materials

1.3.1 General

1.3.1.1 Materials are to be suitable for the purpose intended and for the processes applied, e.g. welding.

Principally the requirements of the **TL** Rules for Materials are valid.

1.3.1.2 Furthermore the materials have to meet the special requirements defined in 1.3.3.

1.3.1.3 Viewports are to be made of acrylic plastic and shall meet the requirements stated in Annex C.

1.3.1.4 For corrosion protection see I.5.

1.3.2 Approved materials

1.3.2.1 Rolled or forged steels and steel castings with guaranteed ductility and toughness according to Table 2.6 are normally to be used for pressure hull fabrication of compression chambers and diving bells.

1.3.2.2 Materials other than those mentioned in 1.3.2.1 may be used provided they have been proved to be suitable for the intended application. If no recognized standards are available, the relevant specifications are to be submitted to **TL** for examination and approval.

1.3.2.3 For parts welded directly to pressure vessel walls, e.g. reinforcing rings, mountings, brackets etc., use is to be made of materials with guaranteed welding properties and similar electrochemical properties which are compatible with the base material.

1.3.2.4 For welding constructions also the **TL** Welding Rules are to be observed.

1.3.3 Special requirements applicable to materials for decompression chambers and diving bells

1.3.3.1 Ductility

All metals shall possess sufficient ductility (in terms of the elongation measured by tensile test). The elongation at fracture A shall conform to the values stated in the standard or material specification and shall not at less than 16 % for steel. For screws an elongation at fracture A ≥ 14 % is required.

1.3.3.2 Impact energy

Steel grades shall conform to the impact energy values measured by notched bar impact test stated in the standard or material specification. In addition there is valid:

- Plates shall possess an impact energy of at least 30 J measured on ISO V-notch transverse specimens at a test temperature corresponding to the plate thickness in accordance with Table 2.4.

- Pipes shall possess an impact energy of at least 27 J measured on ISO V-notch transverse specimens or 41 J on longitudinal specimens at 0 °C.

- Cast iron shall possess an impact energy of at least 31 J measured on ISO V-notch specimens at 20 °C.

- Forgings and steel profiles and bars which are load bearing and are welded directly to the pressure hull, e.g. reinforcing rings, stiffeners, shall possess an impact energy of at least 27 J measured in ISO V-notch longitudinal specimens at a test temperature of 0 °C.

- Screws shall possess an impact energy of at least 52 J for tempered steels or at least 40 J for untempered steels measured on ISO V-notch specimens at a test temperature of 20 °C.

Table 2.5 Test temperature for notched bar impact tests

Plate thickness [mm]	Test temperature [°C]
≤ 20	0
20 < ≤40	-20
40 < ≤ 60	-40
>60	By agreement

1.3.3.3 Non-destructive tests

1.3.3.3.1 Plates with a thickness above 8 mm shall with regard to their internal defects as a minimum satisfy the requirements for Class 2, Table 1 of Stahl-Eisen-Lieferbedingungen (SEL) 072 or S_2/E_3 of the standard EN 10160 or comparable standards.

Zones for longitudinal, round and socket seams with a width equivalent to the plate thickness, but at least 50 mm, shall satisfy the requirements according to Class 1, Table 2 according to SEL 072 respectively of quality class E_3 according to EN 10160.

Areas for the connection of lifting eyes, elements of the exostructure and other plates, which may also be stressed in thickness direction, shall satisfy the requirements according to Class 0, Table 1 according to SEL 072 respectively of quality class S_3 according to EN 10160.

1.3.3.3.2 For forgings greater than DN 250 the material quality is to be checked by the producer using suitable test procedures according to the **TL** Material Rules, Section 3, G. The tolerance boundaries are to be agreed with **TL** depending on the type of the component.

1.3.3.3.3 The producer has to submit to **TL** the proof for the non-destructive tests.

1.3.4 Proof of quality characteristics

1.3.4.1 Proof of the quality characteristics of materials used for pressure chambers is to be supplied in the form of material test Certificates according to the **TL** Rules Principles and Test Procedures. The type of Certificate required for the product concerned is indicated in Table 2.7. Unless otherwise specified, the testing authority for issuance of a **TL** Material Certificate is **TL**.

1.3.4.2 The evidence to be supplied in respect of the characteristics of products made of steel not included in Table 2.7 shall be agreed with **TL**.

1.3.4.3 For small parts, like e.g. supports for consoles, welding lugs or other, not load-bearing and not pressure loaded elements, approval Certificates of the manufacturer are to submitted.

1.4 Principles of manufacture and construction

1.4.1 Treatment

1.4.1.1 Treatments applied to materials are to be professionally carried out. Materials whose characteristics have been impaired by hot or cold forming shall be suitably heat-treated, compare **TL** Material Rules.

Concerning the criteria for adequate workmanship see also Section 1, H.

1.4.1.2 Materials and components are to be so marked as to enable them to be identified and correlated with their respective test Certificates even during and after the fabrication of the pressure chamber.

1.4.1.3 The requirements of Annex C are to be complied with in the manufacture and machining of acrylic windows.

1.4.2 Welding

1.4.2.1 Approval

Companies wishing to fabricate the pressure hulls for pressure chambers have to be approved by **TL** with regard to their facilities, welding personnel and Professional supervision.

1.4.2.2 Procedure tests

Before welding work is commenced, the properties of the joints to be welded are to be proven to **TL** by welding procedure tests at the manufacturer's works.

1.4.2.3 Butt welds

All butt welds of the pressure chamber are to be performed as full-penetration, multi-pass welds executed from both sides. In addition, the work is to be performed in such a way that it can be assigned a weld factor v = 1,0 in accordance with the **TL** Welding Rules, General Requirements, Proof of Qualifications, Approvals.

1.4.2.4 Fillet welds

The proof of the fillet welds is to be performed according to the **TL** Rules Hull Structures, Section 20. If no detailed proof by computation is required, the dimensioning shall follow **TL** Rules, Chapter 53, Submersibles, Section 5, Table 5.4.

Depending on accessibility a suitable test procedure is to be applied and to be agreed with **TL.**

1.4.3 Cutouts and viewports

1.4.3.1 Cutouts causing a weakening of the pressure chamber wall are to be suitably strengthened (for internal pressure see **TL** Machinery Rules, Section 12, D., for external pressure see Annex A, F.7.). The reinforcement shall form an integral part of the pressure chamber or nozzle. Set-on reinforcing rings are not permitted.

1.4.3.2 For the purpose of these Rules, view ports which consist of pressure-tight flat or curved acrylic windows, seals and viewport flanges, are installed in walls of pressure chambers and are used for observing the divers in the chamber respectively the underwater work location (compare also Annex C).

1.4.3.3 In the design and construction of viewport flanges, account is to be taken of the fact that the acrylic windows make no contribution to reinforcing the cutout in the shell of the pressure chamber. Where the inside diameter of viewport flanges is greater than 350 mm, more stringent requirements are to be applied to the permissible radial deformation and angular deformation of the window seats, and these are to be agreed with **TL** in each case.

1.4.3.4 The window seat in the viewport flange is to be designed to give the window sufficient support at the maximum operating pressure. The seat dimensions for various standard windows are indicated in Annex C.

1.4.3.5 For flat windows having a right-angled edge and an O-ring seal, the seat diameter in the viewport flange shall be within + 0,25/ - 0,00 mm of the nominal value, or within + 0,75/ - 0,00 mm where flat gasket seals are used.

Table 2.6 Approved materials for pressure chambers

Product type	Grade of material	TL Material Rules, Standard or specification
Plates	Normalized and heat treated special fine grained steel and pressure vessel steel with characteristics according to J.1.3.3	Part A, Chapter 2, Section 3, B., C., D. and E. EN 10028-3,-6
Ends	Normalized and heat treated special fine grained steel and pressure vessel steel with characteristics according to J.1.3.3	Part A, Chapter 2, Section 14,A.
Profiles and bars	General-purpose shipbuilding and structural steels, provided these are killed, also finegrained structural steel with characteristics according to J.1.3.3	Part A, Chapter 2, Section 3,B. and I. EN 10025-2, -3, -4, -6 EN 10028-3, -5, -6
Pipes	Seamless and welded ferritic steel pipes with characteristics according to J.1.3.3	For wall thickness ≤ 20 mm: Part A, Chapter 2, Section 4,B. 20 mm < wall thickness ≤ 40 mm: Part A, Chapter 2, Section 4, D.
Forgings	Forgings for pressure vessels and piping with characteristics according to J.1.3.3	Part A, Chapter 2, Section 5,E.
Steel castings	Steel castings, pressure vessels and piping with characteristics according to J.1.3.3	Part A, Chapter 2, Section 6,D. and E. EN 10213
Bolts and nuts	Unalloyed or alloy steel bar with characteristics defined in J.1.3.3	Part A, Chapter 2, Section 14,C. ISO 898 : strength class 5.6, 8.8 ISO 3506-1 and -2
Viewports	Acrylic plastic	Annex C to this rule.

Table 2.7 Proof of quality characteristics

Product type	Type of certificate (1)		
	A	B	C
Plates for the pressure hull	X	-	Not applicable for materials for pressure hull
Steel profiles and bars (load-bearing elements)	X	-	
Pipes and sockets			
> DN 50	X	-	
≤ DN 50	-	X	
Forgings			
> DN 250	X	-	
≤ DN 250	-	X	
Steel castings	X	-	
Bolts			
≥ M 30	X	-	
≥ M 16 alloyed and tempered steel	X	-	
Other not here defined bolts	-	X	
Nuts			
≥ M 30	X	-	
Other	-	X	
Acrylic plastic	X **(2)**	-	

(1) *Test Certificates are to be issued in accordance with **TL** Material Rules, Section 1,F. with the following abbreviations:*
*A: **TL** Material Certificate, B: Manufacturer Inspection Certificate, C: Manufacturer Test Report*

(2) *Proof by independent institution may be recognized*

1.4.3.6 For spherical windows with a conical bearing surface, the major diameter of the conical seat in the viewport flange shall be within + 0,002 Do/- 0,000 mm of the nominal value.

The included conical angle of the window seat in the viewport flange shall be within + 0,000/ - 0,25 degrees of the nominal value.

1.4.3.7 The surface roughness of the window seat shall not exceed 1,5 μm.

1.4.3.8 The window seat is to be permanently protected against corrosion (e.g. by overlay welding using corrosion-resistant filler metals).

1.4.3.9 A soft gasket material can be used for the primary seal of standard windows in accordance with Annex C, Tables C.2 to C.4. This seal shall be sufficiently thick to enable it to absorb a reasonable degree of deformation without experiencing permanent setting.

1.4.3.10 In the case of flat windows with a rightangled edge, a secondary seal is required which is normally bonded to the flange seat with contact cement. This seal also acts as a supporting gasket for the window and shall not be more than 3 mm thick.

1.4.3.11 Sealing ring grooves are not allowed in the window bearing surface or the metal flange seat.

1.4.3.12 Retaining rings shall be able to provide the necessary initial deformation of the window seals.

1.4.3.13 When fitting acrylic windows, care is to be taken to ensure that all bearing surfaces are thoroughly cleaned. Where cleaning agents, window seat greases or adhesives for the window seals are used, these are to be tested for compatibility with acrylic plastic prior to use.

1.4.4 Ends

1.4.4.1 Knuckles of dished ends shall not be inadmissibly restricted in their movement by mechanical restraints of any kind, e.g. retaining plates, stiffeners, etc. Supporting legs may only be fixed to ends which have been adequately dimensioned for this purpose.

1.4.4.2 Where covers or ends are secured by swing bolts, measures are to be taken to prevent these slipping off.

1.4.5 Pipe nozzles and flanges

1.4.5.1 The wall thickness of pipe nozzles is to be so dimensioned that they are fully able to withstand additional external loads. The wall thickness of socket-welded nozzles shall be compatible with the wall thickness of the part into which they are welded.

Pipe nozzles and flanges are to be welded fully bearing.

1.4.5.2 Pipe connections in accordance with the **TL** Machinery Rules, Section 16 are to be provided for the connection of pipes.

1.4.6 Screws and bolts

1.4.6.1 Stud bolts screwed directly into the wall of the pressure chamber shall have within the wall of the pressure chamber a load-bearing length at least equal to the bolt diameter. Bolt holes are mainly to be provided in reinforced areas and shall in no case perforate the wall of the pressure vessel. A mathematical verification is to be submitted to **TL.**

For the testing of screws and bolts, see Table 2.7.

1.5 Calculation

1.5.1 Principles of calculation

1.5.1.1 Pressure chambers, hatches, locks, windows, suspensions etc. under internal pressure are to be calculated in accordance with the Rules of **TL** (see 2.) or other recognized engineering codes. Only the values stated in 1.5.3 are to be regarded as permissible stresses.

Diving bells for external pressure are to be calculated according to Annex A.

1.5.1.2 The calculations underlying the dimensional design are to be submitted to **TL**. Where the calculations are to be performed by computer, proof of the suitability of the programs is to be furnished to **TL**.

1.5.1.3 Load factors for dynamic loads are to be agreed with **TL**.

1.5.1.4 The fatigue strength for at least 5000 operation cycles (recommendation: 10000) at rectangular spectrum has to be proven in dependence on the **TL** Hull Rules, Section 3.

1.5.1.5 For the efficiency of welds, see 1.4.2.

1.5.1.6 The allowance for corrosion and wear is normally c = 1 mm. This allowance may be dispensed with in the case of plate with a thickness of 30 mm and over and with stainless steels and other corrosion resistant materials.

1.5.1.7 The wall thickness of the casings and ends of seamless and welded vessels shall normally not be less than 6 mm. A smaller minimum wall thickness may be agreed for tubular and corrosion-resistant vessel casings.

1.5.2 Calculation data

1.5.2.1 For stresses from internal pressure, the design pressure is to be determined by reference to the specification of the diving system. Where applicable, allowance is to be made for additional forces. The design pressure is normally the maximum allowable working pressure.

1.5.2.2 For stresses from external pressure the nominal diving pressure NDP, the test diving pressure TDP as well as the collapse diving pressure CDP according to the definitions in C.2.8 are to be considered. The test diving pressure TDP and the collapse diving pressure CDP depending on the nominal diving pressure NDP are to be taken from Table 2.8a.

1.5.2.3 For design temperatures, see Table 2.2.

1.5.3 Permissible stresses

For the nominal diving pressure is valid:

$\sigma_{perm, NDP}$ = min { $R_{m,20°}$ / A ; $R_{eH,t}$ / B }

For the test diving pressure is valid:

$\sigma_{perm, TDP}$ = min { $R_{m,20°}$ / A' ; $R_{eH,t}$ / B' }

For the collapse diving pressure is valid:

$\sigma_{perm, CDP}$ = min { $R_{m,20°}$ / A'' ; $R_{eH,t}$ / B'' }

Where:

$R_{m,20°}$ = Guaranteed minimum tensile strength [N/mm^2] at room temperature (may be disregarded in case of established fine-grained steels with R_{eH} ≤ 360 N/mm^2 or where external over-pressure exerts a compressive load)

$R_{eH, t}$ = Guaranteed yield point or minimum value of 0,2 % proof stress at design temperature

The safety factors A, A', A'' and B, B', B'' are shown in Table 2.8b.

1.5.4 Safety factors against buckling and tripping Cylindrical and spherical shells are to be designed at collapse diving pressure to withstand elastic-plastic buckling under consideration of manufacturing influences. The adequate reduction factors for steels are defined in Annex A, F.2.5, F.3.3 and F.6.6.

For frames a proof of stability against tripping on the basis of a stress calculation is to be performed, which meets the balance in deformed condition. The relevant limit values for stresses are defined in Annex A, F.4.2, F.5.1, F.5.3 and F.5.4.

Table 2. 8a Test diving pressure and collapse diving pressure depending on nominal diving pressure

Nominal diving pressure NDP [bar]	5 (1)	10	20	30	40	≥ 50
Test diving pressure / nominal diving pressure S_1 = TDP/NDP	1,70 **(2)**	1,40 **(2)**	1,25 **(2)**	1,20 **(2)**	1,20 **(2)**	1,20 **(2)**
Collapse diving pressure/nominal diving pressure S_2 = CDP/NDP	3,20	2,40	2,00	1,87	1,80	1,76
(1) *Minimum diving pressure 5 bar* **(2)** *For vessels and pressure-proof castings in the interior space of compression chambers S1 is at least 1,5*						

Table 2.8b Safety factors

Material	Nominal diving pressure NDP		Test diving pressure TDP		Collapse diving pressure CDP	
	A	B	A'	B'	A''	B''
Ferritic materials	2,7	1,7	-	1,1	-	1,0
Austenitic materials	2,7	1,7	-	1,1	-	1,0
Aluminium **(1)**	4,0	-	2,6	-	-	1,5
(1) *Only for use at compression chambers.*						

1.5.5 Allowance for manufacturing tolerances In calculations relating to pressure vessels under external pressure, allowance is to be made for deviations from the ideal shape, e.g. with regard to the roundness of the shell configuration or the positioning of the stiffening rings, see Annex B.

If the manufacturing tolerances according to Annex B on which calculations have been based are exceeded, the deviations observed shall be used to carry out a mathematical verification of the maximum permissible pressure.

2. Pressure vessels, gas cylinders and apparatus under pressure

2.1 Pressure vessels, gas cylinders and apparatus under external pressure

The calculation procedure of Annex A or of a internationally recognized standard is to be applied. For pressure vessels in decompression chambers and diving bells the calculation data according to 1.5.2.1 are to be used for the design. For pressure vessels outside diving bells 1.5.2.2 is valid.

Test pressures are to be taken from G. (see also Table 2.8a).

2.2 Pressure vessels, gas cylinders and apparatus under internal pressure For pressure vessels, gas cylinders and apparatus under internal pressure the requirements defined in the **TL** Machinery Rules, Section 14 or other recognized regulations according to the state of the art.

K. Pipes, Valves, Fittings, Hoses, Umbilicals

1. General

1.1 These Rules apply to piping systems, including valves and fittings, hoses and umbilicals needed for the operation of the diving system and its ancil- lary equipment. In addition the **TL** Machinery Rules, Section 16 are to be considered.

1.2 The documents to be submitted to **TL** for approval are listed in E.4.

1.3 The necessary tests and markings are stated in G.5. and G.6. as well as H.

1.4 Pipes are subdivided in three pipe classes in accordance with Table 2.9

2. Design principles

2.1 Piping systems

2.1.1 Expansion in piping systems, especially at the pressure chambers, is to be compensated by pipe bends or compensators. Attention is to be given to the suitable location of fixed points.

2.1.2 It has to be made possible that pipelines can be completely evacuated, drained and vented.

Table 2.9 Classification of pipes into “pipe classes”

Medium carried	Design pressure PR [bar] Design temperature t [°C] Pipe class I	II	III
Air, inflammable gases, inflammable hydraulic fluids, water, brine in refrigerating plants	PR > 40 or t > 300	PR ≤ 40 and t ≤ 300	PR ≤ 16 and t ≤ 200
Flammable hydraulic fluids, lubricating oil	PR > 16 or t > 150	PR ≤ 16 and t ≤ 150	PR ≤ 7 and t ≤ 60
Refrigerants	-	all	-
Open-ended lines (without shut-off) such as drains, vent lines, overflow lines, blow-off lines	-	-	all

2.1.3 Pipelines, valves, fittings and hoses which may be subjected in service to pressures higher than the design pressure are to be fitted with overpressure protection.

2.1.4 Pipe lines which are penetrating the wall of pressure chambers are to be fitted with 2 shut-off devices located immediately at the chamber wall.

Wherever possible, one of these devices is to be a non-return valve.

2.1.5 Suction ends in pressure chambers are to be protected against inadvertent covering and suction of foreign bodies.

2.1.6 Pipelines carrying gas under high pressure shall not be routed through accommodation spaces, engine rooms or similar compartments.

2.1.7 Gas lines and electrical cables are to be routed separately.

2.1.8 Materials for breathing gas systems shall not develop poisonous or flammable products.

2.2 Pipe connections

2.2.1 Wherever possible, pipes shall preferably be joined by full-penetration butt welds.

2.2.2 Screwed pipe connections approved by **TL** may only be used.

2.2.3 Flanged connections may be used provided that the flanges and flange bolts conform to a recognized standard.

2.3 Valves and fittings

2.3.1 Shut-off-devices shall conform to a recognized standard. Valves with screw-down bonnets or spindles are to be protected against unintentional unscrewing of the bonnet.

2.3.2 Manually operated shut-off devices are to be closed by turning in the clockwise direction.

2.3.3 The closed and open positions of functionally important shut-off valves shall be clearly indicated.

2.4 Hoses

2.4.1 Except for umbilicals, non-metal and metal hoses are to be reduced to a minimum and are only to be installed in short lengths.

2.4.2 Hose lines, including their connectors, must be of proven suitability for the media, pressures and temperatures concerned. When selecting the material, special attention is to be paid to toxicity, inflammability, gas permeability and, where applicable, to compatibility with oxygen. Only types approved by **TL** may be used.

2.4.3 Hose lines are to be designed for a bursting pressure, which shall be at least for liquids equivalent to 4 times and for gases 5 times the maximum allowable working pressure.

2.4.4 Systems with hose lines are to be fitted with a device for relieving the pressure before the hoses are disconnected.

2.4.5 Hoses are to be connected with a suitable connection to the fittings. Hose fittings are to be made of corrosion resistant material and are to be so designed that they cannot be disconnected accidetally.

2.5 Umbilicals

2.5.1 Umbilicals as the connection element between support ship and diving bells / wet bell may contain control and communication cables, hydraulic and breathing gas lines as well as energy supply lines and a lifting cable in a joint cover.

Umbilicals may also be used as connection element to the diver and may include a supply line for diver heating.

2.5.2 All aspects for the design of umbilicals are defined in Annex E.

2.6 Oxygen systems

For oxygen systems the following special requirements are to be considered:

2.6.1 Pipelines for mixed gases containing more than 25 % oxygen are to be treated as pure oxygen lines.

2.6.2 All components and materials included in the system are to be suitable for oxygen in relation to their type and application and are to be carefully cleaned and degreased before putting into operation.

2.6.3 Manometers for oxygen and/or Nitrox are to be marked as free of oil and grease.

2.6.4 In piping systems containing oxygen only spindle valves are permissible. As emergency shutoff quick-closing valves, like e.g. ball valves, may be provided at a suitable location, if these are adequately marked and secured against unintentional activation.

2.6.5 Wherever possible, the pressure in oxygen lines is to be reduced at the gas storage facility to a pressure which is still compatible with an adequate gas supply to the diving system.

2.6.6 Oxygen pipes are to be routed separately from to oil pipes. Pipelines carrying oxygen under high pressure shall not be routed through accommodation spaces, engine rooms or similar compartments.

2.6.7 For oxygen lines with operating pressures above 40 bar high-alloyed Cr-Ni-steels with a content of Cr and Ni of together at least 22 % or Cr-Si-steels with a Cr content of at least 22 % are to be used.

2.6.8 Connection pieces for oxygen are to be designed to avoid burnout or are to be so arranged or to be protected that the personnel cannot be injured in case of burnout.

2.6.9 Spindle valves for oxygen are to be so designed for nominal diameters above 15 mm and operating pressures of more than 40 bar, that the spindle gear is outside the gas space.

2.6.10 Sealing materials which contain flammable elements and which come into contact with gases under pressure and oxygen influence, may only be approved for connection parts if their suitability for pressures, temperature and type of mounting is proven.

2.6.11 For valves, fittings and connections for oxygen only lubricants are permissible, which are approved for the operating conditions.

2.6.12 Hoses are to be suitable for oxygen.

3. Materials, manufacturing and calculation

3.1 Piping systems, valves, fittings and pumps

3.1.1 Concerning the materials, manufacturing and calculation of piping systems, valves, fittings and pumps the **TL** Machinery Rules, Section 16 are valid.

3.1.2 All pipelines penetrating the wall of the pressure chamber are to be pipe class I.

3.1.3 The permissible stresses for steel pipes and pipes of metallic materials without fully developed yield strength are to be chosen according to the **TL** Machinery Rules, Section 16.

3.1.4 For welding connections of piping systems the **TL** Welding Rules, Chapter 6 are valid.

3.2 Hydraulic systems

For hydraulic systems additionally the **TL** Machinery Rules, Section 10 are valid.

4. Operational media

4.1 Media such as hydraulic fluids, lubricants, etc. are to be selected in accordance with the proposed environmental conditions. They shall not tend to congeal or evaporate over the whole temperature range.

4.2 Solid lubricants are to be so selected that water penetration or contact with seawater does not seriously impair the serviceability of the diving system.

4.3 Operational media shall not contain toxic ingredients which are liable to be hazardous to health through skin contact or when given off in fumes.

4.4 Operational media should not be corrosive or attack other operating equipment (e.g. seals, hose lines, etc.).

L. Compressors

1. General

1.1 These Rules apply to compressors, including valves, used in diving systems for compressing breathing gases.

Where the compressors are electrically driven, the motors and other electrical equipment have to comply with the **TL** Electric Rules.

For the mechanical part of reciprocating compressors see also **TL** Machinery Rules.

1.2 The documents to be submitted to **TL** for approval are listed in E.4.

1.3 The necessary tests are stated in G.4.

2. Design principles

2.1 Compressors are to be suitable for the operation on board of support ships under the effective operation and environmental conditions.

2.2 Compressors are to be designed for the required delivery rates, types of gas and delivery pressures.

2.3 Compressors are to be so designed that no lubricating oil can penetrate the gas circuit.

2.4 Compressors are to be so installed that no harmful gases can be sucked in.

2.5 Where a compressor is used for the divers' air supply, a receiver is to be interposed for the compensation of pressure variations.

2.6 Oxygen compressors are to be installed in separate spaces which have adequate ventilation.

2.7 The breathing air produced by compressors has to meet the requirements of EN 12021. National requirements remain unaffected hereby.

3. Materials

3.1 The materials of compressor parts are to be suitable for the application concerned. They are to be specified with due attention to the operating conditions and the nature of the delivered medium. The **TL** Material Rules are to be complied with. For O_2 compressors the regulations for operation of oxygen systems are to be observed additionally.

3.2 Proof is to be furnished of the quality of the materials used for all components under pressure.

4. Equipment

4.1 Compressors are to be equipped with adequately designed suction filters, coolers and water separators.

4.2 Each compressor stage is to be equipped with a pressure relief valve or rupture disc, neither of which can be disabled. This safety device is to be designed and set in such a way that the specified pressure in the compressor stage concerned cannot be exceeded by more than 10 %. The setting is to be safeguarded against unauthorized alteration. If rupture discs are used it is to be secured that no gas escapes uncontrolled from the gas stock.

4.3 Each compressor stage is to be provided with a suitable pressure gauge indicating clearly the final pressure of that stage.

4.4 Where a compressor stage comprises more than one cylinder and each cylinder can be closed off individually, a pressure relief valve and a pressure gauge is to be provided for each cylinder.

4.5 Cooling liquid systems with a shutoff device are to be so designed that the specified coolant pressure cannot be exceeded.

4.6 Dry-running reciprocating compressors are to be equipped at each stage with a device which activates a warning signal and shuts down the drive motor if the final compression temperature stated in the operating instructions is exceeded.

4.7 Diaphragm-type compressors are to be equipped at each stage with a diaphragm rupture indicator which shuts down the compressor as soon as damage occurs to the drive or compressor diaphragm.

5. Marking

A manufacturer's data plate containing the following details is to be permanently fixed to each compressor:

- Manufacturer
- Type designation
- Serial number
- Year of construction
- Nominal capacity [m^3/h]
- Compression end pressure [bar]
- Number of revolutions [min-1]
- Power demand [kW]

M. Life Support Systems

1. General

1.1 These Rules apply to all those plant components and parts which are needed to ensure life support and a safe environment for the occupants of a diving system.

1.2 The documents to be submitted to **TL** for approval are listed in E.5.

1.3 The necessary tests and markings are stated in G.9. and H.

1.4 Breathing gases, breathing gas mixtures

Breathing gases and breathing gas mixtures are all gas mixtures, which are used during diving missions or during the application of breathing masks.

1.5 Nitrox

Nitrox is a breathing gas consisting of air and oxygen with an oxygen content above 21 Vol%.

1.6 Heliox

Heliox is a breathing gas consisting of helium and oxygen.

1.7 Trimix

Trimix is a breathing gas consisting of helium, nitrogen and oxygen with an oxygen content below 21 Vol.%.

2. Gas supply

2.1 Filling stations

2.1.1 Filling stations serve to fill the gas storage with breathing gas. The station has to include the complete equipment to fill the containers. The boundary of the gas production and filling station is located immediately behind the shut-off valve at the gas line for filling or at the suction side of the delivery system.

2.1.2 Filling stations are to be constructed and operated, that operating, surveillance and maintenance personnel or other persons nearby are not endangered.

2.1.3 Filling stations for breathing gases are not to be installed in areas where internal combustion engines or boilers are in operation.

2.1.4 Filling stations for breathing gases are to be arranged with sufficient place for operation, maintenance and cleaning, escape and rescue corridors as well as for fire extinguishing.

2.1.5 Pipe connections between filling stations for compressed air for production of breathing gases and other compressed air systems on board are only be established with special approval of **TL** and under consideration of additional protection measures.

2.1.6 Filling pipes/hoses and connection or coupling fittings/hoses are to be suitable for rendering pressure-less without danger.

Gas under pressure, which is discharged by the safety devices, is to be drawn off in a suitable way.

2.1.7 Filling connections are to be designed and marked in a way, where confusion of gases to be filled is safely avoided and a correct connection is enabled.

2.1.8 At the position of the gas delivery, the filling station is to be equipped with a manometer showing the delivery pressure.

2.1.9 Filling stations for breathing gases are to be operated manually and to be monitored.

2.2 Gas storage facilities

2.2.1 Each diving system is to be provided with a permanently installed gas storage facility or with a suitable location for the storage of portable gas cylinders.

2.2.2 The capacity of the gas storage facility shall be such that, for all the planned diving operations, a sufficient number and quantity of gas mixtures are available to supply all the decompression chambers, diving bells and divers with the correct gases at all operating depths and under normal and emergency conditions.

2.2.3 The stock of emergency breathing gas supply is to be stored separately in gas cylinders which shall not be opened for normal operation.

2.2.4 The diving bell is to be provided with its own gas cylinders so that the maximum number of occupants in the bell can in an emergency be supplied with a sufficient quantity of breathing gas mixture for at least 24 hours. In addition an oxygen bottle for supplementing the oxygen supply is to be carried on the diving bell.

2.2.5 Oxygen bottles are to be placed in well ventilated positions and may not be stored close to combustible materials.

2.2.6 Spaces in which oxygen is stored are to be separated from the adjoining spaces by bulkheads and decks of Type "A-60" and are to be arranged to facilitate speedy exit in case of danger.

Spaces in which oxygen can penetrate are to be equipped with oxygen indicating and alarm devices. The oxygen sensor is to be installed near the floor. A monitored suction of space air near the floor may be provided as an alternative.

2.3 Gas distribution

2.3.1 General

2.3.1.1 The gas supply system shall be so designed that the pressure in the living compartment of the decompression chamber can be raised at a rate of at least 2 bar/min up to 2 bar and thereafter at a rate of 1 bar/min.

2.3.1.2 The gas venting system shall be so designed that the pressure in a decompression chamber or diving bell can be lowered to 1 bar at a rate of at least 1 bar/min.

2.3.1.3 Sets of breathing masks controlled by respiration which supply breathing gas to persons under pressure and also remove the exhaust gas independently of the chamber atmosphere are to be designed for a gas flow equivalent to 3 times the required breathing rate per minute (AMV).

The required breathing rate per minute depends on the activity to be performed and the environmental conditions.

When designing the breathing mask gas supply and exhaust gas disposal system, the number or persons simultaneously connected to the system is to be allowed for as defined in Table 2.10:

2.3.1.4 The gas circulating systems are to be so designed that the chamber conditions stated in I.2. are maintained.

2.3.1.5 Each decompression chamber compartment and each diving bell is to be equipped with at least the following gas systems:

- 2 independent gas supply systems for compression which may deliver into a single inlet pipe
  immediately at the chamber

- 1 chamber exhaust gas system

- 1 independent mask supply system (BIBS)

- 1 mask exhaust gas system

- 1 gas circulating system for maintaining a breathable chamber atmosphere

Where pure oxygen or gas containing more than 25 % O_2 by volume is supplied to the chamber, a separate piping system is to be provided for this purpose.

Table 2.10 Quantity of breathing gas for simultaneously connected breathing masks

Number of persons	Quantity of breathing gas [litres/min]
1	1 x AMV x 3
2	2 x AMV x 1,8
3	3 x AMV X 1,6
4	4 x AMV x 1,4
5	5 x AMV x 1,3
6	6 x AMV X 1,2
7	7 x AMV x 1,1
8	8 x AMV X 1,1
z>8	z x AMV X 1,0

2.3.1.6 Valves in gas systems are to be arranged so that a leaking valve cannot cause any unintended mixing of gases respectively no oxygen or oxygenlike gas can penetrate into lines intended for other gases. Intersections between oxygen and non-oxygen systems are to be isolated by twin shut-off valves with a vent valve placed between them.

2.3.1.7 Filters and pressure reducers are to be fitted in such a way that they can be dismounted without having to interrupt major gas supply lines.

2.3.1.8 If for diving depths above 50 m the composition of the gas of the chamber atmosphere does not correspond to the required breathing gas of the breathing masks (e.g. Heliox, Trimix), special measures (e.g. redundant masks and pressure reducers) are to be performed and to be agreed with **TL.**

2.3.2 Pressure chambers

2.3.2.1 At least one breathing mask is to be provided for each occupant of each separately pressurized chamber compartment.

2.3.2.2 The masks are to be joined either permanently or by plug connectors to the mask gas supply and exhaust system.

2.3.2.3 The exhaust gas (exhalation line) side of the masks is to be protected against any inadmissible pressure drop or inadmissible pressure difference.

2.3.2.4 The supply of gas to the chamber is to be arranged so as to ensure that a homogeneous gas distribution inside the chamber is achieved as quickly as possible.

2.3.3 Diving bells

2.3.3.1 Besides their normal breathing gas supply diving bells and divers in the water have also to carry an independent reserve gas supply.

2.3.3.2 The supply of breathing gas to the diving bell is to be designed in such a way that, should the diving bell umbilical fail, the carried bell reserve supply can be switched manually or automatically to the diver bell supply without flowing back into the bell umbilical.

2.3.3.3 The divers' umbilical system is to be so designed that each diver has his own independent supply.

2.3.3.4 In the diving bell at least one breathing mask is to be provided for each diver, and this is to be connected to both the normal and the reserve gas supply. Divers' masks and helmets with a gas supply may be recognized as breathing masks.

2.3.3.5 Automatic pressure reducers are to be provided for the breathing masks.

2.3.3.6 The emergency oxygen supply is to be fitted with a dosage system to enable the oxygen in the diving bell to be maintained at the correct partial pressure.

2.4 Conditioning of chamber atmosphere

2.4.1 Each pressure chamber is to be equipped with an oxygen dosing device and a chamber gas circulating unit in which the CO_2 can be absorbed and the air temperature and humidity can be regulated. The rate of circulation shall be such as to satisfy the conditions stated in I.2.

2.4.2 Each diving system is to be equipped with at least 2 chamber gas treatment units which are to be so arranged that they can be switched to adjoining chambers.

2.4.3 Diving bells are to be equipped with a chamber gas treatment unit and also with an autonomous reserve CO_2 absorption unit for emergency use.

2.4.4 Diving bells are to be equipped with a heating system provided with redundant supplies and so designed that the divers in the diving bell and in the water are maintained in a thermal balance. For diving operations at depths greater than 100 m breathing gas preheaters are to be provided additionally for the divers in the water.

2.4.5 Measures are to be taken to enable the divers within the diving bell to be maintained in a safe thermal balance for at least 24 hours in an emergency.

2.5 Treatment and mixing of breathing gases

The use of closed breathing circuits, gas mixing systems for direct breathing gas supply and helium reclaim systems is subject to approval by **TL.**

3. Control and instrumentation

3.1 Central control position

The surveillance and control of the life support systems has to be performed with the assistance of the central control position of the diving system on the support ship, where all essential chamber data are indicated as well as the chamber pressures are controlled and the gases are distributed to the different chambers, if more than one chamber is existing. In addition the operating conditions of the ancillary systems are to be indicated there (see O.1.4 and O.1.5).

3.2 Instrumentation

3.2.1 Indicating instruments

3.2.1.1 The central control position is to be equipped with suitable instruments for the surveillance of each manned decompression chamber compartment or. each diving bell (see Table 2.11).

3.2.1.2 The instrument indicating the pressures in decompression chambers and diving bells are to be accurate to ± 0,25 % of the whole scale with a maximum deviation of 30 cm water column. All other pressure readings shall be accurate to ± 1 % of the whole scale.

3.2.1.3 The central control position is also to be equipped with indicating instruments for the following parameters:

- Pressure of connected breathing gas receivers/bottles
- Pressure downstream of pressure reducers
- Oxygen content in supply lines to:
  - umbilical
  - chamber compartments
- Breathing masks in chambers

3.2.1.4 Inadmissible deviations from the reference values of the vital parameters mentioned in M. shall actuate a visual and audible alarm at the central control position; the same for automatically actuated switching operations in the gas supply system and similar functions.

3.2.1.5 The compartments of decompression chambers are to be fitted with pressure and temperature gauges which can be read from inside. Diving bells are to be equipped with instruments indicating the internal and external pressure and the pressure of the independent gas supply.

3.2.1.6 Pressure indicators connected directly to the pressure chamber system are to be fitted with a shutoff valve

3.2.2 Analyzer systems

3.2.2.1 Each diving simulator is to be equipped with at least one oxygen and one CO_2 analyzing system.

3.2.2.2 Throughout the entire period of operation, the oxygen analyzer has to give a reading accuracy to at least ± 0,015 bar partial oxygen pressure.

3.2.2.3 Throughout the entire period of operation, the CO_2 analyzer has to give a reading accuracy to at least ± 0,001 bar partial CO_2 pressure.

3.2.2.4 In diving bells and living compartments of decompression chambers in addition independent instruments for monitoring the oxygen and CO_2 levels are to be provided.

3.2.2.5 Where gases other than air or helium-oxygen or $He/N_2/O_2$ mixtures are used in diving operation, the necessary instrumentation is in each case to be defined together with **TL**.

3.2.2.6 If impurities of the chamber atmosphere, such as CO, NO, NO_x or hydrocarbons might occur, an adequate analyze system is to be provided. Test tubes may be recognized for this purpose.

The accuracy of the analyzer readings shall be such that the discrepancy between the partial pressure in the gas and the partial pressure readings on the instrument does not exceed 10 %.

3.3 Control equipment

3.3.1 The central control position is to be equipped with controls for at least the following functions:

- Pressurization and pressure control of each independently operated decompression chamber compartment and each diving bell
- Decompression of each independently operated decompression chamber compartment and each diving bell
- Pressure equalization between chamber compartments
- Oxygen addition to the chamber compartments
- Control of gas supply to breathing masks
- Control of temperature and humidity in the pressure chambers

3.3.2 At the control position for the gas distribution a system mimic diagram is to be provided showing the functions of the various valves and the different gas lines marked in colour.

Table 2.11 Operation conditions to be monitored

Parameter	Decompression chamber compartments	Diving bell
Pressure or depth **(1)**	X	X **(2)**
Temperature **(1)**	X	-
Humidity	X	-
O_2 partial pressure **(1)**	X	X
CO_2 partial pressure	X	X

(1) *These parameters are to be displayed continuously.*

(2) *The pressure or the depth inside and outside the diving bell is to be indicated.*

N. Electrical Equipment

1. General

1.1 The following Rules supplement the **TL** Electric Rules and are to be applied to diving systems.

1.2 The documents to be submitted to **TL** are listed in E.6.

1.3 The necessary tests are stated in G.7.

2. Design principles

2.1 General principles

2.1.1 All electrical systems and equipment are to be constructed and installed in such a way that they are serviceable and perform satisfactorily under the design conditions specified for the diving system to minimize the risks for divers through fire, explosion, electric shock and emission of toxic gases.

