PROPOSED APPROACH TO CALCULATE SAFETY DISTANCES FOR HYDROGEN FUELLING STATION IN ITALY

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ABSTRACT

In 2021 only 6 hydrogen fuelling station have been built in Italy, of which 3 are not operational and only 1 is open to the public, while the rest are built in private or industrial areas. While fuelling station which store more than 5000 kg of hydrogen are subjected to the "Seveso Directive", the permitting procedure for refuelling station which store less than the threshold is supervised by the fire brigade command of the province where the station is built. Recently, in the effort to easy the permitting procedure to establish new stations, a Ministerial Decree was published in the official gazette of the Italian Republic which lists minimum safety features and safety distances that, if respected, guarantee the approval by the authority. Nevertheless, the imposed distances are such that the land required to build the station constitute a barrier rather than a facilitation. Exploiting the possibility introduced by the Decree to calculate safety distances following a Fire Safety Engineering approach, a method is proposed for calculation of safety distances. The present paper presents the Italian regulation and describes an approach to calculate the safety distances including an example applied on the dispenser.

1.0 INTRODUCTION

Societies and governments all over the world are placing increasing interests and investments in the development of networks of hydrogen fuelling stations to support and encourage the use of Fuel Cell Vehicles.

The risk posed to the society from hydrogen fuelling station has been considered a critical topic by researcher from the early stages of their introduction and several studies have been published describing risk assessment on hydrogen fuelling stations [1, 2, 3, 4]. In addition studies were conducted to share and compare results of risk analysis applied to the refuelling stations [5] in the effort to investigate the possibility to find a common approach.

International standardization bodies such as ISO, NFPA etc. are recently addressing risk informed processing for permitting hydrogen fuelling stations [6].

The challenge faced in permitting hydrogen fuelling stations is to have a process that is relatively simple and fast but also ensure that the facility are safe.

To date, the experience in permitting hydrogen fuelling station is steadily growing. Both worldwide and at the European level, many different approaches have been implemented by the authorities of different countries to authorize the construction of hydrogen fuelling stations. Some decision-making approaches rely on the respect of societal risk thresholds posed by the installation calculated with a risk analysis [7], some other, like Italy, impose safety distances to be respected by the installation.

2.0 ITALIAN REGULATION ON HYDROGEN FUELLING STATION

In Italy the approval of fuel stations and other installation whose dangerous substances content falls below the threshold of application of the “Seveso Directive” 2012/18/UE [8], is delegated to the local Fire Brigade Command of the province in which the installation is foreseen.

To support the decisional process of authorization for the construction of an hydrogen fuelling station, in 2006 a first Decree, named D.M.31 Agosto 2006 [9], issued by Ministry of the Interior was published on the official gazette of the Italian republic, the official journal of record of the Italian government. Similar to the decision-making process adopted in Korea [10], CNG regulation was initially adopted as a reference to set safety distances to be respected by hydrogen fuelling station. The same safety distances from potential hazardous sources imposed for a methane fuelling station were adopted for a fuelling pressure up to 220 bar, while 50% longer distances were adopted for pressures up to 350 bars, which was the maximum allowed supply pressure.

In 2018 a new Decree, “D.M 23 October 2018” [11], was published on the official gazette of the Italian republic, to keep up with the increased on board storage pressure of fuel cell vehicles. The new regulation supersedes the previous one and allows fuelling pressure up to 700 bars.

A new set of “safety distances” are imposed by the Decree, irrespective of the maximum fuelling pressure for which the station is designed.

Nevertheless derogation to the imposed safety distances is granted if new distances are calculated following the guidelines of the Fire Safety engineering approach which are listed in the Ministerial Decree, “D.M. 9 Maggio 2007” [12].

2.1 Potential hazardous sources

The Ministerial Decree 23 October 2018 lists a number of “potential hazardous sources of the plant” of an hydrogen fuelling station from which safety distances should be respected.

The lists of potential hazardous sources is basically the same with respect of the ones listed in the ISO 19880 standard [13], see table 1, with the exception of the piping. In fact, in the ISO standard welded connection are not considered source of potential hazard, while in the Italian regulation pipes are mentioned irrespective of the fact if they are welded or not. In addition the Italian regulation consider an hazardous source the delivery point of methane or other hydrocarbon gas used for hydrogen production.

