1. International Certification

1.1 CURRENT SITUATION
A growing world market and the increasingly frequent use of machinery and equipment at various locations in the world requires the establishment of new mechanisms for the easy and safe transport of goods. The deployment of air locks in different countries is a case in point.

The global usability and reusability of machine components such as air locks in different countries should be as obvious as it is already the case for ships and aircrafts.

The different condition and requirement profiles of air lock operation affect not only the mechanical components but also the working processes and ergonomic considerations.

Especially ergonomic considerations are becoming more important at increased depths > 50 m. The use of mixed gases and significantly prolonged decompression times requires a combination of the regulatory requirements (often only national legislation) for work in compressed air and the technical requirements for the equipment. For depth down to 50 m, e.g. the technical requirements in Europe (27 countries) are regulated by the European standard EN 12110 [1].

This standard is recognized but little known outside the EU, and therefore not widely applied internationally.

For depths greater than 50 m there are no regulations, however, Germanischer Lloyd (GL) has extended the application of its new underwater technology rules (Edition 2009) [2] to the field of air locks and caissons.

1.2 CHALLENGE OF CURRENT SITUATION
The lack of an internationally recognized standard for technical requirements for air locks, especially in greater depths, makes international and national acceptance difficult and uncertain.

Since there is no internationally valid standard, certification of air locks for use in different countries is not possible - but desirable.
1.3 POSSIBLE SOLUTION

As stated above an urgent need is seen by the authors to establish a standard that takes into account and combines the various national and international requirements. This standard could be created in the form of an ISO standard. However, experience shows that the development of such standards may take many years to complete with the added risk that certain provisions may no longer reflect the state of the art in this industry by the time the standard is published. A more flexible approach for a standard is hence called for.

1.4 ADVANTAGES OF AN INTERNATIONAL STANDARD

- A more simple transport and acceptance of new and used air locks between different countries.

- Standards like EN 12110 or AS 4774.1 [3] cover only the range of down to 40 or 50 m depth, without considering the national requirements for work in compressed air. Therefore, mechanisms and ergonomic considerations only for standard air locks down to 50 m or less are valid. An international standard should expand the contents of the previous standards to the requirements for greater depths.

- Taking into account as much as possible of the national regulations for work in compressed air.

- Basis for tendering, pre-delivery tests, tests prior to commissioning and periodical testing.

- An FMEA (Failure Mode and Effects Analysis) should be implemented especially for new types of air locks to better understand and reduce risks.

- Fire prevention should be a major aspect especially at greater depth with higher partial pressures of oxygen because of the increased potential hazard.

- Opens the possibility for the qualifications of personnel.

Figures 1 and 2: Examples of air locks

1.5 SOLUTION OF GL

GL has created since the beginning of its existence Rules and Guidelines for the design and construction of technical applications. Initially the focus was on ships, but increasingly also on other industrial products derived from marine applications. These standards are in continuous adaptation to the state of the art and the requirements of international partners. Critical review by independent technical committees
safeguards technical accuracy and impartiality. GL Rules have obtained a high level of international acceptance and are a pragmatic way forward to respond quickly to industry needs.

As an example diving decompression chambers certified by GL are operating around the world. They are often accepted by local authorities and sometimes additional national requirements have to be observed.

Only with the help of a standard like this an international recognized certification of air locks is possible.

The following diagram shows a simplified process for GL certification of an air lock.

2. Failure Mode and Effects Analysis (FMEA)

Work under hyperbaric conditions or in compressed air entails several kinds of risk. To keep risks and failures in an acceptable range an adequate Failure Mode and Effects Analysis (FMEA) is an appropriate instrument.

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

For air locks an analysis of the functionality and availability of the air lock after occurrence of a single failure is carried out.

An FMEA should be executed at an early stage accompanying the design to be able to realize system modification in due time. A tabular form as shown in the example below is recommended.

A tabular form e.g. as shown below is to be used.

<table>
<thead>
<tr>
<th>ID Number</th>
<th>Subsystem components</th>
<th>Type of failure</th>
<th>Failure cause</th>
<th>Failure detection</th>
<th>Consequences for subsystem/ components</th>
<th>Consequences for total system</th>
<th>Failure correction</th>
<th>Remarks</th>
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</table>
The FMEA is an independent document that should be self contained without the need to consult further documents. This means that all relevant subsystems need to be described in terms of their basic functions, the installed redundancies and especially the interfaces of the subsystems to each other. The description should be supported by block diagrams of all relevant systems and subsystems. For all subsystems typical failure modes and their effects on the overall function of the system are indicated. Moreover, the corrective actions and control mechanisms to mitigate the effect of any failures are identified.

The FMEA report should contain a summary of the main findings of the analysis. In addition, it should contain a listing of the main failures which may occur during the operation of the air lock and especially with respect to keeping the desired atmosphere in the pressure chambers. For the operating personnel training measures for handling of the system in the event of such failures are to be proposed. According to the FMEA a test program is established. The purpose of this program is to verify the assumptions and the expected operational behaviour of the air lock as defined in the analysis. A periodic check of the FMEA including practical tests is recommended and required after significant design modifications.