2.1.2 Provision is to be made for maintaining the diving system in a normal operating condition without recourse to the emergency power supply.

2.1.3 Even under emergency conditions, the operation of equipment necessary to the divers' safety is to be guaranteed.

2.1.4 Suitable Protective measures are to be taken to exclude any electrical hazards to divers and to the operating personnel of the diving system.

2.2 Materials and insulation

2.2.1 The materials used in the construction of electrical machines, cables and apparatus are to be resistant to moist and salty sea air, seawater and oil vapours. They shall not be hygroscopic and are to be flame-retardant and self-extinguishing. In addition, materials installed inside decompression chambers and diving bells are to be approved for operation in hyperbaric atmospheres and shall not liberate toxic gases or fumes under these conditions.

2.2.2 Materials with high tracking resistance are to be used for the supports of live parts. The air and leakage distances are to be dimensioned devicespecifically according to IEC. Switchgears, penetrations through pressure vessel walls, underwater plug connectors and appliances directly connected to the busbars are to be designed for the next higher nominal insulation rating.

2.2.3 Materials and insulations for electrical equipment used in water are to be agreed with **TL.**

2.3 Supply systems

2.3.1 Approved supply systems are:

- Direct current and single-phase alternating current:
  2 conductors insulated from ship's hull

- Alternating current (three-phase alternating current):
  3 conductors insulated from ship's hull

2.3.2 The use of the diving system, the ship's hull or parts thereof for the return of electrical current is not permitted.

2.3.3 Systems earthing is not permitted.
Exceptions may be allowed in the case of subsystems using isolating transformers and high-resistance systems earthing.

2.4 Maximum permissible operating voltages

2.4.1 The following maximum voltages are permitted for electrical equipment inside decompression chambers (only in dry chamber compartments):

- for permanently installed electrical drives and heating systems: 250 V

- for lighting networks and socket circuits, communications and display equipment and all consumers supplied via cables not permanently installed: 50 V

2.4.2 30 V is the maximum permissible voltage for all electrical equipment in diving bells and wet bells.

2.4.3 Voltages higher than those stated in 2.4.1 and 2.4.2 may be approved where additional safety measures are taken which achieve an equivalent level of safety.

2.4.4 The permissible voltages for electrical equipment used in water are to be agreed with **TL** in each case.

2.5 Protective measures

2.5.1 All electrical equipment is to be protected in accordance with the **TL** Electric Rules, Section 1 unless otherwise stated in the following.

2.5.2 To protect divers against excessive contact voltages and electric shock, additional safety measures are to be taken to avoid or restrict dangerous fault currents. These measures are to be agreed with **TL** in each single case.

2.5.3 For diving systems the minimum degrees of protection according to Table 2.12 are valid. The degree of protection of the equipment is to be guaranteed as installed even when in operation (heeling position). In this context, provision of shielding at the point of installation is deemed as protective measure.

2.5.4 Protective conductors

For the use of protective conductors is to be observed:

a) The protective conductor has to take the form of an additional cable or additional line or an additional core in the power cable. The use of armouring as protective conductors is to be checked case by case and to be approved by **TL.**

b) The cross-section of the protective conductor shall be equivalent to at least half the cross-section of the principal conductor/ phase conductor. However, with crosssections up to 16 mm^2, its cross-section shall be equal to that of the principal conductors/ outer conductors. The minimum crosssection of separately laid protective conductors is 4 mm^2. The cross-section of the protective conductor shall at least comply with the factors shown in Table 2.13.

The dimensional design of the protective conductors is to be based on the maximum possible short-circuit currents of the equipment concerned, the maximum break times of the relevant protective elements and a maximum temperature rise of the protective conductor of 90 °C.

c) The connection of the protective conductor to the hull of the support ship shall be located at a point where it can easily be checked.

2.5.5 Earthing

For earthing is to be considered:

a) Diving systems are to be equipped with an earthing and potential equalizing system. Connections for external earthing are to be provided at all pressure chambers. Also in gas storage and filling station, etc.

b) All metal parts of electrical installations - with the exception of live components - are to be earthed. The casings of electrical equipment mounted directly against the inside wall of pressure chambers are considered to be effectively earthed only if the contact surfaces are permanently free from rust, scale and paint and the casings are fastened with at least two corrosion-resistant screws secured to prevent accidental loosening.

If these conditions are not met, earthing is to be effected by separate earthing conductors.

c) The connections of the potential equalization at the diving bell/wet bell shall be installed where it can easily be checked.
In an easily accessible position of the superstructure of the support ship and on the diving bell/wet bell a connection point in the form of a connecting plate with preferably M 12 stud bolts is to be provided to which protective conductors can be connected without tools.

Table 2.12 Minimum degree of protection against foreign bodies and water (in conformity with IEC 60529)

Type of equipment / Where installed	Safety and measuring equipment	Motors, transformers	Switchgear,electronic units, recording equipment	Telecommunication equipment, input units, signalling equipment, switches, sockets, junction boxes, actuators	Heating equipment, heaters	Lighting fittings
Control rooms and accommodation	-	IP 23	IP 23	IP 23	IP 44	IP 23
Sanitary spaces	IP 55	IP 44	IP 44	IP 55	IP 44	IP 44
Pipe tunnels, bilges	IP 56	-	-	IP 56	-	IP 56
Outside chambers / inside floodable chambers and wet bells	Watertightness under pressure in accordance with design criteria of diving system					

Table 2.13 Cross-sections for protective conductors

Cross-section of outer conductor [mm²]	Minimum cross-section of earthing conductor	
	in insulated cables [mm²]	separately laid [mm²]
0,5 to 4	Equal to cross-section of outer conductor	4
> 4 to 16	Equal to cross-section of outer conductor	Equal to cross-section of outer conductor
> 16 to 35	16	16
> 35 to < 120	Equal to half the cross-section of outer conductor	Equal to half the cross-section of outer conductor
≥ 120	70	70

This connection serves for the compensation of the potential between the diving system and the support ship.

d) The casings of electrical equipment in water are always to be earthed by an earthing conductor included in the supply cable. Where this is not possible, casings mounted on the outside of the diving bell may also be provided with a separate external earth. In this case, however, the entire earth connection (connecting screws and earthing conductor) is to be provided corrosion- resistant.

e) The connections between the earthing conductor and the chamber and to the ship's earth are to be made with corrosion-resistant screw connections effectively safeguarded against accidental loosening. The dimensions of the screw connections are to be dimensioned according to the requisite cross-sections of the earth conductor to be connected and may not be used for other purposes.

f) Machines and devices which are mounted on insulating vibration dampers are to be earthed by flexible cables, wires or stranded copper straps.

g) Earth connections are to be accessible for maintenance and inspection. Wherever possible, they are to be marked. Earthing conductors in multi-core cables are to be marked green and yellow, at least at the terminals.

h) Earthing conductors are to be provided with corrosion protection compatible with their place of installation.

i) Copper earthing conductors are subject to the following minimum cross-sections:

- external connections on support ship and water: 10 mm^2

- external connections inside chambers and living compartments: 6 mm^2

- Separate earthing conductors inside switchgear and casings: 4 mm^2

- Earthing conductors in multi-core cables up to a conductor cross-section of 16 mm^2 shall correspond to the cross-section of the main conductor, subject to a minimum of 1 mm^2

- Earthing conductors in multi-core cables with a conductor cross-section of more than 16 mm^2 equal to at least half that of the main conductor If other materials are used, the minimum crosssection is to be determined by the ratio of the electrical conductivity of these materials to the electrical conductivity of copper.

j) Cable sheaths and armouring are not to be used as earthing conductors.

3. Power supply

3.1 Principles

3.1.1 All electrical equipment essential to the safety of divers and diving operations is to be connected to a mutually independent main and emergency power supply.

3.1.2 Where provision is made for automatic switching from the main to the emergency power supply, each such switching operation has to actuate in the central control position of the diving system a (visual and audible) signal requiring acknowledgement. An indicator has to show which supply is connected.

3.1.3 The main power supply to the diving system can be taken directly from the main switchboard of the support ship or from the main power source of the diving system.

3.1.4 The following may be used as an independent emergency power source:

- An electrical generator with its own drive

- An emergency battery of sufficient capacity

- The emergency power supply of the support ship provided that this is designed to meet the additional emergency power of the diving system

3.1.5 The emergency power source for the diving system is to be installed in a space separated from the main power source and the main switchboard so that it also remains operational in case of a fire or other major damage affecting the main power supply.

3.2 Main power supply

3.2.1 A power balance is to be prepared to prove that units for the generation, storage and conversion of electric power are adequately rated. This balance shall take account of the full power consumption of those consumers which are permanently required in service.

3.2.2 The power consumption of consumers which are connected for limited periods may be determined by applying a simultaneity factor.

3.2.3 To meet the power requirements during brief peak loads, e.g. when motors are started automatically, a reserve capacity is to be shown.

3.2.4 The generating equipment of the main power supply is to be so designed that the voltage and frequency variations allowed by the **TL** Electric Rules, Section 1 are not exceeded.

3.3 Emergency power supply

3.3.1 The emergency power supply shall be able to meet the emergency power requirements of the diving system for a period of at least 48 hours.

3.3.2 The emergency power supply shall be able to meet simultaneously the requirements of at least the following items of equipment:

- Emergency lighting systems in decompression chambers and diving bells as well as in the spaces required for operation

- Emergency communication systems

- Life support systems required for emergency

- Launch, recovery and transfer systems required for emergency

- Central control position as well as required surveillance and alarm systems

3.3.3 In the design of the emergency power supply system, appropriate reserve capacity is to be provided to meet peak loads (e.g. caused by the starting of electric motors).

In determining the necessary battery capacity, allowance is also to be made for the cut-off voltage and voltage drop of battery.

3.3.4 Diving bells are to be equipped with their own independent emergency power supply capable of meeting the power requirements of the autonomous life support system of the diving bell for at least 24 hours.

3.4 Storage batteries and battery chargers

3.4.1 Storage batteries, general

3.4.1.1 Storage batteries are to be rated such as to be capable of supplying the consumers during the period specified in accordance with the power balance, when charged to 80 % of their rated capacity.

3.4.1.2 At the end of the supply period the voltage in the storage battery or at the consumers shall at least reach the values quoted in the **TL** Electric Rules, Section 1, F. and Section 3, C.

3.4.1.3 Approved storage batteries are lead-acid storage batteries with diluted sulphuric acid as electrolyte and steel storage batteries with nickel-cadmium cells and diluted potassium hydroxide as electrolyte.

3.4.1.4 Further types of batteries may be approved under consideration and test of the following points:

- Resistance to short circuits

- Fuse elements at occurring short circuits

- Electrical monitoring elements

- Fire risk/fire behaviour including consequences on adjacent cells or components

- Special requirements for the installation location

- Suitability of the used belonging electrical components

- Integration in the electrical plant including switch gears

- Charging devices and automation system for charging

3.4.1.5 Storage batteries are to be designed such as to retain their undisturbed function at inclinations of up to 22,5° and such that for inclinations of up to 45° electrolyte will not leak. Cells without covers are not admissible.

3.4.1.6 The casing is to be resistant to electrolytes, mineral oils and cleaning agents, as well as to corrosion due to saline mist. Glass and readily flammable materials are not approved as materials for casings.

3.4.1.7 In the case of storage batteries containing liquid electrolyte it shall be possible to check the electrolyte level. The maximum admissible electrolyte level is to be marked.

3.4.1.8 Lead and alkaline storage batteries shall not be accommodated in the same space or be placed in direct proximity to each other.

3.4.1.9 Where the installed battery capacity is 1000 Ah or more, the battery is to be divided into smaller battery units so that restricted operation is still possible in the event of a fault.

3.4.1.10 The weight of the biggest portable unit shall not exceed 100 kg.

3.4.1.11 The rating data of the storage batteries are to be indicated on rating plates.

Storage batteries are to be serviced and operated in accordance with manufacturers' instructions.

3.4.1.12 Measures are to be taken to ensure that neither the crew nor the operational equipment can be endangered by emissions of electrolyte fumes.

3.4.1.13 A sign is to be mounted at the entrance of battery spaces pointing out that only insulated tools are to be used inside and conductive objects like keys, ballpoint pens, watches with conductive watch straps have to be taken off. Explosion hazard shall be pointed out.

3.4.1.14 Storage batteries are to be installed in such a way that mechanical damage is as far as possible excluded. Safe operation under the environmental conditions stated in D. is to be ensured and the leakage of electrolyte is to be prevented.

Suitable measures, e.g. provision of plastic trays or flexible rubber bags, are to be taken to prevent electrolyte from entering the battery space bilges in the event of mechanical damage to individual battery cells.

3.4.2 Special requirements for lead batteries

3.4.2.1 Battery spaces shall be arranged and ventilated, as required for the type of battery, to prevent the accumulation of ignitable gas mixtures.

3.4.2.2 The quantity of air to be supplied and exhausted during charging shall be so calculated, that the lower explosion limit for a hydrogen air mixture will not be exceeded.

H_2-monitors permanently mounted at suitable points have to measure the gas concentration in the battery space, the exhaust system and, where necessary, in further spaces of the diving system. If the gas concentration reaches and exceeds a level equivalent to 35 % of the lower explosion limit (LEL), this shall automatically release a visual and audible alarm at a central control position. Equipment for monitoring the H_2 - concentration shall be type approved.

3.4.2.3 Battery spaces shall contain no other electrical appliances apart from the storage batteries themselves. Lights, fuses (single voltage measuring device) and measuring devices for H_2 concentration may be installed if they are in accordance with the requirements for an atmosphere containing H_2 (see recommendations IEC 60079).

3.4.3 Battery chargers

3.4.3.1 Battery chargers are to be rated such that the maximum admissible charging currents cannot be exceeded.

3.4.3.2 The power demand of the consumers is to be taken into account when selecting the battery chargers.

3.4.3.3 The battery chargers are to be rated such that the tolerances of the limited characteristics and constant characteristics respectively are adhered to irrespective of external disturbance effects.

3.4.3.4 Battery chargers have to cut out automatically in case of:

- Failure of the battery space ventilation (if an ignitable gas mixture may be created)

- Excessive temperature of charging generator

- Overtemperature of the electrolyte (if a temperature control of the single cells is provided)

3.4.3.5 For lead batteries is to be considered additionally:

- If during charging simultaneously consumers are fed, the maximum charging voltage shall not exceed 120 % of the rated voltage.

- Preferably chargers with IU or IUI or IUW characteristics shall be employed.

- If a H_2 concentration measuring device is provided, the charging device has to cut off automatically, if the H_2 concentration is too high, e.g. 60 % LEL.

4. Power distribution

4.1 Distribution and switchgear

4.1.1 Electrical distribution systems are to be so designed that a fault or failure in one circuit cannot impair the operation of other circuits or the power supply.

4.1.2 The following consumers at least are to be supplied via individual circuits equipped with all necessary safety devices and switchgear from a distribution panel supplied directly from the main switchboard of the support ship:

- Launch, recovery and transfer systems of the support ship for the diving bell/wet bell

- Lighting system for decompression chambers and diving bells

- The electrical consumers of the life support systems

- Communication systems

4.1.3 In normal operation the emergency power distribution system may be supplied via a transfer line from the main power distribution system.

4.1.4 Distribution boards with their own individual feed circuits may not be mounted in a shared casing, i.e. each of these switchgear units has to have its own enclosure.

4.1.5 Effective measures are to be taken to prevent the occurrence of vagabond voltages inside switchgear. Circuits at protective low voltage may not be routed with circuits at higher voltage in a joint conductor bundle or cable duct. Terminals for different voltage levels are to be arranged separately and are to be clearly identified.

4.1.6 Switchgear units for a connected load of 50 kW and over are to be tested in the manufacturer's works in the presence of a **TL** Surveyor. The test shall be performed in accordance with the **TL** Electric Rules, Section 5, H.

4.1.7 Switchgear units for a connected load of less than 50 kW are to undergo an internal works test of the same scope. These tests are to be certified by a Manufacturer Inspection Certificate. Test Certificates are to be submitted to **TL** not later than the trial of the diving system.

For voltage ratings below 60 V, the voltage test is to be performed at a power-frequency withstand voltage of 500 V.

4.2 Switching and protective devices

4.2.1 Each circuit is to be protected against overload and short-circuit.

4.2.2 All consumers circuits are to be fitted with switches. The switching action shall be on all poles.

4.2.3 Electrical switches for circuits with a current rating above 0,5 A are permitted inside decompression chambers and diving bells only subject to the use of additional safety features (e.g. pressurized enclosure in protective gas).

4.2.4 Electrical fuses may not be located inside decompression chambers and diving bells. Wherever possible, fuses for the independent emergency power supply to the diving bell are to be located outside the chamber. If installed inside the diving bell, special protective measures are necessary. The fuses shall in any case be protected against intervention by the occupants of the chamber.

4.2.5 Electric motors installed inside chambers are to be fitted with an overcurrent alarm. The alarm is to be tripped in good time before the motor protection responds. This does not apply to those electric motors which cannot be endangered by overcurrent. For motors in the diving bell, the alarm may take place in the diving bell.

4.2.6 Devices are to be fitted which, in the event of danger, enable the power supply to all the electrical consumers in the pressure chamber to be quickly disconnected. The switches needed for this purpose are to be mounted at the central control position. Means are to be provided to enable the disconnection separately for each chamber.

4.2.7 All unearthed distribution systems, including the groups of consumers and individual consumers supplied via isolating transformers, safety transformers, rectifiers and inverters, are to be equipped with a continuously operating insulation monitoring system.

For systems using protective low voltage, an alarm is to be actuated at the central control position if the insulation value drops below a preset limit. For higher voltage systems, the insulation monitor shall trip an alarm at the central control position when a predetermined fault current is reached, and the system concerned is to be automatically disconnected, if no endangerment is created hereby.

For the electrical equipment of the diving bell, the alarm actuated by the insulation monitoring system may take place in the diving bell.

Note:

The current/time characteristics of insulation monitoringsystems directly concerned with personel safety has to meet the requirements of diver protection. In assessing the time characteristics, account is to be taken of the response time of the insulation monitoring system and of the tripping time of the switching devices which it actuates.

4.2.8 Electrical installations are to be so arranged that a flooding with gases or water is to be excluded. If this cannot be avoided, electrical installations are to be designed gas-tight/water-tight or with the ability to be shut-off or other protection measures are to be provided.

4.3 Enclosures for electrical equipment

4.3.1 All items of electrical equipment belonging to a diving system are to be encased or sealed in a suitable enclosure compatible with their nature, location and protection class.

4.3.2 The enclosures of electrical equipment installed inside decompression chambers and diving bells which are operated in water have to be approved by **TL.**

4.4 Cables and lines

4.4.1 Cables and lines for diving systems are to be suitable for the proposed application, their use is subject to approval by **TL.**

4.4.2 For selection, dimensioning and installation of cables and lines **TL** Electric Rules, Section 12 and 17, F. are to be observed.

4.4.3 In addition, the materials of cables and lines inside pressure chambers and in water have to meet the requirements stated in 2.2.

4.4.4 Cables and lines outside of diving bells/wet bells are to be designed for an external hydrostatic overpressure at least equivalent to the collapse diving pressure CDP. The pressure resistance is to be verified by pressure-testing of each made-up length after the connectors have been fitted.

4.4.5 For the design and testing of umbilicals see Annex E.

4.4.6 In cables for winding on drums, no mechanical forces may be transmitted by electrical components of the cable.

4.5 Electrical penetrations in chamber walls, underwater plug connections

4.5.1 Lay out

For the lay out the following is to be considered:

- The lay out has to be done for collapse diving pressure CDP.
- Chamber wall penetrations are to be gas and watertight. The tightness has to be guaranteed even if connected cables are be damaged or shorn off.
- They are not to be used for the passage of other systems.
- The positive and the negative conductor from a power source are not to pass through the same penetrating device at the chamber wall.
- Electrical conductors within the penetrating device shall be of solid material

4.5.2 Type approvals

Electrical penetrations of chamber walls and underwater plug connections are to be type approved.
Type-testing is performed, on application, at the manufacturer's works and comprises at least the following individual tests:

- Hydraulic pressure test, in which the test pressure shall be equal to twice the nominal pressure P_N of the component. The test is to be conducted in accordance with the test pressure/time curve shown in Fig. 2.1, the changes in pressure are to be applied as quickly as possible.
- Gas tightness test with shorn, open cable ends. This test may be performed under air or alternatively under helium. The test pressure is to be 2 times the nominal pressure of the component P_N for air and 1,5 times the nominal pressure of the component P_N for helium. The leakage rate is to be specified by the manufacturer and to be approved by **TL**.

  In all pressure and tightness tests on chamber wall penetrations, the pressure is to be applied in each case from the pressure side of the wall penetration.

  During the pressure and tightness test, the penetration is to be loaded with the rated current in all conductors.

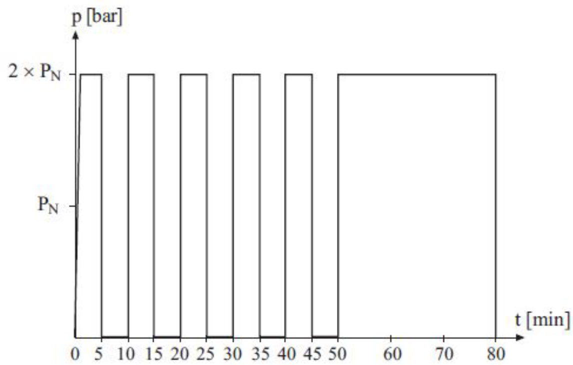

Figure 2.1 Test pressure/time curve for type approval

- High voltage test at an AC voltage of 1000 V plus twice the rated voltage. This test is performed at the rated frequency and is to be carried out for 1 minute in each case between all the conductors mutually and between the conductors and the casing. The test is performed in the disconnected state. The connection side of the chamber wall penetration may be completely wired during the high voltage test, but components with lower rated voltage are to be protected by separating devices. The sealing of the connector shells and the like is permitted to the degree stipulated by the manufacturer in the relevant data sheet. The test voltage for plug connections with a rated voltage of above 500 V is to be agreed with **TL.**

- Measurement of insulation resistance: The minimum value between the conductors mutually and between the conductors and the casing shall be 5 MOhm for the type test, for periodic Classification surveys the minimum value shall be 2 MOhm.

  The insulation resistance is to be measured with an instrument using 500 V DC. With wet plug connections, the minimum insulation resistance is also to be measured after the connection has been made once in saltwater.

- Visual check against manufacturer's documentation.

4.5.3 Individual test after manufacturing (Routine Test)

Each manufactured electrical pressure chamber wall penetration and each plug connection are to be subjected to routine inspection after manufacturing by the manufacturer.

This inspection comprises the following tests:

- hydraulic pressure test at the manufacturer in accordance with Fig. 2.2 at 1,5 times the nominal pressure of the component PN and, if applicable, within an overall test with test diving pressure TDP.

- High-voltage test

- Measurement of insulation resistance

A Manufacturer Inspection Certificate is to be issued covering the inspection.

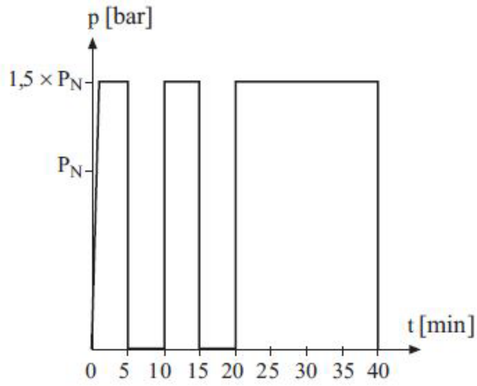

Figure 2.2 Test pressure/time curve for routine test

5. Electrical equipment

5.1 Electrical machines

5.1.1 Electrical machines shall conform to the **TL** Electric Rules, Section 20, A.

5.1.2 For the windings of electrical machines at least isolation class F is to be provided.

5.1.3 The reverse power for reversing, reduction and shut-off is to be considered and shall be limited to permissible maximum values.

5.1.4 In addition to the tests stipulated in the **TL** Electric Rules, Section 20, A.4. the following electrical machines are to be tested in the presence of a **TL** Surveyor:

- all motors driving machines and equipment necessary to the safety of the diving system

5.2 Interior lighting

5.2.1 Service and work spaces, safety and control stations as well as diving bells and accommodation areas of decompression chambers are to be equipped with normal and emergency lighting. Emergency lights are to be marked as such to facilitate easy identification.

5.2.2 The normal lighting is to be so designed and arranged that the interior of the chambers is illuminated at least with 300 Lux.

As far as possible the interior lighting shall be arranged glare-free.

5.2.3 The lighting is to be so designed and arranged that all important instruments and markings can be read and any necessary operations can be safely performed.

5.2.4 All lighting fixtures shall be so mounted that combustible parts are not ignited by the generated heat, and they themselves are not exposed to damage.

5.2.5 The emergency lighting is to be independent from the main lighting. This concerns the power generation as well as the distribution and cable network. The emergency lighting has to be automatically switched on in case of failure of the main lighting. Switches are to be arranged only locally, e.g. for switching-off at the control stand.

O. Automation, Communication and Locating Equipment

1. General

1.1 The following rules supplement the **TL** Electric Rules and Automation Rules and are to be applied to the construction and use of surveillance, control, communications, video monitoring and locating equipment in diving systems.

1.2 The documents to be submitted to **TL** are listed in E.7.

1.3 The necessary tests are stated in G.8. Only components and units approved by **TL** may be used.

1.4 Central control position

1.4.1 Diving systems are to be so arranged and equipped that centralized control of the safe operation of the system can be maintained under all weather conditions.

1.4.2 For the monitoring and control of the diving system a central control position is to be provided which shall be equipped with indicators displaying all essential information about the decompression chambers and diving bells, as well as wet bells, its interior conditions and the operating states of the auxiliary systems and with all the regulating and control devices needed to operate the diving system including its wireless, video and communications equipment. All essential data are to be automatically registered and stored.

1.4.3 At the central control position grouping and arrangement of the instruments for monitoring, open and closed loop control of the diving system shall conform to the principles of safety technology and ergonomics.

1.4.4 All monitoring and control devices are to be unambiguously labelled and marked.

1.4.5 Indicating instruments and synoptic indications are to be arranged and labelled to enable a quick and unambiguously reading.

1.4.6 It shall be possible to check the function of important indication lamps during operation.

1.4.7 As far as feasible and rational, initiated control functions are to be indicated on the console or switchboards respectively.

1.4.8 No units or equipment liable to impede the monitoring and control of the diving system may be installed in the area of the control stand. In addition the operation may not be essentially impaired by communication systems, tripping alarms and general noise.

1.4.9 The central control position has to offer sufficient protection against other operation spaces (noise protection, visual protection, no access/passing to other operating spaces).

1.4.10 The central control position is to be so equipped with a separate ventilation and exhausting system to achieve optimum conditions for personel and equipment. The intake of the air is to be routed from an area not subject to explosion hazard.

1.4.11 As far as possible the installation of piping systems and cable trays is to be performed separately according to constructional groups, in order to avoid that failures in one constructional group may lead to the failure of several constructional groups.

1.4.12 The central control position is to be monitored concerning fire protection and the possibility of effective fire fighting herein is to be provided without endangering the safe operation of the diving system.

1.5 Equipment of the central control position

1.5.1 For each of the functions to be performed on the central control position of the diving system the following indicating instruments are to be provided:

1.5.2 Position indications for diving bells

- Video camera

- One depth indicator
  The scale of the depth indicator is to extend at least 20 % beyond the nominal diving depth NDD. The instrument shall give a reading accuracy of 1 % at NDD and shall not be significantly affected by pressure variations.

- Indication of pressure difference between internal and external pressure, if applicable

1.5.3 Chamber atmosphere

- Indicators and alarms specified in M. for monitoring the chamber atmosphere

1.5.4 Electrical equipment

- Battery current and voltage indicators

- If a capacity indication for the batteries has to be provided will be defined by **TL** in each single case.

- Insulation monitor displays (for complex systems)

1.5.5 Safety equipment/indicators

- Machinery alarm systems

- Fire detection and alarm system

- General alarm system

- Filling level for ballast tanks, if existing

- Indication for release weight

- Pressure gauge for all compressed-air receivers

- Pressure gauge for all oxygen and breathing gas storage tanks

- Pressure gauges for hydraulic systems

1.5.6 Steering and control systems

1.5.6.1 The central control position of the diving system is to be equipped at least with the following systems:

- Chronometer

- External communication

- Internal communication

- Control of the chamber atmosphere in relation to pressure, temperature and humidity, oxygen metering and air renewal rates

- Emergency stopping systems

- Control of electrical power

- Control of auxiliary systems, e.g. hydraulic units and similar

1.5.6.2 Command and control functions are, as far as possible and expedient, to be indicated by displays on monitors or system schemes on the control console.

1.6 Wet bells

At the central control position of the diving system the parameters defined in S.5. are to be considered.

2. Automation equipment

2.1 Design principles

2.1.1 All equipment for the automatic surveillance and control of diving system operating parameters is to be designed and constructed so that it works properly under the design and environmental conditions specified for the diving system.

2.1.2 Any fault or failure which may occur in the automation system shall not provoke a critical operating condition in the decompression chambers or diving bells.

2.1.3 As far as possible, automation equipment is to be safeguarded against faulty operation.

2.1.4 Automation systems are to be in the position, to keep the operation parameters of the diving system.

2.1.5 Any inadmissible variations in the operating parameters has to actuate an automatic/visual and audible) alarm at the central control position. The same shall also occur in the event of automatic switching operations in the gas and power supply systems or faults in the control and surveillance system.

2.1.6 In addition to electronic control and surveillance equipment, independent safety devices are to be fitted which prevent a fault in one system from provoking an improper response in another system.

2.1.7 Automatic surveillance and control equipment shall be capable of being switched to manual operation at all times.

2.1.8 The response values of automation equipment are to be so coordinated with each other that, when a threshold is reached, a warning is initiated, followed, after a certain warning period or if the process variable continues to change at a preset speed, by the actuation of safety devices.

2.1.9 The integral operation of automation systems is to be designed to take account of the lags and time constants of the units and elements making up the system (e.g. by allowing for the length and crosssection of piping systems and the response times of gas analyzers).

2.1.10 For electrical systems IEC 60533 (Electromagnetic Compatibility of Electric Installation in Ships) is taken as standard for interference immunity.

2.2 Structure

2.2.1 Electronic automation systems should comprise easily replaceable assemblies, of the plug-in type wherever possible. Standardization of units is to be encouraged. The number of assembly types is to be kept small in order to minimize the spare parts inventory.

2.2.2 Plug-in cards are to be clearly marked or coded to prevent inadvertent confusion.

2.2.3 Measures are to be taken to prevent condensation inside electronic units, even when switched off. Shutdown heating is recommended.

2.2.4 Wherever possible, automation equipment should be capable of operation without forced ventilation. The function of an cooling system, if existing, is to be monitored.

2.2.5 Components are to be effectively secured. Any mechanical loading of wires and soldered connections due to vibration or jolting is to be reduced to a minimum.

2.2.6 The structure of systems and units is to be simple and straightforward. Good accessibility is to be ensured to facilitate measurements and repairs.

2.2.7 Input equipment such as limit switches, transducers, transformers and reading-in machines, as well as control elements, fire alarm systems, remote control devices for drive systems, engine alarm systems and combined equipment for the recording of measurement data and interferences are to be tested according to 2.5.

2.3 Circuitry

2.3.1 Signalling equipment open and closed loop control systems with a safety function are to be designed on the failsafe principle, i.e. faults due to short-circuit, earthing or circuit breaks shall not be capable of provoking situations hazardous to personel and/or the system. In this respect, it is to be assumed that faults occur singly. The failure of one unit, e.g. due to short-circuit, shall not result in damage to other units.

2.3.2 In stored-program control systems, the electrical characteristics of the signal transmitters shall conform to the safety requirements for instruction and control devices. This means principally

- Activation at H level, i.e. by energization across NO contacts

- Deactivation at L level, i.e. by de-energization across NC contacts

The requirements of 2.3.1 are unaffected.

2.3.3 Instruction and control units for safety functions, e.g. emergency stop buttons, shall be independent of stored-program control systems and shall act directly on the output unit, e.g. the stop solenoid.

2.3.4 Stored-program control systems should be reactionless and, in case of fault, should cause no malfunctions in program-independent safety interlocks or stepped safety circuits for fixed subroutines.

2.3.5 Freely accessible potentiometers and other units for equipment trimming or operating point settings are to be capable of being locked in the operation position.

2.3.6 Mechanical switchgear is to be so designed that the operation of the system is not adversely affected by contact chatter.

2.3.7 Conductive tracks forming part of circuits which extend outside the enclosure housing the circuit boards must have qualified short-circuit protection, i.e. in case of an external short-circuit only the safety devices provided may respond without destroying the conductive tracks.

2.3.8 The equipment shall not be damaged by brief overvoltages in the power supply, due to switching operations. The design is to allow for overvoltages equal to approximately 2,5 times the rated voltage and lasting 1 ms.

Where systems are supplied by static converters, it may be necessary to make allowance for periodic voltage pulses lasting about 0,5 ms. The pulse amplitude depends on the converter type and is to be investigated in each case.

2.4 Power supply

2.4.1 Mains units for automation equipment have to contain at least one short-circuit protection and one overload protection device.

2.4.2 The reference conductor system is to be designed to preclude circuit breaks as far as possible. This may, for example, be achieved by duplicating exposed reference conductor joints and connections.

2.4.3 Automation equipment must be capable of reliable operation under the conditions of voltage and frequency variation stated in the **TL** Electric Rules, Section 1

2.5 Tests

Automation equipment is to be approved by **TL**, preferably type approved components are to be employed.

The nature and scope of the tests will be determined by **TL** in each single case.

Type test is to be performed in line with the **TL** Guidelines for the Performance of Type Approvals.

3. Communication equipment

3.1 Voice communication systems

3.1.1 Diving systems are to be equipped with a suitable communication system providing direct voice communication between the central control position and:

- Divers in water
- Diving bell
- Each compartment of the chambers
- Control stand for launch, recovery and transfer systems
- Mating system
- Control stand for dynamic positioning, if applicable
- Bridge or working floor or Platform and necessary operating rooms

3.1.2 In diving systems using helium gas mixtures, each decompression chamber compartment and the diving bell are to be connected to a speech unscrambler. The unscrambling devices shall be designed to achieve maximum noise suppression and the automatic compensation of sound level fluctuations.

3.1.3 It is recommended that the central control position should be equipped to record all voice communications with the divers.

3.1.4 Voice communications between the decompression chamber compartments and the central control position as well as between the diving bell and the central control position is to be provided by a communication system with loudspeaker which is permanently switched to "Receive" on the control console. Switches for reversing the direction of communication are to be of the self-resetting type. In addition, each decompression chamber compartment is to be provided with at least one headset.

3.1.5 A telephone link independent of the mains power supply is to be provided in addition to the communication system specified in 3.1.4.

3.1.6 Electrically powered voice communication systems shall be provided with a reliable power supply. This normally means that the equipment shall be supplied from a storage battery with a parallel connected mains unit and battery charger supplied with energy in accordance with N.

3.1.7 In wet rooms microphone and receiver systems are to be constructed to prevent the penetration of water. Where considerations of design render this impossible, the penetration of water shall not permanently impair the serviceability of the equipment.

3.1.8 Microphone and receivers in diver masks, hoods and diver helmets are to be functionally separated from each other.

3.2 Video surveillance equipment

3.2.1 Diving systems where the divers have to stay more than 12 hours in the chamber system, are to be equipped with a video surveillance system.

3.2.2 The number of cameras and their visual angle are to be chosen in a way that, as far as possible, the complete interior of the chamber to be monitored is covered.

3.2.3 A sufficient number of video monitors is to be provided. On each monitor it shall be possible to definitely recognize which room is shown at the moment.

3.3 Other signalling systems

3.3.1 Diving bells are to be equipped with an independent underwater communications system for use in emergencies.

3.3.2 Suitable alternative communications equipment (e.g. a 3-button signalling system) is to be provided in all decompression chamber compartments and in the diving bell.

4. Emergency location and communication

4.1 Emergency locating equipment

Each diving bell is to be equipped with an emergency locating device which works at a frequency of 37,5 kHz and is designed to establish and maintain contact between the diving bell under water and the surface, if the normal connections to the surface would be damaged. The device includes the following components:

4.1.1 Transponder

4.1.1.1 The transponder shall be provided with a pressure-proof housing suitable at least for the nominal diving depth NDD and equipped with salt water activation contacts. The batteries shall be of the readily available "alkaline" type and, if possible, be interchangeable with those of the diver and surface interrogator/ receiver.

4.1.1.2 The transponder shall be designed to operate with the following characteristics:

common emergency reply frequency:	37,5 kHz
individual interrogation frequencies:	
- channel A:	38,5 +/- 0,05 kHz
- channel B:	39,5 +/- 0,05 kHz
receiver sensitivity:	+ 15 dB referred to 1µ bar
minimum interrogation pulse width:	4 ms
turnaround delay:	125,7 ± 0,2 ms
reply frequency:	37,5 ± 0,05 kHz
- more than 20 % of battery life remaining:	once per second
- less than 20 % of battery life remaining:	once per 2 seconds
minimum transponder output power:	85 dB referred to 1 µ bar at 1 m
minimum transducer polar radiation:	6 dB at ± 135° solid angle, centred on the transponder vertical axis and transmitting towards the surface
Minimum listening life in water:	10 weeks

Minimum battery life replying at 85 dB: 5 days

4.1.2 Diver-held interrogator/receiver

4.1.2.1 The interrogator/receiver shall be provided with a pressure-proof housing suitable at least for the nominal diving depth NDD with pistol grip and compass. The front end shall contain the directional hydrophone array and the rear end the 3-digit LED display readout calibrated in metres. Controls are to be provided for "on/off receiver gain" as well as "channel selection". The battery pack shall be of the readily available "alkaline" type and, if possible, be interchangeable with that of the interrogator and transponder.

4.1.2.2 The interrogator/receiver shall be designed to operate with the following characteristics:

common emergency reply frequency:	37,5 kHz
individual interrogation frequencies:	
- channel A:	38,5 kHz
- channel B:	39,5 kHz
minimum transmitter output power:	85 dB referred to 1 µ bar at a distance of 1 m
transmit impulse duration:	4 ms
sensitivity for direction:	± 15° Ability to function in immediate proximity to the transponder is to be secured.

detectable range: more than 500 m

4.2 Emergency communication

In addition to the communication systems referred to above, a standard tapping code for emergency communication between persons in the diving bell and rescue divers is to be adopted.

A copy of this tapping code is to be displayed inside and outside the diving bell and also in the central control position.

Tapping code	Meaning
3.3.3	Communication opening procedure
1	Yes or affirmative or agreed
3	No or negative or disagreed
2.2	Repeat please
2	Stop
5	Have you got a seal?
6	Stand by to be pulled up
1.2.1.2	Get ready for through water transfer (open your hatch)
2.3.2.3	You will NOT release your ballasts!
4.4	Do release your ballast in 30 minutes from now!
1.2.3	DO increase your pressure
3.3.3	Communication closing procedure

P. Fire Protection

1. General

1.1 The rules of this Section apply to the fire protection of diving systems holding **TL** Class or with **TL** System Certificate, which are permanently or temporarily installed on a support ship.