Table 1 - Comparison of the potential hazardous sources of ISO 19880 and Italian regulation

Potential hazardous sources	
ISO 19880	**Italian Decree 23 October 2018**
On-site hydrogen production unit as applicable	Hydrogen production unit, if present
Hydrogen delivery system, including mobile storage and remote fill points as applicable	Tube trailer
Compressors	Compressor
Storage	Storage
Piping connections (non-welded)	Piping
Dispensers	Dispensers
	Hydrocarbon delivery system, if present

2.2 Definition of safety distances

Safety distances, also referred to in the literature as setback or separation distances, can be defined as the minimum distance separating a specific target (e.g. people, structure, equipment etc.) from the consequence of potential accidents related to the operation of, in this case, a refuelling station.
Separation distances are also used to reduce the potential that a minor accident in one part of the station propagates to the rest of the facility thus increasing the resulting consequence.
Finally separation or safety distances are used to protect the fuelling station from events initiated by external hazards.
Following this general concepts both ISO 19880 standard than the Italian regulation define a number of “safety distances”. Table 2 lists the definition of ISO 19880 safety distances and offers a comparison with the safety distances as defined in the Italian regulation, DM 30/11/1983 “Fire prevention terms, general definitions and graphic symbols” [14].

Despite of the definition given in the Italian regulation, “minimum distance, established by the regulation, measured horizontally between the respective perimeters of the various hazardous sources of the activity”, the Internal safety distance is used also to set distances between hazardous sources and vulnerable target inside the station limits, as, for example, a store when present. For this reason the “internal safety distance in the Italian regulation assume the meaning of both “clearance distance” and “installation layout distance” as defined in the ISO 19880 standard.

Table 2 - Comparison of safety distance definition of ISO 19880 and Italian regulation

<table>
<tr><th colspan="2">Safety distances definitions</th></tr>
<tr><th>ISO 19880</th><th>Italian regulation
D.M. 30/11/1983</th></tr>
<tr><td>Restriction distances
Minimum distance from hydrogen equipment or the area around where certain activities are restricted or subject to special precautions (e.g. no open ignition sources…)</td><td>The “restriction distance” has no equivalent in the Italian regulation (the definition is similar to an ATEX zone)</td></tr>
<tr><td>Clearance distance
Minimum distance between the fuelling station equipment and the vulnerable target within the fuelling station site boundary</td><td rowspan="2">Distanza di sicurezza interna
(Internal safety distance)
Internal safety distances are defined as the minimum distance, established by the regulation, measured horizontally between the respective perimeters of the various hazardous sources of the activity</td></tr>
<tr><td>Installation layout distance
Minimum distance between the various equipment of the hydrogen installation required to prevent escalation to other equipment in case of an accident.</td></tr>
<tr><td>Protection distances
Is to prevent damage to the hydrogen fuelling station equipment from external hazards not accounted for in the installation layout distance</td><td>Distanza di protezione
(Protection distance)
Minimum value of the distance measured horizontally between the of each source of hazard of an activity and the fence (where required) or the boundary of the area.</td></tr>
<tr><td>External risk zone
Distance (or Area) outside fuelling station which is to be protected from hazards caused by the fuelling station (people and construction offsite are regarded to be the target)</td><td>Distanza di sicurezza esterna
(External safety distance)
Minimum distance measured horizontally between the perimeter of each source of hazard of an activity and the perimeter of the nearest external building or other public or private works or with respect to the boundaries of future building areas.</td></tr>
</table>

2.3 Safety distances in the Italian regulation

The safety distances imposed by the Italian regulation are listed in the following table.

Table 3 - Safety distances imposed by the Italian regulation

Hazardous source	Protection distance [m]	Internal safety distance [m]	External safety distance [m]
Compressor	15		30 (*)
Storage	15	15	30
Tube trailer	15	15	30 (*)
Dispenser	15 (**)	12	30 (**)

(*) For the compressor room, the external safety distance, with the exception of the one calculated with respect to buildings intended for the community, can be reduced by 50% if between the openings of the compressors room and external buildings are placed continuous shields such as concrete or other non-combustible material walls with adequate mechanical resistance to ensure the containment of any projected object towards external constructions.
(**) The external safety and protection distances of the dispensing units can be reduced by 50% if between them and the buildings, except those used for the community, non-combustible shields with adequate mechanical resistance are present.

