IEA TCP TASK 43 - SUBTASK SAFETY DISTANCES: STATE OF THE ART

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ABSTRACT

The large deployment of hydrogen technologies for new applications such as heat, power, mobility and other emerging industrial utilizations is essential to meet targets for CO_2 reduction. This will lead to an increase in the number of hydrogen installations nearby local populations that will handle hydrogen technologies. Local regulations differ and provide different safety and/or separation distances in different geographies. The purpose of this work is to give an insight on different methodologies and recommendations developed for hydrogen (mainly) risk management and consequences assessment of accidental scenarios. The first objective is to review available methodologies and to identify the divergent points on the methodology. For this purpose, a survey has been launched to obtain the needed inputs from the subtask participants. The current work presents the outcomes of this survey, highlighting the gaps and suggesting the prioritization of the actions to take to bridge these gaps.

Keywords: *harmonization, safety distance, state of the art*

INTRODUCTION AND OBJECTIVES

The goal of the International Energy Agency (IEA) Task 43 [1] on Hydrogen Safety is to develop effective risk management methodologies and recommendations via case studies and data analysis, as well as targeted information products that will facilitate the accelerated market penetration of large-scale hydrogen energy systems. This Task will build on the achievements of the predecessor Tasks 19 [2], 31 [3] and 37 [4], as well as a significant number of international hydrogen safety related projects.

The specific objectives of Task 43 are as follows:

- Focus on large scale compressed gaseous and liquid hydrogen energy systems and applications
- Focus on common safety & regulatory attributes of emerging large scale hydrogen energy applications
- Focus on developing uniform methodologies via case studies, available performative research projects and their results' synthesis and analysis
- Focus on practical recommendations for industry and standardization and regulatory bodies:
    - Inform relevant international and national RCS (Regulation, Code and Standards) development activities
    - Help the hydrogen industry with market development and establishment of best safety practices

- Focus on development of joint products such as peer-reviewed publications, educational and training materials, conference papers, white papers, reports, new work item proposals for standard development, etc.

The large deployment of hydrogen technologies for new applications such as heat, power, mobility, and other emerging industrial utilizations is essential to meet targets identified during the 2015 United Nations Climate Change Conference (COP21). However, this will lead to an increase in the number of hydrogen installations in close proximity to local populations that will handle hydrogen technologies:

- rapidly increasing numbers of locations, environments and populations using hydrogen technologies by wide public (for instance hydrogen dispensing at hydrogen refueling stations can be handled by a wide not trained public);
- growth in the scale of applications to meet the associated requirements for hydrogen infrastructure and supply;
- applications which push the technology in terms of inventories, pressures, flows, etc. to meet developing requirements;
- in addition, in the short to medium term as we transition from fossil fuels and technologies to hydrogen, issues associated with mixed fuel technologies sites (e.g. gasoline, diesel, etc.) will also need to be addressed as part of this work. In the medium to long term consideration needs to be given to mixed fuel sites with large scale storage of ammonia and/or methanol for applications such as maritime.

Task 43 is divided into 5 subtasks, in which Subtask C is dedicated to Methodologies for the definition of Safety Distances. The purpose of this work is to give an insight on different methodologies and recommendations developed for hydrogen (mainly) risk management and consequences assessment of accidental scenarios. European Industrial Gases Association (EIGA) doc 75 [5] defines a safety distance as the minimum separation between a hazard source and a human, that will mitigate the effect of a foreseeable incident. A separation distance is defined as the distance that will mitigate the effect of a foreseeable incident and prevent minor incidents escalating into a larger incident [5].

Local regulations differ and provide different prescriptions for safety and/or separation distances in different geographies. There may be various reasons for such divergences:

- the absence of guidelines;
- different methodologies (consequential, quantitative, semi quantitative…) ;
- different assumptions/hypothesis ;
- different scenarios applied ;
- different harm criteria considered.