1.2 The documents to be submitted to **TL** for approval are listed in E.8.

1.3 The necessary tests are stated in G.10.

2. Structural fire protection

2.1 Area of installation of diving system

2.1.1 For the support ship on which the diving system is installed, the fire protection rules of the competent Classification Society respectively the relevant regulations of the International Convention for the Safety of Life at Sea (SOLAS) of 1974, as amended are to be met.

2.1.2 In the area of installation of the diving system, the gas storage facility and the central controlposition, sources of ignition and fire loads are to be reduced to a minimum. As far as possible, materials which are at least flame-retardant are to be used. Heat insulation is to be made of incombustible materials.

2.1.3 Diving systems on support ships are only be installed and operated in areas not subject to explosion hazard in accordance with I.3.

2.1.4 Where diving systems or parts thereof are installed in closed spaces, these spaces including the central control position are to be separated from the deck and the rest of the ship by partitions of type “A- 60”

2.1.5 Enclosed spaces or parts thereof are to be provided with a forced ventilation system capable of effecting at least 8 changes of air per hour. The air is to be drawn from an area not subject to explosion hazard.

2.2 Interiors of decompression chambers and diving bells

2.2.1 As far as possible, all materials used in decompression chambers and diving bells are to be at least flame retardant (for the purpose of these Rules flame-retardant refers to materials which do not continue to burn spontaneously in a compressed air atmosphere of at least 6 bar absolute).

2.2.2 As far as possible, fire loads and sources of ignition are to be avoided. Electrical heating appliances and heaters are to be fitted with protection against overheating.

2.2.3 Components and materials are to be selected with the view to minimizing the danger of static charges.

3. Fire surveillance

3.1 Fire detection and alarm systems

3.1.1 Interior spaces containing parts of the diving system, such as decompression chambers, diving bells, filling stations, compressors and control positions are to be monitored by an automatic fire detection system.

3.1.2 The detected fire is to be signalled visually and audibly in the permanently manned central control position.

3.1.3 The fire alarm may be actuated manually from the permanently manned central control position or may be automatically activated by the fire detection system.

3.2 Fire detection system

3.2.1 Fire detection systems including central fire detection station, fire detectors and wiring of the detection loops require the approval of **TL.**

3.2.2 Fire detection systems are to be so constructed that any fault, as e.g. supply failure, shortcircuit or wire breakage in the detection loops, or the removal of a detector from its base, triggers a visual and audible signal at the fire detection station in the central control position.

3.2.3 For the design and arrangement of fire detection and alarm systems the **TL** Electric Rules and Automation Rules are to be observed.

4. Fire extinguishing systems

4.1 Area of installation of the diving system

4.1.1 Every support ship on which a diving system is installed is to be equipped with a general water fire extinguishing system consisting of hydrants as well as portable and mobile fire extinguishers and extinguishing equipment according to the **TL** Machinery Rules, Section 18.

4.1.2 Where pressure chambers are situated in enclosed spaces, a permanently installed water spray system having an application rate of 10 ℓ/m^2 and per minute related to the horizontal protected area is to be provided for cooling in the event of fire. These water spray systems may be manually activated and operated.

4.1.3 For pressure chambers installed on the open deck, cooling by means of fire hoses connected to the general fire extinguishing system is permitted.

4.1.4 Interior spaces containing diving systems or parts thereof are to be additionally equipped with approved manual fire extinguishers. One of the portable fire extinguishers shall in every case be situated close to the entrance to the space concerned.

4.2 Decompression chambers

4.2.1 Each compartment of a decompression chamber is to be equipped with suitable means for extinguishing a fire in the interior by providing for the rapid and efficient distribution of the extinguishing agent to any area of the chamber.

4.2.2 The fire extinguishing system shall safely deal with every conceivable outbreak of fire under all the environmental conditions for which the diving system is designed. Actuation of the fire extinguishing system may not cause any unacceptable pressure drop inside the chamber. The extinguishing system may be actuated by hand.

4.2.3 Water is the preferred extinguishing agent. Extinguishing agents with a toxic or narcotic effect are not permitted.

4.3 Diving bells

A fire protection/fire extinguishing system adequate to size, mission and equipment of the diving bell is to be provided.

5. Other fire protection equipment

The central control position of the diving system is to be equipped with at least one independent compressed air respirator of approved design having an operating capability of at least 30 minutes and fitted with equipment for voice communication with the divers.

Q. Launch, Recovery, Transfer and Mating Systems

1. General

1.1 These Rules apply to all equipment for the launch and recovery of diving bells of diving systems holding **TL** Class. The requirements for transfer and mating are defined in 6.

1.2 The documents to be submitted to **TL** are listed in E.9.

1.3 The necessary tests and markings are stated in G.11. and H.5.

1.4 If the systems fulfil the defined requirements and are constructed and tested under **TL** surveillance, a Certificate for the system can be issued and a Register of launching appliances can be opened. The purpose of the latter is to provide information about the actual situation with regard to general data plus the test, examination and maintenance status.

1.5 For the eventuality of a single component failure in the launch and recovery system, an alternative system is to be provided to enable the divers to be brought to the decompression chamber. This alternative system is to be supplied with power independently of the normal launch and recovery system. In addition, provision is to be made for emergency retrieval of the diving bell should both, the normal launch and recovery system as well as the alternative system fail.

1.6 Between the launch and recovery system and the coil-up/coil-off mechanism for umbilicals, if separately arranged, a communication facility with the central control position according to O.1.4 is to be established.

2. Principles for design

2.1 General principles

2.1.1 The launch and recovery equipment shall be capable of safely launch and recover the diving bell/wet bell in the seaway conditions stated in D.

2.1.2 The launch and recovery equipment should be fitted with devices for reducing the dynamic loads during launch and recovery operations in a seaway.

2.1.3 Devices are to be provided to stabilize the diving bell/wet bell during launch and recovery. This can be done e.g. by the tensioned wires between a dropped ground weight and the launching system.

2.1.4 The launch and recovery system shall enable a safe and easy to control transport of the diving bell/wet bell.

2.1.5 Unless otherwise specified in the following Sections, the mechanical equipment of launch and recovery systems is to conform to the **TL** Guidelines for the Construction and Survey of Lifting Appliances.

2.2 Power supply, mechanical drives

2.2.1 The launch and recovery system is to be provided with at least two mutually independent power sources, each of which shall be capable of supplying all the power needed to launch and recover the diving bell/wet bell. For hydraulic drives two power pumping sets independent from each other are to be provided.

2.2.2 The power sources, together with their feed lines and switchgear, are to be so arranged that a failure or burn-out of one system cannot lead to the failure of the standby system.

2.2.3 The launch and recovery system is to be equipped with auxiliary drives enabling a launch or recovery manoeuvre which has already been started to be safely concluded should the winches or hydraulic pumps fail.

2.2.4 Launch and recovery systems using an "A" frame are to be equipped with two hydraulic cylinders which are to be so designed and arranged that each is fully capable of safely performing the launch and recovery operation under load. In addition, they are to be connected to the hydraulic system in such a way that a single fault in the hydraulic system cannot lead to the failure of both hydraulic cylinders.

2.3 Control equipment

2.3.1 Launch and recovery systems are to be fitted with control equipment enabling the system to be operated intermittently with smooth accelerations. In addition, the controls are to be designed and arranged in such a way that the operator has the diving bell/wet bell in view throughout complete launch and recovery and is fully able to perform all the necessary actions safely.

2.3.2 The controls are to be fitted with blocking devices which ensure that only those commands can be performed simultaneously which do not produce a dangerous or unintended condition.

2.3.3 Control systems are to be provided with an emergency shut-off button.

2.3.4 Wherever possible, control units are to be provided to the fail-safe principle.

2.3.5 Control units with remote control are to be additionally equipped with a direct control override. In the event of failure or malfunction of the remote control, all operating sequences which have been initiated shall be automatically stopped.

2.3.6 All control units are to be clearly and permanently marked and shall be adequately illuminated.

2.3.7 An operating platform with good view over the complete launch and recovery system is to be provided.

3. Calculation

3.1 Design loads

3.1.1 The minimum "safe working load SWL" of the launch and recovery system summarizes as follows:

- Weight of the diving bell, including its equipment, ballast weights, etc.

- Payload NL of the diving system

- Weight of the load transmitting devices which are not connected in a fixed way with the launch and recovery system

- Resulting loads of the umbilical according to 5.3 if this is transferred via the launch and recovery system

- Ground weight and guide wires.

3.1.2 Calculations are normally to be based on the assumption that the angle of engagement of the load hoisting rope may be 12° off perpendicular in any direction.

3.1.3 For the Calculation also possible external loads, which may occur during operation (e.g. dynamics, wind loads, ice accretion, etc.) are to be considered.

3.1.4 Finally also the forces from maximum ship motions and green seas, wind, ice, etc. have to be checked for the launching and recovery system in resting position and stowed on the support ship. A proof of strength considering the seaway and wind conditions according to D. is to be submitted.

3.1.5 Further on the minimum lifting speed is to be specified by the manufacturer and to be agreed by **TL.**

3.1.6 The driving machine of the winch has to be designed in a way, that a maximum torque according to a maximum pull of 1,5 times the nominal pull of the winch can be developed at reduced speed for at least 5 minutes. In analogy the hydraulic cylinders are to be laid out for 1,5 times the nominal cylinder force. For both a calculation proof is to be provided.

3.2 Materials

3.2.1 For the manufacture, processing and testing of materials the **TL** Material Rules are valid.

3.2.2 Other materials as defined in 3.2.1 are to be manufactured and processed according to recognized standards or according to specifications of the material manufacturer checked and approved by **TL.**

3.3 Calculation procedure

3.3.1 The calculation of the launch and recovery system as well as of the coil-up/coil-off mechanism for umbilicals is to be performed according to the principles of **TL** Guidelines for the Construction and Survey of Lifting Appliances. For this computation the system is to be considered as offshore lifting gear.

If the system is equipped with shock absorbers or swell compensators approved by **TL**, a reduction of the working load may be dispensed with totally or partially if agreed by **TL**.

3.3.2 Deviating from the design of offshore lifting gears, for the dimensioning of launch and recovery systems a hoist load coefficient of 2,7 and a dead load coefficient of 1,5 are to be considered independently of type and size of their safe working load. Hereby is assumed that the operation is restricted to seaway with significant wave heights up to 2 m.

Where it is proposed that launch or recovery operations should be performed in even more unfavourable conditions, previous agreement with **TL** is necessary.

4. Equipment

4.1 Where cranes are used for launch and recovery, measures are to be taken to prevent the uncontrolled turning or slewing of the crane in a seaway. The turning or slewing gear has to be capable of holding the crane in any position. The gear is also to be designed to ensure that all movements are initiated and arrested smoothly.

4.2 Launch and recovery systems are to be equipped to prevent excessive turning or swinging of the diving bell/wet bell during recovery (e.g. by the use of non-spin ropes and additional pendants).

4.3 Measures are to be provided to prevent the diving bell/wet bell from striking against the ship's hull or against the launch and recovery gear.

4.4 Winches are to be equipped with two independent brakes. One of the brakes is to be energy independent, shall be activated in case of energy failure and shall react directly on the rope drum.

4.5 The capacity of the brakes has to be sufficient to safely hold the dynamic test load specified in G.11.1.

4.6 The final positions of the launch and recovery system, like upper and lower hook and jib position as well as the slewing range, are to be monitored.

The starting and braking velocities are to be controlled.

4.7 All interchangeable single components such as blocks, hooks, shackles, etc. are to conform to recognized standards, shall have a safety of 8 against fracture related to the safe working load SWL and are to be marked with their safe working load.

4.8 The maximum static tensile stress imposed on steel wire ropes by the safe working load may not exceed 1/8 of the proven rupture strength.

4.9 The use of ropes made of fibres is only permissible in special cases and with consent of **TL**. For the use of natural or synthetic fibres the maximum static tensile stress imposed by the safe working load may not exceed 1/10 of the proven rupture strength.

5. Coil-up/coil-off mechanism for umbilicals

5.1 Coil-up and coil-off mechanism for umbilicals describe the complete equipment for handling of the umbilical on the support ship. They may be of different types, but often an umbilical winch is an integrated part of this system.

5.2 An adequate coil-up and coil-off mechanism is to be provided for the umbilical, which is tracking the umbilical without restriction of the freedom to move and without additional mechanical loads to the diving bell/wet bell under water.

5.3 The following requirements are to be considered for the design of coil-up and coil-off mechanism for umbilicals:

- Specified operating conditions, e.g. wave height and type of the support ship

- Safe working load SWL of the coil-up and coiloff mechanism for umbilicals considering the weight of the umbilical, its buoyancy in water (filled and empty) as well as the friction in water and dynamic effects, e.g. by the seaway

- The radius of the umbilical in the coil-up and coil-off mechanism is not to be less than the specified bending radius of the umbilical.

- The most unfavourable arrangement of the umbilical in relation to the coil-up and coil-off mechanism (e.g. coil-up angle, position of the winch drum, application of guide pulleys, etc.) is to be considered.

- The material Certificates have to be in accordance to the **TL** Rules Guidelines for the Construction and Survey of Lifting Appliances.

- The coil-up and coil-off mechanism have to have a power source which is in the condition to safely coil-up and coil-off the umbilical under the specified conditions.

- The coil-up and coil-off mechanism is to be equipped with auxiliary drives to be able to finish an already started coil-up and coil-off procedure in a safe way if the main drive respectively the hydraulic pump are failing.

- To avoid overstressing of umbilical and the coil-up and coil-off mechanism measuring of the tension force is to be provided at a suitable position of the system, which triggers an alarm at the control station in case of exceeding the safe working load SWL.

6. Transfer and mating systems

6.1 Stowage and deck transport

6.1.1 General

6.1.1.1 As stowage and deck transport the transfer of the diving bell/wet bell recovered by the launch and recovery system to a deposit location aboard is to be understood. The deposit location is to be protected normally against environmental influences, especially if maintenance and repair work has to be done. The diving bell/wet bell is to be safely transferred stowed and lashed for all thinkable ship movements.

Within the scope of the total diving system the following requirements are to be recognized.

6.1.1.2 If requested, in addition the transport of a diving bell to the decompression chamber or to its mating equipment is to be enabled.

6.1.2 Principles for design and equipment

The requirements of the IMO Code A.714(17): “Code of the Safe Practice for Cargo Stowage and Securing” are to be considered.

6.1.2.1 Mechanical requirements

Aboard of the support ship and under consideration of maximum ship movements, sufficiently dimensioned measures, like cargo securing elements are to be provided from ship side for:

- The complete transport way

- Storage of the diving bell/wet bell

- Lashing on deck or within the containers

- Lashing of containers with equipment

6.1.2.2 Electrical requirements

6.1.2.2.1 At the superstructures of the support ship a connecting possibility in form of a connecting plate with stay bolt preferably M 12 is to be provided at an easily accessible position, on which the protective conductor of the diving bell/wet bell can be connected without using tools.

6.1.2.2.2 For the stay of the diving bell/wet bell on deck of the support ship the measures defined in 6.1.2.2.1 are to be so arranged, that an uninterrupted equalization of the potential is possible.

6.1.2.2.3 Areas for transport and stowage are to sufficiently illuminated.

6.1.2.3 Fire and explosion protection

The stowage location for the diving bell/wet bell on the support ship is to be equipped with suitable fire extinguishing systems. This system may be a part of the fire extinguishing system of the support ship.

Explosion protection measures for areas with explosion danger, from which the diving bell/wet bell shall undergo missions, are to be provided.

6.2 Mating equipment

6.2.1 If it is necessary to transfer divers under pressure from their working place under water to the support ship for a longer lasting decompression procedure with a diving bell, a mating equipment suitable to the decompression chamber on board of the support ship is to be provided. The same is valid for the pre-compression of divers to their working conditions under water.

6.2.2 The mating system shall enable the connection and disconnection of the diving bell and the decompression chamber to be effected easily and securely even under conditions where the ship is rolling, pitching or listing to permissible degrees.

6.2.3 Where a power actuating system is used for mating operations, an auxiliary power actuating system or an appropriate means is to be provided to connect the diving bell to the decompression chamber in the event of failure of the normal power actuating system.

6.2.4 The mating system is to be provided with a safety interlock between the diving bell and the decompression chamber.

6.2.5 Further design and construction requirements are to be agreed with **TL.**

R. Hyperbaric Evacuation System

1. General

1.1 An emergency system is to be provided to evacuate the divers under pressure, in the case that the support ship has to be abandoned.

1.2 Possible evacuation systems

Depending on the local, geographical and other service conditions, different kinds of evacuation systems are conceivable, including:

1.2.1 Hyperbaric self-propelled lifeboats.

1.2.2 Towable hyperbaric evacuation units.

1.2.3 Hyperbaric evacuation units, which may be towable, suitable for offloading onto an attendant vessel.

1.2.4 Transfer of the diving bell to another ship.

1.2.5 Transfer of the divers from one diving bell to another when in the water and under pressure.

1.2.6 Negatively buoyant unit with inherent reserves of buoyancy, stability and life support capable of returning to the surface after a certain time to await independent recovery.

1.3 The documentation submitted for approval is stated in E.10.

1.4 The necessary tests are stated in G.12. Official regulations may necessitate further tests.

1.5 If a self-propelled or towable hyperbaric evacuation system permanently connected to the diving system is provided, the following requirements are to be applied.

2. Design principles

2.1 Pressure chamber

2.1.1 The pressure chamber of the hyperbaric evacuation system shall be so designed that all the divers in the diving system can be evacuated simultaneously at nominal diving depth NDD. At least one seat with safety harness is to be provided for each diver.

2.1.2 The hyperbaric evacuation system is to be equipped with its own life support system enabling the pressure, temperature, humidity and gas composition in the pressure chamber to be maintained for at least 72 hours.

The life support systems are to be provided with connections for external supply and surveillance. These connections are to be marked easily visible and in a permanent way and are to be provided in the following way:

- cold/hot water supply: ¾" NPT female thread
- breathing gases: ¼" NPT female thread

The requirements according to M. are to be considered in analogous way.

2.1.3 The hyperbaric evacuation system is to be equipped with the regulating and control devices needed to guarantee a safe environment for the divers.

2.1.4 An adequate supply of the occupants with provisions and water is to be provided. For these and medical duties a lock with interlocking against simultaneous opening of the internal and external cover is to be provided. The size of the lock has to enable e.g. the entrance of standardized CO2 absorption units.

2.1.5 The connection flange of the pressure chamber is to be s o designed that it is also able to mate to an extraneous system. It has to be possible to open the doors from both sides, but only after pressure equalization. The recovery of unconscious divers is to be enabled.

2.1.6 The pressure chamber is to be fitted with view ports in such a way that, wherever possible, all the occupants can be observed from outside.

2.1.7 The pressure chamber is to be provided with the necessary connections to enable the internal pressure, temperature, gas composition and humidity to be maintained.

2.1.8 The pressure chamber is to be adequately illuminated.

2.2 Boat part of the evacuation system

2.2.1 The boat part is to be so designed that its behaviour in a seaway corresponds to that of an enclosed lifeboat. The stability for the system with maximum load and also under consideration of rescue personnel on the system is to be proven.

2.2.2 The system is to be self-propelled and capable of navigation or shall be provided with means (e.g. suitably equipped rescue boat) enabling the complete evacuation system to be towed away quickly after launching.

2.2.3 The evacuation system is to be provided with lifting attachments enabling it to be hoisted by a standard ship's crane.

2.2.4 The evacuation system is to be constructed of materials which are at least flame-retardant and shall be equipped with a water spray system for cooling the surface in the event of fire.

2.2.5 If the life boats of the support ship are designed as fire-protected life boats, their requirements are also to be applied to hyperbaric evacuation systems.

2.3 Electrical installations

2.3.1 The hyperbaric evacuation system is to be equipped with its own power supply capable of keeping the electrical installations in operation for at least 72 hours.

2.3.2 For electrical installations the requirements according to N. are to be considered in analogous way.

2.4 Communication

2.4.1 The hyperbaric evacuation system is to be equipped with a two-way communication system for talking to the divers. If helium gas mixtures are used, a speech unscrambler is to be provided. The unscrambling devices should be designed to achieve maximum noise suppression and the automatic compensation of sound level fluctuations
A second communication system is to be provided.

2.4.2 Sign-boards with the tapping code according to O.4.2 are to be displayed inside and outside the hyperbaric evacuation system.

2.4.3 Systems with negative buoyancy, which are able to return to the surface after a certain time, are to be equipped with a transponder, which can communicate with the transponder for divers according to O.4.1.

2.5 Marking

2.5.1 The hyperbaric evacuation system shall be painted in orange to increase visibility and reflecting stripes are to be provided. In addition a radar reflector and a flash light are to be provided.

2.5.2 At the evacuation system at least three signboards according Fig. 2.3 are to be fastened, whereby one (sign-board) shall be visible from air and the others are to be fastened at vertical side parts as high as possible.

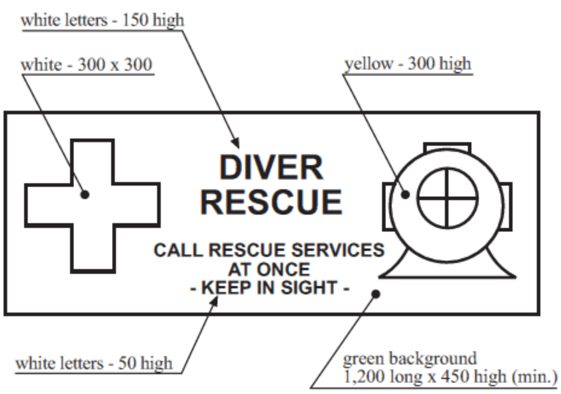

Figure 2.3 Sign-board for identification of the hyperbaric evacuation system

2.5.3 The following advices for establishing contacts are to be fixed easily visible:

- Name and home port of the support ship
- Telephone, telex and telefax connections for emergency cases

2.5.4 The following warning advices are to be fixed at to easily visible positions:

"Unless specialized diving assistance is available:

1. Do not touch any valves or other controls.
2. Do not try to get occupants out.
3. Do not connect any gas, air, water or other supplies.
4. Do not attempt to give food, drinks or medical supplies to the occupants.
5. Do not open hatches."

2.5.5 The following equipment is to be kept available and positioned easily visible:

- Towing equipment
- All external connections, as e.g. for gas, hot/cold water, connections for communication
- Lifting points with nearby definition of total weight in air and instruction for the lifting procedure

2.6 Launch, recovery and mating systems

2.6.1 The mating system of the hyperbaric evacuation system is to be designed to permit rapid and safe connection and disconnection. If a power driven mating system is provided, a manually driven system or a system with stored energy is to be provided additionally.

2.6.2 The launching system shall be able to bring the hyperbaric evacuation system safely to water and where required to take it up and mate again. If the system is floating in water, attention is to be paid especially to easy and rapid separation from the suspension considering that not always an experienced crew will be available.

2.6.3 Disconnection and launching shall also be possible if the ship's power fails.

2.6.4 As far as applicable, the principles and requirements for launch and recovery systems according to Q. are to be considered.

S. Wet Bells

1. General

1.1 Wet bells serve the purpose of safely carrying divers and their equipment from the deck of a support ship to and from the site, using either compressed air or gas mixtures as breathing gas, depending on the depth, however, without saturation being reached.

1.2 The documents to be submitted to **TL** for approval are listed in E.11.

1.3 The required tests are to be taken from G.14., the marking of wet bells is defined in H.2.

2. Design principles

2.1 Wet bells should be designed for the carriage of at least two divers, including their equipment. Normally, they consist of an upper part at head and shoulder level supporting a gas pocket and an open lower part provided with a platform enabling the divers to stand safely and as far as applicable with suitable seating.

2.2 Wet bells and the persons inside are to be adequately protected against impacts during lowering or recovering.

2.3 The supply lines for breathing gas, hot water, etc. are to be arranged from the surface through the wet bell to the divers. Alternatively, supply by a joint umbilical is possible, which is connected to the connections in the wet bell for the individual diver umbilicals.
The wet bell is to be equipped with devices for coiling up the diver umbilicals.

2.4 Wet bells are to be provided with emergency supplies of breathing gas sufficient to supply the divers at nominal diving depth NDD for a period of two hours and with an emergency breathing mask foreach diver.

2.5 The upper part of the bell supporting the gas pocket is to be equipped for scavenging with the respective breathing gas employed.

2.6 The wet bells are to be equipped with appropriate devices for the salvaging and securing of divers having suffered an accident.

2.7 Lighting is to be installed in the wet bell for working and for emergency purposes. In addition a surface communication line is to be provided.

2.8 Wet bells are to be provided with appropriate devices ensuring indication of the respective diving depth in the central control position.

3. Launching and recovery systems

3.1 Launching and recovery systems for wet bells have to safeguard safe launching and recovery under all admissible seaway and weather conditions.

3.2 The launching device has to enable that the decompression phases in the water are reliably and exactly observed. Jerky motions of the wet bell due to ropes becoming slack in a seaway are to be avoided by appropriate design measures.

3.3 Where the hoisting rope and umbilicals are arranged separately appropriate measures are to be taken for preventing these from twisting and from damaging each other during launching and/or recovery operations.

3.4 It is to be ensured that upon recovery the wet bell will be deposited on deck without jerks and impacts.

3.5 As far as applicable, the requirements defined in Q. are to be observed.

4. Equipment for breathing gas supply

4.1 For the wet bell system in accordance with the nominal diving depth NDD and mission periods supplies of breathing gas of appropriate composition are to be kept available.

4.2 Where during a diving operation and the pertinent decompression phases different kinds of breathing gas are employed, it is to be ensured that each of the gases employed can at any time be identified at the central control position.

5. Central control position

The central control position according to O.1.4 is to be equipped with all necessary devices ensuring that the parameters quoted below are at any time adhered to and monitored:

- Supply of divers with adequate quantities of the proper breathing gas

- Possibly supply of divers' thermal suits with an adequate quantity of hot water of adequate temperature

- Indication of diving depth of wet bell

- Adherence to decompression phases and periods

- Maintained communication with divers

- Insulation values of the wet bell's electrical equipment

A visual monitoring of the wet bell and the operating site by video system is recommended.

6. Diver basket

6.1 Diver baskets are simplified wet bells, but no upper part with a gas pocket is existing.

6.2 For diver baskets the relevant requirements for wet bells are to be applied in analogous way.

SECTION 3

RULES for CONSTRUCTION of DIVING SIMULATORS

A. General Rules and Instructions

1. General

1.1 The following Rules of Construction apply to diving simulators which are permanently installed in a building or similar structure and which are built under the survey and in accordance with the Rules of **TL** and which shall receive an appropriate System Certificate.

As diving simulator a pressure chamber system is understood, in which training of divers or manned and unmanned tests can be performed in dry or wet environment, at conditions which are adequate to an underwater mission.

1.2 On application by the manufacturer or operator, diving simulators built in accordance with 1.1 may also be classified by **TL.**

1.3 Buildings, power generating plants, fuel storage and gas storage facilities and similar are required to comply with the relevant national regulations of the country in which the facilities are established.

1.4 Designs other than those stated in the Rules of Construction may be approved provided their suitability has been verified by **TL** and they have been recognized as equivalent.

1.5 **TL** reserve the right to impose requirements additional to those contained in the Rules in respect of all types of facility should this become necessary in the light of new knowledge or practical experience or to sanction exceptions to the Rules in specially justified cases.

1.6 National regulations existing alongside the **TL** Rules are unaffected.

2. Definitions

Definitions are to be obtained from Section 2, C.1.
Additional special definitions for diving simulators are defined in the following:

2.1 Working gas

All gases needed for performing underwater operations such as torch work, cutting, welding etc.

2.2 Handling and transfer system

The plant and equipment necessary for raising, lowering and transporting the diving bell between the work location and the decompression chamber.

2.3 Areas subject to explosion hazard

Those locations in which an explosive gas-air mixture is continuously present, or present for long periods (zone 0); in which an explosive gas-air mixture is likely to occur in normal operation (zone 1); in which an explosive gas-air mixture is not likely to occur and, if it does, will persist for only a short time (zone 2).

2.4 Hyperbaric evacuation system

An emergency system whereby in case of troubles with the diving simulator divers under pressure can be safely evacuated to a location where decompression can be carried out.

2.5 Wet chamber

Pressure chamber with a water pool, in which training of divers as well as manned and unmanned tests can be performed at conditions which are adequate to an underwater mission.

2.6 Test chamber

A pressure chamber in which manned as well as unmanned tests can be carried out.

2.7 Living compartment

The part of the decompression chamber which can be used as the main habitation for the divers during diving simulations and which is adequately equipped.

3. Main dimensions and main parameters

Main dimensions and main parameters are to be obtained from Section 2, C.2. Special definitions for diving simulators are defined in the following:

3.1 Capacity of the wet chamber V_W

The maximum filling capacity of water in the wet chamber is V_W [ℓ].

3.2 Height of water level h_W

The height of water level in the wet chamber for maximum capacity V_W is h_W [m].

3.3 Nominal diving pressure NDP

The nominal diving pressure NDP, which is adequate to the nominal diving depth NDD [m], is the internal pressure for unrestricted operation of the diving Simulator resp. of its chambers and is to be defined for each chamber [bar].

4. Components of diving simulators

Where present, the following components form part of the diving simulator system and are to be designed, manufactured and tested in accordance with these Rules:

- Decompression chambers
- Wet chambers
- Diving bells
- Test chambers
- Gas cylinders
- Pressure vessels
- Pipes, valves, fittings and hoses
- Breathing gas systems
- Life support systems
- Welding gas absorbers
- Diver heating system
- Sanitary systems
- Communication systems
- Automation and control equipment
- Gas analyzing systems
- Electrical systems and equipment
- Fire prevention, fire detection and extinguishing equipment
- Compressors
- Gas mixers
- Helium reclaim system
- Water systems
- Hyperbaric evacuation system

5. Environmental conditions

5.1 General

As a minimum requirement, the design, selection and arrangement of all machinery, instruments and equipment of diving simulators are to be based on the environmental conditions stated in the following. For special environmental conditions coordination with **TL** is required.

5.2 Water

For the design of diving simulators and their components the temperature range of the water and the type of water (fresh or salt water) is to be defined. If not agreed otherwise, the values of Table 3.1 are to be used.

5.3 Climate

Standard values for climate conditions inside or outside the chambers are to be applied from Table 3.1. For extreme installation locations the values to be observed are to coordinated with **TL**. Equipment and instruments in pressure chambers have to function satisfactorily up to the maximum allowable working pressure.

5.4 Vibrations and shaking

Machinery shall not cause any vibration or shaking which imposes unacceptable stresses on other machines, equipment or the diving simulator.

Table 3.1 Environmental conditions

Area	Temperature	Humidity	Miscellaneous
Air in chambers	+5 to +55 ° C	100 %	İf salt water: - air with salt content
Air outside Chambers	0 to +55 ° C	80 %	
Water in wet chambers	0 to +32 ° C	-	If salt water: - 3,5 % salinity - density of 1028 kg/m^3
Control spaces	+5 to +55 ° C	80 %	-

6. Documents for approval

6.1 General

6.1.1 Before the start of manufacture, plans and drawings of all components subject to compulsory inspection, to the extent specified below, are to be submitted to **TL** in triplicate.

6.1.2 The drawings have to contain all the data necessary for checking the design and the loads imposed. Where necessary, design calculations relating to components and descriptions of the plant are also to be supplied.

6.1.3 Once the documents submitted have been approved by **TL**, they become binding for the execution. Any subsequent modifications require **TL**'s consent before they are implemented.

6.2 Total system

The following documents are to be submitted:

6.2.1 Description of plant stating the essential design parameters such as:

- Objective and purpose of the diving simulator
- Diving resp. operating procedure
- Main parameters according to 3.
- Used gases
- Maximum operating period
- Maximum number of divers in system
- Maximum rates of pressure change

6.2.2 General arrangement drawings of the diving simulator (block diagrams).

6.2.3 Installation drawings.

6.2.4 Foundation drawings, showing fixed and free points.

6.2.5 Drawings of supply and disposal systems (water and electricity).

6.2.6 Plans of control panels (control stands) including operating and indicating devices.

6.2.7 Marking system.

6.2.8 Failure Modes and Effects Analysis (FMEA in analogous way to Section 2, F.), if required.

6.2.9 Test schedule.

6.3 Vessels and apparatus under pressure

6.3.1 Drawings are to be submitted of vessels and apparatus under pressure giving full details for appraising the safety of the equipment. Especially are to be included:

- Application
- Capacities of individual compartments
- Media contained, operating overpressures and temperatures
- Proposed materials, thermal insulation paints, buoyancy material

- Specifications for welding
- Heat treatment
- Manufacturing tolerances
- Non-destructive tests

6.3.2 Drawings are also to be submitted of individual items of vessel equipment, such as:

- Windows, window flanges, retaining rings
- Door leaves and frames
- Bayonet locks
- Coupling clamps
- Block flange
- Internal facilities

6.4 Gas Supply

6.4.1 Piping diagrams and descriptions are to be furnished for the entire gas supply system, including a list of valves and fittings.

6.4.2 Description of proposed cleaning procedure for breathing gas system.

6.4.3 Details of gas analysis, including an equipment list.

6.4.4 Description of compressors and their drives with definition of essential design and operating data.

6.5 Life support systems

The following are to be submitted:

6.5.1 Piping diagrams, block diagrams and descriptions of systems.

6.5.2 Descriptions of system components and equipment.

6.5.3 Calculation of cooling and heating requirements.

6.5.4 Description and drawings of the water supply, disposal, circulation and treatment systems.

6.5.5 Description and design details of the diver heating system.

6.6 Electrical equipment

6.6.1 General arrangement drawing of the electrical equipment containing at least the following information:

- Voltage rating of systems
- Power or current ratings of electrical
- Switchgear, indicating settings for short-circuit and overload protection; fuses with details of current ratings
- Cable types and cross-sections

6.6.2 Energy balance of the main and emergency power supply system.

6.6.3 Drawings of switchgear and distribution equipmen witht part lists.

6.6.4 Complete documentation for electric motor drives with details of control, measuring and monitoring systems.

6.6.5 Battery installation drawing with details of battery types, chargers and battery room ventilation.

6.6.6 Details of electrical penetrations through pressure chamber walls.

6.7 Automation and communications equipment

It is to be submitted:

6.7.1 General arrangement drawings/block diagrams of control equipment, including lists of measuring points.

6.7.2 Equipment list for sensors, indicating instruments, etc.

6.7.3 Drawings and descriptions of electronic components such as instrument amplifiers, computers and peripheral units.

6.7.4 General arrangement drawings and equipment lists for communication systems and signalling equipment.

6.7.5 Arrangement drawing and description of the video system.

6.8 Fire protection

It is to be submitted:

6.8.1 Description of the preventive fire protection measures.

6.8.2 Details of the fire loads in the system.

6.8.3 Drawings and descriptions of:

- Fire detection system
- Fire alarm equipment
- Fire extinguishing system(s)
- Building
- Drawings of fire protection and fire escapes

6.9 Hyperbaric evacuation system

The following are to be submitted:

6.9.1 Description of system.

6.9.2 Arrangement drawing.

6.9.3 Construction drawing of the evacuation chamber.

6.9.4 Drawings of mating and handling system.

6.9.5 Emergency plan with definition of procedures for all kinds of emergency cases.

7. Tests and trials

7.1 General

7.1.1 Diving simulators and their ancillary equipment are subject to constructional and materials tests as well as to pressure and tightness tests and trials. All the tests called for in the following are to be performed under **TL** supervision.

7.1.2 For serial manufactured parts, test procedures other than those prescribed may be agreed with **TL** provided that they are recognized as equivalent by **TL.**

7.1.3 **TL** reserve the right to increase the scope of the tests, if necessary, and also to extend tests to parts for which testing is not expressly required according to the Rules.

7.1.4 Parts requiring approval are to be replaced with tested parts. The same applies to spare parts.

7.1.5 Gas storage, pressure chambers and life support systems including piping system are to be subjected to a tightness test with the adequate breathing gas or a gas mixture with similar properties at maximum allowable working pressure. As maximum permissible leakage rate 1 % pressure drop within 24 hours for the whole pressure chamber system is valid.

7.1.6 After the pressure chambers and their ancillary equipment have been installed in the operations building, the diving simulator and its auxiliary systems are to be subjected to a functional test. All items of safety equipment are to be tested except where an adequate test has already been carried out in the manufacturer's works in the presence of **TL.**

7.2 Vessels and apparatus under pressure

7.2.1 On completion, vessels and apparatus under pressure are to be subjected to a constructional test. This test covers verification that the vessel conforms to the approved drawings and that the workmanship is satisfactory. All components have to be accessible to allow proper inspection.

7.2.2 The materials test Certificates for the materials used, the reports on the non-destructive testing of welds and, where applicable, the results of inspection of workmanship the proofs for heat treatments applied are to be submitted.

7.2.3 A hydraulic pressure test is to be performed prior to insulation and preservation treatment of the vessels. Each pressure chamber compartment is to be tested individually. The walls may exhibit no permanent deformation or leakage.

7.2.4 The test pressure normally applied to vessels and apparatus shall be 1,5 time the maximum allowable working pressure.

7.2.5 Diving bells and vessels which may be exposed in service to external overpressure are, in addition, to be subjected to an external pressure test.

7.2.6 Vessels and pressure tight housings, which are arranged internally in pressure chambers and may be subjected to external overpressure, are to be tested with 1,5 times of the maximum allowable working pressure in the chamber.

7.3 Pressure chamber windows

7.3.1 Each pressure chamber window shall be subjected to a hydraulic pressure test which may be performed in a testing device or for the window and pressure chamber together after assembly. The test pressure shall normally be equal to 1,5 times the maximum allowable working pressure.

7.3.2 After the pressure test, the windows shall not exhibit any scratches, cracks or permanent deformation

7.4 Compressors

7.4.1 Compressor components subjected to pressure have to undergo a hydraulic pressure test at a test pressure equal to 1,5 times the delivery pressure of the stage concerned.

7.4.2 On completion, compressors are to be subjected to a tightness test at the maximum allowable working pressure applicable. In addition a performance test shall be performed during which the final moisture content and any possible contamination of the compressed gas shall also be determined.

7.5 Piping systems

7.5.1 On completion but before the application of insulation or paint, all piping systems are to be subjected to a hydraulic pressure test at 1,5 times the design pressure.

7.5.2 Wherever possible, all butt welded joints in gas lines for life support systems are to be subjected to 100 % X-ray examination.

7.5.3 Piping systems for breathing gas and oxygen are to be subjected to a purity test.

7.6 Hoses, hose assembly, umbilicals

7.6.1 All aspects for tests and trials of umbilicals are defined in Annex E, D.

7.6.2 As far as the requirements in Annex E, especially in B.2.4, are right for hoses, these have to be applied.

7.7 Life support systems

A functional test is to be performed to demonstrate the satisfactory operation of the life support systems under normal and emergency operating conditions.

7.8 Electrical equipment

7.8.1 Electrical machines, components, cables and lines are to be subjected to testing in the manufacturer's works in accordance with the **TL** Electric Rules.

7.8.2 All electrical systems and equipment are to be surveyed and tested before the diving simulator is put into operation.

7.8.3 The electrical safety devices are to be tested and, in addition, the electrical equipment in the pressure chambers is to be subjected to an insulation test.

7.9 Automation and communications equipment

7.9.1 Indicating and monitoring instruments are to be checked for the accuracy of their readings and their limit settings.

7.9.2 The satisfactory operation of automatic control systems is to be checked under service conditions. Proof is required of the autonomy of safety systems.

7.9.3 The communications equipment for normal and emergency operation is to be subjected to a functional test. The suitability of the helium speech unscrambler is to be verified at the nominal diving pressure NDP of the facility.