The Italian regulation takes into account possible "mitigation" that can be implemented to reduce the imposed distances, nevertheless the mitigation accounted for are only related to shields that protect the potential target from the effect of a potential hazardous source. Other type of mitigation, such as safety systems that can affect the frequency of occurrence of a dangerous event (i.e. shutdown system or equivalent emergency system aimed to identify and isolate an unintended release), are not directly introduced. Instead the second conceptual type of mitigations are addressed in the ISO 19880 standard, which is cited by the Italian regulation. As can be acknowledged looking the external safety distances to be respected the hazardous sources in the Italian regulation, imply that land occupancy for the fuelling station is very large and difficult to fit in an urban environment.

2.4 Derogation from imposed safety distances

Despite the general approach of the Italian regulation being the imposition of "safety distances" instead of rely on risk analysis to demonstrate that the installation meets predetermined acceptable risk level, the decree 23 October 2018 leaves the door open to apply the "fire safety engineering approach" to calculate safety distances in derogation to the imposed ones.

The fire safety engineering approach in the Italian regulation is described in the Ministerial Decree 9 Maggio 2007. The approach is characterized by a first phase where the steps that lead to identify the representative conditions of the risk posed by the activity under investigation are formalized. The engineering fire safety approach should set the objectives to pursue and identify the performance levels needed to meet the objectives. The regulation do not provide frequency thresholds or other risk acceptance criteria to select the representative scenarios, nevertheless suggests to take into account events that can "reasonably" occur.
Once the accidental scenarios have been identified, in the second phase a quantitative analysis of the effects is performed. If the obtained results meet the identified performance level, than the defined objectives are met.
In relation to the external safety distances the main objective has been identified in safeguarding the human life. To meet the objective a lists of thresholds levels have been introduced to set the performances. The threshold levels selected in this study are taken from the Italian regulation, published in a ministerial decree, D.M. 9 Maggio 2001, see table 4.

In particular, the threshold taken into account for the different hazardous scenarios are the ones related to reversible injuries. The terms LFL and VCE in the table refer to Lower Flammability Limit and Vapour Cloud Explosion respectively.

Table 4 - Damage threshold levels defined in the Italian regulation

Accidental scenario	Lethality threshold	Start of lethality threshold	Irreversible injuries	Reversible injuries	Damage to structures
Jet-fire (heat flux) [kW/m^2]	12.5	7	5	3	12.5
Flash fire	LFL	½ LFL			
VCE (overpressure) [bar]	0.3	0.14	0.07	0.03	0.3 0.6 in open space

2.5 Motivation of the present work

The following graph shows the distances at which the threshold limit of 3 kW/m^2 is reached on the jet axis in case of a rupture of a pipe, for different pipe diameter and pressures. Red dots refer to 700 bar internal pressure, while the blue dots refer to 350 bar internal pressure.
The calculation of the thermal radiation has been performed using the one-dimensional model described by Houf and Winters [15] implemented in the HyRAM toolkit [16].
The HyRAM software toolkit, developed by Sandia National Laboratorie, provides a basis for conducting quantitative risk assessment and consequence modelling for hydrogen infrastructure and transportation systems.

