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NETWORK OF EXCELLENCE

Safety of Hydrogen as an Energy Carrier

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Risk Analysis Methodology and Acceptance Criteria
Deliverable D26 (WP 12)

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EXECUTIVE SUMMARY

This report summarises the work on risk acceptance criteria carried out in the NoE HySafe WP12, with input from WP7.

Subtask 12.1 Risk acceptance criteria - harmonisation

The safe introduction of hydrogen technologies and applications being the aim for the HySafe NoE, a common understanding of the term "safe" would definitely be a premise for success. In a philosophical context "safe" may be interpreted as "absence of danger", but as this is not achievable in the real world, a technical interpretation of "safe" would rather be "danger is acceptably low".

Harmonisation towards common risk acceptance criteria or a common understanding of what danger is acceptably low is one of the objectives for WP12. Subtask 12.1 was to initiate this work by mapping the status of risk acceptance criteria, identify gaps and suggest priorities for the further work towards common acceptance criteria for hydrogen safety.

The work so far on risk acceptance criteria has focused on collecting available knowledge and experience on risk acceptance criteria (as well as risk perception). A letter was sent out in July to European safety authorities in order to gather information on existing legal requirements on risk acceptance and risk communication. Information has also been sought within the network; primarily from WP7 and WP16.

This initial screening formed the basis for a workshop in October 2004. The aim of the workshop was to assess the current situation, identify gaps and contradictions in legislation and practice and define actions that should be taken to reach the final objective. The proposed further action resulting from this workshop has been broken down to a four-step plan.

Public perception of risk has been addressed in discussions and may be an important driving force for the further work in WP12.

Subtask 12.2 Methodologies for risk based determination of safety distances and zone classification

The goal of this subtask is development and harmonisation of methodologies for risk based determination of safety distances and hazardous zones classification. The work in phase 1 has been based on collecting existing experience. Knowledge, experience and methods known by the partners have been collected, and gaps have been identified for prioritisation of further work.

Both for hazardous zones and safety distances several norms, standards and guideline documents for determination of hazardous zones have been collected, some with a risk based approach and others with a deterministic approach. Some of these also included examples specifically addressing hydrogen. However, all of the documents are focusing on offshore and onshore chemical installations, and do not take into account localisation in a public environment and a public interface. Very high pressures, as can be expected at e.g. hydrogen refuelling stations, are not taken into consideration.

Hazardous zones:

EU directive1999/92/EC "Safety and Health Protection of Workers potentially at risk from explosive atmospheres" will be the basis for determination of hazardous zones. This regulation is focused on protection of workers, and it will be relevant for hydrogen installations, such as refuelling stations, repair shops and other stationary installations where some type of work operations will be involved. It may not be so relevant for domestic installations and cars.

IEC/EN60070-10 "Electrical apparatus for explosive gas atmospheres. Part 10 Classification of hazardous areas" should be chosen as a basis for development of the methodology since many central aspects are handled here and this is a widely acknowledged and used norm.

The methodology will be developed within HySafe phase 2, in a separate subtask within WP12.

Safety distances:

Seveso II 1996/82 Directive will be a basis related to legal framework for decision of safety distances. There are not many guidelines or standards related to risk based determination of Safety distances. There are however, a few guidelines that should be considered in development of a risk based methodology, e.g. IGC Document 75/01/E/rev ""Determination of Safety Distances. An example from Australia where a quantitative risk analysis was carried out to estimate regulatory separation distances associated with medium size LPG refuelling facilities is another example of good practice. Here hazard scenarios, risk analysis procedure, selection and application of data were decided and experimental tests were carried out to estimate realistic consequences. Risk acceptance criteria were suggested. An approach like this should be considered by the HySafe consortium, and eventually linked to HyGuide or HyApproval, if approved by the EC.

Further development of methodology and decision of safety distances will be carried out within phase 2, in risk analysis studies for hydrogen refuelling stations. Comparison with conventional refuelling stations will also be included.

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1. RISK ACCEPTANCE CRITERIA

1.1 Introduction

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Harmonisation towards common risk acceptance criteria or a common understanding of what danger is acceptably low is one of the objectives for WP12. Subtask 12.1 was to initiate this work by mapping the status of risk acceptance criteria, identify gaps and suggest priorities for the further work towards common acceptance criteria for hydrogen safety.

1.2 Status on Risk acceptance criteria

1.2.1 Enquiry to European Safety Authorities

A request was sent out to national “Seveso-authorities” in EU/EEA countries, as well as some non-European countries, requesting information on relevant legislation concerning risk acceptance criteria, especially for hydrogen, but also for methane and LPG refuelling facilities.

Replies were collected from Australia, the Czech Republic, Denmark, France, Germany, Iceland, Italy, Luxembourg, Norway, Spain, Sweden and the UK.

The replies from the different authorities were further discussed in a workshop where DNV, Hydro, HSE/HSL, JRC and Risø participated. A summary of the information collected and the discussions is given below:

Most of the replies encompassed references to the Seveso II Directive 96/82/EC, which focus on risk analysis and communication.

There were also a number of references to NFPA standards:

- NFPA 50A Standard for Gaseous Hydrogen Systems at Consumer Sites
- NFPA 50B Standard for Liquefied Hydrogen Systems at Consumer Sites

A permit/authorisation, including a risk assessment, will normally be required for a refuelling station with LPG or Hydrogen.

Sweden has developed standards and guidelines for methane refuelling facilities.