7.10 Fire protection

7.10.1 The fire behaviour of the chamber equipment is to be checked by reference to the relevant test Certificates and symbols.

7.10.2 A check is to be made as to whether the electrical heating systems and heaters are fitted with protection against overheating.

7.10.3 Fire alarm, detection and extinguishing appliances are to be subjected to a functional test.

7.11 Hyperbaric evacuation system

By a functional test it is to be proven that the hyperbaric evacuation system is able to convey divers under pressure to a safe position and to supply and keep them under surveillance during this mission.

8. Marking

Concerning marking reference is made to Section 2, H. This is to be applied to diving simulators in analogous way.

B. Principles of Design and Construction of Diving Simulators

1. General principles

1.1 Wherever appropriate and practicable, diving simulators are to be designed and built in such a way that the failure of any single component cannot cause a dangerous situation.

1.2 Diving simulators and their components are to be designed for the conditions of service described in the equipment specification.

1.3 Diving simulators are to be so designed that the planned diving operation can be performed with maximum safety for the simulator crew.

1.4 Diving simulators for technical experiments are to be equipped with suitable test chambers which shall be separable from the remaining chamber system in respect of operating media, pressure and atmospheric conditions. The living compartment of the simulator is to be so arranged that its occupants are not endangered or inconvenienced by the experiments.

1.5 Diving simulators which can be operated simultaneously with different chamber pressures are to be provided with effective means of preventing any unintentional pressure drift within the chamber system.

1.6 Diving simulators are to be designed in such a way that injured divers can be carried on a stretcher inside the pressure chamber system.

1.7 It is recommended that diving simulators shall be equipped with a hyperbaric rescue system.

1.8 If a handling and transfer system for the diving bell is used it is to be designed and constructed according to recognized regulations.

1.9 Diving simulators are to be designed and built to perform safe operation, adequate maintenance and necessary surveys.

1.10 All parts of a diving simulator are to be designed, constructed and mounted in a way which facilitates cleaning and desinfection.

2. Environmental conditions

Diving simulators, including their accessories and ancillary equipment, are to be designed for the environmental conditions likely to be encountered at the installation site or to be expected under the planned diving and test conditions, compare A.5.

3. Conditions in chambers

3.1 Diving simulators are to be equipped in such a way that a breathable atmosphere can be maintained in the pressure chambers throughout the total period of operation.

3.2 The partial pressure of CO_2 in the chamber atmosphere has to be kept permanently below 0,005 bar and for this purpose a CO_2 production of 0,05 Nm³/h per diver shall be assumed.

3.3 Under steady conditions, diving simulators shall be capable of keeping the temperature in the decompression chamber constant to ± 1 °C in the range from 27 to 36 °C while maintaining a relative atmospheric humidity of at least 50 %.

3.4 Pressure chambers are to be so arranged and equipped that a uniform chamber atmosphere can be maintained (CO_2 and O_2 levels, temperature and humidity).

3.5 Under steady conditions, the permanent noise level (over 8 hours) in the pressure chambers shall not exceed 65 dB(A).

3.6 In test chambers or for special simulation missions deviations from the aforementioned chamber conditions are permitted in agreement with **TL**, if the safety of the divers is guaranteed by special measures.

4. Arrangement

4.1 Diving simulators may only be installed and operated in areas not subjected to an explosion hazard.

4.2 As far as possible, the area of installation of diving simulators is to be kept free of fire loads.

4.3 Diving simulators and breathing gas storage facilities are to be located in areas which can be adequately ventilated and provided with suitable electric lighting.

4.4 The area of installation of diving simulators is to be separated from other operational facilities. The partition has to possess, as a minimum requirement, Class F 30 fire resistance as defined in DIN 4102.

5. Chamber equipment and chamber facilities

5.1 Pressure chamber equipment and facilities are to be suitable for operation in hyperbaric atmospheres. Under these conditions they shall not liberate any toxic or strongly irritant gases. This also applies to protective coatings and paints used inside chambers.

5.2 Only incombustible, or at least flameretardant, materials should be used in the chambers.

5.3 Permanently installed chamber equipment is to be so designed that it suffers no damage when the chamber is subjected to hydraulic pressure tests.

5.4 Equipment items in pressure chambers are to be designed and installed in such a way as to minimize the danger of injury to the divers and leave sufficient room for movement. In addition, chamber equipment and experimental apparatus shall not prevent or limit unduly the possibility of observing the divers from outside the test chamber resp. with the aid of video equipment.

5.5 Ancillary systems and equipment needed to perform tests or create experimental boundary conditions are to be designed and constructed so that they are able to perform their functions safely without danger to the divers or the simulator. The relevant requirements will be stipulated by **TL** in each case.

5.6 If diving bells are part of a diving simulator, the equipment, if applicable, shall conform to Section 2, J.

6. Corrosion protection

6.1 Diving simulators and all their ancillary components are to be effectively protected against corrosion. The corrosion protection shall be capable of being repaired or retouched at a later stage.

6.2 Anti-corrosion coatings exposed to the chamberconditions have to meet the requirements stated in 5. In addition, they shall not tend to blister or flake off under hyperbaric conditions. In wet chambers it may be necessary to make special provision for the effect of helium-saturated seawater.

6.3 Wet chambers are to be provided with an adequate anodic protection system.

C. Vessels and Apparatus under Pressure

1. Pressure chambers

1.1 General

1.1.1 The following Rules apply to pressure vessels used as pressure chambers in diving simulators.

1.1.2 The documents to be submitted to **TL** for approval are listed in A.6.3.

1.1.3 The necessary tests and markings are stated in A.7.1 - 7.3 and A.8.

1.2 Design principles

1.2.1 General requirements

1.2.1.1 Each pressure chamber or compartment is to be so equipped that it is protected against inadmissible working pressure and inadmissible pressure drops.

1.2.1.2 All open penetrations for gas, measurements and analysis are to be protected by replaceable filters mounted on the inside of the pressure chamber.

1.2.1.3 Locks are to be designed to prevent accidental opening under pressure; if necessary, suitable interlocks are to be provided.

1.2.1.4 Each pressure chamber compartment is to be fitted with view ports so that, wherever possible, all the occupants can be observed from outside.

1.2.1.5 Wherever necessary, the view ports of pressure chambers are to be protected internally and externally against mechanical damage. View ports are also to be protected against ultraviolet radiation and unacceptably high temperatures.

1.2.1.6 Each pressure chamber compartment is to be sufficiently illuminated.

1.2.1.7 Wet and test chambers are to be provided with drainage connections at their lowest points. Sumps and other drains are to be protected to prevent impurities being sucked in.

1.2.1.8 Pressure chambers are to be provided with external insulation compatible with the test conditions and with the environmental conditions at the location where the simulator is installed.

1.2.2 Decompression chambers

1.2.2.1 Decompression chambers are to be designed to allow at least two persons to pass in or out simultaneously through the locks without subjecting the other divers in the system to a change of pressure.

1.2.2.2 The living compartment of decompression chambers shall be so designed and equipped that the occupants can stand upright and each diver is provided with a bunk on which he is able to stretch out comfortably. A toilet and shower are also to be provided. The toilet and shower are to be located in a separate space. Toilets with arrangements for the external discharge of human waste as well as further waste water systems are to be equipped with suitable interlocks to prevent pressure losses in the chamber system.

1.2.2.3 The living compartment of decompression chambers and other compartments used for decompression are to be provided with a lock through which provisions, medicines and equipment can be passed in and out without subjecting the occupants of the chamber to a change of pressure.

1.2.3 Wet chambers

1.2.3.1 Wet chambers may be designed as chambers for training of divers and general duties and also as test chambers. The special conditions for test chambers are summarized in 1.2.4.

1.2.3.2 Where water partitions are fitted, an Access opening with a clear diameter of at least 800 mm is to be provided. The water level control system is to be so designed, that no water can penetrate into dry compartments in the event of pressure variations.

1.2.3.3 Water circuits are to be designed and constructed so that switching from high-pressure to lowpressure circuits cannot cause any inadmissible pressure drop in the test chamber. Furthermore, such switching operations shall not cause any unacceptable rise in pressure in low-pressure circuit.

1.2.4 Test chambers

1.2.4.1 Test chambers are to be designed and built in such a way that the proposed tests can be performed safely and any danger to the rest of the chamber system is avoided.

1.2.4.2 The dimensional design of test chamber walls is to allow for possible additional loads due to test equipment.

1.2.4.3 Depending on the type of tests, test chambers are to be separated by double doors from the rest of the chamber system.

1.2.4.4 Test chambers for technical tests are to be provided with a lock for materials.

1.2.4.5 Test chambers compartment are to be provided with sufficient mountings for test equipment. Adequate means are also to be provided for the transport and handling of test equipment.

1.2.4.6 Each test chamber compartment is to be equipped with separate gas analysis connection.

1.2.4.7 Each test chamber compartment is to be provided with separate connections for communications equipment. In addition, at least one blind flange each is to be fitted for power and measuring data transmission.

1.2.5 Diving bells

If diving bells are part of a diving simulator, these are to be laid out according Section 2, J

1.2.6 Doors and access openings

1.2.6.1 Doors and mating devices in diving simulators which are not sealed by pressure are to be equipped with a closing mechanism which precludes opening under pressure. The closing mechanism is to be so designed that the correct position of closure is clearly indicated before pressure is applied.

1.2.6.2 Means are to be provided to enable doors to be opened from both sides.

Door trunks are to be provided with pressure equalizing valves.

Devices are to be fitted which hold doors in the open position.

Doors which open or close under their own weight are to be so designed that divers are not endangered when operating them.

1.2.6.3 Doors and access openings for persons shall have a clear diameter of at least 500 mm, or at least 700 mm in the case of test chambers.

1.2.6.4 The length of door trunks should not exceed the trunk diameter.

1.2.6.5 For doors in wet chambers, the sealing groove and seal counter face should be made of not corroding materials.

1.2.6.6 Hydraulically operated doors have to meet the following additional requirements:

- The doors are to be capable of being opened manually if the hydraulic system fails.

- Steps are to be taken to ensure that doors which open under their own weight if thehydraulic system fails cannot endanger the divers.

- Steps are to be taken to ensure that the opening action can only be initiated after the pressure has been equalized.

- Operating elements fitted outside chambers to be arranged so that the operations of opening and closing the door can be observed through the view ports provided in the chamber.

- The design and dimensions of the hydraulic system for internal doors shall be compatible with the specified working pressures and with the boundary conditions of the pressure chamber system. The hydraulic fluid has to be suitable for use in the chambers and shall not under hyperbaric conditions release gas or vapours which are toxic or capable of supporting combustion.

1.2.6.7 Doors and access openings are to be laid out for the maximum allowable working pressure.

1.2.7 Pressure-proof bulkheads

Pressure-proof bulkheads for subdivision of the internal space are to be laid out for the maximum allowable working pressure.

1.3 Materials

For materials used for diving simulators the provisions of Section 2, J.1.3 are to be considered.

1.4 Principles of manufacture and construction

Pressure vessels for diving simulators are to be manufactured and constructed in accordance with Section 2, J.1.4.

1.5 Calculations

Calculations relating to pressure vessels for diving simulators are to be performed in accordance with Section 2, J.1.5. If a calculation of the diving bell for external pressure is required, this is to be agreed with **TL** according to the specification.

1.6 Acrylic windows

Acrylic windows are to be designed and manufactured in accordance with Annex C.

2. Pressure vessels, gas cylinders and apparatus under pressure

2.1 Pressure vessels, gas cylinders and apparatus under external pressure

The dimensioning procedure of Annex A or of an internationally, by recognized standard is to be applied.

2.2 Pressure vessels, gas cylinders and apparatus under internal pressure

For pressure vessels, gas cylinders and apparatus under internal pressure the requirements defined in the **TL** Machinery Rules, Section 14 or in other recognized regulations are valid.

D. Pipes, Valves, Fittings, Hoses, Umbilicals

Pipes, valves, fittings, hoses and umbilicals for diving simulators are to be designed and manufactured in accordance with Section 2, K.

E. Compressors

Compressors for the compression of breathing gases for diving simulators are to be designed and manufactured in accordance with Section 2, L.

F. Life Support Systems

1. General

1.1 These Rules apply to all parts and components of the system which are necessary to ensure the life support and safe environment of the occupants of a diving simulator.

1.2 The documents to be submitted to **TL** for approval are listed in A.6.5.

1.3 The necessary tests and markings are stated in A.7.7. and A.8.

2. Gas supply

2.1 Filling stations

2.1.1 Filling stations serve to fill the gas storage with breathing gas. The station has to include the complete equipment to fill the containers. The boundary of the gas production and filling station is located immediately behind the shut-off valve at the gas line for filling or at the suction side of the delivery system.

2.1.2 Filling stations are to be constructed and operated, that operating, surveillance and maintenance personnel or other persons nearby are not endangered.

2.1.3 Filling stations for breathing gases are not to be installed in areas where internal combustion engines or boilers are in operation.

2.1.4 Filling stations for breathing gases are to be arranged with sufficient place for operation, maintenance and cleaning, escape and rescue corridors as well as for fire extinguishing.

2.1.5 Pipe connections between filling stations for compressed air for production of breathing gases and other compressed air systems of the plant are only be established with special approval of **TL** and under consideration of additional protection measures.

2.1.6 Filling pipes/hoses and connection or coupling fittings/hoses are to be suitable for rendering pressure-less without danger. Gas under pressure, which is discharged by the safety devices is to be drawn off in a suitable way.

2.1.7 Filling connections are to be designed and marked in a way, where confusion of gases to be filled is safely avoided and a correct connection is enabled.

2.1.8 At the position of the gas delivery, the filling station is to be equipped with a manometer showing the delivery pressure.

2.1.9 Filling stations for breathing gases are to be operated manually and to be monitored.

2.2 Gas storage facilities

2.2.1 Each diving simulator is to be provided with a permanently installed gas storage facility or with a suitable location for the storage of gas cylinders.

2.2.2 The capacity of the gas storage facility shall be such that for all planned diving missions a sufficient number and quantity of gas mixtures are available to supply sufficiently all pressure chambers and divers with the right gases at all simulated depths under both normal and emergency conditions.

2.2.3 The emergency breathing gas supply is to be stored separately in gas cylinders which shall not be opened for normal operation.

2.2.4 Wherever possible, the gas storage facility is to be housed in a separate building. Rooms for the storage of oxygen are to be constructed of components having at least class F 30 fire resistance according to DIN 4102.

2.2.5 The gas storage facility is to be separated from adjoining rooms by fireproof partitioning (F 90 acc. to DIN 4102), if these rooms are subject to a fire or explosion hazard.

2.2.6 The roofing of the gas storage facility shall have adequate resistance to airborne incandescent particles and radiant heat. The floor covering is to be at least flame-retardant.

2.2.7 Gas store rooms are to be adequately ventilated. The exits are to be so arranged that it is possible to quit the rooms quickly in case of danger.

Rooms where oxygen may escape, are to be equipped with oxygen indicating and alarm devices. The sensor for oxygen is to be installed near the floor. A monitored suction of the room air near the floor may be provided as an alternative.

2.2.8 No combustible materials shall be stored in the gas storage facility.

2.2.9 Gas stores in the open are to be established in such a way that they are protected from mechanical damage and the action of outside fires. The containers shall be readily accessible from all sides. The valves are to be capable of being operated from a fixed control point.

2.2.10 Gas storage facilities are to be safeguarded against unauthorized entry. In addition, warning signboards are to be mounted prohibiting the introduction of mobile fire loads as well as the use of open fires and smoking inside the gas store.

2.3 Gas distribution

2.3.1 General

2.3.1.1 The gas supply system shall be so designed that the pressure in the living compartment of the decompression chamber can be raised at a rate of at least 2 bar/min up to 2 bar and thereafter at a rate of 1 bar/min.

2.3.1.2 The gas venting system shall be so designed that the pressure in a decompression chamber or diving bell can be lowered to 1 bar at a rate of at least 1 bar/min.

2.3.1.3 Sets of breathing apparatus controlled by respiration which supply breathing gas to persons under pressure and also remove the exhaust gas independently of the chamber atmosphere are to be designed for a gas flow equivalent to 3 times the required breathing rate per minute (AMV).

The required breathing rate per minute depends on the activity to be performed and the environmental conditions (where heavy work is performed in open water, the rate may be as much as 75 litres/ min per person).

When designing the breathing mask gas supply and exhaust gas disposal system, the number of persons simultaneously connected to the system is to be allowed for as defined in Table 3.2:

Table 3.2 Required quantity of breathing gas for breathing masks

Number of persons	Quantity of breathing gas [litres/min]
1	1 x AMV x 3
2	2 x AMV x 1,8
3	3 x AMV x 1,6
4	4 x AMV x 1,4
5	5 x AMV x 1,3
6	6 x AMV x 1,2
7	7 x AMV x 1,1
8	8 x AMV x 1,1
z>8	z x AMV x 1,0

2.3.1.4 The gas circulating systems are to be so designed that the chamber conditions stated in B.3. are maintained.

2.3.1.5 Each pressure chamber is to be equipped with at least the following gas systems:

- 2 independent gas supply systems for compression which may deliver into a single inlet pipe immediately at the chamber
- 1 chamber exhaust gas system
- 1 independent mask supply system (BIBS)
- 1 mask exhaust gas system
- 1 gas circulating system for maintaining a breathable chamber atmosphere

Where pure oxygen or gas containing more than 25 % O_2 by volume is supplied to the chamber, a separate piping system is to be provided for this purpose.

2.3.1.6 Valves in gas systems are to be arranged so that a leaking valve cannot cause any unintended mixing of gases respectively no oxygen or oxygenlike gas can penetrate into lines intended for other gases. Intersections between oxygen and non-oxygen systems are to be isolated by twin shut-off valves with a vent valve placed between them.

2.3.1.7 Filters and automatic pressure reducers are to be fitted in such a way that they can be dismounted without having to interrupt major gas supply lines.

2.3.1.8 All gas supply and exhaust lines are to be effectively protected against mechanical damage. When routed through zones subject to fire hazard they shall be provided with fireproof cladding.

2.3.1.9 If the composition of the gas of the chamber atmosphere is not breathable or contaminated, special measures (e.g. redundant masks und pressure reducers) are to be established and agreed with **TL.**

2.3.2 Pressure chambers

2.3.2.1 At least one breathing mask is to be provided for each occupant of each separately pressurized chamber compartment.

2.3.2.2 The masks are to be joined either permanently or by plug connectors to the mask gas supply and exhaust system.

2.3.2.3 The exhaust gas (exhalation line) side of the masks is to be protected against any inadmissible pressure drop or inadmissible pressure difference.

2.3.2.4 The supply of gas to the chamber is to be arranged so as to ensure that a homogeneous gas distribution inside the chamber is achieved as quickly as possible.

2.4 Conditioning of chamber atmosphere

2.4.1 Each accessible pressure chamber is to be equipped with an oxygen dosing device and a chamber gas circulating unit in which the CO_2 can be absorbed and the air temperature and humidity can be regulated. The rate of circulation shall be such as to satisfy the conditions stated in Section 2, I.2.

2.4.2 Each diving simulator is to be equipped with at least 2 chamber gas treatment units which are to be so arranged that they can be switched to adjoining chambers.

2.4.3 Test chambers for the performance of manned experiments in which gases, vapours, dust or fumes injurious to health are generated are to be equipped with extraction systems capable of aspirating the harmful substances as close as possible to their point of origin.

Such test chambers are also to be provided with purification systems (welding gas absorbers) for keeping the chamber atmosphere breathable, inert and within the permitted temperature limits, e.g. during welding operations. In addition to this, such test chambers are to be equipped with a personal breathing system and respirators independent of the chamber atmosphere. Additional equipment is to be provided to enable not only the chamber atmosphere but also the breathing gases supplied to the divers to be permanently monitored directly at the mask when work/tests are being carried out in a non-breathable atmosphere.

2.5 Treatment and mixing of breathing gases

The use of closed breathing circuits, gas mixing systems for direct breathing gas supply and helium reclaim systems is subject to approval by **TL.**

3. Control and instrumentation

3.1 Central control position

The surveillance and control of the life support systems has to be performed with the assistance of the central control position of the diving simulator according to H.1.4, where all essential chamber data are indicated as well as the chamber pressures are controlled and the gases are distributed, if more than one chamber is existing. In addition the operating conditions of the ancillary systems are indicated there.

3.2 Instrumentation

3.2.1 Indicating instruments

3.2.1.1 The instruments for the surveillance, control and operation of the diving simulator are to be grouped and arranged in the central control position in accordance with the principles of safety technology and ergonomics.

3.2.1.2 In the central control position a separate control console is to be provided for each independently operated pressure chamber compartment. For test chambers, an additional independent control position should be placed in the immediate vicinity of the test chambers.

3.2.1.3 At least the following operating parameters are to be displayed at the central control position for each manned pressure chamber compartment:

- Pressure
- Temperature
- Humidity
- Partial oxygen pressure

- Partial CO_2 pressure
- Pressure of connected breathing gas containers/ gas cylinders
- Pressure at pressure reducer outlets
- Oxygen content in supply lines to
  - umbilicals
  - chamber compartments
  - breathing masks in chambers

3.2.1.4 The instrumentation of test chambers used exclusively for unmanned tests shall be compatible with the test conditions.

3.2.1.5 The pressure gauges of pressure chambers shall give a reading accuracy of to ± 0,25 % of the full instrument scale subject to a maximum deviation of 30 cm water column. All other pressure readings may be accurate ± 1 % of the full instrument scale.

3.2.1.6 Inadmissible deviations from reference values of the vital parameters shall actuate a visual and audible alarm at the central control position. Automatically actuated switching operations in the gas supply system and similar functions shall also trip such alarms.

3.2.1.7 Pressure chamber compartments are to be equipped with pressure and temperature gauges which can be read from inside.

3.2.1.8 Pressure indicators connected directly to the pressure chamber system are to be fitted with a shutoff valve.

3.2.2 Analyzer systems

3.2.2.1 Each diving simulator is to be equipped with at least one oxygen and one CO_2 analyzing system.

3.2.2.2 Throughout the entire period of operation, the oxygen analyzer has to give a reading accuracy of at least ± 0,015 bar partial oxygen pressure.

3.2.2.3 Throughout the entire period of operation, the CO_2 analyzer has to give a reading accuracy of at least ± 0,001 bar partial CO_2 pressure.

3.2.2.4 Decompression chamber living compartments are to be equipped in addition with independent instruments for monitoring the oxygen and CO_2 levels.

3.2.2.5 Where gas mixtures other than air or helium-oxygen or $He/N_2/O_2$ are used in diving operation, suitable additional analyzing devices are to be provided for analyzing the gases used. The necessary instrumentation is in each case to be defined together with **TL.**

3.2.2.6 Test chambers in which welding operations are performed are to be equipped with analyzers for continuously monitoring the chamber atmosphere for impurities such as CO, NO, NOx, hydrocarbons and ozone. It is necessary to ensure that the analyzers are also able to monitor the chamber atmosphere of the other pressure chambers. Devices are also to be provided for the analysis of pure gases, breathing gas mixtures and purified helium gases.

The accuracy of the analyzer readings shall be such that the discrepancy between the partial pressure in the gas and the partial pressure readings on the instrument does not exceed 10 %.

3.2.2.7 For diving simulators where the chamber atmosphere is not subject to contamination as a result of technical experiments, test tubes may be recognized as a suitable means of monitoring the chamber atmosphere for contamination.

3.3 Control equipment

3.3.1 The central control position is to be equipped with controls for at least the following functions:

- Pressurization and pressure control of each independently operated pressure chamber compartment and each diving bell
- Decompression of each independently operated pressure chamber compartment and each diving bell

- Pressure equalization between chamber compartments

- Oxygen addition to the chamber compartments

- Control of gas supply to breathing maks

- Control of temperature and humidity in the pressure chambers

3.3.2 At the control position for the gas distribution a system mimic diagram is to be provided showing the functions of the various valves and the different gas lines marked in colour.

G. Electrical Installations

1. Electrical installations and systems for diving simulators are to be designed and constructed according to Section 2, N.

The electrical components and systems which are installed outside pressure chambers are to be at least equivalent to a recognized standard such as e.g. VDE, DIN resp. IEC.

2. The documents for approval are defined in A.6.6.

3. The required tests are defined in A.7.8.

H. Automation Equipment and Communications Equipment

1. General

1.1 The following Rules supplement of **TL** Electric Rules are to be applied to the construction and application of equipment for the surveillance, control and closed loop control of diving simulators as well as for communications and video monitoring systems.

1.2 The documents for approval to **TL** are listed in A.6.7.

1.3 The necessary tests are stated in A.7.9. Only components and units which have been approved by **TL** may be installed.

1.4 Central control position

The requirements for the central control position are to be applied in analogous way according to Section 2, O.1.4.

2. Automation equipment

Automation equipment for diving simulators is to be designed and constructed in accordance with Section 2, O.2.

3. Communication equipment

3.1 Voice communication systems

3.1.1 Diving simulators are to be equipped with a suitable communications systems allowing direct communication between the central control position and:

- Diving bells

- Each compartment of pressure chambers

- Test equipment control positions

- Pressure chamber control consoles

- Ancillary units

- Offices and service rooms (e.g. the operations manager's office and mechanical and electrical workshops)

3.1.2 Where diving simulators are operated with helium gas mixtures, each pressure chamber compartment is to be connected to a helium speech unscrambler. The speech unscramblers shall be designed for maximum noise suppression and automatic compensation of changes in signal level.

3.1.3 It is recommended that the central control position is equipped to record all communications with the divers.

3.1.4 Voice communications between the pressure chamber compartments and the central control position is to be provided by a communication system with loudspeaker which is permanently switched to "Receive" at the control console. Switches for reversing the direction of communication are to be of the self-resetting type. In addition, each pressure chamber compartment is to be provided with at least one headset.

3.1.5 A mains-independent telephone link shall be provided in addition to the telephone system called for in 3.1.4.

3.1.6 Electrically powered telephone systems are to be provided with a reliable power supply. This normally means that they are to be supplied from a storage battery with a parallel-connected mains unit and battery charger supplied with energy in accordance with Section 2, N.

3.1.7 In wet rooms microphone and receiver systems are to be designed to prevent the penetration of water. Where this cannot be ensured by the design, the penetration of water shall not render the equipment permanently unserviceable.

3.1.8 The microphone and receiver in diver's masks, hoods and diver helmets are to be functionally separated from each other.

3.2 Video surveillance equipment

3.2.1 Diving simulators are to be equipped with a video surveillance system.

3.2.2 The number of cameras and their angles of view shall be chosen to cover all chambers of the diving simulator. In wet chambers it is to be considered that the chambers may be partially filled with water and adjustable test equipment may obstruct the view.

3.2.3 A sufficient number of video monitors is to be provided. Each video monitor has to indicate clearly which compartment is being viewed at any time.

3.2.4 The image reproduced on the monitors has to enable the recognition of necessary details.

3.2.5 The installation of a video recorder is recommended.

3.3 Other communications equipment

3.3.1 All pressure chamber compartments are to be provided with suitable alternative communications equipment (e.g. a 3-button signalling system).

3.3.2 Diving simulators should be provided with equipment for transmission of radio and video programmes which can, if necessary, carry operational telephone communications as priority traffic.

I. Fire Protection

1. General

1.1 The following Rules apply to the fire protection of diving simulators built in accordance with the Rules of **TL**.

1.2 The documents to be submitted to **TL** for approval are listed in A.6.8.

1.3 The necessary tests are stated in A.7.10.

2. Structural fire protection

2.1 Area of installation of the diving simulator

2.1.1 Buildings for diving simulators and their ancillary units are to be designed and constructed in accordance with the building regulations in force at the site where the diving simulator is to be installed.

2.1.2 Diving simulators may only be installed and operated in areas not subject to an explosion hazard.

2.1.3 The rooms in which the diving simulator, the central control position and the gas storage facility are installed are to be separated from other service rooms by floors and walls with class F 30 fire protection according to DIN 4102. If the adjoining rooms are considered to be subject to a fire hazard, the relevant partitions are to be established fireproof (F 90).

2.1.4 The rooms in which diving simulators and their ancillary units are installed are to be provided with forced ventilation systems capable of effecting at least 8 changes of air per hour. The air is to be aspirated from an area not subject to an explosion hazard. The rooms are also to be equipped with an effective smoke extraction system.

2.1.5 In the area of installation of the diving simulator, the gas storage facility and the central control position, sources of ignition and fire loads are to be limited to a minimum. Wherever possible, materials which are at least fire-retardant are to be used. Heat insulation is to be made of non-combustible materials.

2.2 Pressure chamber interiors

2.2.1 Wherever possible, all materials used in pressure chambers are to be at least flame-retardant. (For the purpose of these Rules, flame-retardant refers to materials which do not sustain combustion on their own in a compressed air atmosphere of at least 6 bar absolute.)

2.2.2 As far as possible, fire loads and sources of ignition are to be avoided. Electrical heating appliances and heaters are to be fitted with protection against overheating.

2.2.3 Components or materials are to be selected with a view to avoid acquisition of static charges as far as possible.

3. Fire surveillance

3.1 Fire detection systems and alarm systems

3.1.1 The rooms in which diving simulators and their ancillary units are installed are to be protected by an automatic fire detection system.

3.1.2 The fire detection system has to trip visual and audible signals at least in the permanently manned central control position.

3.1.3 The fire alarm can be activated manually from the permanently manned central control position or automatically by the fire detection system.

3.2 Fire detection systems

3.2.1 Fire detection equipment such as the central fire detection station, the detectors and the wiring of the detection loops are to be recognized by **TL.**

3.2.2 Fire detection systems are to be constructed so that any faults, e.g. failure of the power supply, short-circuit or wire breakage in the detection loops or the removal of a detector from its base, trip visual and audible signals in the fire detection station at the central control position.

3.2.3 For the installations and arrangement of fire detection and signalling systems the **TL** Electric Rules, Section 9, C. and Automation are to be observed.

4. Fire extinguishing equipment

4.1 Area of installation of the diving simulator

4.1.1 The area of installation of the diving simulator and its ancillary units is to be equipped with a water fire extinguishing system as well as with portable and mobile fire extinguishers and extinguishing appliances.

4.1.2 The water fire extinguishing system is to be fed by a wet 100 mm nominal width ring main in the building. The ring main is to be fitted with hose connections in a way which ensures that a fire inside the building can be effectively and safely combated.
Hose connections are to conform to DIN 14461, Part 3. Suitable hose boxes (e.g. to DIN 14461, Part 1) containing hoses and nozzles are to be placed close to the hose connections.

In addition, a non-freeze water hydrant is to be placed close to the diving simulator operations building (e.g. an underfloor hydrant acc. to DIN 3221 or an abovefloor hydrant acc. to DIN 3222).

4.1.3 In the case of diving simulators without a hyperbaric evacuation system, the pressure chamber system is to be provided with means of cooling in case of fire in the form of a permanently installed water spray system with a capacity of at least 10 ℓ/m^2 per minute related to the projected horizontal area concerned. The water spray system has to encompass at least all the living areas. These spray systems may be activated and operated by hand.

4.1.4 Rooms in which diving simulators and their ancillary units are installed are to be equipped additionally with approved hand extinguishers. In each case, one of the portable extinguishers is to be mounted close to the entrance to the room concerned.

4.1.5 Where the room in which the diving Simulator is installed is also used wholly or in part as a workshop, the room in question is to be additionally equipped with at least one mobile 50 kg dry extinguisher.

4.2 Pressure chambers

4.2.1 Each compartment inside a pressure chamber is to be equipped with suitable means of extinguishing a fire in the interior and such means shall be capable of applying the extinguishing agent quickly and effectively to all parts of the chamber.

4.2.2 The fire extinguishing system is to be designed and constructed in such a way that it is fully able to deal with any conceivable cases of fire under all environmental conditions for which the diving simulator is designed. Activation of the fire extinguishing system shall cause no inadmissible loss of pressure in the chamber. The extinguishing system may be activated by hand.

4.2.3 The preferred extinguishing agent is water. Extinguishing agents with a toxic or narcotic effect are not allowed.

4.3 Diving bells

A fire protection/fire system equipment according to size, mission and equipment of the diving bell is to be provided.

5. Other fire protection equipment

The central control position of the diving simulator is to be provided with at least one independent compressed-air respirator of approved design having an operating capability of at least 30 minutes and fitted with equipment for voice communication with the divers.

J. Hyperbaric Evacuation System

1. General

1.1 Where a hyperbaric evacuation system permanently connected to the diving simulator is provided, the following Rules are to be applied.

1.2 Where the evacuation chamber is also to be used as a decompression chamber the relevant requirements for decompression chambers in this Section are also to be applied additionally.

1.3 The documents to be submitted to **TL** for approval are listed in A.6.9. The necessary tests are stated in A.7.11.

2. Design principles

2.1 Evacuation chamber

2.1.1 The hyperbaric evacuation chamber is to be designed for the simultaneous rescue of all the divers in the diving simulator at the nominal diving depth NDD. At least one seat with safety harness is to be provided for each diver.

2.1.2 The evacuation chamber is to be provided with a lock for supplies.

2.1.3 The evacuation chamber is to be equipped with view ports enabling all the occupants to be observed from outside.

2.1.4 The chamber connections for gas, water and electrical energy are to be designed for rapid coupling and uncoupling.

2.1.5 The evacuation chamber is to be illuminated adequately.

2.1.6 The rescue chamber is to be equipped with an autonomous life support system enabling the pressure, temperature and gas composition in the chamber to be maintained for at least eight hours. The life support system respectively the rescue chamber is to be provided with connections for external supply and surveillance.

2.1.7 The evacuation chamber is to be equipped externally with regulating and control devices enabling a safe atmosphere for the divers to be maintained in the chamber.

2.1.8 The evacuation chamber is to be equipped with a telephone system allowing communication with the divers.

2.1.9 The evacuation chamber is to be provided with its own power supply enabling the operation of the essential electrical installations for at least eight hours.

2.1.10 The evacuation chamber is to be so designed that it can be operated in the open air.

2.1.11 The evacuation chamber is to be equipped with a mating and handling system enabling it to be quickly and safely connected and disconnected and conveyed to a safe position without external power.

2.1.12 The evacuation chamber is to be provided with attachment points enabling it to be hoisted by a standard crane.

SECTION 4

RULES FOR CONSTRUCTION OF DIVER PRESSURE CHAMBERS

Page

A. General Rules and Instructions

1. Scope

1.1 The following Rules apply to diver pressure chambers (treatment chambers, transport chambers) which are intended for the treatment or transport of sick divers under pressure and which are constructed under survey of and in conformity with the Rules of **TL** and are to get an adequate Certificate. They also apply to all equipment necessary to the safe operation of the diver pressure chambers.

2. Definitions

Definitions are to be learned from Section 2, C.1. Additional special definitions for diver pressure chambers are defined in the following:

2.1 Breathing connection

Connection between the demand breathing system and the user's respiratory passages.

2.2 Working pressure

The internal over pressure in a part of the system necessary for the operation.

2.3 Treatment chamber

Diver pressure chamber intended for the treatment of diver sicknesses under pressure.

2.4 Compressed air /breathing gas stock

Total quantity of stored compressed air or breathing gases.

2.5 Main chamber

Part of pressure chamber used for carrying out treatment under pressure.

2.6 Demand breathing system

Respiration-controlled metering system.

2.7 Test pressure

The overpressure to which a component is subjected for test purposes.

2.8 Diver pressure chamber

Pressure chamber intended for the treatment or transport of sick divers under pressure.

2.9 Transportable chamber

Mobile diver pressure chamber intended for the transport of sick divers to a treatment chamber under pressure.

2.10 Antechamber

Part of pressure chamber for the lock in and out of persons and equipment

3. Documents for approval

3.1 General

3.1.1 Before the start of manufacture, plans and drawings of all components subject to compulsory inspection are to be submitted to **TL** in triplicate.

3.1.2 The drawings shall contain all the data necessary to check the design and the loading of the equipment. Wherever necessary, calculations relating to components and descriptions of the system are to be submitted.

3.1.3 Once the documents submitted have been approved by **TL**, they become binding for execution. Any subsequent modifications require **TL**'s consent before they are implemented

3.2 Pressure chambers, vessels and apparatus under pressure

3.2.1 Drawings are to be submitted of pressure chambers, vessels and apparatus under pressure giving full details for appraising the safety of the equipment. In addition component drawings and detailed data of the equipment of pressure chambers and vessels are to be submitted.

3.2.2 Plans, block diagrams and descriptions, including lists of valves and fittings are to be submitted for the supply, operating and control systems.

4. Tests and trials

4.1 General

4.1.1 Diver pressure chambers and their ancillary equipment are subject to preliminary examination, constructional and materials tests as well as to pressure and tightness tests and trials. All the tests called for in the following are to be performed under **TL** supervision.

4.1.2 After the diver pressure chambers and ancillary equipment have been installed at the installation location, the system is to be subjected to functional testing and all items of safety equipment are to be tested except where this has already been done on the manufacturer's premises in the presence of **TL.**

4.2 Diver pressure chambers, vessels and apparatus under pressure

4.2.1 On completion, pressure chambers, vessels and apparatus under pressure are to be subjected to a constructional test.

The constructional test includes verification that the vessel conforms to the approved drawings and that the workmanship is faultless. All components are to be accessible for adequate inspection.

4.2.2 The material test Certificates for the materials used, the reports on the non-destructive testing of welds as well as the results of inspections of workmanship and evidence of the heat treatments applied are to be submitted, where appropriate.

4.2.3 A hydraulic pressure test is to be performed prior to preservation treatment of the vessel. Each pressure chamber compartment is to be tested individually. The walls may exhibit no permanent deformation or leakage.

4.2.4 The test pressure shall normally be equivalent to 1,5 times the maximum allowable working pressure.

4.2.5 The gas storage facility and the diver pressure chamber including the piping system are to be subjected to a tightness test using air at the maximum allowable working pressure.

4.2.6 Gas cylinders are to be checked to determine whether they bear the test date and marking applied by a recognized expert and whether the test period has not yet expired.

4.3 Pressure chamber windows

4.3.1 Each pressure chamber window has to undergo a hydraulic pressure test which may be performed after installation together with the pressure chamber or in a testing device. The test pressure shall normally be equivalent to 1,5 times the maximum allowable working pressure, and the pressure direction is to be permanently marked in the window.

4.3.2 After the pressure test, windows shall exhibit no scratches, cracks or permanent deformation.

4.4 Compressors

Compressors are to be subjected to a tightness test at their maximum allowable working pressure of the compressor stage concerned. In addition, a performance test is to be carried out in which the final moisture content and any possible contamination of the compressed gas are to be determined. The safety devices are to be checked.

4.5 Piping systems

On completion of manufacture but before insulation or painting, all piping systems are to be subjected by the manufacturer to a hydraulic pressure test at 1,5 times the maximum allowable working pressure and are to be cleaned. A Manufacturer Test Report is to be issued to this effect.

4.6 Control, communications and safety equipment

4.6.1 Indicating and monitoring instruments are to be tested for the accuracy of their readings and their limit value settings.

4.6.2 Automatic monitoring systems are to be checked for satisfactory performance under service conditions.

4.6.3 Normal and emergency communications equipment is to be subjected to a functional test.

4.6.4 Proof is required of the reliable functioning of all safety systems.

4.7 Electrical equipment

4.7.1 All electrical systems and equipment are to be inspected and tested before the diver pressure chamber is put into service.

4.7.2 Electrical protective devices are to be checked; in addition, an insulation test is to be performed on the electrical equipment in the pressure chambers.

4.8 Fire protection

4.8.1 The fire behaviour of the chamber equipment is to be checked by reference to the relevant test Certificates and symbols, as applicable.

4.8.2 A check is to be made as to whether the electrical heating systems and heaters are fitted with protection against overheating.