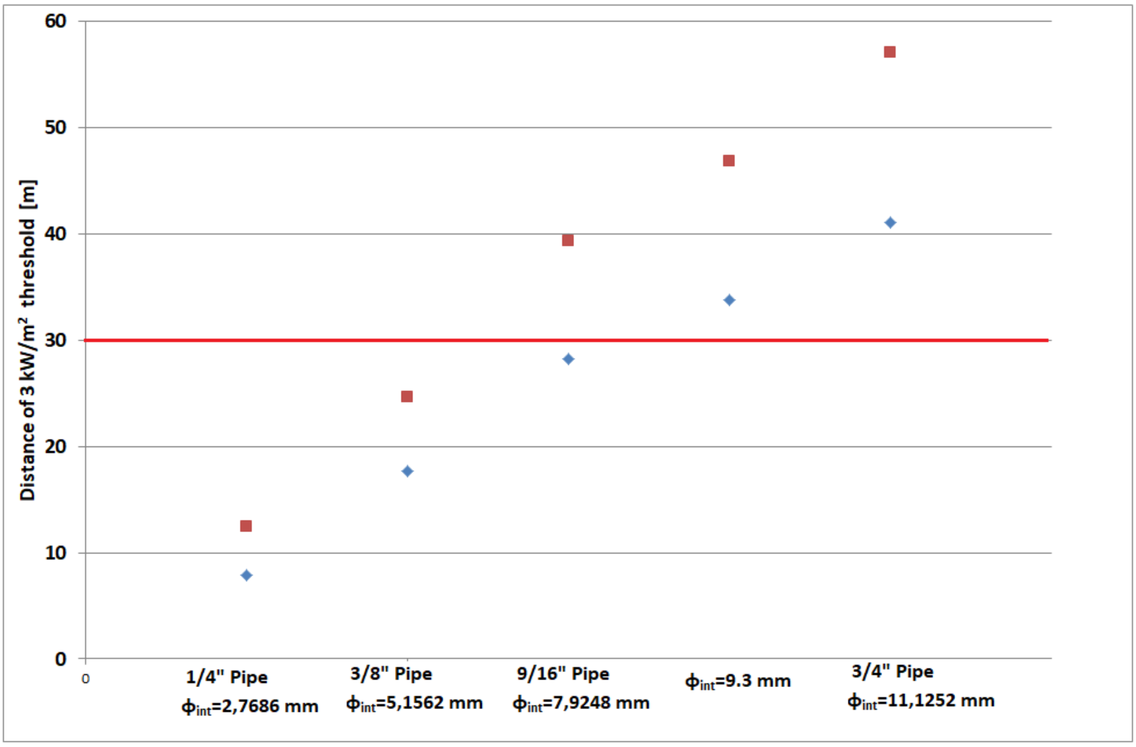

Figure 1 - Distance at which the thermal radiation falls below the 3kW/m^2 threshold as a function of the pipe rupture diameter

Taking into account the worse possible release, due pipe rupture, the imposed safety distance can be either underestimated or overestimated depending on the fuelling pressure provided by the station and the maximum pipe diameter which is in turn related to the "size" of the fuelling station.
In addition, as discussed above, the mitigations aimed to identify and isolate an unintended release, not considered by the Italian regulation, can be introduced when calculating the distances in the derogation request, specifically in the selection of the hazardous scenarios that can "reasonably" occur.

3.0 EXAMPLE OF APPLICATION OF THE TESTED PROCEDURE

The presented procedure is aimed to set a simplified method to estimate safety distances from the listed sources of hazard of an hydrogen fuelling station. As an example of the application of the procedure the example of the dispenser is presented.
The main hazard posed to the public from a gaseous hydrogen fuelling station are associated with uncontrolled combustion of accidentally released hydrogen. Possible modes of gaseous hydrogen combustion include jet-fires, flash-fires, deflagrations and detonation.
Other gas related hazards as asphyxiation are excluded from this study since generally considered of secondary importance.
Being the focus of this study the external safety distance, the primary consequence from fire hazards consists of injury of a member of the public due to heat radiation from a jet-fire or direct contact with hydrogen flames.
Possible consequence should include blast wave overpressure and impact from fragments generated by an explosion, nevertheless being the source of hazard taken into account in this example generally located in an open environment the effect of overpressures are considered negligible.
The current demonstration of the proposed approach has been then limited to the evaluation of radiant heat flux from jet-fire.

To demonstrate the application of the proposed approach on calculation of safety distances in derogation of the imposed external safety distance from hazardous sources of hydrogen filling plant, the procedure is applied to a 70 MPa dispenser.
The first step of the procedure consists in collecting information on all the component and connection included in the source of hazard, in this case the dispenser. The lists of component included in the dispenser, taken from a fuelling station installed in Italy, is reported in the following table.

Table 5 – Component considered for a dispenser

Component	Number of items
Hose	1
Valves (including nozzle and break away)	11
Instruments	4
Length of pipes [m]	10
Flanged connections	4
Non flanged connections	12
Heat exchanger	1 (*)
(*) Heat exchanger has been "broken down in its components and included in the previous lists of items	

For each of the component of the dispenser a leakage failure rate has then been taken into account, the failure rates have been taken from the database of HyRAM toolkit, only random component failures are included.