Standards for LPG refuelling facilities are in use in Luxembourg, France, UK/Ireland, Czech Republic and Australia.

Generally, a number of prescriptive requirements (safety distances, breaking joints etc.) are also mentioned, as well as the European Directives for pressure equipment and for hazardous zone classification.

Risk analysis is generally suggested where suitable standards are not available. Mandatory acceptance criteria are only in use in Netherlands, Switzerland and the UK, but Danish authorities have guiding acceptance criteria.

Authority approval of installations, based on QRA/semi-quantified/qualitative risk assessment is used by Sweden, UK, Norway, Denmark, Iceland and Australia.

Prescriptive requirements are also a way of controlling risk. This approach is to some extent applied in all countries replying to the request, and it is the main risk control instrument mentioned by the authorities in Luxembourg, France, Spain, Italy and Germany. The workshop discussions revealed however that French authorities are shifting towards using risk acceptance criteria and demanding a risk analysis.

1.2.2 Survey among hydrogen experts

As part of a survey carried out among “hydrogen experts” in WP 7, the experts were asked about legislation and standards relevant for hydrogen. A summary of the information collected was presented in the workshop.

Generally the results supported and supplied the information already collected. An issue raised by several experts was the want of standards for safe handling of H2 in confined areas.

1.3 <u>Identification of Gaps</u>

Working towards harmonisation of risk acceptance criteria will necessarily involve identifying the gaps to be filled in. A substantial part of the Acceptance Criteria workshop was assigned to identification of gaps.

These discussions were summarised as follows:

In the absence of defined risk acceptance criteria, mandatory standards will serve as risk acceptance criteria. Meeting the requirements of the standard will imply that the installation is approved and that the “remaining risk” is seen as acceptable. For some standards, this may include guidelines or requirements to risk analysis.

However, there is no complete set of standards for H2 infrastructure and applications.
Risk assessment may substitute standards, but what risk is acceptable? Some countries have legally binding quantified risk acceptance criteria. These will also apply to hydrogen infrastructure. For the remaining countries neither general risk acceptance criteria nor hydrogen specific acceptance criteria are identified so far.

Codes and standards are not specific/adapted for hydrogen refuelling or hydrogen applications in general. (Codes/standards are available for compressed hydrogen up to 200 barg and for LH2).

The standardisation work will probably be on hold as long as decisions regarding storage solutions (e.g. hydrogen pressure levels) remain uncertain. The impact of such decisions on risk also remains uncertain.

Generally, some essential definitions for risk assessment and acceptance are used differently in the different countries.

1.4 Suggestions for further work

The workshop concluded with 4 recommended actions, which are seen as complementing the existing legal framework and facilitating harmonisation of risk acceptance, but not directly confronting the existing legislation:

1 Harmonized classification of incidents, damages and benefits (end points) will form a framework for comparison of risk – to other energy carriers and between countries.

2 This work should initially extract definitions from WP5 [3] (accident definition) and SHAPERISK [1] (general criteria) to prevent mix-up of definitions and double-work.

3 A basis for comparing risk information and extract general principles should be formed by:

a) Collect Risk Assessment information

b) Conduct Risk Assessment case studies; both hydrogen station cases and conventional petrol station cases. Relevant additional cases could be household production with slow filling (decentralised energy storage) and private garages.

c) Accident information available from HIAD [3] and other sources should be collected and analysed.

4 Different types of impact and benefits should be weighted, e.g. for Global Environment, Local Environment (operational – e.g. noise - and accidental), Health and safety and Economy.

2. METHODOLOGIES FOR RISK BASED DETERMINATION OF SAFETY DISTANCES AND ZONE CLASSIFICATION

2.1 Introduction

This report summarises of the work that has been carried out in Subtask 12.2 “Risk based determination of hazardous zones and safety distances” in the NoE HySafe.

2.2 Subtask goal

The goal of this subtask is development and harmonisation of methodologies for risk based determination of safety distances and hazardous zones classification. The work in phase 1 has been based on collecting existing experience. Knowledge, experience and methods known by the partners have been collected, and gaps have been identified for prioritisation of further work.

2.3 Hazardous zones

The aim of zone classification is to decide the extension of hazardous zones where explosive atmospheres might be present continuously or infrequently at installations processing flammable substances (gases, dusts). The decision of the type and extension of the zones are dependent on the probability of occurrence and extension of explosive atmospheres. The selection of proper equipment (electric al and mechanical) within these zones depends on the type of zone.

2.3.1 Definitions

An explosive atmosphere is defined as follows (based on EU directive 1999/92/EC):

A mixture with air, under atmospheric conditions, of flammable substances in the form of gases, vapours, mists or dusts in which, after ignition has occurred, combustion spreads to the entire unburned mixture.

The definition of hazardous zones is given in directive 1999/92/EC ANNEX I, as follows:

ANNEX I: Classification of places where explosive atmospheres may occur

- Zone 0: A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is *present continuously or for long periods or frequently*
- Zone 1: A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is *likely to occur in normal operation occasionally*
- Zone 2: A place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is *not likely to occur in normal operation, if it does occur, will persist for a short period only*.

The electrical and mechanical equipment is then decided dependent on the type of the zone, where zone 0 put the strictest requirements on prevention of ignition by the equipment to be located in zone 0, less strict requirements to equipment in zone 1 and even less in zone 2. Related to a risk based determination of hazardous zones, this will mainly be relevant for Zone 2, since the scenarios deciding Zone 1 and Zone 0 will be much more easy to determined based on the knowledge and experience from everyday operation of the plant.