4.8.3 Fire extinguishing appliances are to be subjected to a functional test, as far as applicable,

4.9 Mating systems

4.9.1 The mating procedure is to be tested; in case of power drive the main drive as well as the auxiliary drive has to be tested for correct functioning.

4.9.2 A check is to be carried out to verify that the bayonet flange connection cannot be subjected to pressure until the inner ring of the bayonet mechanism has turned fully home, and that the bayonet flange connection cannot be opened until the pressure has been relieved. Furthermore, the pressure relief device of the flange connection is to be checked.

5. Marking

5.1 All diver pressure chambers are to be fitted in a prominent position with a permanently mounted name plate containing at least the following details:

- Name or company designation of manufacturer
- Year of construction and serial number
- Maximum allowable working pressure [bar]
- Test pressure [bar]
- Capacity [ℓ] (data of each chamber compartment)
- Total weight including persons (only for transport chambers) [kg]
- Maximum permissible number of persons for each chamber compartment
- Date of test
- Test stamp

5.2 Concerning the marking of all other pressure vessels and gas bottles reference is made to Section 2, H.4.

5.3 Concerning the marking of all valves and fittings, operating elements, indicators and warning devices reference is made to Section 2, H.3.

B. Principles for Design and Construction

1. General principles

1.1 Diver pressure chambers are to be designed and built to ensure safe operation and facilitate the performance of proper maintenance and necessary surveys.

1.2 All parts of diver pressure chambers are to be designed, constructed and mounted in such a way as to facilitate cleaning and disinfection.

1.3 Diver pressure chambers are to be so designed that a working pressure of at least 5 bar can be reached and maintained without fail. Provision is to be made for raising the working pressure from 0 bar to 5 bar within 6 minutes. A pressure reduction from 0,4 bar to 0,2 bar shall be possible within one minute.

1.4 Diver pressure chambers are to be equipped with a suitable safety device which automatically prevents the maximum allowable working pressure from being exceeded by more than 10 %.

In addition, diver pressure chambers are to so be equipped, that they are safeguarded against inadmissible pressure drop.

1.5 Safety valves are to be so designed that they respond only when the maximum allowable working pressure has been exceeded and close before the pressure drops below this level.

Safety valves are to be mounted in such a way that they are protected from mechanical damage and accidental operation.

The connection of safety valves on diver pressure chambers are to be so designed that they cannot be sealed off unintentionally.

1.6 Instead of the pressure relief device, equipment may be fitted which automatically interrupts the pressure supply when the maximum allowable working pressure is exceeded and simultaneously trips a visual and audible alarm. The alarm signal shall be such that it is at all times clearly perceptible to the operating personnel.

1.7 The door opening of diver pressure chambers shall allow the passage of a patient laying on a stretcher according to DIN 13024. Round door openings are to have a clear diameter of at least 0,70 m. Doors fitted with an interlock shall be capable of being operated from both sides when the pressure has been equalized. Diver pressure chambers operated on ships, floating structures or in containers have to be fitted with a device that avoids swinging of the doors also in the open position.

1.8 Diver pressure chambers are to be fitted with observation windows giving a good view of all the occupants of treatment chambers and of the head of the occupant of transport chambers. The windows are to be made of acrylic plastic.

1.9 Each pressurized gas supply and exhaust line has to be fitted at least with a shut-off valve immediately at the pressure chamber wall. This shut-off valve may be dispensed with if the connection to the first valve is short and well protected.

1.10 Diver pressure chambers are to be so designed and equipped that the noises in the chamber do not exceed a peak level of 90 dB(A) measured as an A(pulse) acoustic pressure level according to DIN 45645, part 2 or an evaluation level (according to DIN 45645, part 1, related to 3 hours) of 70 dB(A).

These values apply to the head level of persons situated inside.

1.11 The interior equipment of diver pressure chambers shall be made of materials which are at least flame-retardant (class B1 acc. to DIN 4102 or acc. to ISO 6941). The use of plastics for the interior equipment of chambers is to be kept to a minimum.

2. Treatment chambers

2.1 General requirements

2.1.1 Treatment chambers have to comprise at least a main chamber and an antechamber. They should also be equipped with a connecting flange for transport chambers subject to DIN 13256, part 6, (NATO flange).

2.1.2 The inside diameter of the treatment chamber should be at least 1,48 m.

2.1.3 The configuration of the main chamber shall provide space for at least one person laying down and two persons seated.

The number of persons allowed in the main chamber is to be stated on a plate easily visible and permanently fixed above the entrance.

2.1.4 Seats have to be provided according to the number of persons admitted. Seats are to be designed to provide each person with a seat width of at least 0,5 m and a seat depth of at least 0,4 m and shall avoid loss of body heat due to contact with cold surfaces.

2.1.5 After deduction for interior equipment, the chamber shall provide at least 0,5 m^3 of space for each person to be accommodated.

2.1.6 The main chamber is to be equipped with means of changing the air.

2.1.7 Each person to be accommodated is to be provided in the main chamber with a source of oxygen supplying at least 75 ℓ/min at atmospheric pressure.
The oxygen is to be supplied to the breathing connection via a demand breathing system at the pressure prevailing in the chamber. The exhaled gas shall not be introduced in the chamber atmosphere.

2.1.8 Main chamber and antechamber shall be separately serviced with air and oxygen for breathing. Means are to be provided to prevent the pressure in the antechamber exceeding that in the main chamber.

2.1.9 The main chamber is to be equipped with heating. The heating capacity has to be equivalent to at least 0,25 kW per m^3 of chamber volume and shall have at least 3 settings.

2.1.10 The main chamber is to be provided with a supply lock. The dimensions of the supply lock shall not be less than 200 mm in diameter and 300 mm in length. The means of closure of the supply lock are to be interlocked in such a way that they can on no account open simultaneously. Pressure equalizing apertures are to be safeguarded to prevent them from being rendered ineffective by obstructions. The pressure in the supply lock is to be indicated by a pressure gauge or a suitable device mounted externally at the lock controls.

2.1.11 The vessel wall of the main chamber is to be fitted with at least one DN 80 blind flange for later installations.

2.1.12 The main chamber has to be provided with easily accessible means of mounting for an additional pressure gauge for checking the chamber pressure.

2.1.13 The configuration of the antechamber shall be such that it can accommodate two seated persons.

2.2 Compressed air and oxygen supply

2.2.1 A supply of compressed air is to be provided for the operation of the treatment chamber which is sufficient to

- Raise the pressure in the main chamber once and in the antechamber twice from 0 bar to 5 bar overpressure,

- Hold an overpressure of 5 bar in the main chamber for 30 minutes with an adequate rate of air change, and

- Hold an overpressure of 1 bar overpressure in the main chamber for 300 minutes with an adequate rate of air change.

The design of the air change system is adequate if it is capable of exchanging 30 litres of air per minute per person at working pressure.

In the main chamber it shall be possible to effect the aforementioned pressure rise within 6 minutes.

2.2.2 The air supply system is also to be equipped with an air compressor at least capable of meeting the air change requirements stipulated in 2.2.1.

2.2.3 The capacity of the air compressor called for in 2.2.2 may be reduced provided that the treatment chamber is equipped with an efficient CO_2 absorber and suitable quantities of lime or other CO_2 absorption media are carried.

2.2.4 Notwithstanding 2.2.2 an air compressor may be dispensed with if an additional emergency air supply is carried in compressed air containers which corresponds to at least 50 % of the quantity of air specified in 2.2.1.

2.2.5 The air supply system is to be provided with an additional inlet for compressed air.

2.2.6 The air supplied to the treatment chamber shall conform at least to the purity requirements specified in EN 12021 "Compressed Air for Breathing Apparatus".

2.2.7 For oxygen treatment a supply of oxygen of at least 20 m^3 has to be provided.

2.2.8 For treatment chambers which are designed for a working pressure higher than 5 bar, above requirements for the available gas volumes are to be applied in analogous way.

2.3 Electrical equipment

2.3.1 All electrical equipment including lighting shall conform to DIN 57100, part 706/VDE 0100, part 706 and VDE 0100.

2.3.2 All electrical equipment is to be safeguarded to prevent overheating.

2.3.3 The lighting in the antechamber and main chamber of treatment chambers has to provide a nominal illuminance of at least 200 lux at the seating level. It shall be possible to illuminate lying surfaces with an illuminance of 500 lux (e.g. by adjustable spotlight).

2.3.4 An emergency power supply is to be provided to illuminate the treatment chamber, the control console and all consumers necessary to operational safety. In case of mains failure, this has to take over the power supply to the consumers and shall ensure continued operation for at least 5 hours.

2.4 Controls and indicating instruments

2.4.1 The controls and indicating instruments for the antechamber and main chamber are to be grouped in one control console. They are to be clearly marked, arranged according to function and shall be illuminated in accordance with DIN 5035, part 2. The nominal illuminance shall be 300 lux.

2.4.2 The pressure in each antechamber and main chamber is to be indicated by at least one class 0,25 pressure gauge.

2.4.3 A facility is to be provided for continuously recording the pressure in the main chamber. The system shall register pressure variations of 0,03 bar and time intervals of 1,0 min in a manner which enables the data to be evaluated. The pressure variations over the previous 2 hours shall be visible.

2.4.4 The console is also to be fitted with indicators registering the following:

- Pressure in the compressed air storage containers
- Pressure in the oxygen storage containers or further breathing gas storage containers
- Scavenge air flow rate
- Inside temperature in the main chamber
- Volumetric concentration or partial pressure of the oxygen

2.4.5 A clock with a second hand, independent of the mains supply, is to be mounted where it can be seen at the control console. Clocks with a digital display as the sole indicator are not permitted.

2.5 Communications

2.5.1 A communication system with loudspeaker is to be provided between antechamber and control console and between main chamber and control console. The communication system is to be permanently switched to "Receive" on the control console, and reversal of the direction of communication shall be possible only by self-resetting switches.

2.5.2 A telephone link independent of the mains supply shall be provided in addition to the communication system called for in 2.5.1.

2.5.3 At least one emergency signalling system each has to be installed between the antechamber and the control console and between the main chamber and the control console. The signal buttons in the chambers are to be clearly marked and easily accessible.

2.6 Fire protection equipment

Treatment chambers are to be equipped with suitable fire-extinguishing appliances (e.g. deluge system, bucket spray, fire-extinguishing blanket).

3. Transportable chambers

3.1 For consideration of safety the use of one man transportable chambers should no longer be envisaged. In addition to the sick diver the transport chamber should be capable of accommodating an accompanying person. Apart from the general requirements according to 1. the following requirements apply.

3.2 Transportable chambers shall have an inside length of at least 2,0 m and shall have an access port with a clear diameter of at least 0,5 m.

3.3 It shall be possible to lodge the diver in the transportable chamber securely enough to prevent injury due to motions during transfer. Suitable holding devices or belts are to be provided.

3.4 Transportable chambers shall regarding their total weight and dimensions be designed such that they can be carried or moved otherwise by helpers over short distances and loaded onto a transport vehicle without the assistance of a crane.

3.5 Transportable chambers are to be equipped with lifting handles, at least two fastening eyes and the necessary hoisting sling.

3.6 Transportable chambers are to be fitted with a bayonet flange connection as per DIN 13256, part 6, (NATO flange) to enable them to be coupled to a treatment chamber. It has to be secured that the bayonet flange connection cannot get under impermissible overpressure.

3.7 The design has to ensure that, for operation according to instructions, the means of closure of the transportable chamber can only be opened until the closure is subjected to the same pressure from inside and outside.

3.8 Transportable chambers are to be equipped with compressed air containers with at least 8000 litres (at atmospheric pressure) air supply.

This supply of air is intended for the sole purpose of scavenging the atmosphere in the event of an interruption of the normal air supply. Adequate scavenging of the atmosphere means 25 litres per minute and person measured at the maximum pressure in the chamber.

3.9 Transportable chambers are to be equipped with at least the following controls and monitoring instruments:

- Air inlet valve

- Exhaust air valve

- Scavenge air valve

- Pressure gauge (class 0,25) for chamber pressure

- Pressure-reducing valve, with inlet and outlet pressure gauge, to which the compressed air containers called for in 3.8 are connected

- An additional means of connection, with shut-off device, comprising a suitable high-pressure hose at least 1,5 m in length for connecting the operational compressed air supply to the pressure reducing valve

- Measuring instrument for monitoring of the oxygen volume concentration or partial pressure

3.10 The controls and indicating instruments shall continue to be capable of being operated or observed when the transportable chamber is coupled to the treatment chamber. They are to be located close to a window in the vessel in such a way that the operating personnel can observe the persons in the transportable chamber without having to change position.

3.11 A flow of scavenge air of at least 25 litres per minute and person (measured at the chamber pressure) shall be secured at each pressure stage.

3.12 For the purpose of scavenging transportable chambers shall be operated only with breathing air meeting the purity requirements as per EN 12021, "Compressed Air for Breathing Apparatus". Connections for sources of oxygen as per 2.1.7 are to be provided.

3.13 A communication system with loudspeakers is to be provided between the inside of the transportation chamber and the outside controls. On the outside, the system shall be permanently switched to "Receive", and reversal of the direction of communication shall only be possible by the operation of a self-resetting switch mounted on the outside. On the outside the communication system is also to be equipped with a head-set.

3.14 Transportable chambers are to be provided with a supply lock as per 2.1.10.

4. Materials

The materials used for walls subjected to pressure are subject to the requirements set out in Section 2, J.1.3.

5. Manufacture

The manufacture of diver pressure chambers is subject to the requirements set out in Section 2, J.1.4.

6. Calculations

For the calculation of diver pressure chambers Section 2, J.1.5 is valid.

ANNEX A

CALCULATION of the PRESSURE HULL

A. General

1. Introduction

1.1 In the following a calculation method is described which investigates the stress and stability situation in the pressure hull for the load cases I, II and III with the pressures:

- Nominal diving pressure NDP (load case I according to **TL** Rules for Submersibles Section 4, E.)
- Collapse diving pressure CDP (load case II)
- Test diving pressure TDP (load case III)

In the following the method of calculation for stiffened cylindrical shells is presented. For unstiffened cylindrical shells with dished ends the calculations are analogously performed for the sectional area of the stiffening ring $A_{eff} = A_F = 0$, whereas the buckling length is limited by the dished ends. If the buckling length is limited by dished ends, 40 % of the curve depth is to be added for each dished end to the cylindrical length.

The method of calculation presented takes account of manufacturing related deviations from the ideal form of the shell (e.g. out-off-roundness). The manufacturing tolerances defined in Annex B have to be applied for the calculation.

1.2 Conical shells are calculated in sections, each of which is treated like cylindrical shells.

1.3 The overall collapse of the construction is regarded as buckling of the pressure hull between bulkheads, web frames and dished ends.

For the states of stability described, proof is required of sufficient safety in respect to the particular form of damage concerned.

1.4 When using the method of calculation it is to observe, that both elastic and elastic-plastic behaviour can occur in the materials of the shell structure and the frames.

It is generally the case that:

- At nominal diving pressure, the stress is within the purely elastic range of the material
- At test diving pressure, the stress may lie at the commencement of the elastic-plastic range of the material
- But for calculation against exceeding of the permissible stress elastic material behaviour of the material can be assumed
- At collapse diving pressure, the stress may lie in the elastic or the elastic-plastic range of the material

1.5 When calculating a pressure hull the calculation data are to be introduced according to the planned operating conditions under consideration of **TL** Rules for Submersibles, Section 5, D.

1.6 Pressure hulls subjected to internal overpressure are to be calculated in addition according to the **TL** Machinery Rules, Section 14.

2. Longitudinal Strength

For the longitudinal strength of the pressure hull the longitudinal bending moments and shear forces are to be considered. It is to be checked only on request of **TL.**

3. Vessels Similar to the Pressure Hull

For vessels which are partly or totally arranged like the pressure hull and from which the safety of the submersible depends in the same way, like e.g. entrance trunk, containers for rescue equipment, etc., the same proofs have to be carried out as for the pressure hull.

4. Acrylic Windows

The requirements for design and manufacturing of acrylic windows are defined in Annex C.

B. Fatigue Strength

1. Proof of fatigue strength has to be carried out for load case I determined by nominal diving pressure NDP according to the **TL** Rules for Submersibles Section 4, B.2.1. and Underwater Equipment, Section 3, C.1.6.1.1.

2. The proof of stresses is to be based on the nominal geometry.

3. For the calculation of the stresses in the pressure hull, the following influences have to be considered with sufficient accuracy:

- Increase of stress at frames, web frames, bulkheads and tripping/transition rings

- Increase of stress at penetrations

- Disturbances of the state of stress because of connection with pressure-proof extensions

C. Stresses at Nominal Diving Pressure

1. Proof of stress has to be carried out for load case I characterized by nominal diving pressure NDP according to the Rules for Submersibles, Section 4, B.2.1 respectively Underwater Equipment, Section 3, C.1.6.1.1.

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the Rules for Submersibles, Section 5, D.3.

3. The proof of stress has to be performed using the methods in F.1., F.6.2, F.4.4, F.7.2 and F.7.4.

D. Stresses at Test Diving Pressure

1. Proof of stresses has to be carried out for load case III characterized by test diving pressure TDP according to **TL** Rules for Submersibles, Section 4, B.2.2 respectively Underwater Equipment, Section 3, C.1.6.1.3.

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the **TL** Rules for Submersibles, Section 5, D.3.

3. For nominal diving pressures of at least 10 bar proof of strength for load case III can be omitted.

4. The proof of stress has to be performed using the methods in F.1., F.6.2, F.4.4), F.7.2 and F.7.4.

E. Proof of Ultimate Strength at Collapse Diving Pressure

1. The proof of ultimate strength has to be carried out for load case II characterized by the collapse diving pressure CDP according to the **TL** Rules for Submersibles, Section 4, B.2.3 respectively Underwater Equipment, Section 3, C.1.6.1.2 as proof of stability and stress.

For the following types of failure it has to be proven that the pressures for a failure are greater or equal to the collapse diving procedure:

- Symmetric buckling between the frames

- Asymmetric buckling between the frames

- General instability under consideration of the partial effect of the web frames

- Tilting of the frames

- Buckling of the dished ends and spheres

- Local yielding in the area of discontinuities

2. For the calculation of the stresses in the pressure hull the stress limits are defined in the Rules for Submersibles, Section 5, D.3.

3. The proof of stress has to be performed using the methods in F.1., F.6.2, F.4.4, F.5.3, F.7.2 and F.7.4.

F. Calculation

1. Calculation of Stresses in A Uniformly Stiffened Cylinder Or Cone As A Basis for the Calculation of the Collapse Pressure

1.1 The geometrical situation is defined in Fig. A.1 and a summary of the stresses is given in Table A.1.

Designations in Fig. A.1:

R_m = Mean radius of the cylindrical shell

R = Internal radius of the cylindrical shell

s = Nominal wall thickness of the cylindrical shell after deduction of corrosion allowance c

h_w = Web height of the frame

s_w = Web thickness of the frame

bf = Flange width

s_f = Flange thickness

L_F = Frame spacing

A_F = Cross sectional area of the frame

R_C = Radius to the centre of gravity of the frame cross section

R_f = Inner radius to the flange of frame

1.2 Calculation of factors and basic formulas

$$F_1 = \frac{4}{\theta}\left\{\frac{\cos h^2\eta_1\theta - \cos^2\eta_2\theta}{\frac{\cos h\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}\right\} \qquad (A1)$$

$$F_2 = \frac{\frac{\cosh\eta_1\theta\cdot\sin\eta_2\theta}{\eta_2} + \frac{\sinh\eta_1\theta\cdot\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}} \qquad (A2)$$

$$F_3 = \sqrt{\frac{3}{1-\nu^2}}\left\{\frac{-\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}\right\} \qquad (A3)$$

$$F_4 = \sqrt{\frac{3}{1-\nu^2}}\left\{\frac{\frac{\cosh\eta_1\theta\cdot\sin\eta_2\theta}{\eta_2} - \frac{\sinh\eta_1\theta\cdot\cos\eta_2\theta}{\eta_1}}{\frac{\cosh\eta_1\theta\cdot\sinh\eta_1\theta}{\eta_1} + \frac{\cos\eta_2\theta\cdot\sin\eta_2\theta}{\eta_2}}\right\} \qquad (A4)$$

$$p^* = \frac{2\cdot E\cdot s^2}{R_m^2\sqrt{3\,(1-\nu^2)}} \qquad (A5)$$

E = Modulus of elasticity

= 2,06 . 105 N/mm^2 for ferritic steel

= Adequate values for other materials to be agreed

v = Poisson ratio in elastic range

= 0,3 for steel

v_p = Poisson ratio in elastic-plastic range

$$\gamma = \frac{p}{p^*} \qquad (A6)$$

p = Calculation pressure

= Alternatively NDP, TDP and CDP

$$\eta_1 = \frac{1}{2}\sqrt{1-\gamma} \qquad (A7)$$

$$\eta_2 = \frac{1}{2}\sqrt{1+\gamma} \qquad (A8)$$

$$L = L_F - s_w \qquad (A9)$$

$$L_{eff} = \frac{2}{\sqrt[4]{3\,(1-\nu^2)}}\sqrt{R_m\cdot s} \qquad (A10)$$

$$A_{eff} = A_F\frac{R_m}{R_C} \qquad (A11)$$

$$\theta = \frac{2\cdot L}{L_{eff}} \qquad (A12)$$

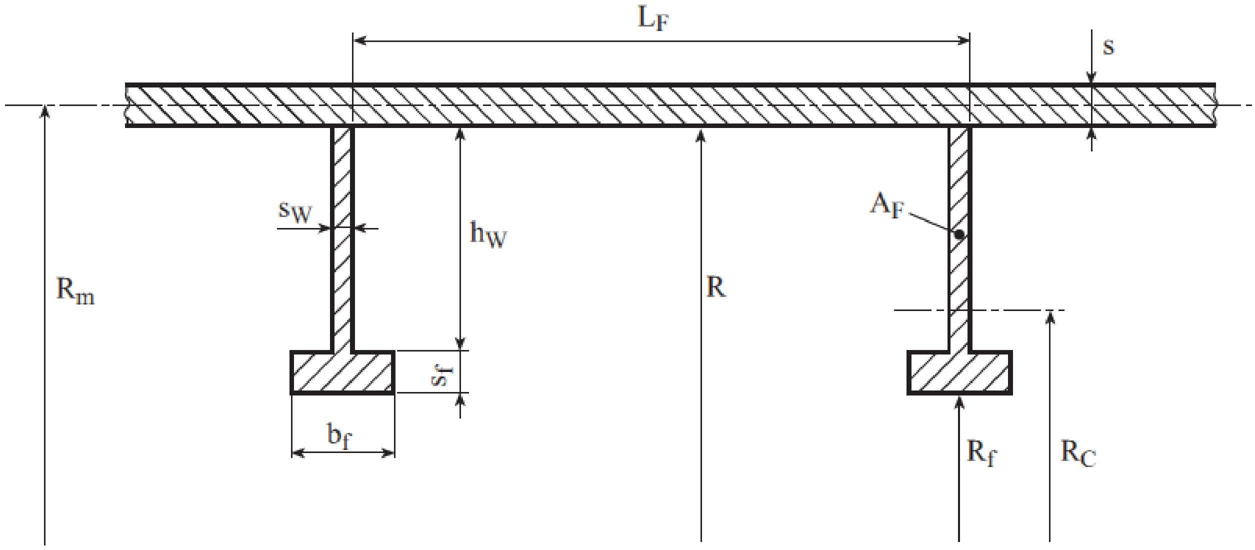

Figure A.1 Geometrical situation of frames stiffening the pressure hull

Table A.1 Summary of stresses in a stiffened cylindrical shell

Stress in the cylindrical shell						
Types of stresses	**At the frame**			**In the middle of the field**		
	Circumferential	**Equivalent**	**Axial**	**Circumferential**	**Equivalent**	**Axial**
Membrane stress	$\sigma^{m}_{\varphi,F}$ (A19)		$\sigma^{m}_{x,F}$ (A17)	$\sigma^{m}_{\varphi,M}$ (A18)		$\sigma^{m}_{x,M}$ (A18)
Membrane equivalent stres		$\sigma^{m}_{v,F}$ (A14)			$\sigma^{m}_{v,M}$ (A14)	
Bending stress	$\sigma^{b}_{\varphi,F}$ (A23)		$\sigma^{b}_{x,F}$ (A21)	$\sigma^{b}_{\varphi,M}$ (A22)		
Normal stres outside	$\sigma^{m}_{\varphi,F} + \sigma^{b}_{\varphi,F}$ (A19) + (A23)		$\sigma^{m}_{x,F} + \sigma^{b}_{x,F}$ (A17) + (A21)	$\sigma^{m}_{\varphi,M} + \sigma^{b}_{\varphi,M}$ (A18) + (A22)		$\sigma^{m}_{x,M} + \sigma^{b}_{x,M}$ (A18) + (A22)
Equivalent normal stres outside		$\sigma^{m+b}_{v,F,o}$ (A14)			$\sigma^{m+b}_{v,M,o}$ (A14)	
Normal stres inside	$\sigma^{m}_{\varphi,F} - \sigma^{b}_{\varphi,F}$ (A19) - (A23)		$\sigma^{m}_{x,F} - \sigma^{b}_{x,F}$ (A17) - (A21)	$\sigma^{m}_{\varphi,M} - \sigma^{b}_{\varphi,M}$ (A18) - (A22)		$\sigma^{m}_{x,M} - \sigma^{b}_{x,M}$ (A17) - (A20)
Equivalent normal stres inside		$\sigma^{m+b}_{v,F,i}$ (A14)			$\sigma^{m+b}_{v,M,i}$ (A14)	
Remark *The numbers in brackets represent the numbers of the formulas to be applied.*						

For the stress designations the following indices are valid:

0 - reference value
m - membrane stress
b - bending stress
v - equivalent stress
x - longitudinal direction
φ - circumferential direction
r - radial direction
t - tangential direction
o - outer side
i - inner side
F - at the frame
D - at the web frame
F/D - at the frame/ at the web frame
M - in the middle of the field
f - in the flange of the frame
w - in the web of the frame
C - at the centre of gravity of the frame cross section
c - in the crown of the dished ends

The reference stress is the circumferential stress in the unstiffened cylindrical pressure hull:

$$\sigma_o = -\frac{p \cdot R_m}{s} \qquad (A13)$$

The equivalent stresses are composed of the single stresses in longitudinal and circumferential direction:

$$\sigma_v = \sqrt{\sigma_x{}^2 + \sigma_\varphi{}^2 - \sigma_x \cdot \sigma_\varphi} \qquad (A14)$$

The radial displacement in the middle between the frames w_M:

$$w_M = -\frac{p \cdot R_m^2}{E \cdot s}\left(1-\frac{\nu}{2}\right)\left\{1-\frac{A_{eff} \cdot F_2}{A_{eff}+s_w \cdot s + L \cdot s \cdot F_1}\right\} \qquad (A15)$$

The radial displacement at the frames w_F:

$$w_F = -\frac{p \cdot R_m^2}{E \cdot s}\left(1-\frac{\nu}{2}\right)\left\{1-\frac{A_{eff} \cdot F_2}{A_{eff}+s_w \cdot s + L \cdot s \cdot F_1} \cdot \left[\cosh \eta_1\theta \cdot \cos \eta_2\theta + \frac{\sqrt{\frac{1-\nu^2}{3}}\frac{F_4}{F_2}+\gamma}{4 \cdot \eta_1 \cdot \eta_2}\sinh \eta_1\theta \cdot \sin \eta_2\theta\right]\right\} \qquad (A16)$$

Average membrane stress in longitudinal direction (independent of the longitudinal coordinate x):

$$\sigma_x^m = -\frac{p \cdot R_m}{2 \cdot s} \qquad (A17)$$

Membrane stress in circumferential direction in the middle between the frames:

$$\sigma_{\varphi,M}^m = E\frac{w_M}{R_m} + \nu \cdot \sigma_x^m \qquad (A18)$$

and at the frames:

$$\sigma_{\varphi,F}^m = E\frac{w_F}{R_m} + \nu \cdot \sigma_x^m \qquad (A19)$$

Bending stresses in longitudinal direction in the middle between the frames:

$$\sigma_{x,M}^b = \pm\sigma_o\left(1-\frac{\nu}{2}\right)F_4\frac{A_{eff}}{A_{eff}+s_w \cdot s + L \cdot s \cdot F_1} \qquad (A20)$$

and at the frames:

$$\sigma_{x,F}^b = \pm\left(\sigma_o - \sigma_{\varphi,F}^m\right)F_3 \qquad (A21)$$

The positive sign is valid for the outside of the cylindrical shell, the negative preceding sign for the inner side.

Bending stresses in circumferential direction in the middle between the frames:

$$\sigma_{\varphi,M}^b = \nu \cdot \sigma_{x,M}^b \qquad (A22)$$

and at the frames:

$$\sigma_{\varphi,F}^b = \nu \cdot \sigma_{x,F}^b \qquad (A23)$$

The circumferential stress follows from the radial displacement to:

$$\sigma_{\varphi,Fw}^m = E\frac{w_F}{R} \qquad (A24)$$

İn the frame foot,

respectively

$$\sigma_{\varphi,Ff}^m = E\frac{w_F}{R_f} \qquad (A25)$$

in the frame flange.

The equivalent stresses as well as the circumferential stresses in the frame summarized in Table A.1 are to be limited with the value of the permissible stresses $\sigma_{perm,NDP}$, $\sigma_{perm,TDP}$ or $\sigma_{perm,CDP}$ belonging to each load case according to **TL** Rules for Submersibles, Section 5, D.3.

1.3 Calculation of the stresses for a conical pressure hull

The formulas given above are also applicable to stiffened conical shells.

The relevant formulas have to be modified using the half apex angle α. For this, the mean radius yields to:

$$R_{m,eqv} = R_m / \cos\alpha \qquad (A26)$$

and the equivalent frame spacing turns to:

$$L_{F,eqv} = L_F / \cos\alpha, \text{ resp.} \qquad L_{eqv} = L / \cos\alpha. \qquad (A27)$$

R_m = Radius midway between the frames of the area under consideration

The calculation has to be carried out for both frames of the bay under evaluation. The dimensions of the frames have to be multiplied by the radius ratio $R_m/R_{m,F}$. For the following calculation of the collapse pressures the (absolutely) greatest value is decisive.

2. Calculation of the collapse pressure for the asymmetric interstiffener buckling of the shell in uniformly stiffened sections of the pressure hull

2.1 For conical pressure hulls the same values as defined for the stress calculation above are to be used.

For calculation of the minimum buckling pressure which depends on the number of circumferential lobes, the following approximation may be used:

2.2 Elastic buckling pressure

$$p_{cr}^{el} = \frac{2 \cdot \pi^2 \cdot E \cdot f}{3 \cdot \Phi \cdot \left(1 - \nu^2\right)} \cdot \left(\frac{s}{R_m}\right)^2 \cdot \frac{\frac{R_m \cdot s}{L^2}}{3 - 2 \cdot \Phi \cdot (1 - f)} \qquad (A28)$$

Theoretical elastic-plastic pressure:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{1-\nu^2}{1-\nu_p^2} \cdot \left\{ \frac{E_t}{E} \cdot \left(1 - \frac{3\Phi}{4}\right) + \frac{E_s}{E} \cdot \frac{3\Phi}{4} \right\} \qquad (A29)$$

with:

$$\Phi = 1{,}23 \frac{\sqrt{R_m \cdot s}}{L} \qquad (A30)$$

$$f = \frac{\sigma_x^m}{\sigma_{\varphi,M}^m} \qquad (A31)$$

$$\sigma_v = \sqrt{\left(\sigma_{\varphi,M}^m\right)^2 + \left(\sigma_x^m\right)^2 - \sigma_{\varphi,M}^m \cdot \sigma_x^m} \qquad (A32)$$

For secant module:

$$E_s = \frac{\sigma_v}{\varepsilon_v} \qquad (A33)$$

For tangential module:

$$E_t = \frac{d\sigma_v}{d\varepsilon_v} \qquad (A34)$$

For elastic-plastic Poisson's ratio:

$$\nu_p = 0{,}5 - (0{,}5 - \nu)\frac{E_s}{E} \qquad (A35)$$

f, σ_v, E_s, E_t are functions of the elastic-plastic buckling pressure p_{cr}^{i} to be determined. For the iterative evaluation of p_{cr}^{i} the value f can be computed for the calculation pressure CDP and be assumed as constant in the following calculation. σ_v can be determined by linear extrapolation starting from the value of the calculation pressure CDP.

2.3 Secant module and tangential module of steels

For various types of steel is valid:

$$z = \frac{\sigma_e}{\sigma_{0,2}} \qquad (A36)$$

σ_e = Limit of proportional extension

$\sigma_{0,2}$ = 0,2 % yield strength, R_{eH}

z = 0,8 for ferritic steel

= 0,6 for austenitic steel

If $\sigma_v > \sigma_e$ the formulas defined in 2.3.1 and 2.3.2 are valid.

For $\sigma_v \le \sigma_e$ is valid:

$$E_s = E_t = E \qquad (A37)$$

2.3.1 Modules for z ≥ 0,8

$$E_t = E \cdot \left\{ 1 - \left(\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z) \cdot \sigma_{0,2}} \right)^2 \right\} \qquad (A38)$$

$$E_s = E \cdot \frac{\sigma_v}{\sigma_{0,2} \left(z + (1-z) \operatorname{arc\,tanh} \frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z) \cdot \sigma_{0,2}} \right)} \qquad (A39)$$

2.3.2 Modules for z < 0,8

$$E_t = E \cdot \left\{ 1 - k \left(\frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z) \cdot \sigma_{0,2}} \right) \right\} \qquad (A40)$$

$$E_s = E \cdot \frac{\sigma_v}{z \cdot \sigma_{0,2} - \frac{1}{k}(1-z) \cdot \sigma_{0,2} \ln \left(1 - k \frac{\sigma_v - z \cdot \sigma_{0,2}}{(1-z) \cdot \sigma_{0,2}} \right)} \qquad (A41)$$

k has to be calculated from the condition:

$$\sigma_{0,2} + 0,002 \cdot E = z \cdot \sigma_{0,2} - \frac{1}{k}(1-z) \cdot \sigma_{0,2} \cdot \ln(1-k) \qquad (A42)$$

at least with the accuracy of two decimals.

2.4 Secant modules and tangent modules for other metallic materials

For other metallic materials z is to be agreed.

2.5 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure P_{cr}^{i} multiplied by the reduction factor r, is at least equal to the calculation pressure CDP of the pressure hull.

With the reduction factor:

$$r = 1 - 0,25 \cdot e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1 \right)} \qquad (A43)$$

3. Calculation of the Collapse Pressure for the Symmetric Interstiffener Buckling of the Shell in Uniformly Stiffened Sections of the Pressure Hull

3.1 For conical pressure hulls the equivalent values as defined for the stress calculation above have to be used

3.2 Elastic buckling pressure

$$p_{cr}^{el} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E \cdot \frac{s^2}{R_m^2} \left\{ \left[\frac{2 \cdot L}{\pi \cdot L_{eff}} \right]^2 + \frac{1}{4} \left[\frac{\pi \cdot L_{eff}}{2 \cdot L} \right]^2 \right\} \qquad (A44)$$

Theoretical elastic-plastic buckling pressure:

$$p_{cr}^{i} = \frac{2}{\sqrt{3(1-\nu^2)}} \cdot E_s \cdot \frac{s^2}{R_m^2} \cdot C \cdot \left\{ \left[\frac{\alpha \cdot L}{\pi} \right]^2 + \frac{1}{4} \left[\frac{\pi}{\alpha \cdot L} \right]^2 \right\} \qquad (A45)$$

with:

$$\alpha = \sqrt[4]{\frac{3 \left(\frac{A_2}{A_1} - \nu_p^2 \frac{A_{12}^{\,2}}{A_1^2} \right)}{R_m^2 \cdot s^2}} \qquad (A46)$$

$$C = \sqrt{\frac{A_1 \cdot A_2 - \nu_p^{\,2} \cdot A_{12}^2}{1 - \nu_p^2}} \qquad (A47)$$

$$\nu_p = \frac{1}{2} - \frac{E_s}{E} \left(\frac{1}{2} - \nu \right) \qquad (A48)$$

$$A_1 = 1 - \frac{1 - E_t / E_s}{4(1-\nu_p^2) K^2 \cdot H} \left[(2 - \nu_p) - (1 - 2 \cdot \nu_p) k \right]^2 \qquad (A49)$$

$$A_2 = 1 - \frac{1 - E_t / E_s}{4(1-\nu_p^2) K^2 \cdot H} \left[(1 - 2 \cdot \nu_p) - (2 - \nu_p) k \right]^2 \qquad (A50)$$

$$A_{12} = 1 + \frac{1 - E_t / E_s}{4 \nu_p (1-\nu_p^2) K^2 \cdot H} \left[(2 - \nu_p) - (1 - 2 \cdot \nu_p) k \right] \cdot \left[(1 - 2 \cdot \nu_p) - (2 - \nu_p) k \right] \qquad (A51)$$

$$H = 1 + \frac{1 - E_t / E_s}{4(1-\nu_p^2) K^2} \left\{ \left[(2 - \nu_p) - (1 - 2 \cdot \nu_p) k \right]^2 - 3(1-\nu_p^2) \right\} \qquad (A52)$$

$$k = \frac{\sigma_{\varphi,M}^{m}}{\sigma_{x}^{m}} \qquad (A53)$$

$$K^2 = 1 - k + k^2 \qquad (A54)$$

The procedure for the evaluation of the theoretical elastic-plastic buckling pressure is analogous to that described for asymmetric buckling.

3.3 It has to be proven, that the collapse pressure, which is the theoretical elastic-plastic buckling pressure p_{cr}^{i} multiplied by the reduction factor r, is at least equal to the calculation pressure CDP of the pressure hull.

ith the reduction factor:

$$r = 1 - 0,25\, e^{-\frac{1}{2}\left(\frac{p_{cr}^{el}}{p_{cr}^{i}} - 1\right)} \qquad (A55)$$

4. Proof of the Collapse Pressure for the General İnstability Under Consideration of the Web Frames

4.1 The proof of the general instability has to be done on the basis of a stress calculation which meets the equilibrium criteria in a deformed state. As predeformation, the out-of-roundness of the frames has to be considered. It has to be proven, that the out-of-roundness permissible according to Annex B can not lead to a global collapse.

4.2 Consideration of the stress-strain behaviour

For austenitic steels and other materials, for which $\sigma_{0,01} < 0,8 \cdot \sigma_{0,2}$ is valid, the actual stress-strain behaviour has to be considered by adequate calculation. The pressure hull, pre-deformed to the permissible out-of-roundness and inclinations of the frames, has to be incrementally pressure loaded. For the calculation of the increasing elastic displacement and stresses, the deformations in equilibrium condition and the actual, local material behaviour have to be considered.

For materials with $\sigma_{0,01} > 0,8 \cdot \sigma_{0,2}$ a linear elastic behaviour can be assumed for a stress calculation according to a theory of 2nd order. In this case the following stress limits (without consideration of local weaknesses) have to be met:

- The sum of basic stress and stress due to out-of-roundness in the frame flange shall not exceed $\sigma_{0,2}$.

- The sum of basic stress and stress due to out-of-roundness in the web frame flange shall not exceed 80 % of $\sigma_{0,2}$

4.3 The calculation procedure is described in the following:

Definitions:

p = Collapse diving pressure of the pressure hull CDP

$n \geq 2$ = Number of circumferential lobes of out-of-roundness

w_0 = Maximum permissible out-of-roundness of the pressure hull according to Annex B

R_m = Mean radius of the pressure hull in the considered field

$R_{m,F/D}$ = Mean radius of the pressure hull at particular frame or web frame

e = Distance from the centroid of the frame or web frame plus the effective length of shell to the furthest surface of the flange (see Fig. A.2). For conical shells e' =e/cosα is valid.