Failure rates present in the HyRAM database are provided as a function of the leak size following the guidance provided by Cox [17], supported by a recent review by Spunge [18], equating the size of a

component rupture to the pipe flow area (A), a large leak to 10% of the flow area, and a small leak to 1% of the flow area.
The overall leak frequency of the dispenser, for each leak size (rupture, large leak, small leak) is calculated as the sum of the correspondent type of leak of each component. The results are listed in table 6.

Table 6 - Calculated cumulative leak frequency from a dispenser

Hazardous source	**Rupture** 100% of the pipe area **[ev/year]**	**Large leak** 10% of the pipe area **[ev/year]**	**Small leak** 1% of the pipe area **[ev/year]**
Dispenser	2.57 E-04	1.04 E-03	2.29 E-03

The leak frequency is then used as the input for the event tree of which an example is depicted in figure 2.

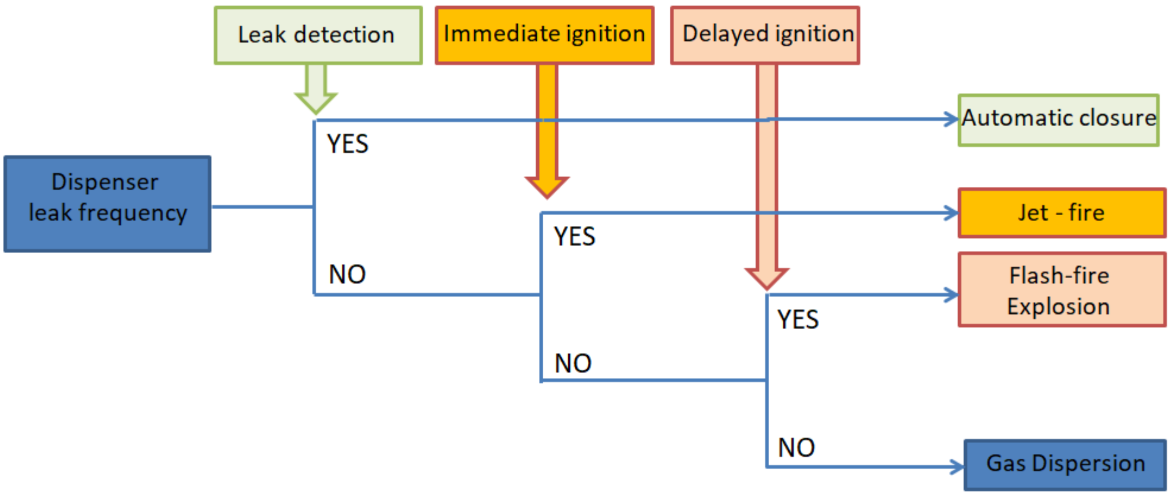

Figure 2 - Event tree for hydrogen leakages

Immediate and delayed ignition probabilities are also taken from the value provided in the Toolkit HyRAM, they are expressed as a function of hydrogen release rate and their values were derived from [19]. The adopted ignition probabilities are listed in table 7.

Table 7 - Adopted ignition probabilities

Release rate [kg/s]	**Immediate ignition**	**Delayed ignition**
<0.125	0.008	0.004
0.125 - 6.25	0.053	0.027
>6.25	0.230	0.120

In the present example only thermal radiation from a jet-fire are presented. To be noted that due to the dispenser being generally located in an open area, without the presence of significant obstacles, in absence of a configuration which allow for an accumulation of the relesed gas, the overpressure generated from a deflagration resulting from a delayed ignition is expected to be low.
As for the pipe dimension five different internal diameter and related area have been considered, taking into account commercial schedule for 700 bar pressure pipes.

Resolving the event tree with the cited data the results for jet fire scenarios are reported in Table 8 as a function of different pipe diameter and leak area.