2.3.2 Legal framework in Europe - Directive 1999/92/EC

The general safety requirements to evaluation of explosion risk and determination of hazardous zones are outlined in the European directive 1999/92/EC "Minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres".

The responsibility in relation to this directive is on employers and owners of installations where explosive atmosphere may arise.

The directive outlines requirements to:

- Prevention of and protection against explosions
- Assessment of explosion risks (probability of occurrence of explosive atmosphere, ignition sources, consequences of ignition)
- Establishment of a so called "Explosion protection document", based on the risk assessment
- Special requirements for work equipment and workplace
- Classification of places where explosive atmospheres may occur

According to the requirements in the directive the employer shall ensure that a document – the "explosion protection document", is drawn up and kept up to date. The explosion protection document shall demonstrate, in particular:

- That the explosion risks have been determined and assessed
- That adequate measures will be taken to attain the aims of the Directive,
- Places which have been classified into zones in accordance with Annex I
- Those places where the minimum requirements set out in Annex II will apply
- That workplace and work equipment, including warning devices, are designed, operated and maintained with due regard for safety
- That arrangements have been made for the safe use of work equipment (concordance with Council Directive 89/655/EEC)

The European Commission has also prepared a document with title "Non-binding Guide of Good Practice for implementing of the European Parliament and Council Directive 1999/92/EC on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres."

2.3.3 Work carried out so far

2.3.3.1 Survey of available methods/guidelines/standards for determination of hazardous zones

The available documents within this subject known to the WP12 partners have been collected and are summarised below in table below. Supplementary information is included in appendix 1 for most of the documents.

The norm IEC/EN60079-10 “Classification of hazardous areas” is a central document. Central content is listed below

- Type of zone decided by likely frequency and duration of release
- Extension of zone decided by extension of flammable gas cloud
- Type and extension of zone may be influenced by ventilation
- Implemented in national standards, e.g. NEK 420 and SEK 426
- Some examples given, also for hydrogen, may vary between the countries

There are also several guidelines for risk based methods proposing risk acceptance criteria, frequency date and which give calculation examples, also for hydrogen. However, there does not seem to be any guidelines for domestic installations. The examples given are mainly focused on process installations.

It should be underlined that even if the subtask 12-2 partners know of these documents we have not necessarily practical experience with use of the methodologies/guidelines. It has therefore been difficult to rank the documents or make a conclusion on which methodology that should be recommended.

Table 1 Available methods/guidelines/standards for determination of hazardous zones

Title, reference	Type of document and Short Description	Risk based (Y/N)	Widely used (Y/N/?)
IEC/EN60079-10 Electrical apparatus for explosive gas atmospheres. Part 10: Classification of of hazardous areas	EU norm (not harmonised norm) used for decision of hazardous zones. The zones are estimated by assessing the likelihood of an explosive atmosphere to occur (likely frequency and duration), and to assess the area/volume of the explosive atmosphere. Ventilation can be used to reduce the extension of the zone or to avoid persistence of an explosive atmosphere. Important norm, reference in many guidelines and methods for zone classification. Some examples given, on for a H2 compressor inside a building	Y (partly)	Y
NEK 420:2003 Elektriske anlegg i eksplosjonsfarlige områder med gass og støv (untatt gruver)	Norwegian translation of the norms: NEK EN 60079-10, NEK EN 60079-14, NEK EN 60079-17 NEK EN 60079-19 NEK EN 50281-3, NEK EN 50281-1-1, NEK EN 50281-1-2 NEK IEC 62086-1, NEK IEC 62086-2		Y (in Norway)

SEK Handbook 426 Klassning av explosionsfarliga områden, 2000	Includes a Swedish translation of IEC EN 60079-10, but with several more examples, also for hydrogen	Y	Y in Sweden, will also be used in Norway
Brandteknisk vejledning 19, Eksplosionsfarlige områder, 3. udgave april 2004, Dansk Brand-og sikringsteknisk Institut.	A guideline how to use the zone classification for explosive areas introduced by the ATEX directive 1999/92/EF that are implemented in Denmark through the “bekendtgørelse nr. 478” from “Arbejdstilsynet” (occupational health agency) and bekendgørelse nr. 590 Ministry of the internal and health. It describes the demands on ventilation and ignition sources. Concrete examples are given to perform a classification. Danish standards for this are DS/EN 60079-10:2003 part 10 and DS/EN 50281-3:2002 part 3. It contains links to other relevant legislation on the field.	Y	Y
Error! Unknown document property name. CEI 31-35, “Costruzioni elettriche per tmosphere potenzialmente esplosive per la presenza di gas. Guida all’applicazione della Norma CEI EN 60079-10 (CEI 31-30). Translation: CEI 31-35, Electrical apparatus for explosive atmospheres, Guide for classification of hazardous areas.	Guideline giving specific figures for the application of the EU norm IEC/EN 60079-10 . The contents of the document are as follows: Principles of area classification, Procedure of area classification, Source of emission, Location with explosion’s controls, Location with temperature’s monitoring. Appendixes give list of flammable or combustible substances and list of their physic and chemical properties, principles for the definition of hazardous zone extent, statistical data of the Italian territory concerning the wind frequency in order to assess a reliable natural ventilation, examples of hazardous area classification (several examples for natural gas, including transport and refuelling stations and one example for hydrogen used as generator’s coolant in confined spaces), bibliographic references. In paragraph 2.2.4 (Determination of the zone type) it is said that for the predisposition of Zone 2 the total duration of a gas mixture in air should be less than 10 h/yr and more than 0,1 h/yr or in probabilistic terms 10-3≥P>10-5 source-event yr-1.	N	Y, in Italy
IP (Institute of Petroleum): “A risk-based approach to hazardous area classification”, November 1998, ISBN 0 85293 238 3, 1998.	Presents a methodology for calculation of hazardous areas. Risk acceptability criteria are proposed, and description of a generalized risk calculation procedure. Frequency data are given. Appliances of the methodology to continuous, primary and secondary releases are given. Focused on offshore installations, but can be used generally. Flow rates and corresponding hazard radii are proposed dependent on type of gas(incl. refinery hydrogen), pressure, release hole diameter	Y	?
IP: Calculations in Support of IP15: The area Classification Code for Petroleum Installations, 2001	Provide a record for the calculations, methodology and assumptions used to calculate dispersion distances as a support to the document above.	N, focus only on consequenc e calculations	?
API 505, 1997: Classification of locations for	Recommended practice. Provide guidelines for classifying locations Class I, Zone 0, Zone 1, and Zone 2 locations at petroleum facilities for the selection and installation of electrical	N	Y, for petroleum installations