R_C = Radius to the centroid of the frame or web frame cross section

L_D = Length of the generating shell line at the considered area of the web frame

$L_{D,r}$, $LD_{,l}$ = Length of the generating shell line of the left hand or the right hand adjacent field, depending on the field boundary for which the proof is made (see Fig. A.3)

L_B = Distance between bulkheads

$$\beta_D = \frac{\pi \cdot R_m}{L_D}; \quad \beta_B = \frac{\pi \cdot R_m}{L_B} \qquad (A56)\ (A57)$$

α = Half apex angle (see Fig. A.2)
Generally the apex angle is not constant, neither in the actual web frame field nor in the adjacent field. Which angle is decisive will be described in the following for eachparticular case.

I, ID = Area moment of inertia of frame respectively web frame including effective length of pressure hull shell, to be assumed always paralel to the axis of the pressure hull.

The effective length is:

$$L_{eff} = \frac{2}{\sqrt[4]{3\left(1-\nu^2\right)}}\sqrt{R_{m,F} \cdot s / \cos\alpha} \qquad (A58)$$

but not greater than the average value of both adjacent frame distances.

α_{Dl}, α_{Dr} = The local half apex angle at the adjacent web frame, right or left

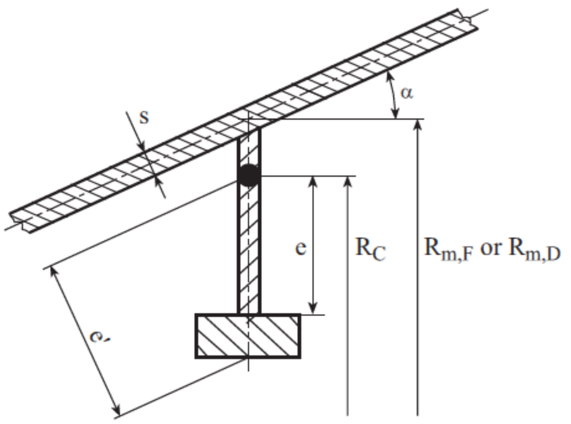

Figure A.2 Situation at a frame or web frame

The area moment of inertia has to be converted to the radius R_m of the actual field by multiplying them by the ratio $(R_m/R_{m,F})^4$.

The proof has to be done for each section of the pressure hull, bounded by web frames, bulkheads or dished ends. Dished ends are to be considered as bulkheads.

A pressure hull section relevant for general instability may be limited by two web frames, followed by two adjacent web frame (or bulkhead) fields at each end, compare Fig. A.3. The calculation has to be performed for both relevant, adjacent fields in question. The most unfavourable case is decisive.

4.4 Basic stress in the frames and in the web frames

The basic stress in a frame flange has to be calculated according to 1.2, equation (A25) for $R = R_f$.

The effect of the half apex angle α is explicitly considered in the following formulas.

The basic stress in a deep frame can be conservatively evaluated according to the following formulas:

$$\sigma_{\varphi,D} = -\frac{p \cdot R_m \cdot L_{eff}\left(1-\nu/2\right)\frac{R_m}{R_f}}{A_D \frac{R_m}{R_D} + L_{eff} \cdot s} \frac{1}{\cos\alpha} \qquad (A59)$$

R_f = Radius of the flange

$$L_{eff} = \frac{2}{\sqrt[4]{3\,(1-\nu^2)}}\sqrt{R_m \cdot s / \cos\alpha} \qquad (A60)$$

It has to be observed that A_D is the sole section area of the web frame and R_D the corresponding radius. For the thickness of the shell s the locally reinforced shell thickness at the web frame has to be used, if applicable.

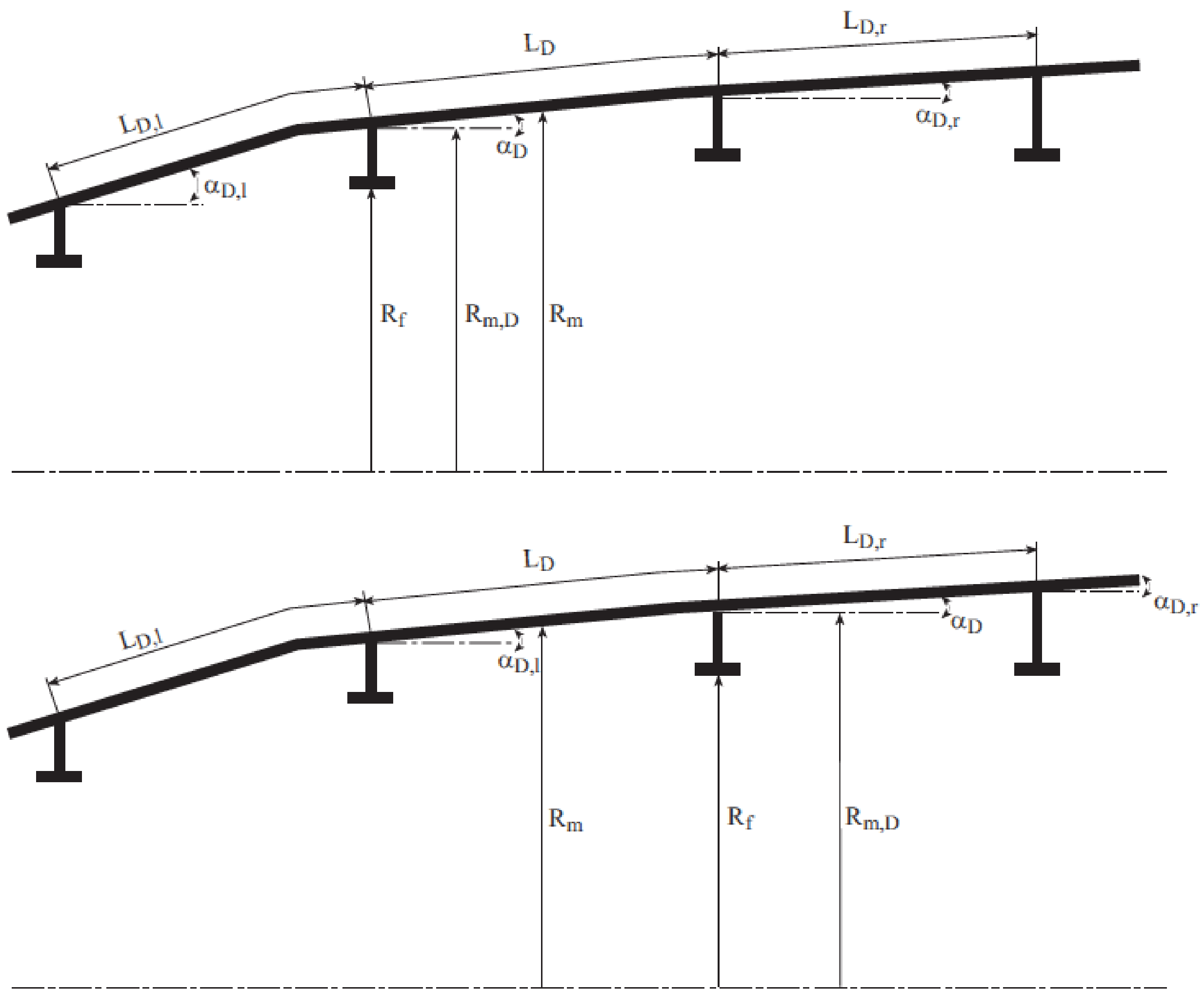

Figure A.3 General stability - both calculation cases for a conical pressure hull

The bending stress in the frame respectively web frame is:

$$\sigma_{\varphi,D} = \pm w_{el} \cdot E \cdot e \frac{n^2-1}{R_C{}^2} \qquad (A61)$$

R_C = See Fig. A.2

The elastic deflection wel for the frames reads:

$$w_{el} = w_0 \frac{p}{p_g^n - p} \qquad (A62)$$

and for web frames:

$$w_{el} = w_0 \frac{p}{p_g^n - p} \frac{p_m}{p_m + p_D} \qquad (A63)$$

With the membrane part:

$$p_m = \frac{E \cdot s}{R_m} \cos^3 \alpha \frac{\beta^4}{(n^2 - 1 + \beta^2/2)\,(n^2 + \beta^2)^2} \qquad (A64)$$

α is the average half apex angle and s the average cylinder shell thickness in the considered field.

And with the web frame part p_D:

$$p_D = \frac{2(n^2-1)E \cdot I_D \cdot \cos^3 \alpha}{R_{C,D}^2 [R_m - 4\,(R_m - R_{C,D})]\,(L_D + L_{D,l/r})} \cdot \frac{n^2-1}{n^2 - 1 + \beta_B^2/2} \qquad (A65)$$

α is the maximum half apex angle along the pressure hull section starting at the middle of the field under consideration and ending at the middle of the adjacent field:

α_{max} = max (α; α_{Dl}) or α_{max} = max (α; α_{Dr})

see Fig. A.3

$R_{C,D}$ applies to web frames.

The total instability pressure p_g^n has to be evaluated as follows:

$$p_g^n = p_F + \frac{p_m \cdot p_D}{p_m + p_D} + p_B \qquad \text{(A66)}$$

using p_m and p_D as described above, and the frame part p_F as well as the bulkhead part p_B as follows:

$$p_F = \frac{(n^2-1)E \cdot I_F}{R_{C,F}^3 \cdot L_F} \cos^4\alpha \frac{n^2-1}{n^2-1+\beta^2 \dfrac{1}{2}\dfrac{p_D}{p_D+p_m}} \qquad \text{(A67)}$$

$R_{C,F}$ applies to frames.

$$p_B = \frac{E \cdot s}{R_m} \cos^3\alpha \frac{\beta_B{}^4}{(n^2-1+\beta_B{}^2/2)\,(n^2+\beta_B{}^2)^2} \qquad \text{(A68)}$$

α is here to be understood as the average half apex angle in the field considered.

The frame part has to be calculated with the dimensions of an equivalent frame including equivalent frame spacing. Generally these are the dimensions of the frame closest to the midway point of the field under evaluation, which have to be converted to the average field radius in a manner described in 1.3.

The following condition has to be met:

For each frame of the considered field the permissible out-of-roundness has to be calculated for n = 5, assuming for p_g^5 an infinitive field length (β_D = 0). The arithmetic average of the out-of-roundness values evaluated in this way for three adjacent frames divided by the related frame radius shall not be less than the out-of-roundness for the equivalent frame evaluated in analogous way.

5. Proof of the Collapse Pressure for Tripping of Frames

5.1 Stability against tripping

The proof of the tripping stability has to be done for frames and web frames on the basis of a stress calculation, which fulfils the status of equilibrium in deformed condition. As pre-deformations the tolerances of the frames as defined in Annex B may be considered.

Concerning the consideration of the stress-strain behaviour the rules defined in 4.2 are valid.

For materials with $\sigma_{0,01}$ ≥ 0,8 . $\sigma_{0,2}$ linear elastic behaviour can be assumed for a stress calculation according to 2nd order theory. The following stress limits have to be observed (disregarding local material weakening):

- The equivalent stress in frame web shall not exceed $\sigma_{0,2}$.
- The circumferential stress in frame flange shall not exceed $\sigma_{0,2}$.

The effects to be considered in this procedure are defined further on.

5.2 Additional stresses caused by frame imperfections

The additional stresses caused by imperfections of the frame cross section have to be evaluated for internal frames according to the following formulas. See also Figure A.4.

The imperfections "inclination of web to plane of frame Θ", "eccentricity of flange to web u_{ex}" and "misalignment of frame heel to frame plane d" are defined in Annex B, C.2.5 to C.2.7.

$$h'_w = h_w + \frac{s_f}{2} \qquad \text{(A69)}$$

$$\beta = \frac{h'_w}{R} \quad \text{(A70a)}$$

$$R'_f = R_f + \frac{s_f}{2} \quad \text{(A70b)}$$

$$\beta_f = \frac{h'_w}{R'_f} \quad \text{(A71)}$$

$$A'_f = b_f\, s_f - \frac{s_f \cdot s_w}{2} \quad \text{(A72)}$$

$$I_f = \frac{b_f^3 \cdot s_f}{12} \quad \text{(A73)}$$

$$J_f = \frac{b_f \cdot s_f^3}{6\,(1+\nu)} \quad \text{(A74)}$$

$$A'_w = h'_w \cdot s_w \quad \text{(A75)}$$

$$D = \frac{E \cdot s_w^3}{12\,(1-\nu^2)} \quad \text{(A76)}$$

$$L_0 = \frac{\sigma_0 \cdot A_F}{R} \quad \text{(A77)}$$

$$F_f = \sigma_0 \cdot A'_f \quad \text{(A78)}$$

σ_0 = Basic stress in flange according to 5.3 / 5.4.

$$\lambda = \frac{A'_w}{A_F} \quad \text{(A79)}$$

n = Number of circumferential lobes of imperfections; the calculation has to be performed for n = 3.

$$e = \frac{h_w'^2 \cdot L_0}{D} - 2 \cdot n^2 \cdot \beta^2 \quad \text{(A80)}$$

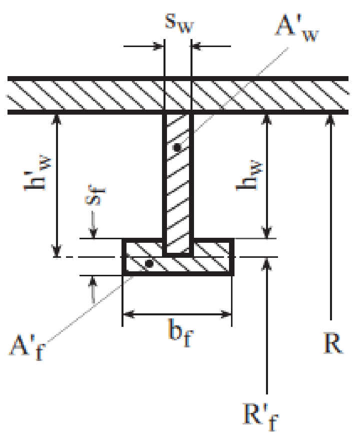

Figure A.4 Local situation at the frame

$$\varepsilon = \lambda \frac{h_w'^2 \cdot L_0}{D} \quad \text{(A81)}$$

$$g = n^2 \cdot \beta \left(\lambda \frac{h_w'^2 \cdot L_0}{D} - n^2 \cdot \beta^3 \right) \quad \text{(A82)}$$

$$k_{11} = 12 - 1{,}2 \cdot e + 0{,}6 \cdot \varepsilon - \frac{13}{35} g \quad \text{(A83)}$$

$$k_{12} = 6 - 0{,}1 \cdot e - \frac{11}{210} g + \nu \cdot n^2 \cdot \beta^2 \quad \text{(A84)}$$

$$k_{22} = 4 - \frac{2}{15} e + 0{,}1 \cdot \varepsilon - \frac{g}{105} \quad \text{(A85)}$$

$$k_{31} = 6 - 0{,}1 \cdot e + 0{,}1 \cdot \varepsilon + \frac{13}{420} g \quad \text{(A86)}$$

$$k_{32} = 2 + \frac{e}{30} - \frac{\varepsilon}{60} + \frac{g}{140} \quad \text{(A87)}$$

$$A_{11} = \frac{n^2\, E}{R_f^4} \left(n^2 \cdot I_f + J_f \right) + \frac{D}{h_w'^3} k_{11} - n^2 \frac{F_f}{R_f^2} \quad \text{(A88)}$$

$$A_{12} = \frac{n^2 \cdot E}{R_f^3} \left(I_f + J_f \right) - \frac{D}{h_w'^2} k_{12} \quad \text{(A89)}$$

$$A_{22} = \frac{E}{R_f^2} \left(I_f + n^2 \cdot J_f \right) + \frac{D}{h_w'} k_{22} \quad \text{(A90)}$$

Amplitudes of the elastic displacement u and twist ω of the connection web-flange:

$$u = \frac{1}{Det} \left(B_1 \cdot A_{22} - B_2 \cdot A_{12} \right) \quad \text{(A91)}$$

$$\omega = \frac{1}{Det} \left(B_2 \cdot A_{11} - B_1 \cdot A_{12} \right) \quad \text{(A92)}$$

with

$$Det = A_{11} \cdot A_{22} - A_{12}^2 \quad \text{(A93)}$$

$$B_1 = \theta\left[\frac{F_f}{R_f}\left(1+n^2\cdot\beta_f\right)-L_0\cdot\lambda\cdot k_{1,\theta}\right]+u_{ex}\frac{F_f}{R_f\cdot h_w^{'}} \cdot n^2\cdot\beta_f+d\frac{L_0\cdot n^2\cdot\beta_f}{h_w^{'}}\left[\left(1-\lambda\right)\frac{R}{R_f}-\lambda\cdot k_{1,d}\right] \quad (A94)$$

$$B_2 = -\theta\cdot L_0\cdot\lambda\cdot h_w^{'}\cdot k_{2,\theta}+u_{ex}\frac{F_f}{R_f}-d\cdot L_0\cdot\lambda\cdot n^2\cdot\beta_f\cdot k_{2,d} \quad (A95)$$

Where:

$$k_{1,\theta} = \frac{1}{2}\left(-1-\frac{\varepsilon}{420}+0,013\cdot g+0,015\cdot e^2 -0,025\cdot e\cdot\varepsilon-0,7\cdot n^2\cdot\beta\right) \quad (A96)$$

$$k_{1,d} = \frac{1}{2}\left(-1-\frac{\varepsilon}{420}+0,013\cdot g+0,015\cdot e^2-0,025\cdot e\cdot\varepsilon\right) \quad (A97)$$

$$k_{2,\theta} = \frac{1}{12}\left[1+\frac{e}{60}-\frac{\varepsilon}{105}-\frac{g}{140}-0,008\cdot e^2 +0,013\cdot e\cdot\varepsilon+0,6\cdot n^2\cdot\beta\left(1+\frac{19\cdot e}{1260}+\frac{25\cdot\varepsilon}{336}\right)\right] \quad (A98)$$

$$k_{2,d} = \frac{1}{12}\left(1+\frac{e}{60}-\frac{\varepsilon}{105}-\frac{g}{140}-0,008\cdot e^2+0,013\cdot e\cdot\varepsilon\right) \quad (A99)$$

Stresses in the flange are as follows:

$$\sigma^b_{r,F/Df} = \pm\frac{E\cdot b_f}{2\cdot R_f^2}\left(n^2\cdot u+R_f\cdot\omega\right) \quad (A100)$$

Bending stress around radial axis, and

$$\tau_{t,F/Df} = \frac{n\cdot E\cdot s_f}{2\left(1+\nu\right)R_f^2}\left(u+R_f\cdot\omega\right) \quad (A101)$$

Torsion around the tangential axis, which is phase-shifted against $\sigma_{r,F/Df}{}^b$ by a quarter period.

The bending stress at the toe of the web is:

$$\sigma^b_{r,F/Dw} = \pm\frac{6}{s_w^2}\left[\frac{D}{h_w^{'2}}\left(k_{31}\cdot u-k_{32}\cdot h_w^{'}\cdot\omega\right) + \lambda L_0\left(k_{3,\theta}\cdot h_w^{'}\cdot\theta+k_{3,d}\cdot n^2\cdot\beta\cdot d\right)\right] \quad (A102)$$

with

$$k_{3,\theta} = \frac{1}{12}\left(1+\frac{e}{60}-\frac{\varepsilon}{140}+0,4\cdot n^2\cdot\beta \cdot\left(1+0,019\cdot e-0,009\cdot\varepsilon\right)\right) \quad (A103)$$

and

$$k_{3,d} = \frac{1}{12}\left(1+\frac{e}{60}-\frac{\varepsilon}{140}\right) \quad (A104)$$

The stresses resulting from imperfections of the frames are to be checked for frames and web frames, using different procedures.

5.3 Frames

For the stress σ_0 always $\sigma_{0,2}$ of the frame material has to be used.

The bending rigidity of the flange has to be neglected, i.e. set to zero ($I_f = 0$).

The equivalent stress at the web toe has to be evaluated with the calculation pressure for both signs of the bending stress $\sigma_{r,Fw}{}^b$ according to formula (A102).

Circumferential stress:

$$\sigma^{m+b}_{\varphi,F} = \sigma^m_{\varphi,Fw}+\frac{e_2}{e_1}\cdot\sigma_{O/R}\pm\nu\cdot\sigma^b_{r,Fw} \quad (A105)$$

with $\sigma_{\phi,Fw}{}^m$ according to 1.2, equation (A24), compare Fig. A.5 and

$$\sigma_{O/R} = \sigma_{0,2}+\sigma^m_{\varphi,Ff} \quad (A106)$$

with $\sigma_{\phi,Ff}{}^m$ according to 1.2, equation (A25).

Radial stress:

$$\sigma_r = -\frac{L_0}{s_w}\pm\sigma^b_{r,Fw} \quad (A107)$$

The equivalent stress:

$$\sigma_v = \sqrt{\sigma_\varphi{}^2+\sigma_r{}^2-\sigma_\varphi\cdot\sigma_r} \quad (A108)$$

shall not exceed $\sigma_{0,2}$.

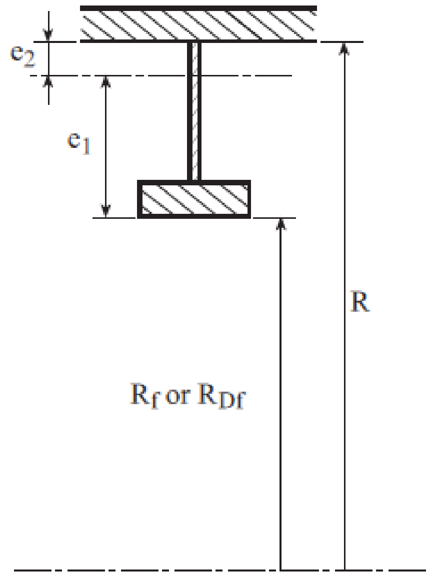

Figure A.5 Situation of the frame in relation to the axis of the pressure hull

5.4 Web frames

For the basic stress in the flange σ_0 the absolute value of the circumferential stress $|\sigma_{\phi,D}|$ according to formula (A59) has to be taken, as obtained for the half value of the permissible out-of-roundness resulting from the general instability proof performed for n = 2 circumferential lobes according to 4.

It has to be proven that:

a) $$\sigma_0 + \left|\sigma^b_{r,Df}\right| \le \sigma_{0,2} \qquad \text{(A109)}$$

b) $$\sqrt{\sigma_0^2 + 3 \cdot \tau^2_{t,Df}} \le \sigma_{0,2} \qquad \text{(A110)}$$

with $\sigma_{r,Df}{}^b$ according to formula (A100) and $\tau_{t,Df}$ according to formula (A101) considering the relevant dimensions of the web frames

and the equivalent stress at the web toe.

$$\sigma_v = \sqrt{\sigma_\varphi^2 + \sigma_r^2 - \sigma_\varphi \cdot \sigma_r} \le \sigma_{0,2} \qquad \text{(A111)}$$

The circumferential stress σ_φ is the sum of the basic stress $\sigma_{\varphi,D}$ obtained with the formula (A59) in 4.4 and v-times the web bending stress $\sigma_{r,Dw}{}^b$ according to formula (A102):

$$\sigma_\varphi = \sigma_{\varphi,D} + \nu \cdot \sigma^b_{r,Dw} \qquad \text{(A112)}$$

The radial stress is:

$$\sigma_r = \frac{-A_f \cdot \sigma_0 + A_w \cdot \sigma_D}{R_D \cdot s_w} \pm \sigma^b_{r,Dw} \qquad \text{(A113)}$$

For calculation of σ_0 the following simplified Formula can be used:

$$\sigma_0 = \frac{1}{2}\left|\sigma_{\varphi,D}\right| + 0,4 \cdot \sigma_{0,2} \qquad \text{(A114)}$$

5.5 Modifications for frames arranged outside

For frames arranged outside all radii (R, R_f, R_{Df}) have to be applied as negative values.

6. Spherical Shells and Dished Ends

6.1 General

Spherical shells and dished ends are to be investigated for the load cases defined in **TL** Rules for Submersibles, Section 4, E. respectively Underwater Equipment, Section 3, C.1.6. against exceeding stresses and buckling. For dished ends the stresses in the crown and the knuckle are to be investigated. Spheres are to be treated like the crown area of dished ends.

6.2 Stresses

For the crown area the stress results from Formula (A118). For the knuckle area the stress can be evaluated by formula (A119). The coefficients β are to be determined according to the **TL** Machinery Rules, Section 12, D.4.3.2. They can also be evaluated directly with assistance of the following formulas:

For torispherical ends:

$$\beta = 0,6148 - 1,6589\,x - 0,5206\,.\,x^2 - 0,0571\,x^3 \qquad \text{(A115)}$$

And for semi-ellipsoidal ends:

$$\beta = 1,3282 - 0,3637\,x - 0,1293\,.\,x^2 - 0,0171\,x^3 \qquad \text{(A116)}$$

with $x = \ln(s/D_a)$ (A117)

for range of validity $0{,}001 \le s/D_a \le 0{,}1$

Da = Outside diameter of the dished end

In the range $0{,}5 \cdot \sqrt{s \cdot R}$ besides the transition to the cylinder the coefficient β = 1,1 for hemispherical ends.

Under the assumption that deviations in the form of dished ends stay within the permissible tolerances, the stresses can be calculated with the following formulas. If the tolerances are exceeded, a separate proof of stress is to be performed.

$$\sigma = -\frac{R_{c,o,l}^{\ 2} \cdot p}{2 \cdot R_{c,m,l} \cdot s} \qquad (A118)$$

$R_{c,o,l}$ = Local outside radius of sphere crown of the dished end

$R_{c,m,l}$ = Local radius of the sphere crown of the dished end at half thickness of the shell

$$\sigma = -\frac{p \cdot D_a \cdot 1{,}2 \cdot \beta}{4 \cdot s} \qquad (A119)$$

For p NDP, TDP and CDP are to be introduced respectively.

The proof has been made if the permissible stresses according to the Rules for Submersibles, Section 5, D.3. are not exceeded.

6.3 Calculation of the collapse pressure

The calculations are based on the local thickness and curvature of the shell and they are considering an out-of-roundness of the shell in the sense of a local flattening up to maximum u = 0,218 . s_l / R_o. This is valid for pressed spherical shells and is adequate to a local outside curvature radius of $R_{o,l}$ = 1,3 . R_o of the outer nominal radius.

The out-of-roundness and herewith the local radius is to be evaluated with a bridge gauge as described in Annex B, E. There a measuring length $L_{cr,l}$ according to formula (A120) has to be used. The out-ofroundness defined in this way is to be understood as local flattening from the theoretical form of the sphere within the diameter $L_{cr,l.}$ For the lay out a local radius of 1,3 times the nominal radius and a nominal thickness of the shell (eventually reduced by the corrosion addition) is to be assumed. The corrosion addition shall be considered by keeping the outside radius.

If other tolerances are provided or another out-of-roundness is resulting from the measurement checks according to Annex B, E.3. or E.4., then a recalculation of the permissible pressure according Annex B, E.5. is required.

For mechanically machined spherical shells local radii less than 1,05 . R_o are reachable from point of manufacturing. The more favourable geometrical condition of the shell can be introduced in the calculation with at minimum $R_{o,l}$ = 1,05 . R_o under the assumption that the measurement procedure, as described in Annex B, has proven a maximum permissible local flattening of u = 0,035 . s_1 / R_o with an accuracy of at least 0,001 . s.

6.4 Definitions

The following definitions are valid:

$R_{m,l}$ = Maximum local mean radius of curvature of the sphere at shell half thickness

$R_{0,1}$ = Maximum local outside radius of curvature of the sphere

s = Nominal thickness of the shell

s_1 = Local average shell thickness

Critical arc length or diameter of the measuring circle to be used for measuring the deviations from the perfect form of the sphere according to Annex B, E.3. and E.4.:

$$L_{cr,l} = \frac{2{,}2}{\sqrt[4]{\frac{3}{4} \cdot (1 - \nu^2)}} \cdot \sqrt{R_{o,l} \cdot s_l} \qquad (A120)$$

Elastic buckling pressure of the sphere:

$$p_{cr}^{el} = \frac{1,4}{\sqrt{3 \cdot (1-\nu^2)}} \cdot E \cdot \left(\frac{s_1}{R_{o,1}}\right)^2 \qquad (A121)$$

Theoretical elastic-plastic buckling pressure of the sphere:

$$p_{cr}^{i} = p_{cr}^{el} \cdot \frac{\sqrt{E_t \cdot E_s}}{E} \qquad (A122)$$

$$p_{0,2} = \frac{2 \cdot \sigma_{0,2} \cdot s_1 \cdot R_{m,1}}{R_{o,1}^2} \qquad (A123)$$

6.5 Spherical ends made of ferritic steel

For spherical ends made of ferritic steel grade TLM550 or similar material pcr can be calculated as follows:

6.5.1 For spherical ends which are not stress relieved the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,47 \qquad (A124)$$

$$p_{cr} = p_{0,2}\left(0,38 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \text{if} \quad 0,47 < \frac{p_{cr}^{el}}{p_{0,2}} \le 3,18 \qquad (A125)$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 3,18 \qquad (A126)$$

6.5.2 For stress relieved spherical ends (tempered and stress relieved) the following is valid:

$$p_{cr} = p_{cr}^{el} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} \le 0,595 \qquad (A127)$$

$$p_{cr} = p_{0,2}\left(0,475 + 0,195\frac{p_{cr}^{el}}{p_{0,2}}\right) \quad \text{if} \quad 0,595 < \frac{p_{cr}^{el}}{p_{0,2}} \le 2,7 \qquad (A128)$$

$$p_{cr} = p_{0,2} \quad \text{if} \quad \frac{p_{cr}^{el}}{p_{0,2}} > 2,7 \qquad (A129)$$

The fabrication of ends by welding of stress relieved segments and the welding of the penetrations into the shell after stress relieving is permitted.

The calculated collapse pressure p_{cr} shall be at least equal to the collapse diving pressure CDP of the pressure hull.

6.6 Spherical shells of other materials

For spherical ends made of other steel materials the elastic-plastic buckling pressure $p_{cr}^{\,i}$ which has been evaluated according to the formulas described above has to be multiplied by the reduction factor k defined in Fig. A.6. The reduction factor k is also summarized in tabular form in Table A.2. Intermediate values can be defined by linear interpolation.

For the application of non-iron metal materials the reduction factors are to be evaluated in accordance with **TL** by model tests.

7. Penetrations of the Pressure Hull and Discontinuities

7.1 Discontinuities

Discontinuities like

- Connections of cylinders and conical segments
- Transition rings (tripping rings)
- Flanges for the attachment of dome shaped windows

are to be subjected for the load cases nominal diving pressure and test diving pressure to an analysis of the stress and elongation behaviour similar to [10] **(1)** and [11] **(1).** The equivalent stress follows from formula (A14). Sufficient safety is given, if the permissible stresses according to **TL** Rules for Submersibles, Section 5, D.3. are not exceeded. If stiffeners are interrupted by penetrations, suitable reinforcements are to be provided.

(1) *See data about literature in G.*

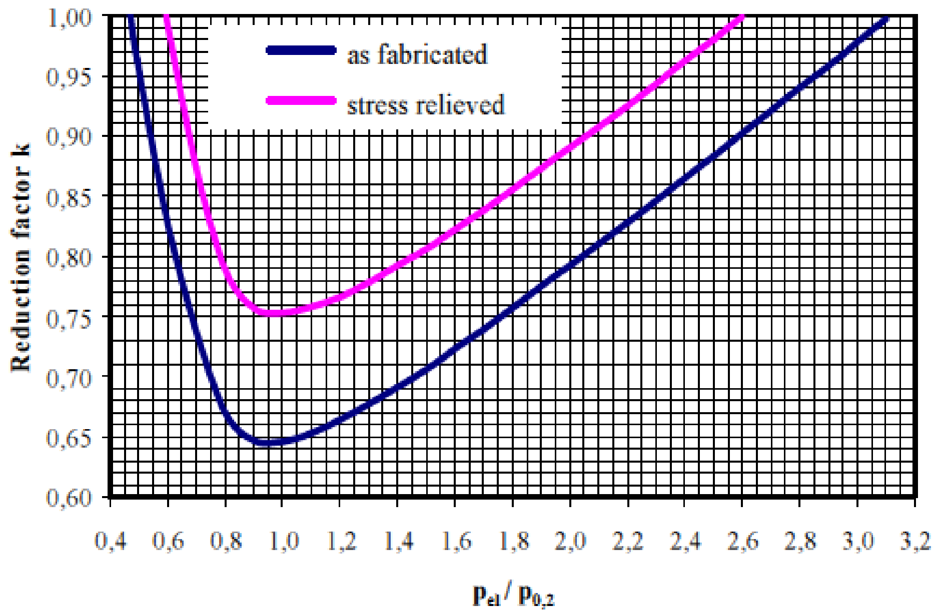

Figure A.6 Reduction factor "k" for different kinds of steel treatment

Table A.2 Reduction factor "k" for different kinds of steel treatment

Pressure relation	Reduction factor	
$P_{el}/p_{0,2}$	As fabricated	Stress relieved
0,470	1,000	1,000
0,495	0,963	1,000
0,595	0,834	1,000
0,700	0,738	0,874
0,800	0,670	0,789
0,900	0,647	0,757
1,000	0,646	0,753
1,100	0,653	0,758
1,200	0,664	0,766
1,300	0,677	0,778
1,400	0,691	0,792
1,500	0,706	0,806
1,600	0,723	0,822
1,700	0,739	0,838
1,800	0,757	0,855
1,900	0,775	0,873
2,000	0,792	0,890
2,100	0,810	0,907
2,200	0,828	0,925
2,300	0,846	0,943
2,400	0,865	0,962
2,500	0,883	0,980
2,600	0,902	0,999
2,700	0,921	1,000
2,800	0,940	1,000
2,900	0,958	1,000
3,000	0,978	1,000
3,100	0,997	1,000
3,200	1,000	1,000

7.2 Penetrations in the cylindrical or conical part of the pressure hull - area comparison principle

Penetrations in cylinders are to be preferably evaluated according to the **TL** Machinery Rules, Section 12, D. 2.3.4 with a design pressure pc for which NDP, TDP or CDP are to be inserted alternatively. There is:

$$D_i = 2 . R$$

and

s_A = Necessary wall thickness at the penetration boundary according to **TL** Machinery Rules Section 12,D.2.2 which is to be evaluated by iteration.

The following rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material characteristics the rules have to be modified in an analogous way.

7.3 Penetrations in the cylindrical or conical part of the pressure hull - cross sectional area substitution principle

After approval by **TL** the required reinforcement of the penetration boundary can be evaluated also with the cross sectional area substitution principle.

These rules for dimensioning are valid under the assumption that the material strength is the same for the shell of the pressure hull and for the reinforcement of the penetration boundary.

For different material strength the rules have to be modified in an analogous way.

7.3.1 Small penetrations which do not interrupt frames

7.3.1.1 Circular penetrations in radial direction

The situation is characterised by Fig. A.7 where for the calculation one half of the nozzle is considered.

Designations in Fig. A.7:

s = Thickness of the shell of the pressure hull after deduction of corrosion allowance

s_v = Thickness of the shell of the pressure hull in the reinforcement vicinity

R = Internal radius of the pressure hull

d_a = External diameter of the nozzle

ℓ_s, ℓ'_s = Excess lengths of the nozzle

ℓ_{min} = min (ℓ_s, ℓ'_s)

= smaller excess length of the nozzle

ℓ_{max} = max (ℓ_s, ℓ'_s)

= Bigger excess length of the nozzle

s_s = Wall thickness of nozzle

A = Cross sectional area to be substituted

A_{eff} = Effective substitutive cross sectional area

l_{eff} = Effective length of the nozzle

$$\ell^* = \frac{\sqrt{0,5(d_a - s_s)\cdot s_s}}{\sqrt[4]{3(1-\nu^2)}} \qquad \text{(A130)}$$

$$r_m = 0,5\cdot(d_a - s_s) \qquad \text{(A131)}$$

It has to be proven that the effective substitutive cross sectional area of the boundary reinforcement A_{eff} of the penetration is at least equal to the cross sectional area A cut out of the shell which is to be substituted.

The area to be substituted is

$$A = 0,5\cdot d_a\cdot s \qquad \text{(A132)}$$

For penetrations, which are designed in the form shown in Fig. A.7 the effective substituted cross sectional area can be calculated according to the following formula:

$$A_{eff} = b_{min}\cdot(s_v - s) + s_s\cdot\ell_{eff} \qquad \text{(A133)}$$

$$b_{min} = 0,78\cdot\sqrt{R\cdot s_v}$$

Effective length of the nozzle:

Case 1:

$$\ell_{eff} = 2\cdot\ell^* + s_v \quad \text{for} \qquad \text{(A134)}$$

$$\ell_s \ge \ell^*;\ \ell'_s \ge \ell^* \qquad \text{(A135)}$$

Case 2:

$$\ell_{eff} = 2\cdot\ell_{min} + s_v \qquad \text{(A136)}$$

$$\frac{\ell^*}{2} \le \ell_{min} \le \ell^* \qquad \text{(A137)}$$

Case 3:

$$\ell_{eff} = \ell_{min} + \min\left(a, \frac{\ell^*}{2}\right) + s_v \qquad \text{(A138)}$$

$$\ell_{min} < \frac{\ell^*}{2};\quad \ell_{max} > \frac{\ell^*}{2} \qquad \text{(A139)}$$

$$a = \ell_{max}\left(0,4 + 0,6\frac{\ell^2_{min}}{\ell^2_{max}}\right) \qquad \text{(A140)}$$

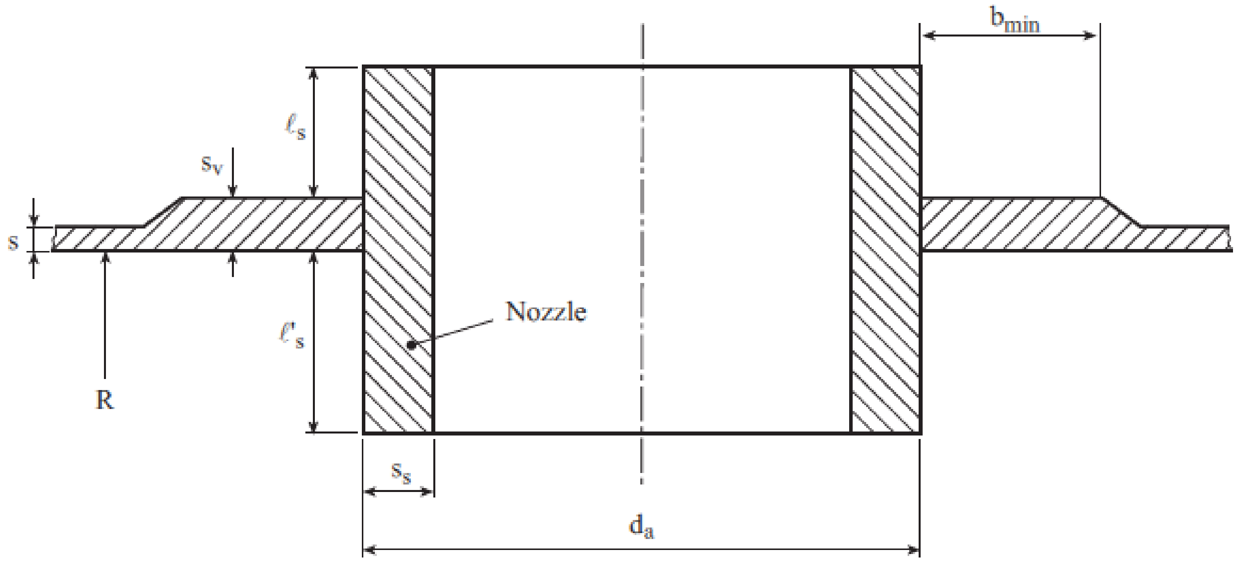

Figure A.7 Penetration through the enforced shell

7.3.1.2 Flush form of circular penetrations in radial direction

Penetrations in flush form of the pressure hull (ℓ_s = 0), may have in the penetration area a cut out to include a zinc ring, see Fig. A.8.

In this case ℓ_{eff} can be evaluated with the formulas given above. In addition the strength of the cross section A-A has to be proven.