3. Fire Fighting under Hyperbaric Conditions

To highlight one of the highest potential risks in the following an introduction into passive fire prevention and active fire fighting is given. Hyperbaric conditions usually by compressed air with an increased partial pressure of oxygen generate a higher potential fire risk. This potential fire risk is even more increased by using oxygen breathing gas for a safe decompression. This may sound confusing but decompression with oxygen shortens the decompression time, is safer from the medical point of view, gives more time to work under pressure and can therefore help to reduce the number of pressure exposures of the workers.

During the construction phase much can be done for the passive fire prevention: There are three things needed for a fire: oxygen, spark and combustible material. Oxygen is the one that can not be omitted, whereas the other two can be minimized.

This means that the interior and equipment of air locks shall be flame-retardant, spark-free and combustible material shall be kept to a minimum. The design of an air lock shall also include an effective fire fighting system that has been tested for the conditions of use. A wave for designing new fire fighting systems was initialized by the tragic accident in a medical treatment chamber in Milan, Italy in 1997- where 11 people were killed. The reasons: incompatible equipment (gas heated handwarmer) in the chamber, oxygen leakage, no water in the sprinkler system, no quick decompression possibilities, personnel without emergency training.

As a result of that accident GL supported the German Federal Ministry of Health to prepare a “Guideline on fire prevention at pressure chambers for hyperbaric oxygen therapy”. [4] Since that time significant efforts have been made together with many manufacturers to find out which performance is needed to have an effective fire fighting system for the use under hyperbaric conditions and with increased partial pressures of oxygen. (see Figures 3 and 4)
During that time a standardisation group was formed around Germanischer Lloyd to develop a new standard for fire fighting under hyperbaric conditions. Almost all of the European fire fighting systems for hyperbaric conditions have been certified by Germanischer Lloyd. Furthermore this standard has been taken as a draft for the new European standard for fire fighting systems in hyperbaric chambers.

Experimental comparison of hyperbaric conditions with compressed air and an oxygen content of 30% at the same pressure (2.0 bar) showed that with the increased partial pressures of oxygen it is much more difficult for the fire fighting systems to extinguish the fire. If for example the pressure is increased to 10 bar it is even more difficult than at the pressure of 2.0 bar and 30% oxygen. (see Figure 5)
The training of the personnel is also an important point for the safety especially for the fire safety. If e.g. the people in the air lock do not pay attention to perfect fit of the breathing masks oxygen leakages may occur which lead to a high fire risk. Long before the alarm level of the oxygen monitor is reached the clothes of a person with a leaking mask are oxygen rich. In such a case a single spark or another ignition source like a heat sink may lead to a fatal accident.
If for example compressed air workers have been in contact with grease, oil or other flammable liquids it may be necessary to change clothes before locking in or out through the air lock.

Equipment, materials or consumables which imply a fire risk shall always be locked in or out through a material lock or separately through a combined lock without people.

Lock attendants and personnel being locked in or out through an air lock have to undergo a training and introduction about the environs and all emergency procedures especially fire fighting.

Common portable fire extinguishers that are very useful under normobaric conditions usually are less effective or even unsuitable for extinguishing fire under hypobaric conditions. In this respect the fire extinguishing agent as well as the extinguishing effectiveness are of very high importance and have to be selected and tested carefully. Extinguishing agents like CO$_2$, foam or powder in an extinguisher used in hyperbaric atmosphere can result in fatal secondary accidents.

Looking at air locks operated with air as breathing gas an evacuation in a shorter period is in most cases possible. Compared with air locks for greater depth and with other breathing gases than air an evacuation in short time is usually not possible. Therefore special provisions have to be made for these chambers having the people under “saturated conditions” to ensure a high level of safety.
State of the Art fire fighting systems, if released in due time, have the possibility even with an increased oxygen content to keep the effects of a fire in an air lock in a reasonable scope. Temperatures around the hot spot of the fire can be kept to an acceptable limit by an effective extinguishing system. (see Figure 6)

![Figure 6: Temperature – Time Diagram of a fire extinguishing test](image)
Conclusion

To make air locks and their equipment which are used worldwide acceptable an international recognised standard is necessary. Furthermore the certification of an international recognised body competent in air lock testing is needed to make the process of moving equipment across the borders more smooth.

To provide the design of an air lock with a high amount of safety an FMEA is a tool to identify failures in subsystems and components and their influence on the entire system and parts of it. If done well this FMEA is a helpful instrument for the manufacturer and after putting it into service also for the operator.

Apart from other risks fire is always an unexpected companion. Therefore fire prevention and reliable fire fighting equipment that is able to cope with the hyperbaric conditions is very important in air locks. GL rules and guidelines with their international recognition cover all mentioned aspects for air locks in combination with initial and periodical inspections and offer so the chance for an easier way of national acceptance.
References

[1] EN 12110 Tunnelling machines - Air locks - Safety requirements