electrical installations in petroleum refineries – API recommended practice 505 – (ANSI/API RP 505-1998	equipment. Guidelines for classifying and determining the extent of hazardous zones for common applications in many petroleum facilities. Examples of diagrams propose extents of zones established by the use of industrial feedback, use of experimental data, diffusion models and by careful weighing of pertinent factors such as number of potential sources, release rate and volume of possible release. No information given about the choice of hole sizes and leak flows. Draws attention on careful use of proposed diagrams		
NFPA 497, 2004 Classification of flammable liquids, gases, or vapours and of hazardous (classified) locations for electrical installations in chemical process areas	Describes division classification and zones classification. Gives factors, which have to be taken into account to determine the extent of classified locations. Proposes also a series of diagrams that illustrate how typical sources of combustible material should be classified and recommended extent of the classified location. Includes practices, which exist to classify hazardous locations. A procedure for classifying locations into 4 steps is proposed. Two diagrams dedicated to liquid hydrogen storage and gaseous hydrogen storage	N	Y (In USA) (INERIS suggest this to be developed for H2)
Netherlands Government Labour Inspection, 1993:Area classification with respect to gas explosion hazard – Health and Safety Executive (HSE), P182 E	Rules for classification of industrial installations where gases or flammable vapours may form explosive atmospheres are given. Procedure can be applied to complicated situations guaranteeing a good safety level since it includes safety margins. Ventilation is taken into account. The extent of zones depends on: degree of ventilation, ventilation conditions, combustible material relative density, and obstacles near the leakage source. Typical examples of classification are given and also some more specific examples illustrated for a few equipment or situations.	N	?
ATS France 1992: Recommendations for electrical equipment used in explosive atmospheres	Guideline prepared for steel industry. Includes general aspects for explosive atmospheres and protected equipment, a method for classification of zones and selection of equipment, details the calculations of release flow dependent of pressure, compares empirical calculations with FAUSKE and CEA SUTTON, give distances from leak source to zone limit for different release rates and wind speed of 5 m/s (Fauske's law.)	N	?
TNO 1987. Principles of classification of hazardous zones	General overview of zone classification, definition analogous to EN 60079-10. Determines the extension of the zone where there is a probability to have an explosive atmosphere. Reference situation is an unconfined area. When lack of ventilation (confined?) evaluation is more stringent.	Y?	?
Inter-institutional group on the classification of hazardous locations 1990. Classification on haz locations (Cox and Lees, Ang)	Zones definition analogous to EN 60079-10. Empirical approach for zone classification. Quantitative methods for zone classification based on risk based approach, divided into several steps:1) List of leakage sources and release scenarios, list of industries where there is a explosion risk, evaluation of sources sizes (many sources sizes defined for a lot of industries), Estimation of release frequencies according to source size and situation where release occurs, use of release and dispersion models, selection of representative fluids (H2, CH4, etc), Numerical investigation of release and dispersion models for a few leakage sources (joins, pumps, compressors, sampling points, etc) and evaluation of the distance to LFL	Y	?
Guide de l'union des industries	Guideline. Method based on analysis of locations where explosive atmosphere may occur. Basic principles are	N?	?

Chimiques 1996 Electrical equiopment in potential explosive atmospheres	fundamental safety concepts and factors which play an important role for classification and extension of zones. Ventilation important. Maps and typical diagrams illustrate use of the method. Some numerical methods are suggested – equations based on FAUSKE and CEA SUTTON		
SIRA, 1989. Classification of hazardous areas containing potentially explosive atmospheres	Document summarising a conference related to hazardous zone classification. Reference to EN60079-10. Qualitative analysis describes specific situations by using examples and typical diagrams. Presentation of structure useful for zone classification (process conditions, equipment, comb. Materials, leak sources, release and ventilation). Specific examples of classification such as for electrolyser and sea petroleum installation	N?	?

2.3.3.2 Practice and experience of the HySafe partners

All process partners have some type of experience with determination of hazardous zones. All partners are familiar with the ATEX directive 1999/92/EC, and most partners know the EN norm EN60079-10 and several other standards and guidelines. However, a systematic risk based approach for determination of the zones - zone 2 - do not seem to be very widely used. Usually decision of the type and extension of the hazardous zones use to be based on earlier experience and specific figures or graphs or numerical tools (usually some type of integral model). CFD-tools do not seem to be widely used for determination of the extension of the zones.