Table 8 - Calculated frequency of occurrence of the jet fire scenario (no leak detection)

Dispenser pipe dimension Diameter/Area	**Rupture** 100% of the pipe area **[ev/year]**	**Large leak** 10% of the pipe area **[ev/year]**	**Small leak** 1% of the pipe area **[ev/year]**
1/4"	1.36E-05	8,31E-06	1.83 E-05
3/8"	1.36E-05	8,31E-06	1.83 E-05
9/16"	1.36E-05	5,50E-05	1.83 E-05
9.3 mm	1.36E-05	5,50E-05	1.83 E-05
3/4"	1.36E-05	5,50E-05	1.83 E-05

The leak detection system taken into account for the dispenser is implemented through pressure sensors that react to sudden pressure drop, the activation of the safety system prompts the isolation of pipe. The assumption is made that the described system is able to isolate in case of a rupture but not in case of a large or small leak.
The generic IEC 61508 standard [20] for electrical/electronic and programmable electronic safety-related system has been used as a reference to address the require unavailabity to eliminate the worst case scenarios from the selected "reasonable" event to take into account in the calculation.
IEC 61508 introduces the concept of safety integrity, which is the likelihood that a safety system will achieve the needed risk reduction.

Table 9 - SIL levels according to IEC 61508

SIL Levels According IEC 61508 / IEC 61511

SIL Safety Integrity Level	**PFDavg** Average probability of failure on demand per year (low demand mode)	**RRF** Risk Reduction Factor	**PFDavg** Average probability of failure on demand per hour (high demand or continuous mode)
SIL 4	**$\geq 10^{-5}$ and $< 10^{-4}$**	**100000 to 10000**	**$\geq 10^{-9}$ and $< 10^{-8}$**
SIL 3	**$\geq 10^{-4}$ and $< 10^{-3}$**	**10000 to 1000**	**$\geq 10^{-8}$ and $< 10^{-7}$**
SIL 2	**$\geq 10^{-3}$ and $< 10^{-2}$**	**1000 to 100**	**$\geq 10^{-7}$ and $< 10^{-6}$**
SIL 1	**$\geq 10^{-2}$ and $< 10^{-1}$**	**100 to 10**	**$\geq 10^{-6}$ and $< 10^{-5}$**

The required safety integrity must be such that the frequency of failure of the safety related system is sufficiently low to prevent a hazardous event frequency that exceed what is required to consider the prevented event "not reasonable".

It is than required to set a frequency threshold in order to choose the integrity level needed to consider the undesired event "not reasonable".
The following figure shows the frequency of the jet-fire scenario calculated with the cited data and model for any single component. The minimum occurrence frequency calculated for the jet fire scenario resulting in the rupture of as single component is 10^{-7} ev/year, see figure 3. The selected threshold frequency of occurrence for the scenario resulting on the leakage of the dispenser is than selected as the minimum frequency of occurrence calculated for the single component, as mention the value is 10^{-7} ev/year.