The objectives of the subtask C- Safety Distances Methodology are:

1. **Review available methodologies** and develop **recommendations for a methodology** for determining safety distances for large scale gas hydrogen (GH_2) and liquid hydrogen (LH_2) systems and applications, accounting for the different vulnerability of potential targets

2. Identify where methodologies can converge **and develop recommendations for harmonization of such methodologies**

3. Define a **reference document for minimal requirements** for safe hydrogen deployment

ACTIVITIES AND SCOPE OF WORK

Benefits and Measures

This work is essential for global standardization of safety distance methodologies and as a consequence the reduction of the time, effort, and resources for hydrogen installation plot design; the demonstration of as low as reasonably practicable (ALARP) risks; and assurance it will contribute to the harmonization of regulations and permitting applying to hydrogen installations worldwide.

Scope of work

The scope includes but not limited to

- Review of safety distance methodologies for the following industry use cases:
  - Electrolysers (Gaseous hydrogen) - large scale and on-site production
  - Hydrogen refueling stations (gas-to-gas, liquid-to-gas, and liquid-to-liquid)
  - Marine bunkering (liquid hydrogen)
  - Liquid storage of capacity higher than 10t (airport, ports, hydrogen liquefiers, HRS, etc. applications)
- Review of safety distance methodologies for the following regions :
  - Japan
  - Australia
  - North America - USA, Canada
  - Europe – France, Belgium, Netherlands, Germany, UK, Denmark, Sweden, Austria, etc.

The following is out of scope for this Task:

- Consequence modeling and QRAs,
- Prescriptive separation distances and guidance on mitigating measures for safe siting of equipment and occupied buildings
- In-equipment explosions
- Equipment and building design to allow the development of new technological and innovative solutions

As it was mentioned before, modeling is out of scope, however, the identification of models gives a potential clue to understanding of the reasons for gaps between the results obtained by different participants.

Key Activities

The following activities are necessary to achieve the objectives of the subtask:

- survey to obtain information regarding current safety distance calculation methods within each region and industry, submitted by subtask participants;
- review relevant industry standards/local laws (EIGA Doc 75/21 Rev 1 [5], NFPA 2 [6], NFPA 55 [7], ISO 19880-1 [8], Arrêté 1415 [9], KHK [10], etc.);
- identify critical gaps and recommended route for harmonizing standards;
- compare harm criteria across regions and suggest a harmonized approach.

The Task looks at how to provide generic recommendations and conclusions for some specific cases as mentioned above. This paper focuses on the description of the survey and the summary of the results from the subtask participants.

SURVEY ORGANISATION

The survey contains two main sections and one general section, which includes the information about the person and organisation, which submitted the result. This is essential in order to obtain the additional information if needed in the future.

The first technical section requires the general description, see table 1

USE CASE *Please only fill this in if your use case is one of the following:* *Industrial electrolyser & storage* *Hydrogen refueling station* *Marine bunkering or other*	***Describe the use cases of hydrogen in your company:*** ***Specify the quantity of hydrogen on site (GH2 or LH2):*** ***Specify the country of location****:*
REGULATION FOR INSTALLATION	***Describe the mandatory standards and requirements on safety distances with regards to applicable national regulations. Please give references & methodology (values or insert relevant tables):*** ***Describe your company specific <u>approaches</u> to safety distances (e.g. if internal safety distances have been developed and how):***

Table 1 – The general information conceding the case submitted by the survey

The second section gives more insight on the details needed for the risk assessment, see table 2.

RATIONALE	***Please describe here the rationale behind the safety distances specified (where applicable):*** ***Methodology (Consequence based, risk based, etc.):*** ***Assumptions:*** ***Scenarios considered (full bore rupture, small leaks, etc.):*** ***Basis for safety distance/harm criteria:*** ***Please give any additional detailed information on methodology used to determine safety distances:***
MITIGATION MEASURES	***Please give detailed information on safety measures that can be used to reduce safety distances (restricted orifice, ventilation, vent panels, solenoid valve, etc.):*** ***Passive mitigation measures; please give detailed description*** *For example: Design features / Access restriction / Occupancy limits / Ignition hazard protection / Natural ventilation / fire walls…* ***Active mitigation measures (example : safety loops…); please give detailed description*** *For example: Mechanical ventilation / Fire or gas detection / Automatic shutdown / Fire alarms* ***Are these mitigation measures defined in some regulation, codes or standards (which one, please give a reference)?***

ADDITIONAL REQUESTS	***In addition to the previous requirements, are you aware about specific request on safety distances from customers, authorities, third parties?***

Table 2 – The detailed information conceding the case submitted by the survey

SURVEY RESULTS AND OUTCOMES

At present, 8 subtask participants have submitted their inputs to the survey. The results are presented in Table 3.