INERIS is probably the partner with most experience related to determination of hazardous zones. INERIS have developed method specific for determination of hazardous zones:
It is based on the European Directive 1999/92/EC principles. To classify hazardous zones, the procedure is divided into different steps:

- Gathering of information concerning the process, equipment and materials,
- Description of the process, equipment and their safety instrumentation,
- Description of hazards related to the materials,
- Database of accidents which occurred in the installation or in similar installations,
- Identification of potential leakage sources of combustible fluids,
- Estimation of leakages' frequency and identification of their causes,
- Quantification of leakages' effects: estimation of the severity,
- Survey of ignition sources and consequences evaluation of explosive atmospheres' ignition,
- Classification of hazardous zones,
- Mitigation measures to control the risk: technical and organisational principles

Two ways are used to assess the extent of hazardous zones:

1) The first one is based on diagrams, can be found find in guidelines, codes and standards,
2) The second one is based on systematic calculations.

Predefined zones extents are less used; INERIS often use modelling tools, such as EXPLOJET for supersonic and turbulent subsonic releases. For laminar subsonic releases, EXPLOJET in its current version can not be used. INERIS experience is that EN 60079-10 gives conservative results.

To conclude, INERIS's approach considers that hazardous zones can not be classified without performing risk assessment, even if the European Directive distinguishes the hazardous zones classification and the evaluation of explosion risks.

UNIPI has also experience in the application of the European Directive 1999/92/EC and the relative Italian Guide CEI 31-35 for the determination of hazardous zones.

UNIPI experience is based on the Italian methodology proposed by the Guide CEI 31-35, "Electrical apparatus for explosive atmospheres, Guide for classification of hazardous areas" in which is presented a specific approach to apply for the determination of hazardous zones and the calculation of the relative extensions.

Concerning the decision about the type of the zone (zone 0, 1 and 2) the method is the same presented in the EN 60079-10, while for the determination of the zone's extension the Guide gives formulas and many reference parameter to apply, as the most suitable size of leakage to apply as a function of the type of component and of the type of emission under study (continuous, primary or secondary). The Guide gives also a list of flammable and/or combustible substances with the principal physic and chemical properties and a table with statistical data of the Italian territory, concerning the wind frequency, in order to assess reliable natural ventilation. Moreover, in the Annex are given examples of hazardous area classification (several examples for natural gas, including transport and refuelling stations and one example for hydrogen used as generator's coolant in confined spaces).

The Italian methodology to assess hazardous zones is as follows:

- Brief description of the flammable substance, the components under study and its environment (localisation). This means that we have to estimate the ventilation (degree and availability, and that we have to well identify the environment (open spaces or semi-confined or confined environment; in this last case we have to identify and measure all the openings and the inside air velocity).
- Characterization of the type of the emission, continuous, primary or secondary, with identification of its grade, its size, and the physical parameters (pressure, temperature, etc.).
- Characterization of the flux: is it sonic or subsonic? Depending on these results we proceed with the last two points in a different way.
- Calculation of the emission flow (kg/s)
- Calculation of the zone extension (m)

2.3.4 Identified gaps

EN60070-10 seems to be one of the most central norms related to decision of hazardous zones. Identified gaps and needs are therefore connected to this standard. However, most of the aspects listed below are also relevant for the other documents as listed in Table 1.

- Clear criteria of scenario/acceptable risk to be used as basis for decision of zone 2 are not given (The likelihood and duration of release is not specified).
- Only in the Italian Guide 31-35, “Electrical apparatus for explosive atmospheres, Guide for classification of hazardous areas” there are some rules to assess the typology of a zone on the basis of the likelihood and duration of the release. Beneath there is reproduced (translated) the table contained in the above mentioned Guide (Tab. 2.2.4-1, page. 13 of 110).

Zone	Likelihood of presence of the explosive atmosphere in 365 days (1 year)	Total duration of the release (explosive atmosphere) in 365 days (1 year)
Zone 0	P > 10 –1	More than 1000 hours
Zone 1	10 -1 ≥ P > 10 –3	More than 10 hours up to 1000 hours
Zone 2 (2)	10 -3 ≥ P > 10 –5	More than 0.1 hours up to 10 hours (1)
(1) In the case of total duration of the release (explosive atmosphere) in 365 days (1 year) less than 0.1 hours, the area is generally non hazardous, in particular when the emission are more than one in 365 days. However, to be sure that the area is really non hazardous, it is better case by case to perform a risk assessment analysis. (2) In the case that reliable fault rates are not available, it can be assumed that at least one event is likely to occur in one year.		

- IEC/EN60079-10 does not apply to catastrophic failures, intended as, for example, “the rupture of a process vessel or pipeline, and such events that are not predictable” (Note 3, Par 1.1 “Scope”). So there is the need to define which failures are predictable and where is the limit for including a failures in the definition of “catastrophic”, since these last events are subjected to the application of the Norm
- Available leak frequency data are usually based on large scale hydrocarbon installations located at a certain distance from a public environment. For gaseous hydrogen refuelling stations there will be significantly higher storage pressures, smaller equipment dimensions, often smaller production capacity, unmanned installations, and the technology is young. So far there are no indications that the hydrogen installations as expected to leak more seldom than the large scale industrial installations, but the consequences might be different.
- The knowledge on hydrogen ignition probability in different situations and environments is not complete. The ignition probability of hydrogen is high, especially at concentrations close to stoichiometric, ref. 4 and 5. How does this influence on the zones –
    - should there be very strict requirements to the equipment located in the hazardous zones, to reduce the probability of ignition to an absolute minimum, or
    - Might hazardous zones even increase the risk since hydrogen will ignite anyway? The last question is usually only relevant for confined situations where removal of ignition sources might lead to a *later* ignition instead of *no*

ignition, with the chances of a larger gas – and the result might be a higher explosion hazard.