In the case that the wall of the pressure hull is not reinforced, the following condition has to be met:

$$c > \sqrt{4 \cdot \frac{s \cdot d_a \left(g - \frac{s}{2}\right) - c \cdot g^2}{d_a - c} + c_\tau^2} \qquad \text{(A141)}$$

$$c_\tau = \sqrt{3} \cdot \frac{s \cdot d_a - 2 \cdot c \cdot g}{d_a - c} \qquad \text{(A142)}$$

7.3.1.3 Non-circular penetrations or penetrations not in radial direction to the shell

If the penetration is not circular or does not cut the shell of the pressure hull in radial direction the diameter da has to be replaced by:

$$d_a = \max\left(L_x, L_\varphi \cdot \frac{\sigma_x^m}{\sigma_\varphi^m}\right) \qquad \text{(A143)}$$

L_x = Width of the penetration line in longitudinal direction

L_φ = Width of the penetration line in circumferential direction

σ_x^m = Membrane stress in the pressure hull in longitudinal direction

σ_φ^m = Membrane stress in the pressure hull in circumferential direction

In special cases, if the Rules can only be utilized in limited way, the strength has to be proven by numerical computation

7.3.2 Big penetrations interrupting frames

For preliminary dimensioning the following procedure can be used:

The effective border reinforcement for the penetration has, in a similar way as for the small penetrations, to substitute the area cut out. The cross sections of the interrupted frame webs are to be considered additionally. The effective substitutive cross sectional area has to be evaluated in analogous way as for small penetrations. Compact reinforcement rings are fully load carrying if they are located directly in the penetration line.

The construction in the flange plane of the frame has to be designed in such a way that the maximal permissible forces in the flange (A_f . σ_{perm}) can be transmitted further.

For σ_{perm} the value of the permissible stress belonging to the individual load case acc. to **TL** Rules for Submersibles, Section 5, D.3. is to be inserted.

Big penetrations have to be proven by numerical computation.

7.4 Penetrations of spherical shells

Penetrations in spherical shells are to be evaluated according to the **TL** Machinery Rules, Section 12, D.4.3.3 with a design pressure p_c for which 1,2 NDP, 1,2 TDP or 1,2 CDP are to be inserted alternatively. There is:

Di = 2 . R

and

s_A = Necessary wall thickness at the penetration boundary according to **TL** Machinery Rules, Section 12,D.2.2 which is to be evaluated by iteration.

After approval by **TL** the cross sectional area substitution principle as described in 7.3 may be applied analogously. For this R is the internal radius of the sphere.

In cases, where area comparison respectively cross sectional area substitution principle are not fulfilled, a numerical proof has to be done. For this the local radius of the spherical shell according to 6.3 is to be chosen adequately in the vicinity of the penetration. The achieved failure pressure is then to be reduced like the elastic-plastic buckling pressure, which has been evaluated for undisturbed dished ends, see Fig. A.6.

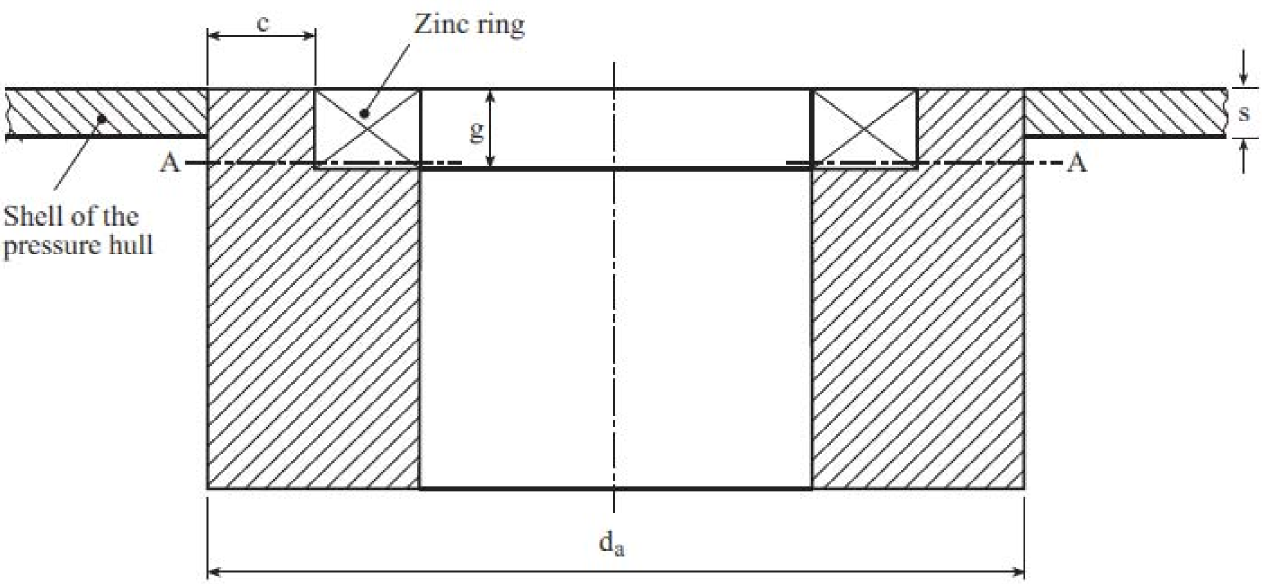

Figure A.8 Penetration of flush form

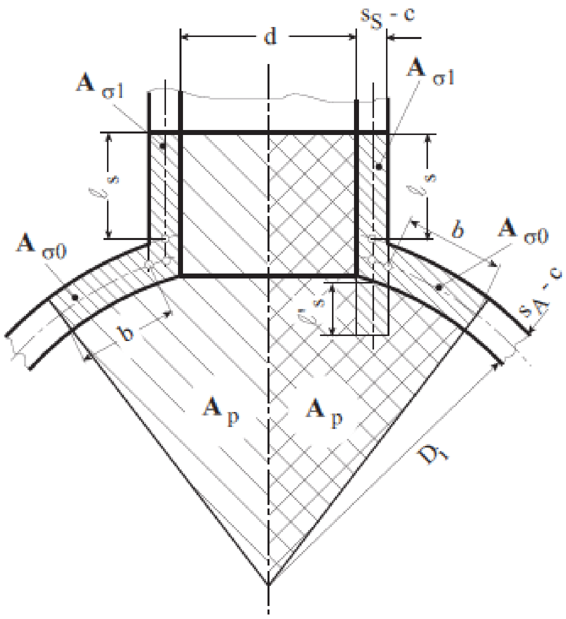

Figure A.9 Penetrations of spherical shells

G. Literature

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[5] Development in Pressure Vessel Technology, Herausgeber: R. W. Nichols, Applied Science Publishers, 1983

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[7] DIN 4114, Blatt 2: Stabilitätsfälle (Knickung, Kippung, Beulung), Ausgabe 2.53

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[12] William F. Blumenberg: The Effect of Intermediate Heavy Frames on the Elastic General- Instability Strength of Ring-Stiffened Cylinders Under External Hydrostatic Pressure, DTMB-Report No. 1844

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ANNEX B

MANUFACTURING TOLERANCES for the PRESSURE HULL

Page

A. General

1. This Annex describes the permissible manufacturing tolerances for the pressure hull as prerequisite for the application of the strength calculations defined in Annex A.

2. All tests are to be performed by the manufacturer in presence of a **TL** Surveyor and a measurement report has to be sent by the manufacturer to **TL.**

3. The required checks defined in the following are only to be performed, if no following changes of the measurement values are to be expected. Areas with welding seams which have been worked over in the mean time because of impermissible defects have to be measured again.

The component to be investigated shall be cooled down to ambient temperature and is so to be relieved from any tensions by means of installation aids in order to prevent falsification of the measurement results.

B. Dimensions of the Pressure Hull

1. General

1.1 As far as not defined otherwise in these Rules the following tolerances are valid.

1.2 All longitudinal and circumferential seams in the pressure hull plating shall be inspected for edge offset, weld sinkage, undercuts and hollow grinding. This shall also be valid for the welding connection of the plating with the tripping/transition ring. The inner and outer surface of the plates is to be inspected for damage.

2. Dimensions of the Cylindrical and Conical Parts

2.1 Diameter

The actual mean outside diameter of cylindrical respectively conical pressure hulls shall, calculated from the circumference, deviate not more than ± 0,5 % from the outside diameter on which the calculation is based. The measurements are to be performed in distances of maximum $\sqrt{3\ R}$ s over the complete length of the component.

s = Nominal shell thickness [mm]

R = Internal radius of the shell [mm]

2.2 Generating line

The deviation of the theoretical generating line from the straight line shall not exceed ± 0,2 % of the length of the straight forward part of a cylinder or cone over three adjacent measuring points, which are given by web frames, bulkheads and connections of cones and dished ends. If web frames, cones and bulkheads are not provided, only between dished ends is to be measured. The deviation is to be measured at minimum 8 positions equally distributed over the circumference.

2.3 Length

The length of the pressure hull rings in manufacturing is to be measured at minimum 4 positions equally distributed over the circumference and to be averaged.

The allowable tolerance of the length of the pressure hull ring shall not be bigger than the sum of the existing deviations of the frame distances within this ring. If no frames are provided, the tolerance is ± 1 % of the nominal length, but not more than 15 mm.

3. Dimensions of Spherical Shells and Dished Ends

3.1 Radius of spherical shells and crown of dished ends

For determination of the spherical form of the spherical shell the outside radius is to be evaluated according to E.3.
The spherical form of the spherical shell has to remain within a tolerance of ± 1 % of the nominal outside radius.

3.2 Course of theoretical geometry lines of dished ends (knuckle/crown radius)

The tolerances are to be defined by the manufacturer according to recognized regulations and deviations from it are to be approved by **TL**, compare E.2.

4. Component Thickness

Tolerances for components of the pressure hull: –0/+ t

Tolerance value t according to material delivery specifications (if the material delivery standard allows minus tolerances, these are to be considered for the calculations)

5. Edge Offset and Weld Sinkage

5.1 The radial deviations x_1 and x_2 are the basis for the determination of weld sinkage and edge ofset of sheet metal surfaces with regard to their nominal positions next to a welding seam, compare Fig. B.1.
They are measured at a distance v = s_{max} + 20 mm on both sides centred over the welding seam.

5.2 The tolerances for the gradient of the theoretical line of the middle plane at the tripping/transition ring are to be documented in the manufacturing protocols and to be checked.

5.3 Edge offset for cylindrical and conical parts The edge offset of both plates which is determined by the difference of the measuring values $|x_2 - x_1|$, compare Fig. B.1.

For circumferential seams the edge offset shall not exceed 15 % of the nominal thickness of the thinner plate, but maximum 4 mm.

For longitudinal seams the edge offset shall not exceed 10 % of the nominal thickness of the thinner plate, but maximum 3 mm.

5.4 Edge offset for spherical shells and dished ends

For butt joints within these shells and dished ends the edge offset shall not exceed 10 % of the nominal thickness of the thinner plate, but maximum 3 mm.

5.5 Weld sinkage for cylindrical and conical parts

The mean value of the deviations

$$h = (x_1 + x_2) / 2$$

is defined as weld sinkage. If not otherwise agreed with **TL**, the following tolerances are valid:

For circumferential seams the weld sinkage shall not exceed h = ¼ . s, but maximum 5 mm.

For longitudinal seams the weld sinkage shall not exceed h ≤ 1/6 . s, but not more than 3 mm.

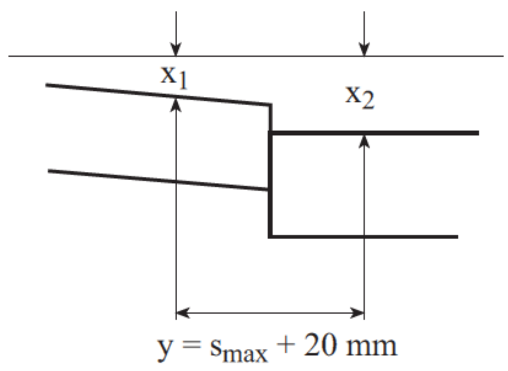


Figure B.1 Radial deviation of the sheet metal surface of the pressure hull

5.6 Weld sinkage for spherical shells and dished ends

For butt joints within these shells and dished ends the weld sinkage shall not exceed h = 1/6 . s, but maximum 3 mm.

6. Damages to the Component Surface

Damage to the surface, such as scores, scratches, arc strikes, indentation pits, etc. shall be thoroughly smoothed and inspected for surface cracks. The flaws treated in this way are permissible without proof of strength, if the following requirements are met:

- The depth shall at maximum 0,05 . s or 3 mm, the smaller value is decisive.

- The area of the undercut of the thickness shall be within a circular area with 2 . s as diameter or 60 mm, the smaller value is decisive.

- The distance between two areas of thickness undercut and the distance from points of disturbance, like e.g. penetrations, shall be at least $\sqrt{2.R.s}$.

Deeper flaws are to be treated specially in agreement with **TL.**

C. Pressure Hull Frames

1. Measurements

The following measurements shall be carried out on every frame of the pressure hull at eight measuring points uniformly distributed around the circumference:

- Flange width
- Flange thickness
- Web thickness
- Frame spacing (measured at frame heel)
- Frame height at frame moulding edge
- Eccentricity flange to web
- Web tilt to plane of frame

The spacing k of the frame heel from a reference plane shall be determined by direct measurement, see Fig. B.2. The location of the frame heel is shown as detail "A" in this Figure. For cylindrical pressure hull parts this measurement shall be carried out on a minimum of one frame per ring (with a ring length of up to a maximum of 8 pressure hull frames) and for conical pressure hull parts on every frame at 16 points uniformly distributed around the circumference.

2. Tolerances

2.1 The following tolerances are maximum values and shall not be exceeded. The tolerances calculated from percentages may be rounded up to half of a millimetre.

2.2 Flange width: 0 % to + 4,5 %
Flange thickness: 0 mm to + 3 mm
Web thickness: 0 mm to + 3 mm

With regard to the flange width or flange thickness the nominal cross sectional area of the flange is considered to be a permissible acceptance criteria. Height tolerances of 0,2 + 0,04 . s ≤ 1 mm (s = material thickness in mm) due to flat grinding of nicks may be exceeded locally, however, the nominal cross section of the flange or web shall not be reduced to more than 90 %.

2.3 Frame spacing: generally ± 1 %

At circumferential seams
+1 % to –3 %

2.4 Frame height at frame moulding edge:

0 % to + 5 %

Tolerances up to –2 % are allowed locally if the mean value of the 8 measuring points reaches nominal value.

2.5 Eccentricity of flange to web:

2 % of frame height

2.6 Inclination of web to reference plane of frame:

± 2 °

2.7 Misalignment of frame heel to reference plane:

+ 4 mm for frames
± 6 mm for web frames

If the maximum difference of determined spacings (k_{max} – k_{min}) is larger than 8 mm for frames and 12 mm for web frames, the real deviations of h shall be determined by evaluation according to the following formula:

$$h_i = k_i - k_0 - \Delta k_x \sin \varphi_i - \Delta k_y \cos \varphi_i \qquad (B1)$$

$k_0 = 1/J\ (k_1 + k_2 + k_3 + \ldots + k_J)$ (B2)

$\Delta k_x = 2/J\ (k_1 \sin \varphi_1 + k_2 \sin \varphi_2 + k_3 \sin \varphi_3 + \ldots + k_J \sin \varphi_J)$ (B3)

$\Delta k_y = 2/J\ (k_1 \cos \varphi_1 + k_2 \cos \varphi_2 + k_3 \cos \varphi_3 + \ldots + k_J \cos \varphi_J)$ (B4)

$\varphi_i = 360°\ i / J$

h_i = Deviation of the frame heel from the actual plane of frame at measuring point i

k_i = Measured distance of frame heel from the reference plane of measuring point i

J = Number of measuring points

3. Transition Rings and Strengthening of Pressure Hull

Transition rings, strengthenings of cut-outs and other strengthenings of the pressure hull are not to be applied with tolerances which weaken the components.

D. Out-of Roundness of the Cylindrical or Conical Pressure Hull

1. The out-of-roundness shall be measured at each frame and also at each transition ring. The measurements are to be conducted with a maximum distance according to $\sqrt{3.R\ .s}$ over the complete length of the component. For frame spacings above $\sqrt{3.R\ .s}$ the out-of-roundness is to be determined also at the shell between the frames considering this measuring distance.

Moreover the course of the theoretical geometry lines at the transition ring is to be determined.

2. The following requirements shall be met prior to conducting out-of-roundness measurements:

- The required tests shall only be carried out when no subsequent changes of measured values are to be expected.

- The section is to be cooled down to ambient temperature and relieved from any tension by means of appropriate aids in order to prevent falsification of measurement results.

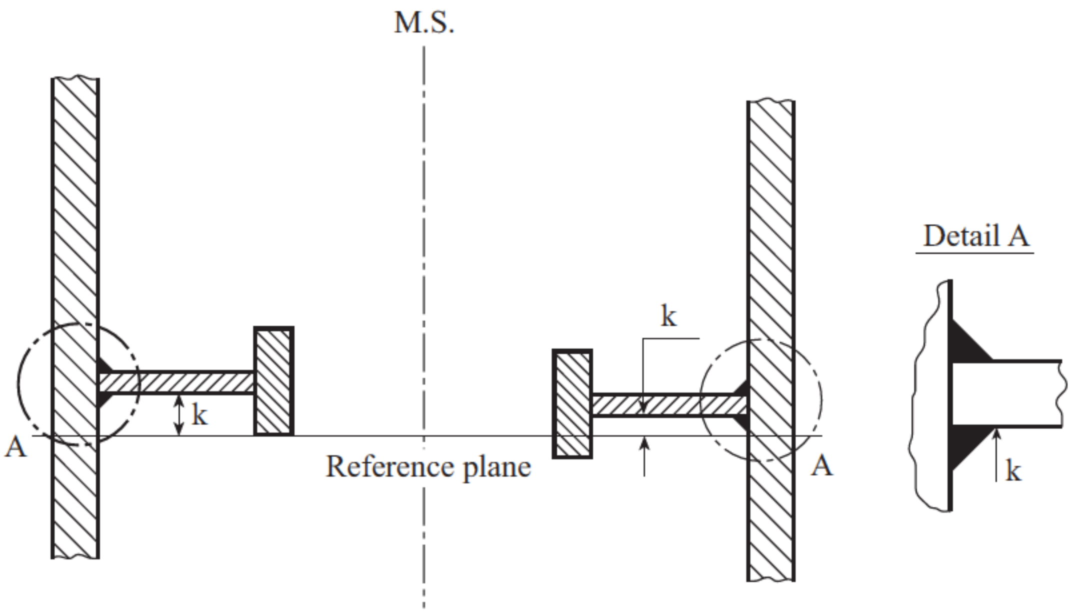


Figure B.2 Definition of the reference plane of a frame

3. The measurement of the pressure hull can be carried out from outside or from inside. In principle the measurement of out-of-roundness shall be carried out at 24 points distributed as uniformly as possible around the circumference. It can be conducted with the help of a circular template, callipers, a two point bridge gage (see Fig. B.4), photogrammetry or theodolite methods, in which case access has to be provided by appropriate means. If the measuring of individual values is not possible due to constructionalreasons (e.g. in the area of larger openings), it shall be supplemented as far as practically possible (in generalby linear interpolation). The measurement shall not be impaired by welding seams (e.g. weld reinforcement)or local imperfections on the surface.

4. The results of the evaluation shall be presented to **TL** as tables and graphs.

5. The maximum permissible out-of-roundness is ± 0,5 % of the nominal pressure hull diameter unless otherwise agreed by **TL.**

6. Measuring Method 1: Direct Measurement of the Radii and Their Deviation From Constant Radius; From Inside or From Outside

The measurement can be performed from inside - measurement of the radii, and from outside – measurement of the deviations from the constant, mean radius by rotating the pressure hull around an assumed axis (centre). The assumed centre shall be as near to the true centre as possible, compare Fig. B.3.

The following formulas apply to J = 24 measuring points distributed uniformly around the circumference:

$$u_i = R_i - \overline{R} - \Delta x \sin \varphi_i - \Delta y \cos \varphi_i \qquad \text{(B5)}$$

$$\overline{R} = 1/J\,(R_1 + R_2 + R_3 + \ldots + R_J) \qquad \text{(B6)}$$

$$\Delta x = 2/J\,(R_1 \sin \varphi_1 + R_2 \sin \varphi_2 + R_3 \sin \varphi_3 + \ldots + R_J \sin \varphi_J) \qquad \text{(B7)}$$

$$\Delta y = 2/J\,(R_1 \cos \varphi_1 + R_2 \cos \varphi_2 + R_3 \cos \varphi_3 + \ldots + R_J \cos \varphi_J) \qquad \text{(B8)}$$

i = Measuring points 1 to J (for above formula J = 24)

R_i = Radial measuring value at the curve shape at measuring point i; measured from assumed centre

$\overline{R}$ = Average calculated radius

Δx = Deviation of measurement, horizontal

Δy = Deviation of measurement, vertical

u_i = Calculated out-of-roundness of the pressure hull at the measuring point i

φ_i = Angle of the measuring point, see C.2.7

The calculation procedure shall be documented according to Table B.1.

7. Measuring Method 1: Non-Uniformly Distributed Measuring Points

In case of non-uniformly distributed measuring points and angular separation of measuring points ≤ 18° the following formulas apply:

$$u_i = R_i - \overline{R}' - \Delta x' \sin \varphi_i - \Delta y' \cos \varphi_i \qquad \text{(B9)}$$

$$\overline{R}' = [1/(2\pi D)]\,[R_1 x_2 + R_2 (x_3 - x_1) + R_3 (x_4 - x_2) + \ldots + R_J (x_1 - x_{J-1} + \pi D)] \qquad \text{(B10)}$$

$$\Delta x' = [1/(\pi D)]\,[R_1 \sin \varphi_1\, x_2 + R_2 \sin \varphi_2\, (x_3 - x_1) + R_3 \sin \varphi_3 (x_4 - x_2) + \ldots + R_J \sin \varphi_J (x_1 - x_{J-1} + \pi D)] \qquad \text{(B11)}$$

$$\Delta y' = [1/(\pi D)]\,[R_1 \cos \varphi_1\, x_2 + R_2 \cos \varphi_2\, (x_3 - x_1) + R_3 \cos \varphi_3 (x_4 - x_2) + \ldots + R_J \cos \varphi_J (x_1 - x_{J-1} + \pi D)] \qquad \text{(B12)}$$

i = Measuring points 1 to J (for above formula J = 24)

J = Actual number of measuring points

R_i = See definition in 6.

R ' = Average calculated radius

Δx' = Deviation of measurement, horizontal

Δy' = Deviation of measurement, vertical

u_i = See definition in 6.

D = Diameter of the measuring circuit

x_i = Circumferential coordinate at measuring point i (measuring distance from starting point $x_J = x_0 = 0$)

φ_i = Angle at measuring point
= $360 . x_i / (\pi D)$

Table B.1 Protocol and calculation table for evaluation of the out-of-roundness according to method 1

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**	**(10)**	**(11)**
i	R_i [mm]	φ_i [°]	sin φ_i	cos φ_i	R_i sin φ_i	R_i cos φ_i	Δx . sin φ_i	Δy. cos φ_i	(7)+(8)	(9)+$\overline{R}$	u_i = (1)-(10)
1		15	0,2588	0,9659							
2		30	0,5000	0,8660							
3		45	0,7071	0,7071							
4		60	0,8660	0,5000							
5		75	0,9659	0,5000							
6		90	1,0000	0,0000							
7		105	0,9659	-0,2588							
8		120	0,8660	-0,5000							
9		135	0,8660	-0,7071							
10		150	0,5000	-0,8660							
11		165	0,2588	-0,9659							
12		180	0,0000	-1,0000							
13		195	-0,2588	-0,9659							
14		210	-0,5000	-0,8660							
15		225	-0,7071	-0,8660							
16		240	-0,8660	-0,5000							
17		255	-0,9659	-0,2588							
18		270	-1,0000	0,0000							
19		285	-0,9659	0,2588							
20		300	-0,8660	0,5000							
21		315	-0,8660	0,7071							
22		330	-0,5000	0,8660							
23		345	-0,2588	0,9659							
24		360	0,0000	1,0000							

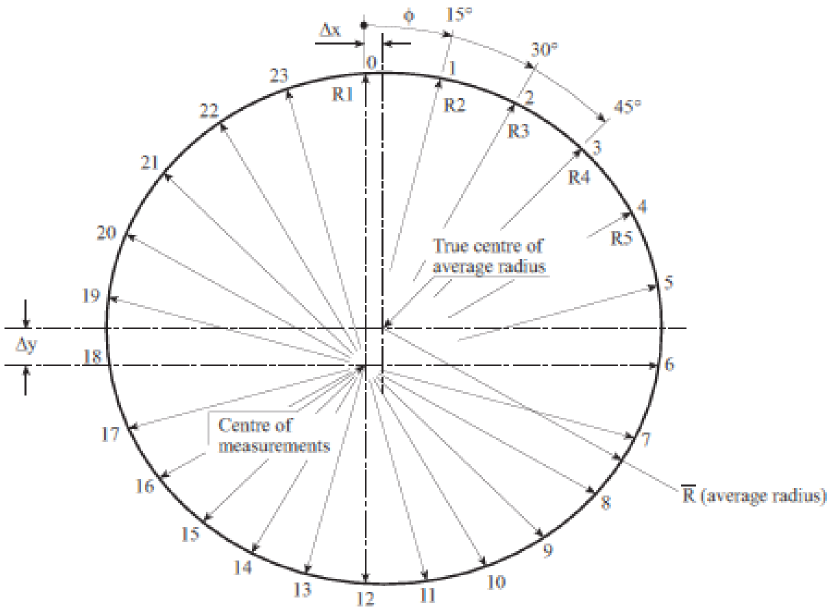


Figure. B.3 Measurement of the out-of-roundness at the cylinder; measuring method 1, explanation of symbols

8. Measuring Method 2: Indirect Measurement of the Deviation From The Average Arc Height of The Measuring Bridge; From Outside

The number of planes used for measuring the out-of-roundness of cylindrical pressure vessels is to be agreed with **TL.** For each measuring plane, at least J = 24 measuring points shall be provided and evenly distributed round the circumference. The height of arc x (j) is measured with a bridge extending over a string length $L_s = 4 \cdot \pi \cdot R_0/J$ (see Fig. B.4). From the values x (j) and the influence coefficients C, the out-of-roundness values can be calculated by applying formula (B13). Table B.2 gives the influence coefficients C where J = 24. The values of the out-of-roundness U (j) measured in this way shall not exceed the maximum permissible values defined in 5.

R_0 means here the outer radius of the cylindrical shell.

$$U_j = \sum_{i=0}^{J-1} x_i \cdot C_{|i-j|} \qquad (B13)$$

Example for out-of-roundness U at the point j=2 for J=24:

$$U_2 = x_0 \cdot C_2 + x_1 \cdot C_1 + x_2 \cdot C_0 + x_3 \cdot C_1 + ... + x_{21} \cdot C_{19} + x_{22} \cdot C_{20} + x_{23} \cdot C_{21} \qquad (B14)$$

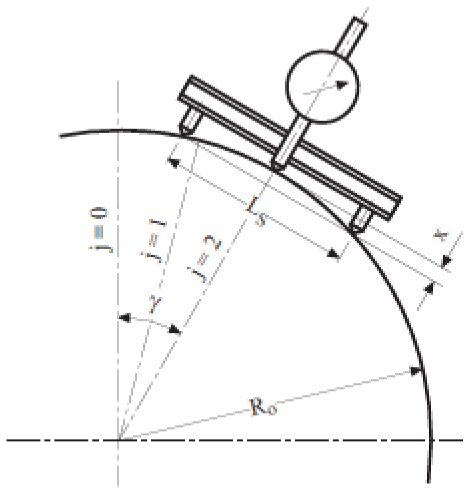


Figure B.4 Measuring the uot-of-roundness of a cylindrical shell, measuring method 2

Table B.2 Influence factor C_i for J=24

i=j	$C_{\|i-j\|}$	i=j	$C_{\|i-j\|}$
0	1,76100	12	0,60124
1	0,85587	13	0,54051
2	0,12834	14	0,36793
3	-0,38800	15	0,11136
4	-0,68359	16	-0,18614
5	-0,77160	17	-0,47097
6	-0,68487	18	-0,68487
7	-0,47097	19	-0,77160
8	-0,18614	20	-0,68359
9	0,11136	21	-0,38800
10	0,36793	22	0,12834
11	0,54051	23	0,85587

E. Spherical Shells and Dished Ends

1. The following measurements are to be performed for spherical shells and dished ends:

- Course of the theoretical geometry lines at the transition ring (tripping ring)
- Out of roundness, circumference and inclined position of the cylindrical attachment of dished ends
- Out of roundness of the spherical shell (local flattening)
- Spherical form of the shell

2. For dished ends with torispherical or semielliptical shape the tolerances according to recognized standards, e.g. DIN 28011 or DIN 28013 are to be kept. But for the deviations in shape:

- Local flattening
- Out of roundness of the cylindrical attachment the tolerances defined in this Annex are valid, compare 4. and D.5.

3. A permissible spherical form is a shell which keeps a defined radius with a defined tolerance. For evaluation of the spherical form of the shell the outside radii are to be measured in 6 equally distributed (i.e. displaced by 30°) planes cutting a joint axis (Fig. B.5). For spherical segments an analogous procedure is to be established.

The values for the out-of-roundness measured in this way shall not exceed 1 % of the nominal outer radius. If smaller local radii as 1,3 times the nominal outer radius are agreed for local flattenings, a less permissible out-of-roundness of the spherical shell is of advantage. The permissible value of the out-of-roundness is to be agreed with **TL**.

4. Measurement of the local flattening at spherical shells

The measurement shall not be impaired by welding seams (e.g. seam reinforcement) or local imperfections of the surface. The height of arch x' is measured with a 3 point bridge gauge (see Fig. B.6), where the measuring diameter $L_{c,l}$ is to be calculated with formula (B15).

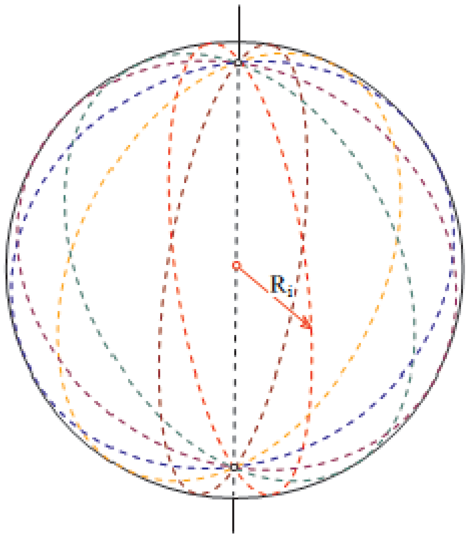


Figure B.5 Measurement planes of a spherical shell- measuring method 1

The out-of-roundness of the spherical shell follows from the local flattening U according to formula (B17). The maximum permissible value of the local flattening, on the basis of a local radius $R_{o,l}$ = 1,3 . R_o is u = 0,218 . s_l/ R_o. Consequently the maximum permissible local flattening U of the spherical shell from the theoretical spherical form is 21,8 % of the plate thickness sl (average value of the measured thickness in the measuring area). If a deviating local radius for the layout of the pressure hull is agreed, a corrected collapsing pressure p_{cr}' and a corrected permissible local flattening is to be evaluated according to 5.

$$L_{c,l} = \frac{2,2}{\sqrt[4]{\frac{3}{4}\cdot(1-\nu^2)}}\cdot\sqrt{R_{o,l}\cdot s_l} \qquad (B15)$$

$$x = R_o - \sqrt{R_o^2 - \frac{L_{c,l}^2}{4}} \qquad (B16)$$

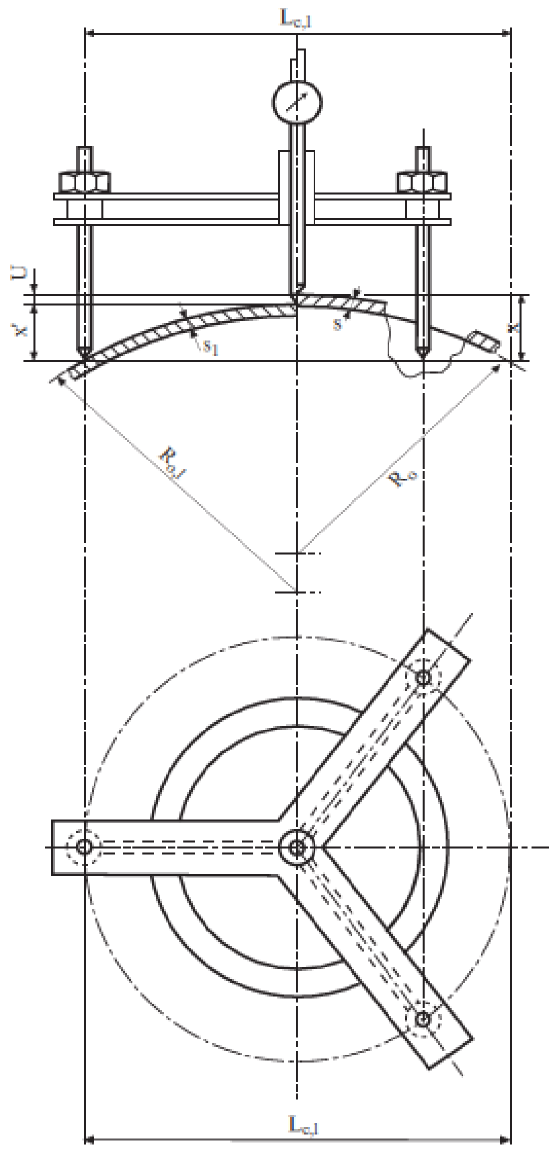


Figure B.6 Measuring the out-of-roındness of a sphere

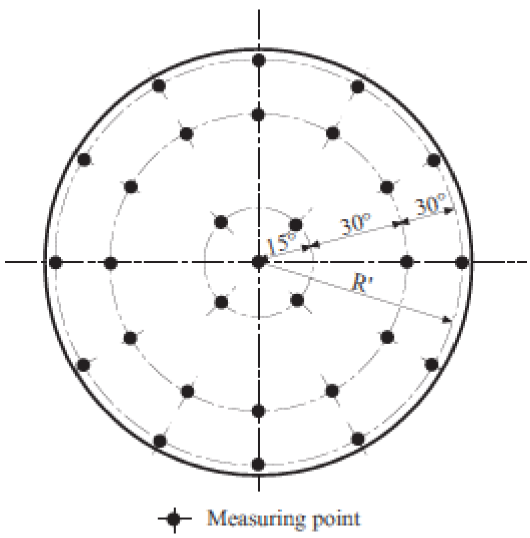


Figure B.7 Distribution of the measuring points over a hemisphere

$$U = x - x' = u \cdot R_0 \qquad \text{(B17)}$$

$L_{c,l}$ = Critical arch length (diameter of measuring circle)

s_l = Local average shell thickness

x = Arch height at nominal shell radius R_o

x' = Measured arch height

v = Poisson's ratio in elastic range
= 0,3 for steel

U = Local flattening of the spherical shell within diameter $L_{c,l}$

u = Local flattening, related to the nominal radius R_o

The distribution of the measuring points is defined in Fig. B.7. In each measuring point two measurements are to be made: once in a plane through the middle axis and once vertical to it.

5. Calculation of the Failure Pressure For Spherical Shells With A Deviating out-of-Roundness ($u \neq 0{,}218 \cdot s/R_o$)

The corrected maximum permissible out-of roundness can be evaluated with the aid of Table B.3.

The corrected elastic-plastic buckling pressure p_{cr}^{i} ' is to be evaluated with formula (B18) using the correction factor cp under consideration of the actually existing local curvature radius $R_{o,l}$ (relation $R_{o,l}$ / R_0). The local curvature radius is to be calculated with formula (B19). The thus evaluated elastic-plastic buckling pressure p_{cr}^{i} ' is to be multiplied with the reduction factor k according to Annex A, F.6.6. Local radii larger than two times the nominal radius are to be avoided. For radii less than 1,3 times the nominal radius the definitions in Annex A, F.6.3 are to be observed.

$$p_{cr}^{i}{}' = \frac{p_{cr}^{i}}{c_p} \qquad \text{(B18)}$$

$$R_{o,1} = \frac{x'}{2} + \frac{L_{c,1}^2}{8 \cdot x'} \qquad (B19)$$

The corrected failure pressure p_{cr}' which is evaluated in this way shall at least be equal to the collapse diving pressure CDP of the pressure hull:

$$p_{cr}' = \frac{p_{cr}^{i}{}'}{c_p} \cdot k \geq \mathbf{CDP} \qquad (B20)$$

F. Literature

Concerning literature reference is made to Annex A, G.

Table B.3 Maximum permissible local flattening for deviating local radius

Relation $\frac{R_{o,1}}{R_o}$	Maximum local flattening $U = \frac{L_{c,1}^2}{8} \cdot \left(\frac{1}{R_o} - \frac{1}{R_{o,1}}\right)$	Corrected diameter of the measuring circle * $L_{c,1} = \frac{2,2}{\sqrt[4]{\frac{3}{4} \cdot (1-\nu^2)}} \cdot \sqrt{R_{o,1} \cdot s_1}$	Correction factor for the elastic-plastic buckling pressure $p_{cr}^{i}{}'$ $c_p = \left(\frac{R_{o,1}}{1,3 \cdot R_o}\right)^{1,07}$
1,3	**0,218 · s_1**	$2,759 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,000**
1,4	**0,290 · s_1**	$2,863 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,083**
1,5	**0,363 · s_1**	$2,964 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,165**
1,6	**0,435 · s_1**	$3,061 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,249**
1,7	**0,508 · s_1**	$3,155 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,332**
1,8	**0,580 · s_1**	$3,247 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,417**
1,9	**0,653 · s_1**	$3,336 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,501**
2,0	**0,725 · s_1**	$3,422 \cdot \sqrt{R_{o,1} \cdot s_1}$	**1,586**

* $L_{c,1} = \frac{2,2}{\sqrt[4]{\frac{3}{4} \cdot (1-\nu^2)}} \cdot \sqrt{\frac{R_{o,1}}{R_o}} \cdot \sqrt{R_{o,1} \cdot s_1}$

Table B.3 is valid for a wall thickness ratio $s/R_o \geq 0,02$ and for materials with yield strength $\sigma_{0,2} \leq 550$ MPa.

ANNEX C

ACRYLIC WINDOWS

Page

A. General

1. Scope

In the sense of these Rules, acrylic windows are flat or curved windows for the view ports of pressure hulls which are made of cast, unlaminated polymethyl methacrylate plastic.

2. Limits of application

For acrylic windows following limits for application apply:

- designed service life 10 or 20 years (see explanatory notes below)
- temperature range -18 °C to +66 °C
- rate of pressurization max. 10 bar/s
- pressure cycles at design pressure max. 10.000
- period under pressure at design pressure max. 40.000 h
- maximum allowable working pressure max. 1380 bar

The design service life for acrylic windows depends on numerous factors, in particular on the kind of loading. The maximum design service life to be assumed for spherical or cylindrical windows subjected to external overpressure, which are exclusively exposed to compressive stresses or minor bending stresses only, is generally 20 years, while for flat windows with flat seat it is 10 years. The design service life starts with the date of manufacturing regardless of the use in the submersible.

Depending on the previous actual loads acting on the windows and testing to be agreed with **TL** in detail, extension of the service life of acrylic windows may be approved.