In general, the comparison demonstrated a large variety of practices. As expected, different geographies refer to different regulations and several participants highlighted the fact that there are no international standards for equipment such as the electrolyser. This highlights the need for a harmonised methodology for the determination of safety distances. Furthermore, a benchmarking activity on the harm criteria would be highly beneficial, as the results suggest that the limits used change depending on the location of the application.

The survey results demonstrate that there is no common approach for the definition of the most impactful scenarios leading to a loss of containment. For instance, for the electrolysers, several participants considered the potential explosion of the separator due to the cross-over of oxygen to hydrogen and suggested barriers to reduce the risk, whereas other contributors did not consider this scenario in their risk assessments. Several participants of Task 43 also highlighted a gap in the methodology for the definition of the separation distances between hydrogen and oxygen atmospheric vents at an electrolyser.

In addition, the results show that there was a difference in the leak scenarios considered. Once more due to the lack of international standard on this, Aa wide range of hole sizes were used with each participants applying a different approach for the leak size to be used to determine the safety distance.

A wide range of harm criteria were reported by the participants. For instance in several geographies the radiation heat flux from the flame is mainly considered, whereas in other geographies the temperature of the products (convective heat flux) also shall be taken into account [11]. Furthermore, some participants considered overpressure threshold limits for people based on an explosion, while others did not. The recommendations on the harm criteria threshold and the harmonisation of the approach is also of high importance.

The methodology for the definition of the safety distances is very important but varies, according to the survey results, from one participant to another and from one geographical region to another.

In general, the following conclusions can be made:

- Regulation takes precedence over company standards/approaches, code and standards will inform/feed company standards/approaches. If there is clear guidance available, companies will use that
- In the absence of any specific guidance, consequence modeling based on scenarios derived from qualitative risk assessment methodologies is a popular approach for determining initial safety distances

Another important topic highlights the difference in the concentration threshold to the ability to sustain ignition between different regions, for instance the NFPA – 2 [6] recommends to use 8% by volume, whereas in several other regions it is recommended to take the low flammability limit in air (4%).

Category/ Participant	Participant A	Participant B	Participant C	Participant D	Participant E	Participant F	Participant G	Participant H
Use Case	HRS, Electrolysers, Storage	Electrolysers	Electrolysers	HRS, Electrolysers, Storage	Electrolysers	HRS	HRS	Any H2 installations
Country	France, South america, South Africa	Global	Global	Sweden	Global	Netherlands, Germany, UK	France	USA
Regulation /Standard/ Code	ICPE 4715/1416 for French project	No legal mandatory standards found for electrolysers	BCGA GN 41 'Separation Distances in the Gas Industry'	MSBFS 2020:1 (answers based on version currently under review)	No legal mandatory standards found for electrolysers	PGS 35 TRBS-3151 APEA/BCGA/EI Guidance – UK 'Blue Book'	national regulation, standards are used to evaluate the failure probability	NFPA-2
Company Methodology For Safety Distances	Consequence based at feasibility stage Risk based at detailed design stage	Consequence based at feasibility stage Risk based at detailed design stage	Follow BCGA documentation on separation distances, unless there is a specific requirement. In such case, consequence based distances are applied	Follow MSBFS 2020:1 approach which is consequence based with pre-calculated tables	Consequence and risk based approach	Follow safety distances in relevant standards	Safety distance objective is to prevent any consequences on target (human beings). The evaluation is risked based, consequences and probabilities are taken into account.	Consequence-based distances using a risk-informed leak size
Leak Scenarios	Feasibility: Full bore (external safety distance) 10% diameter leak (internal safety distance) Detailed design: Same approach but further refinements	50mm leak for consequence analysis Small/Medium/Large/FBR leak for risk based	Prescribed safety distances from BCGA GN 41 followed. For specific requirements, releases are imposed by characteristics of the release/operation.	3% leak - asset damage 10% leak - single fatality 100% leak - multiple fatalities Size can be reduced with automatic isolation.	Small leak (% of pipe diameter depending on country specific RCS)/medium/large leaks for risk based analysis	Safety distances based on 10% leaks of typical pipe diameters at HRS for PGS 35 Unknown for Germany & UK	Full bore rupture and 10% of the diameter leak, thermal aggression on storage	Multiple leak sizes (from 0.01%-100% of flow area) for the risk-informed analysis, but then setback distances themselves use a constant 3% (now 1%) fractional leak size for gaseous hydrogen and 5% for liquid hydrogen