- The mathematical formula for determination of the effect of ventilation on the hazardous zones in IEC60079-10 might be too pessimistic in some situations and too optimistic in other situations.
- Numerical tools for calculation of consequences need verification for relevant accident situations. This regards also simulation of the effect of gas detection, ventilation, explosion venting etc.

These considerations indicate that there must be a close link from WP 12 to WP5, WP8, WP9, WP10 and WP11.

2.4 Safety distances

Safety distances are generally coupled to have a safe distance from a hazardous installation to various types of vulnerable "targets". These "targets" will typically be

- Residential areas
- Areas where people are likely to congregate
- Bulk flammable storage
- Oxygen storage
- Air compressors,
- Ventilation intakes
- Buildings
- Open flames

The intention of the safety distance is usually coupled to prevent escalation of a small incident to a larger incident and to prevent exposure of a large amount of persons.

2.4.1 Definitions

There are no explicit definitions of safety distances in European regulations. However, some guideline documents have suggested definitions or *purpose* of the safety distance:

From IGC Doc 75/01/E/rev "Determination of safety distances:"The *safety distance from a piece of equipment with inherent hazard is that minimum separation which will mitigate the effect of a likely foreseeable incident and prevent a minor incident escalating to a larger incident. … will also be determined to provide protection from foreseeable external impact or activities outside the control of the operation"*

ISO/TR 15916:2004(E): "Basic considerations for the safety of hydrogen systems": *The separation distance requirements, also commonly referred to as the quantity-distance (Q-D) requirements, are determined as a function of the quantity of hydrogen involved. Generally, the larger the quantity of hydrogen involved, the greater are the recommended separation distances. Under some circumstances, small quantities of hydrogen may be stored and used in a room or building, but generally outdoor storage and use is recommended. The separation* *distance can be determined for the potential hydrogen events or for the potential events at other facilities, whichever requires the greater distance.*

Separation distance: coupled to keeping a hydrogen facility or system far enough away from people and other facilities… provides protection of a hydrogen facility from incidents at other nearby facilities….

The WP12. 2 group has not agreed on any specific definition, but the definition from IGC Doc 75/01/E/rev is in line with the WP12.2 partners understanding of the conception.

2.4.2 Legal framework in Europe

There are no European directives directly addressing safety distances from installations with flammable substances. However, the Seveso II directive[1] – address requirements to Land use planning for "Major Hazard Establishments" as follows: "*maintain appropriate distances between establishments covered by this Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest*"

> Land-use planning
>
> 1. Member States shall ensure that the objectives of preventing major accidents and limiting the consequences of such accidents are taken into account in their land-use policies and/or other relevant policies. They shall pursue those objectives through controls on:
>
> (a) The siting of new establishments,
>
> (b) Modifications to existing establishments covered by Article 10,
>
> (c) New developments such as transport links, locations frequented by the public and residential areas in the vicinity of existing establishments, where the siting or developments are such as to increase the risk or consequences of a major accident.
>
> Member States shall ensure that their land-use and/or other relevant policies and the procedures for implementing those policies take account of the need, in the long term, to maintain appropriate distances between establishments covered by this Directive and residential areas, areas of public use and areas of particular natural sensitivity or interest, and, in the case of existing establishments, of the need for additional technical measures in accordance with Article 5 so as not to increase the risks to people.

It should be noted that the SEVESO II directive will only be relevant for installations where the amount of hydrogen exceeds 5 tonnes, and will not relevant for several of today's small scale installations, e.g. most of the hydrogen refuelling stations. Still, the SEVESO directive requirements related to risk assessment requirements and land use planning might be a basis for the risk based approach related to determination of safety distances.

[1] COUNCIL DIRECTIVE 96/82/EC of 9 December 1996 on the control of major-accident hazards involving dangerous substances

2.4.3 Work carried out so far

2.4.3.1 Survey of available methods/guidelines for determination of Safety distances

The available documents within this subject known to the WP12 partners have been collected and are summarised below in Table 2 below. Supplementary information is included in appendix 2 for most of the documents.

There are not so many documents coupled to risk based determination of safety distances. There are, however, several standards or guidelines suggesting specific safety distances for hydrogen installations. The background for these recommendations - specific accident scenarios or reflection of the process/layout conditions at the installation - is usually not given.