3. Permissions/Approvals

For the design and manufacturing of acrylic windows the following permissions/approvals are required:

- Approval of drawings and of the design for each type of window and each form of application by **TL**
- Approval as material manufacturer by **TL**
- Manufacturer Inspection Certificate for the material, compare B.3.
- Approval by **TL** as manufacturer of acrylic Windows
- **TL** Certificate which certifies the manufacturing inspections and the pressure tests according to C.6.

B. Materials

1. Materials for acrylic windows are to be manufactured in accordance with a recognized Standard (e.g. ANSI/ASME PVHO 1, Section 2). The producer is required to certify this before manufacture commences.

2. Acrylic windows have to meet the minimum physical requirements stated in Table C.1.

3. For each batch of acrylic plastic processed to windows the manufacturer has to issue a Manufacturer Inspection Certificate containing at least the following details:

- Number and date of Certificate
- Manufacturer's name and address
- Designation and application of casting type
- Batch number, quantity, shape and size of castings
- Marking of castings
- Results of tests applied in accordance with Table C.1
- Stamp and signature

4. Where a Manufacturer Inspection Certificate of the kind required is not available for the acrylic plastic or where the conditions for recognition of the Inspection Certificate are not satisfied, the tests are to be extended in a manner to be agreed with **TL** in each individual case.

5. Each casting is to be provided at one point at least with a marking which identifies the type of casting, the batch number, the date of manufacture and the name of the manufacturer.

C. Manufacture of Windows

1. The manufacture of acrylic windows covered by these Rules may only take place in specialized workshops which have been approved by **TL** for that purpose. Such approval can be granted only to those companies which employ properly trained specialists and which have available the necessary technical facilities enabling them to undertake the expert forming, machining, heat treatment and quality control of acrylic windows. Application for approval is to be made to **TL** before the manufacture of windows commences.

2. The acrylic plastic to be used has to meet the requirements stated in B. After machining and any necessary forming operations, each window is to be subjected to heat treatment (tempering) in accordance with the acrylic plastic manufacturer's specification. After tempering no further mechanical polishing may be carried out on the window.

Flat disk windows for diving chambers where only the surrounding area is professionally machined need not to undergo a heat treatment after manufacturing.

3. Window surfaces are to be polished in such a way as to meet the optical clarity requirement stated in Table C.1.

4. For each window or series of windows the window manufacturer has to issue a component Certificate specifying all the stages of manufacture such as cutting, sticking, polishing, forming and tempering. In addition the tests carried out, the test results, the marking of the windows and the date of manufacture are to be indicated.

5. Each window is to be permanently marked with at least the following details:

- Design pressure PR = **NDP** [bar]
- Design temperature [°C]
- **T**L approval stamp
- Manufacturer's name or identifying mark
- Serial number and year of manufacture.
- Direction of pressure, if it is not clear

Wherever possible, the marking is to be engraved in the non-load-bearing portion of the window edge. The use of punches is not allowed.

6. Acrylic windows are to be presented to **TL** for an inspection of manufacture. In addition, each window is to be subjected, in the presence of a **TL** Surveyor, to a pressure test in accordance with **TL** Rules for Underwater Equipment, Chapter 54, Section 2, G.4. At the pressure test the direction of pressure has to be observed. If the windows are subjected to pressure from both sides, this is to be considered for the testing.

D. Window Shapes and Sizes

1. The standard shapes and sizes shown in Table C.2, C.3 and C.4 are to be selected for the acrylic windows. For design pressure PR in general the nominal diving pressure NDP is to be used, see also the Rules for Submersibles, Table 4.2 or Underwater Equipment, Table 3.2.

2. Acrylic windows of other shapes and sizes or for other ranges of pressure may be used on application if approved by **TL** or if they are designed and manufactured to a standard recognized by **TL.**

Acrylic windows may be performed e.g. according to ASME PVHO-1, Section 2.

3. The design temperature to be assumed for acrylic windows shall be the mean value of the maximum external and internal temperatures to be expected under design pressure conditions.

4. Windows subjected to pressure from both sides are to be designed for the maximum pressure applied, regardless of whether this pressure is external or internal.

5. Pressure may only be applied to the convex side of spherical shell windows.

6. The thickness of the window has to be everywhere equal to, or greater than, the minimum value determined by reference to Tables C.2, C.3 and C.4. For intermediate temperatures linear interpolation may be applied.

7. With flat windows having right-angled edge and an O-ring seal, the outside diameter of the disk shall be within + 0,00/-0,25 mm of the nominal value, or within + 0,00/-0,75 mm where flat gasket seals are used.

8. Because of stress increasing effects grooves for seals shall not be located in the acrylic window bearing surface and also not in the window itself.

9. The greater diameter of the conical bearing surface of an acrylic window shall be within +0,000/-0,002 D_o of the nominal value.

The included conical angle of the window shall be within + 0,25/-0,00 degrees of the nominal value.

10. The concave or convex surface of the window shall not differ from an ideal spherical sector by more than ± 0,5 % of the nominal external spherical radius.

11. The surface roughness R_a of the window bearing surface shall be 0,75 μm or better.

E. Installation of Windows

1. If the window seat is not made of corrosion resistant material, it is to be sufficiently preserved with a suitable agent. In addition window and window seat are to be carefully cleaned using only cleaning material which is compatible with acrylic glass.

2. Conical window seats are to be treated with silicone or a suitable grease before the installation.

3. During installation of the window care is to be taken that the bolts of the fastening ring are to be tightened with the prescribed and all the same torque.

Table C.1 Mechanical and optical properties of acrylic plastics

Properties	Specified values	Test method	ASTM
Ultimate tensile strength Elongation at break (in relation to necking zone) Modulus of elasticity measured by tensile test	≥ 62 N/mm^2 ≥ %2 ≥ 2760 N/mm^2	DIN 53455 **(1)** specimen type 3 test velocity II standard climate 23/50 DIN 53457	D 638 **(1)**
Compressive yield strength Modulus of elasticity measured by compression test	≥ 103 N/mm^2 ≥ 2760 N/mm^2	DIN 53454 **(1)** standard climate 23/50 size of test specimen: 25 × 12,5 × 12,5 mm. DIN 53457 **(1)**	D 695 **(1)**
Compressive deformation	≤%1	Constant compressive stress (1) of 27,5 N/mm^2 for 24 h at 50 °C test cube: 12,5 mm edge length	D 621 **(1)**
Ultraviolet transmittance	≤%5	UV-spectrophotometer wave length range: 290 - 370 nm thickness of specimen: 12,5 mm	E 308
Visual clarity	Legibility	A 25 x 25 mm standard type set comprising 7 lines of 16 letters each is to be clearly legible through the acrylic plastic pane at a distance of 500 mm.	D 702
Residual monomers methyl methacrylate aethyl acrylate	≤% 1,6	Gas chromatograph	

1) *The mechanical properties are to be verified on at least 2 specimens.*

Table C.2 Standard dimensions for flat disk windows

Range of application:

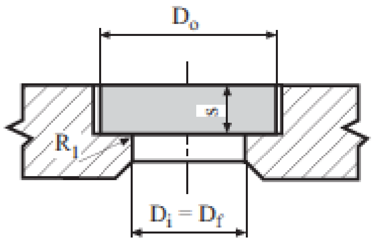
Minimum wall thickness : $s \geq 12,5$ mm

Slenderness ratio : $s/D_o \geq 0,125$

Edge radius : $1 \text{ mm} \leq R_1 \leq 2$ mm

Window seating : $1,25 \leq D_o/D_f \leq 1,5$ mm

Max. allowable working pressure : $p \leq 170$ bar



Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i at				
	10 °C	24 °C	38 °C	52 °C	66 °C
5	0,134	0,146	0,154	0,164	0,188
10	0,154	0,173	0,188	0,201	0,226
15	0,173	0,195	0,210	0,223	0,253
20	0,188	0,210	0,226	0,240	0,281
25	0,201	0,223	0,240	0,257	0,305
30	0,210	0,233	0,253	0,274	0,324
35	0,219	0,243	0,267	0,292	0,344
40	0,226	0,253	0,281	0,305	0,363
45	0,233	0,264	0,295	0,317	0,383
50	0,240	0,274	0,305	0,329	0,402
60	0,253	0,295	0,324	0,354	0,441
70	0,267	0,310	0,344	0,378	0,480
80	0,281	0,324	0,363	0,402	0,520
90	0,295	0,339	0,383	0,427	0,559
100	0,305	0,354	0,402	0,451	0,598
110	0,315	0,368	0,422	0,476	0,637
120	0,324	0,383	0,441	0,500	0,676
130	0,334	0,398	0,461	0,524	0,715
140	0,344	0,412	0,480	0,549	0,754
150	0,354	0,427	0,500	0,573	0,793
160	0,363	0,441	0,520	0,598	0,832
170	0,373	0,456	0,539	0,622	0,871

Table C.3 Standard dimensions for spherical shell Windows with conical seat (opening angle 60° / 90°)

Range of application:

Opening angle : $\alpha \geq 60°$

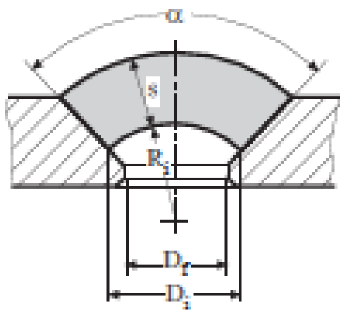
Minimum wall thickness : $s \geq 12{,}5$ mm

Minimum values for s/R_i :

α	$60° \leq \alpha < 90°$	$90° \leq \alpha < 120°$
s/R_i	0,09	0,06

Window seating : $D_i/D_f \geq 1{,}02$

Max. allowable working pressure : $p \leq 170$ bar



Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i for $60° \leq \alpha < 90°$ at					Design pressure PR [bar]	Minimum wall thickness / inside diameter of seat s/D_i for $90° \leq \alpha < 120°$ at				
	10 °C	24 °C	38 °C	52 °C	66 °C		10 °C	24 °C	38 °C	52 °C	66 °C
5	0,090	0,090	0,090	0,090	0,090	5	0,042	0,042	0,042	0,042	0,049
10	0,090	0,090	0090	0,090	0,112	10	0,042	0,043	0,049	0,054	0,070
15	0,090	0,090	0,097	0,108	0,140	15	0,043	0,052	0,060	0,067	0,089
20	0,090	0,097	0,112	0,126	0,166	20	0,049	0,060	0,070	0,080	0,107
25	0,090	0,108	0,126	0,143	0,191	25	0,054	0,067	0,080	0,091	0,124
30	0,097	0,119	0,140	0,160	0,215	30	0,060	0,075	0,089	0,102	0,142
35	0,104	0,129	0,153	0,176	0,238	35	0,065	0,082	0,098	0,113	0,160
40	0,112	0,140	0,166	0,191	0,259	40	0,070	0,089	0,107	0,124	0,177
45	0,119	0,150	0,179	0,206	0,279	45	0,075	0,095	0,116	0,135	0,194
50	0,126	0,160	0,191	0,221	0,298	50	0,080	0,102	0,124	0,146	0,210
60	0,140	0,179	0,215	0,248	0,332	60	0,089	0,116	0,142	0,168	0,242
70	0,153	0,197	0,238	0,274	0,363	70	0,098	0,128	0,160	0,190	0,272
80	0,166	0,215	0,259	0,298	0,391	80	0,107	0,142	0,177	0,210	0,300
90	0,179	0,232	0,279	0,320	0,416	90	0,116	0,155	0,194	0,230	0,327
100	0,191	0,248	0,298	0,340	0,439	100	0,124	0,168	0,210	0,250	0,351
110	0,203	0,264	0,315	0,359	0,460	110	0,133	0,181	0,226	0,269	0,373
120	0,215	0,279	0,332	0,377	0,480	120	0,142	0,194	0,242	0,287	0,393
130	0,227	0,293	0,348	0,394		130	0,151	0,206	0,257	0,304	0,411
140	0,238	0,307	0,363	0,410		140	0,160	0,218	0,272	0,320	
150	0,248	0,320	0,377	0,425		150	0,168	0,230	0,287	0,336	
160	0,259	0,332	0,391	0,439		160	0,177	0,242	0,300	0,351	
170	0,269	0,344	0,404	0,452		170	0,185	0,254	0,314	0,365	

Table C.4 Standard dimensions for spherical shell windows with conical seat (opening angle 120° / 180°)

Range of application:

Opening angle : $180 \geq \alpha \geq 120°$

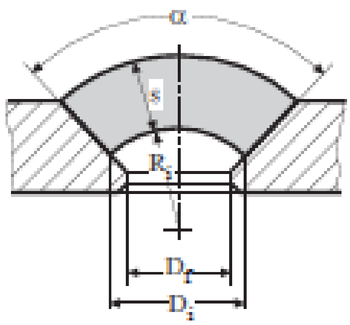
Minimum wall thickness : $s \geq 12{,}5$ mm

Minimum values for s/R_i :

α	120° ≤ α < 180°	α = 180°
s/R_i	0,06	0,03

Window seating : $D_i/D_f \geq 1{,}02$

Max. allowable working pressure : $p \leq 170$ bar



Design pressure PR [bar]	Minimum wall thickness / Inside diameter of seat s/D_i for $120° \leq \alpha < 180°$ at					Design pressure PR [bar]	Minimum wall thickness / Inside diameter of seat s/D_i for $\alpha = 180°$ at				
	10 °C	24 °C	38 °C	52 °C	66 °C		10 °C	24 °C	38 °C	52 °C	66 °C
5	0,021	0,023	0,025	0,028	0,034	5	0,018	0,018	0,019	0,021	0,026
10	0,025	0,030	0,034	0,038	0,050	10	0,019	0,023	0,026	0,030	0,041
15	0,030	0,036	0,042	0,048	0,067	15	0,023	0,028	0,034	0,039	0,056
20	0,034	0,042	0,050	0,059	0,083	20	0,026	0,034	0,041	0,049	0,071
25	0,038	0,048	0,059	0,069	0,100	25	0,030	0,039	0,049	0,058	0,086
30	0,042	0,054	0,067	0,079	0,117	30	0,034	0,045	0,056	0,068	0,101
35	0,046	0,061	0,075	0,090	0,131	35	0,038	0,051	0,064	0,077	0,115
40	0,050	0,067	0,083	0,100	0,146	40	0,041	0,056	0,071	0,086	0,129
45	0,054	0,073	0,092	0,110	0,161	45	0,045	0,062	0,079	0,096	0,142
50	0,059	0,079	0,100	0,119	0,175	50	0,049	0,068	0,086	0,105	0,155
60	0,067	0,092	0,117	0,138	0,204	60	0,056	0,079	0,101	0,122	0,182
70	0,075	0,104	0,131	0,157	0,232	70	0,064	0,090	0,115	0,139	0,207
80	0,083	0,117	0,146	0,175	0,259	80	0,071	0,101	0,129	0,155	0,232
90	0,092	0,127	0,161	0,193	0,285	90	0,079	0,112	0,142	0,172	0,256
100	0,100	0,138	0,175	0,211	0,310	100	0,086	0,122	0,155	0,188	0,278
110	0,108	0,149	0,190	0,228	0,334	110	0,094	0,132	0,168	0,204	0,299
120	0,117	0,161	0,204	0,245	0,357	120	0,101	0,142	0,182	0,220	0,319
130	0,123	0,171	0,218	0,262	0,379	130	0,108	0,152	0,194	0,235	0,337
140	0,131	0,182	0,232	0,278	0,400	140	0,115	0,162	0,207	0,250	0,352
150	0,138	0,193	0,245	0,294		150	0,122	0,172	0,220	0,264	0,366
160	0,146	0,204	0,259	0,310		160	0,129	0,182	0,232	0,278	
170	0,153	0,214	0,272	0,325		170	0,135	0,191	0,244	0,292	

ANNEX D

MANUFACTURE and TREATMENT of FIBRE REINFORCED PLASTICS (FRP)

Page

A. General

1. Definition

Fibre rei nforced plastics are heterogeneous materials, consisting of a thermosetting resin as the matrix and an embedded fibrous reinforcing material.

2. Scope of application

For submersibles plastics are mainly used for the following components:

- Exostructure
- Rudder and propeller
- Pressure vessels

B. Requirements for the Materials and their Processing

1. Materials

1.1 Approval

1.1.1 The materials used for the manufacturing of components from FRP shall be assessed and approved by **TL**.

1.1.2 The approval refers only to the approved material. The applicability of this material in connection with other materials shall be demonstrated independently by the manufacturer or the user in a suitable manner.

1.2 Quality assurance

1.2.1 A constant material quality shall be secured by the manufacturer through constant quality assurance measures.

1.2.2 **TL** reserve the right to demand or carry out spot tests of the material properties during the duration of the material approval.

1.3 Types of materials

For the construction of submersibles in general the following materials are to be considered:

- Laminated resins, e.g. cold-setting or hot-setting unsaturated polyester (UP) resins and cold setting epoxy (EP) resins
- Reinforcing materials, e.g. fibre reinforcements made of glass and carbon
- Prepregs as reinforcing materials, which are preimpregnated with a thermosetting resin and which can be processed without any further addition of resin or hardener
- Core materials, e.g. rigid foams with adequate compressive strength
- Adhesives, e.g. cold- and hot-setting thermosetting adhesives and hot-melt adhesives
- Flame retardant laminates produced by additives to the resin system, whereby the viscosity of the resin or the mechanical properties of the manufactured laminates not be changed essentially

Other materials may be approved in agreement with **TL** Head Office.

2. Manufacturing

2.1 Approval

2.1.1 Manufacture of FRP-components shall only be performed by workshops which are approved by **TL** for the manufacture of components made from fibre-reinforced thermosetting resins.

2.1.2 The manufacture of FRP-components shall only be carried out by persons with Professional knowledge. This professional knowledge shall in general be verified by certificates of the corresponding training courses.

2.1.3 All manufacturing facilities, store-rooms and their operational equipment shall fulfil the requirements of the responsible authorities. The manufacturer is alone responsible for compliance with these requirements.

2.2 Store rooms and laminating workshops

The danger of contamination of laminating materials is to be minimized through separation of production facilities from store rooms.

2.3 Guidelines for processing

2.3.1 As a matter of principle, only materials approved by **TL** shall be used. In addition to the choice of suitable and approved materials, special care shall be taken when working with them because of the great influence on the properties of the product.

2.3.2 For the preparation and processing of the resin compounds and reinforcing material, beside the **TL** Rules, the instructions issued by the material manufacturers and the regulations of the competent authorities are to be observed.

2.4 Manufacturing surveillance

For components made of FRP, manufacturing surveillance has to consist of the quality control of the basic materials, production surveillance and the quality inspection of the finished components.

2.5 Repair of components

2.5.1 Repairs of structural FRP-components shall only be performed by workshops which are approved by **TL.**

2.5.2 For the approval of a repair, all design and repair drawings needed to assess the repair of the relevant components are to be submitted to **TL**. The repair plan is to be examined by **TL** Head Office and approved.

2.5.3 A report is to be established for each repair which has to be signed by the head of the repair team.

2.5.4 If the materials and laminates used for the repair are not identical to those employed when the component was manufactured, equivalence of the combination of materials shall be verified with respect to their properties.

C. Requirements for the Design

1. Design data

The mechanical properties and the nominal thickness of the laminate as well as weight, type and portion of the reinforcement layers, which can be individually used, are to be defined on the design drawings.

2. Design measures

For the design of components the following measures are to be considered:

2.1 Changes in the laminate thickness are to be established with a smooth transition of 25 mm per 600 g/m². In the transition area from a sandwich design to massive laminate the core material is to be gradually tapered (at least 3 : 1).

2.2 In general frame and stiffening sections are to be built up by layer and layer on the laminate, as far as the last layer is not yet cured. Where internal structural members are crossing each other, special care is to be taken that the load-bearing capacity remains unchanged.

2.3 Closed hollow spaces in the structure which may be subjected to external pressure are to be avoided.

2.4 If core materials are used in areas which may be subjected to external pressure, pressure-proof materials like e.g. rigid foams are to be used.

2.5 Stress concentrations, peaks in stiffness and discontinuities are to be avoided. It has to be ensured, that because of cut-outs, openings in load carrying elements and the connection of fittings the strength of the component is not impaired.

2.6 If various components which have been produced in different moulds are to be connected with each other, then the connecting laminates have to be finished before curing of the components.

If components of FRP are bolted which each other or with components of other materials, the connecting elements (bolts, nuts, washers) are to be of seawater resistant material. Bolted connections are to be dimensioned according to the occurring forces.

2.7 In areas with local force introduction (e.g. connecting elements of the exostructure, bitts, cleats) sole pieces and/or shims of adequate strength are to be situated. The strength, e.g. bearing strength is to be proven in a suitable way. The connecting area of these sole pieces is to be prepared in a suitable way and shall be free of contamination.

2.8 Metallic materials used in the design, like e.g. steel or aluminium alloys have to be suitable for the intended purpose and shall not impair the curing of the laminating resins.

Local reinforcements of metallic materials are to be cleaned and degreased carefully and, if possible, are to be shot blasted or roughened up to achieve a toothing effect.

2.9 For sandwich laminates in way of bolted connections and fittings, inserts of a material, which can withstand the compression and the design loads, are to be provided. The inserts are to be connected with the core material and the laminate layers in the best way.

2.10 Laminate edges and holes are to be sealed.

2.11 Further design measures which are recommendable for different shipbuilding components made of plastics are contained in the **TL** Rules for Yachts.

ANNEX E

BASIC REQUIREMENTS for UMBILICALS

A. General

1. Definition

The umbilical is regarded as the connecting link between support ship and an element under water, which may include hose assemblies for liquid and gas transport and monitoring, communication, data transfer and energy supply cables as well eventually a lifting cable.

This bundled or integrated supply line may also be used between elements under water.

As elements under water in the sense of this Annex are to be regarded e.g.:

– diving chambers

– non-autonomous (manned) and remotely controlled (unmanned) submersibles

– launchers

– underwater working machines

– diving equipment

The integrated or also independent lifting cable serves for launching and recovery, as well as for lifting and lowering of an element under water as well as for absorption of tension loads during operation. The lifting cable may also be designed as bearing element, e.g. as netting within the sheathing of the umbilical.

2. Scope

This Annex is valid for the technical requirements and the testing of umbilicals including connecting pieces as well as shut-off devices at the ends and the load transfer points. The load transfer points of the support ship/element are not subject of this Annex.

Furtheron this Annex is valid for cables and hose asemblies which may be subjected to external overpressure and integrated lifting cables.

The penetration into the pressure hull or a vessel under pressure is part of the element.

Some basic requirements for the coil-up/coil-off mechanism are defined.

The supply systems for the materials, data and energies transferred by the umbilical form part of the support ship or element and are not treated in this Annex.

Umbilical systems for production duties, as e.g. used in the oil and gas industry, are primarily not subject of this Annex.

3. Quality Management System

The manufacturer of umbilicals has to apply a recognized quality management system, like e.g. ISO 9001 or equivalent. This system has to cover design, manufacture and testing.

4. Equivalence

Umbilicals deviating from this Annex in their type, structure and the compliance with some detailed requirements may be accepted by **TL,** provided that they are found to be equivalent to the principle requirements defined in this Annex.

B. Principles for Layout and Design

1. General

1.1 The requirements defined in the following are minimum requirements for the majority of the prospective applications. For special use the selection of the requirements is to be agreed with **TL.**

1.2 Generally the following requirements are to be considered for the design:

– environmental influences, see the **TL** Rules for Submersibles, Section 2, D.

– influence of weight (deadweight, empty, full)

– buoyancy behaviour (positive and negative buoyancy, neutral buoyancy)

– dynamic influences because of ship movements and increasing and lowering the pressure inside

– thermal influences on expansion and shrinking because of possible temperature changes inside and outside

– thermal influences because of power cables partly on drum

– pressure differences in hoses between upper and lower end of umbilical

– chemical and electrochemical influences

1.3 The control of the coil-up/coil-off mechanism for the umbilical and the monitoring of the supply flow through the umbilical including the production of materials to be supplied are to be concentrated at a central position.

For manned, non-autonomous submersibles the control and monitoring is to be integrated into the control stand which maintains the connection with the submersible. For unmanned, remotely controlled submersibles and other elements these are to be integrated into the control station.

1.4 Umbilicals shall be produced in one piece for the complete required length and shall not be divided into different parts.

1.5 Requirements and tests of umbilicals for hose supplied diving equipment are to be taken from Standard EN 15333-1.

2. Mechanical requirements

2.1 Materials

Only materials according to generally recognized standards are to be used and their application has to be clearly recorded and traced.

The materials are to be suitable for the use in salt water. If a mission in other media than water is planned, these are to be adequately considered.

The material of hose assemblies is to be suitable for the media to be transported.

The materials are to be suitable for permanent and varying bending stress.

If hoses are used for breathing gases their suitability is to be proven (e.g. off-gassing test).

Umbilicals, hose assemblies and cables are to be protected against abrasion and damages.

For the protection cover of umbilicals attention is to be given that no internal pressure can be built up if little leakages occur in the hose. Metal inserts in the protection cover are to be avoided.

2.2 Tensile load

2.2.1 For umbilicals with integrated lifting cable the mechanical characteristics are to be judged according to the submitted documentation. Hereby the maximum permissible tension load and the minimum breaking load of the umbilical are to be defined by the manufacturer. For the use of lifting cables made of steel the maximum static tension load created by the safe working load shall not exceed 1/8 of the proven breaking load of the cable. For the use of lifting cables made of chemical fibre the maximum static tension load created by the safe working load shall not exceed 1/10 of the proven breaking load of the cable.

For the use of lifting cables for simple scientific devices a reduced breaking load of the cable may be approved in agreement with **TL** under consideration of risk potential and intended use.

Further on the functionality of the elements contained in the umbilical at maximum possible longitudinal extension of the umbilical is to be considered.

The umbilical is to be constructed to reach neutrality to tension for the whole range of tensional stresses.

2.2.2 If there is no lifting cable included, the integrated cables and hose lines are to be protected from longitudinal stress by a strain relief. The minimum tension load is to be defined considering the duty of the mission, is to be agreed with **TL** and to be proven.

2.2.3 If buoyancy elements or weights are used to change the buoyancy behaviour, these are to be securely fastened without damaging the umbilical.
Over the complete appearing tension range no additional torsional effects shall be created.

For hoses with non corrosion-resistant wire mesh inlets the mesh is to be protected against the surrounding media.

2.3 Bending and buckling

Umbilicals shall be buckling safe and bending resistant respectively being adequately arranged to avoid buckling safely. According to the structure of the umbilical the minimum bending radius is to be agreed with **TL.**

The minimum bending radius of a single component (e.g. lifting cable, cable, hose assembly, etc.) shall not be bigger than the minimum bending radius of the complete umbilical.
If special elements are used for avoidance of bending and buckling, these have to be securely fastened without damaging the umbilical.

2.4 Hose lines

2.4.1 Lay out

For the layout is to be considered:

– Each hose line is to be designed for an internal burst pressure, which shall at least be for liquids 4 times, for gases 5 times of the maximum allowable working pressure.

– Hose assemblies to be subjected to external pressure, are to be designed for at least 1,1 times (manned submersibles) and 1,0 times (unmanned submersibles and other elements) the collapse diving pressure CDP.

– Moreover the maximum possible pressure difference Δp between inside and outside pressure has to be considered.

2.4.2 Type test

– Burst pressure test:

  Each hose is to be subjected to internal pressure until bursting. The minimum burst pressure is to be for liquids 4 times, for gases 5 times the allowable maximum working pressure.

– External pressure test:

  Hose assemblies which are additionally subjected to external overpressure have to undergo a hydraulic pressure test with 1,5 times the maximum possible pressure difference between inside and outside (but at least 10 bar).

2.4.3 Routine test

Within the series production the routine test contains the following test steps:

– Pressure test:

  Before integration into an umbilical, each hose is to be tested with an internal pressure according to 1,5 times (metallic hose assemblies) respectively 2 times (non-metallic hose lines) maximum allowable working pressure.

– External pressure test:

  Hoses which are additionally subjected to external overpressure have to undergo a hydraulic pressure test with 1,5 times the maximum possible pressure difference between inside and outside.

2.5 Fittings

Connecting elements and fittings have to meet the same inside and outside design pressures as the umbilical, shall not unintentionally disconnect, shall be corrosion resistant and suitable for the planned media.

3. Electrical requirements

3.1 Umbilicals may contain monitoring and communication/ data transfer cables and also energy supply lines.

3.2 Lay out

For the lay out has to be considered:

– Flexible cables or highly flexible cables e.g. of class 5 acc. to IEC have to be used, whereby for energy supply cables a minimum sectional area of the single copper conductor of 2,5 mm^2 is to be provided. Empty spaces are to be filled with suitable filler material like petroleum jelly, to maintain form stability.

– Electrical cables and optical conductors are to be designed according to their specification. The maximum length is to be considered hereby.

– For special duties it may be necessary to construct cables with longitudinal water tightness.

– For different cables with several levels of voltage negative influences between them have to be avoided.

– For cables mechanical forces shall not be transferred by the conductors or their insulation.

– ables have to provided at least cross water tight.

– Each cable is to be designed for an external Pressure which is at least for manned submersibles 1,1 times and for unmanned submersibles and other elements 1,0 times the collapse diving pressure **CDP**.

– Extended stowage of cables in water shall not lead to a remarkable reduction of the insulation resistance.

3.3 Type test

Fundamentally the electric and electronic characteristics specified for the project have to be proven, e.g. by a type test according to IEC 60092-350/351.

The type test contains the following test steps:

– visual check

– check of dimensions, structure and marking

– The cross - watertightness of electrical cables / single conductors is in general to be tested with 2 × P_N (cyclic). If the cables are integrated in a cross-watertight umbilical, the test may be cancelled in agreement with **TL.**

– evaluation of voltage insulation strength according to Table E.1

Measurement of the insulation of energy supply lines with at least 500 V (guiding value: > 500 MΩ × km)

For cables with a nominal voltage up to 1 kV a check of the insulation values is to be performed with a test voltage equal to 2 times the nominal voltage, but at least 500 V.

For energy supply lines with a nominal voltage above 1 kV a check of the insulation values is to be performed with a test voltage of at least the nominal voltage.

The test comprises the evaluation of the insulation value of all conductors against each other as well as of each single conductor against the external insulation layer. The measurement of the insulation is to be performed before and after the test of cross water tightness and after the test for voltage insulation strength.

– resistance measurement of all single conductors

– measurement of partial discharging according to IEC 60885-2 at voltages above 3,6/6 kV (U_0/U) for all single conductors of the cable

– impedance and capacity test depending on voltage and duty of mission in agreement with **TL.**

– check of compliance with the specifications for İnsulation, capacity and eventually impedance

3.4 Routine test

Within the series production the routine test contains the following test steps:

– visual check

– check of dimensions, structure and marking

– covering failure test, if applicable

– evaluation of voltage insulation strength according to Table E.1

– The cross - watertightness of electrical cables / single conductor is in general to be tested with 1,5 × P_N (cyclic) according to **TL** Rules for Submersibles, Section 11, Fig. 11.2 If the cable is integrated in an umbilical which is cross - watertight, this test may be avoided in agreement with **TL.**

– The insulation measurement according to 3.3 is to be performed before and after the test of cross water tightness and after the test for voltage insulation strength.

3.5 Electrical connecting elements

Connecting elements are to be designed for the same external pressure as the cables, shall not unintentionally disconnect and shall be corrosion-resistant. Electrically they shall follow the layout of the adjacent cables and are to be watertight in longitudinal direction in addition. The electrical and mechanical characteristics are not to be influenced in a negative way by the connecting elements.

4. Coil-up/coil-off mechanism for umbilicals

Concerning technical requirements for coil-up/coil-off mechanism for umbilicals on the support ship see the **TL** Rules for Underwater Equipment, Section 6, E.3. or Submersibles, Section 17, E.5.

5. Jettisoning of the umbilical

5.1 In case the umbilical is caught at an underwater obstacle and this hindrance cannot be removed by relevant manoeuvring, it may be necessary to separate the umbilical from the element under water and to initiate an independent surfacing procedure.

Table E.1 Test voltages for cables

U_m	kV	1,2	3,6	7,2	12
U_0 / U	kV/KV	0,6/1,0	1,8/3,0	3,6/7,2	6,0/10
AC test voltage	kV	3,5	6,5	11	15
DC test voltage	kV	2 x U	1,5 x U	1,3 U (1)	1,25 x U(1)

Remarks:

U_0 : nominal main voltage between conductor and earth or metallic screen

U : nominal main voltage between the conductors for which the cable is designed

Um : maximum permissible voltage for equipment

(1) *test voltage case by case according to agreement with **TL***

The test period is in case of using AC as test voltage 15 minutes.

The test period is in case of using DC as test voltage 1 minute.

5.2 For manned submersibles it has to be possible to drop respectively to cut-off the umbilical by the crew from inside the submersible. The jettisoning system is to be so designed that two operational actions which are independent from each other and which need no electric energy are required to activate the separation.

5.3 For unmanned elements, for which jettisoning is required, the umbilical has to be dropped respectively cut-off at the connecting point with the submersible from the control station. The jettisoning system is to be designed that an unintentional jettisoning is avoided.

5.4 For other elements under water the possibility for jettisoning is to be agreed with **TL** according to type and mission duty.

C. Documents for Approval

It is to be submitted:

– general description of the mission duty

– description of the structure and the applied materials of the single components

– definition of main parameter, compare E.

– drawing of the cross section

– data concerning connecting elements and fittings, eventually drawings, if existing

– data concerning pressure and flow conditions and capacity for gas and liquid transport

– data concerning the energy, communication and data transfer, e.g. voltage, amperage, transfer rates

– specification of impedance, capacity and resistance values

– data concerning tests with Certificates already performed

– data concerning installation, maintenance, operation and repair

– description of marking

D. Tests and Trials

1. General

1.1 The required tests are to be divided into a type test for the prototype and a routine test within the manufacturing for the effective use.

1.2 A trial and test program is to be established by the manufacturer of the umbilical according to the specification of the requirements profile defined by the end client (element producer or operator) and to be submitted to **TL** for approval. Generally this program shall contain at least the test steps defined in the following.

1.3 About the scope of the presence of **TL** Surveyors at these tests and trials **TL** will decide in each individual case.

2. Type test

2.1 Mechanical requirements

The type test contains the following test steps:

– visual check

– check of dimensions, structure and markings

– weight evaluation:

The effective weight for missions of the umbilical [t/1000 m] is to be determined in air, water (if not specified otherwise: seawater with 1028 kg/m^3) empty and filled and under defined dynamic load (with friction in water) with the aim to determine the safe working load SWL at the upper end of the umbilical.

– Test of tensile strength:

The minimum tensile strength of the elements provided for the tension load of the umbilical is to be determined.

– Buckling test:

The umbilical is to buckle 5000 times with the defined bending radius at one location and in one direction. Subsequently insulation and resistance measurement of the single conductors are to be performed.

– Torsion test:

A part of at least 1 m length is to be loaded vertically with 0,3 SWL and to be twisted by 90° for 5 minutes. After the test no remarkable lengthening or twist shall be noticeable. Subsequently electrical lines are subjected to a resistance measurement, hose lines to a tightness test under working pressure.

– Stretch loading test:

A part of at least 1,5 m length is to be fixed at the ends and a pretension in longitudinal direction will be brought up. The size of the pretension is to be agreed with **TL.** For 5 cycles the size of the pretension will be increased by 5 times and lowered again. Subsequently electrical lines are subjected to a resistance measurement, hose lines to a tightness test under working pressure.

– External pressure test:

In general the umbilical is to be subjected to a cyclic hydraulic pressure test with 2 times the nominal pressure of the umbilical P_N. For big water depths the test pressure is to be agreed with **TL.**
Attention is to be paid to the fact, that for the use of hose lines the internal pressure is not below the diving pressure, as far as possible.

– Tightness test of the complete umbilical type:

All hose assemblies are to be subjected at the same time to the maximum allowable working pressure and an eventual loss of pressure because of leakage is to be checked. A maximum allowable leakage rate of 1 % pressure loss within 24 hours is acceptable for the different hose lines.

– If gases with a content by volume greater 25 % oxygen shall be transported, all materials coming into contact with oxygen are to be checked for their oxygen suitability (e.g. according to EN 559). For allowable working pressures of more than 25 bar an oxygen pressure surge test is to be performed (e.g. according to EN 15333-1).

– In an actual case of application, depending on mission duty and operational conditions it will be decided by **TL** if all defined tests are to be performed.

– If required, the specified liquid and gas volume which can be put through is to be checked (if need be with projection to the effective length of the umbilical).

2.2 Electrical/electronic requirements

Principally the electric and electronic characteristics specified for the project are to be proven e.g. by a type test according to IEC 60092-350.

The type test contains the following steps:

– Each single cable has to meet the requirements according to B.3.3.

– The cross - watertightness of the umbilical is to be proven within the external pressure test according to 2.1.

– The measurements of the insulation according to B.3.3 are to be performed before or after the test of cross - watertightness.

– Impedance and/or capacity tests are to be performed depending on voltage and duty of mission in agreement with **TL**.

– evaluation of voltage insulation strength according to Table E.1

– check of compliance with the specifications for insulation, capacity and eventually impedance

– check of transfer of the specified data volume/ time unit
(If data cables are tracked together with cables for voltage supply within the umbilical, the check of data transfer is to be done with active nominal voltage. Voltage peaks by e.g. switching actions are to be considered.)

3. Routine test

3.1 Mechanical requirements

Within the series production the routine test contains the following test steps:

– visual check

– check of dimensions

– external pressure test:

In general the umbilical is to be subjected to a hydraulic pressure test with 1,5 times the nominal pressure of the umbilical P_N (cyclic according to the **TL** Rules for Submersibles, Section 11, Fig. 11.2). Attention is to be paid to the fact, that for the use of hose assemblies the internal pressure is not below the diving pressure.

– pressure and tightness test of the complete finally assembled umbilical including end fittings:

All hose lines are to be subjected to 1,5 times (metallic hose lines) or 2 times (non-metallic hose lines) the maximum allowable working pressure at the same time using the original media (as far as possible) and an eventual pressure decrease because of leakage is to be checked.

– The cleanliness of the hose lines is to be checked.

3.2 Electric/electronic requirements

Within the series production the routine test contains the following test steps:

– Each single cable has to meet the requirements according to B.3.4.

– covering failure test, if applicable

– Measurements of the insulation according to B.3.4 are to be performed before and after the test of cross water tightness within the external pressure test according to 3.1.

– evaluation of voltage insulation strength according to Table E.1 in agreement with **TL.**

– check of faultless transfer of the specified data volume/time unit by the data cables.

E. Marking

1. Marking of umbilicals

A durable marking fixed at the upper end of the umbilical shall contain the following data:

– name of manufacturer

– year of construction and serial number

– safe working load of the umbilical SWL [t]

– total length [m]

– overall diameter [mm]

– minimum bending radius [m]

– maximum allowable internal working pressure of hose lines [bar]

– allowable external pressure of the umbilical PN [bar]

– data about cables for transmission of electric power (maximum voltage and amperage)

– data concerning communication/data transfer

Further on the umbilical is to be marked with a longitudinal marking for torsion control as well as with longitudinal markings every 100 m and at the first and last 100 m every 10 m.

Placed markings shall not contain elements which may create corrosion damages.

2. Marking of hose assemblies

The marking on hose assemblies shall contain the following data:

– name of manufacturer

– year of construction and serial number

– outside and internal diameter [mm]

– maximum allowable working pressure of the hose line [bar]

– media of the different hose lines

The different hose assemblies of the umbilical are to be repeatedly marked at suitable distance to easily recognize duty and medium.

3. Marking of cables

– name of manufacturer

– year of construction and serial number

– maximum voltage [V]

– maximum amperage [A]

– cross section of the single conductors [mm^2]

It is recommended to mark the different electrical wires with different colours.

The cables are to be repeatedly marked at suitable distance.