Harm Criteria	French Regulations thresholds Company specific harm criteria based on NFPA 2020 (in the absence of regulation) **People**: 4.7kW/m^2 & 50mbar (5 kPa) **Buildings**: 25kW/m^2 & 140mbar (14 kPa) **Equipment**: 25-40kW/m^2 & 200mbar (20 kPa)	**People**: 5kW/m^2 & 140mbar **Buildings**: 70-140mbar (7- 14 kPa) **Equipment**: 37.5kW/m^2 & 200mbar (20 kPa) Risk Based: 10^{-4}/yr or 10^{-5}/yr LSIR contour inside fence Societal Risk: PLL, FN-curve at specific location	**For consequence based approach:** **People**: 70mbar (7 kPa) & Thermal Effects from Table 3 from EIGA Doc 211/17 **Equipment**: 35kW/m^2	**People**: 309ºC / 10kW/m^2 / 5 kPa / 8 % H_2 for single, 115ºC / 2.5kW/m^2 / 5kPa / 8 % H_2 for crowds **Buildings**: Flame impingement / 5 kPa & 8 % H_2 at air intake **Equipment**: 10 or 30kW/m^2 for tanks depending on material, size and pressure **Highly obstructed region**: 30 % H_2	French regulations: **Thermal radiation**: 3kW/m^2, 5kW/m^2, 8kW/m^2 **Overpressure**:20 mbarg (2 kPa), 50mbarg (5 kPa), 140mbarg (14 kPa), 200mbarg (20 kPa)	**PGS 35 basis:** **People**: 3kW/m^2 (public), 10kW/m^2 (1% lethality) **Buildings**: 10-35kW/m^2 **Equipment**: 10-35kW/m^2	French regulation (29/09/2005) : **Thermal radiation** : 3 kW/m², 5 and 8 kW/m² **Overpressure** : 50 mbar (5 kPa) for non-reversible effect, 140 (14 kPa) and 200mbarg (20 kPa) for 1 to 5% of lethality	**Heat Flux:** 4.732 kW/m2 exposure of employee for 3 minutes 9 kW/m^2, for LH2, 4.732 kW/m^2 for GH2 for cars and exposed persons not servicing the system and combustible buildings 20 kW/m^2 for non-combustible buildings and other hazardous materials **Overpressure** (only considered for LH2): 7 kPa (1 psi), 13.7 kPa (2 psi), 17 kPa (3 psi)

Table 3 – Survey results

GAPS, ON-GOING ACTIVITIES AND NEXT STEPS

As was mentioned in the previous section, NFPA – 2 [6] recommends using 8% by volume as the concentration threshold defining the ability to sustain ignition, whereas in several other regions it is recommended to take the low flammability limit in air (4%) as the threshold value. Guessan, Chaumeix et al. [12] preparer a paper demonstrating that the appropriate threshold, which can be used for deflagration calculations, is between 8% and 10% of hydrogen in air. This severity threshold is directly linked with harm criteria thresholds.

The analysis of the harm criteria for hydrogen and suggestions for the harmonisation was done by LaChance et al. [13]. A literature review on the harm criteria threshold for thermal radiation refers to the skin temperature consequences [14] and on the ISO 13571 document for the auto-evacuation capability [15]. The comparison to the thresholds from other geographies and the discussion on the basis of these numbers are still on-going. The thresholds for the overpressures will also be considered by the subtask C participants.

More information on the basis of the most impactful scenarios in terms of the safety distances for different user cases are needed to better understand the approaches and bridge the gaps.

Lastly, the rationality on the leakage scenarios, i.e. range of hole sizes for consequence and risk based approaches will also be addressed by the Task 43 participants.

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