Table 2 Available methods/guidelines/standards for determination of safety distances

Title, reference	Type of document and Short Description	Risk based (Y/N)	Widely used (Y/N/?)
NFPA 50A Standard for gaseous hydrogen systems at consumer sites	A table lists minimum distance from outdoor gaseous hydrogen systems to exposures (buildings, wall openings, flammable and combustible liquids, public assembly areas, etc.). Distances increase with increased amount of H2	N	Y
NFPA 50B Standard for liquid hydrogen systems at consumer sites	See NFPA50A, but for liquid systems	N	Y
IGC document 15/96/EFD Gaseous Hydrogen stations	A table gives minimum recommended horizontal safety-distances for hydrogen stations to exposures (buildings, wall openings, flammable and combustible liquids, public assembly areas, etc.).	N	Y (in Europe)
IGC Doc 121/04/E Hydrogen transportation pipelines	Typical safety distances (specific figures) for control and isolating/metering stations suggested	N	?
EIHPII Draft: GASEOUS HYDROGEN VEHICLE REFUELLING STATIONS, rev.2	Minimum recommended safety distances (to buildings, wall openings, storage of flammable substances, ignition sources, power lines, etc.) for hydrogen vehicle filling stations are given in a table. The distances are measured from those points in plan view at which, in the course of operation, an escape of hydrogen may occur. Where equipment is installed within buildings or enclosures, the distances to outside types of exposure are measured from the openings, e.g. windows, doors etc.	N	Probably used for H2 refuelling stations
ISO/TR15916 Basic considerations for the safety of hydrogen systems	Includes a paragraph describing the quantity distance, a distance chosen to keep a hydrogen facility or system far enough away from people and other facilities. Distance should be decided based on “most credible” event. Decision should involve parameters such as amount, conditions (pressure,temp.), gas dispersion, presence of other fuels or oxidisers, protection	N (no reference to scenario probability/frequency)	?
Melchers A., Feutrill W.R.: “Risk assessment of LPG automotive refuelling facilities, published in Reliability Engineering &System Safety 2001	Article: A QRA was carried out to estimate regulatory separation distances associated with medium size LPG refuelling facilities. Hazard scenarios, risk analysis procedure, selection and application of data are described. Tests were carried out to estimate realistic consequences. Risk acceptance criteria were suggested (individual risk level 10-6/yr). Results implemented in Australian Standard ASI1596-1997	Y	N

IGC Document 75/01/E/rev Determination of safety distances	An approach describing a method for determining safety distances based on quantitative risk analysis. Acceptance criteria are proposed. For hazardous materials installations in general. Some general failure data are given	Y	?
BUWAL: “Methodikbeispiel fuer eine Risikoermittlung einer Fluessiggastankanlage (Methodical example how to assess the risk of an LPG tank facility)", Swiss Bundesamt fuer Umwelt, Wald und Landschaft (BUWAL), May 1996.	This is a risk based approach. The contents of the document is as follows: • Introduction • Basic data, including facility and surrounding, inventory of substances, description of facility, safety measures • Analysis, including methods, hazard potentials, main accident scenarios • Results, including relevant scenarios, risk summary curves, comments to risk curves and uncertainties • Conclusions Proposed risk acceptability criteria are societal risk type of criteria based on integrated "accident gravity scores" due to health, economical and environmental effects	Y	Y, in Switzerland for LPG tank facilities
INERIS’s General method for safety distances	Safety distances are the results of risk analysis and they are systematically calculated with the help of adequate models (e.g. PHAST, EXPLOJET, CFD models, etc). The French regulation expects safety distances to be based on thermal and over-pressure effects. Two types of safety distances are calculated: 1) considers that mitigation techniques fail to operate; 2) considers that mitigation techniques act efficiently to reduce the risk. Efficiency, reliability and response time of mitigation measures are taken into account.	Y	?
Italian Draft guideline “Technical rule for fire fighting in design, construction and operation of hydrogen filling stations”, June, 15th 2004	Guideline giving specific figures for H2 and multi-fuel refuelling stations concerning the design, the measures to apply for the protection of the components and the safety distances, both internal and external. An internal safety distance is the distance to assess between the various components of the plant, while the external safety distance is the distance to assess in order to protect the external vulnerable targets and prevent the so called “domino effect”. This Guideline constitutes a draft to the writing of an Italian regulation. Deterministic approach for all the components with exception only for the hydrogen production where a risk based approach is required.	N, only for production unit	Normative in Italy when approved
Fuzzy based decision method	A method for an efficient and robust decision making process applicable both for hazardous zones and safety distances. Transform experience (also not complete) of a problem in linguistic rules to obtain useful numerical data. Hazardous zones classification and safety distances quantification will be the model outputs, hydrogen quantities and the characteristics of the installation will be its inputs. Method gives more results compared to a single handed one because it’s possible to merge the indications of more experts, standards and guidelines to get more precise results than using only one. Acceptance criteria are to be defined	Y	?

2.4.3.2 Practice and experience of the HySafe partners

All partners are familiar with the SEVESO II directive, and in most European countries risk assessment and safety rapports are demanded to ensure the safety and sufficient distances to neighbours and equipment for the Major Hazard Installations. In countries where quantitative risk analyses can be used as basis for documentation there will be quantitative acceptance criteria – official or unofficial – that are used as decision basis for determination of safe distances to residential or public assembly area or other dangerous substance installations.

Risø:
Risø's usual approach to such a risk assessment coupled to Seveso II is:
Hazard identification using our method of functional modelling

- Development of accident scenarios
- Ranking and/or probability assessment and consequence calculations with Risø spread model "Great", or following established methods e.g. the very general Yellow Book CPR 14E **-** Methods for the calculation of physical effects from The Netherlands (consequence calculations). Three other general books are also used: 1) Red book CPR 12E – Methods for determining and processing probabilities (1997), 2) Purple book CPR 18E – Guidelines for quantitative risk assessment (1999), 3) Green book CPR 16E– Methods for the determination of possible damage (1992)

DNV:
DNV use a risk based method for determination of safety distances, and quantitative risk acceptance criteria are used:

1. Safety Zone: Individual risk $>10^{-5}$ or
2. Frequency of ignitable gas cloud $> 10^{-5}$
3. No schools, kindergartens, sport stadiums, assembly buildings are permitted within safety zone. Restrictions on ignition sources: Hunting, camping etc. not permitted within safety zone

Determination of frequency of ignitable gas cloud is based on equipment failure rate data, and on modelling of extension. This could be relevant for hydrogen in the absence of failure rate date for hydrogen equipment. Individual risk is (also) based on ignition data/assumptions on ignition probability. These are specific for either petroleum or natural gas and would probably not be relevant for hydrogen.

DNV uses a wide range of tools for determination of safety distances. If a high level of accuracy is requested, when the dispersion parameters are uncertain or when the terrain is complex, use of CFX or other CFD tools is recommended.

The method is intended for general use and generally recognized within Norway, and is accepted by **Error! Unknown document property name.**authorities as a basis for determination of safety distance (safety zones).

Hydro:
Hydro use an approach similar to DNV related to risk assessment, and Hydro have company specific acceptance criteria for individual risk which are in line with the criteria mentioned

above. Hydro use equipment failure data based on own data and other available accident statistics, but have not specific failure frequencies for small scale hydrogen installations. Ignition probabilities are assumed, dependent on e.g. hazardous zone classification or industrial/public area locations (residential area, public road, farmland etc.). The ignition probability for hydrogen is assumed to be significantly higher than for other flammable gases/chemicals. Hydro use several calculation tools for discharge, gas dispersion and explosion/fire, both more simple integral tools, such as PHAST, and CFD tools (FLACS, Fluent, Kameleon).

INERIS:
To determine safety distances, INERIS do not use any predefined values for a given installation.

Safety distances are the results of risk analysis and they are systematically calculated with the help of adequate models (e.g. PHAST, EXPLOJET, CFD models, etc).
The French regulation expects safety distances to be based on thermal and over-pressure effects.

Two types of safety distances are calculated:

- The first one considers that mitigation techniques fail to operate;
- The second one considers that mitigation techniques act efficiently to reduce the risk.

There is still a debate on how far those mitigation techniques are considered to work as intended. Systematically, INERIS pay attention to efficiency, reliability as well as response time.

UNIPI:
To determine safety distances, UNIPI proceeds like INERIS, i.e. do not use any predefined values for a given installation.

Also in Italy the safety distance should be the results of a risk analysis systematically conducted with the help of adequate models (e.g. PHAST, EFFECT II, CFD models, etc). The Italian regulation expects safety distances to be based on thermal and over-pressure effects both on structures and on people (based on different referenced limit values in force through an Italian regulation: Ministerial Decree of 9th May 2001).

2.4.4 Identified gaps

The concept of safety distances for installations storing or processing flammable substances are not clearly expressed in EU regulations in the same way as for hazardous zones, even if the SEVESO II directive include the concept for the Major Hazard installations. However, the concept of safety distances is included in several standards and guidelines. So far there does not seem to be a clear definition, but the purpose of the safety distance is coupled to prevent escalation of a small incident to a larger incident and to prevent exposure of a large amount of persons.

Otherwise, the gaps identified for a risk based methodology for decision of safety distance, are quite similar to the gaps identified for hazardous zones, and can be summarized by the following key words:

- "Design accident event" or acceptance criteria should be defined as basis for decision of the scenario used to decide the safety distance. (Design accidental event means the incident determining the extent of the safety distance.)
- Ignition probability – more knowledge on hydrogen ignition probability in different situations is needed to carry out reliable risk assessment studies.
- Available leak frequency data may not be relevant for small scale hydrogen installations located in a public environment
- Numerical tools for calculation of consequences need validation for relevant release scenarios and environments

2.5 Conclusions

Hazardous zones:

ATEX 199/92/EC will be the basis for determination of hazardous zones. However, this regulation is focused on protection of workers, and it will be relevant for hydrogen installations, such as refuelling stations, repair shops and other stationary installations where some type of work operations will be involved. It may not be so relevant for domestic installations and cars.

EN60070-10 should be chosen as a basis for development of the methodology since many central aspects are handled here and this is a widely acknowledged and used norm.

The methodology will be developed within phase 2, in a separate subtask within WP12.

Safety distances:

Seveso II 1996/82 Directive will be a basis related to legal framework for decision of safety distances. There are not many guidelines or standards related to risk based determination of Safety distances. There are however, a few guidelines that should be considered in development of a risk based methodology, e.g. IGC Document 75/01/E/rev. The example from Australia where a QRA was carried out to estimate regulatory separation distances associated with medium size LPG refuelling facilities is another example of good practice. Here hazard scenarios, risk analysis procedure, selection and application of data were decided and experimental tests were carried out to estimate realistic consequences. Risk acceptance criteria were suggested. An approach like this should be considered by the HySafe consortium, and eventually linked to HyGuide, if approved by the EC.

Further development of methodology and decision of safety distances will be carried out within phase 2, in risk analysis studies for hydrogen refuelling stations. Comparison with conventional refuelling stations will also be included.

3. REFERENCES

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5 Bain A, Barclay J.A., Bose T.K, Edeskuty F.J., Fairlie M.J., Hansel J.G., Hay R, Swain M.R.: "Sourcebook for Hydrogen Applications", Hydrogen Research Institute and National Renewable Energy Laboratory, 1998.