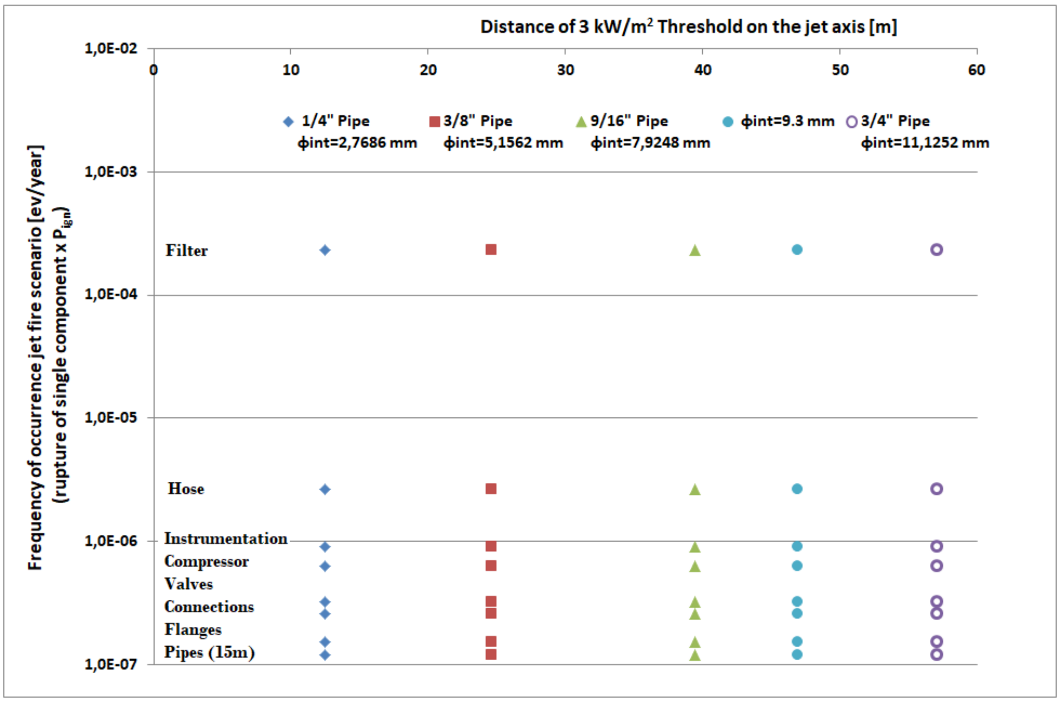

Figure 3 - Frequency of occurrence of jet-fire scenarios generated from rupture of single components

The required frequency reduction to meet the selected threshold is calculate in 7.34 E-03 for the scenarios of a jet fire generated by a rupture of the pipes, equivalent to a SIL2 level.
Figure 4 shows the distance at which the threshold limit of 3 kW/m^2 is reached as a function of different pipe diameter and different pressures in case of a rupture (leak area equal to the pipe area), and large leak (leak area equal to 10% or the pipe area).
The frequency of occurrence of the jet fire resulting from a rupture event shown both with and without a safety related function having unavailability of 5 10-3 ev/year.

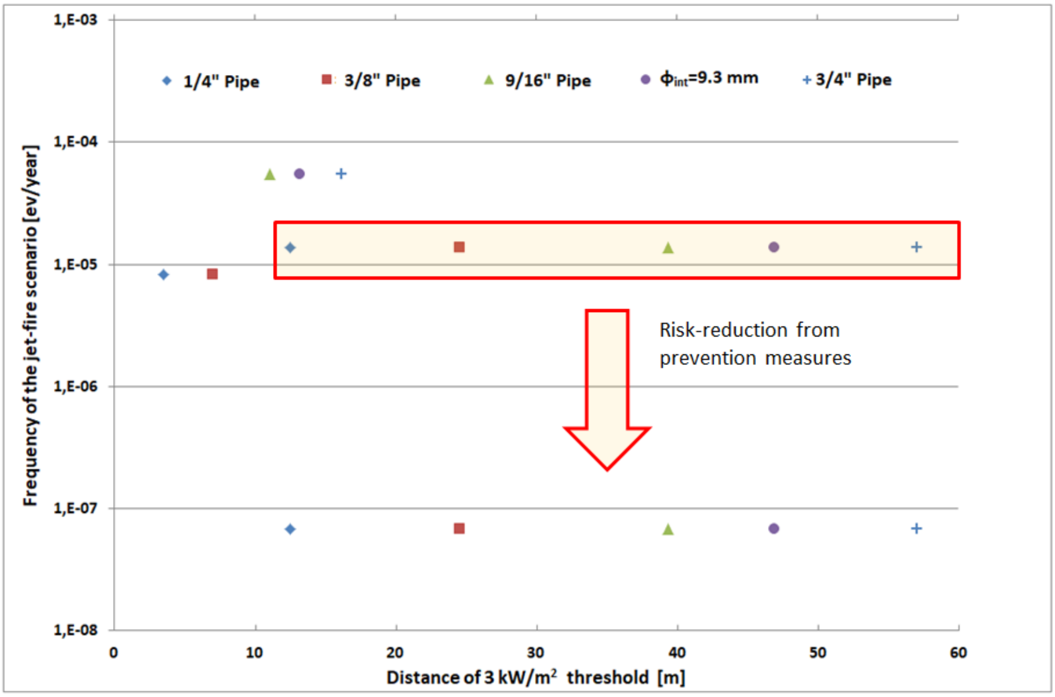

Figure 4 - Frequency of occurrence of jet-fire scenarios vs. 3kW/m2 threshold distance for different pipe dimensions

4.0 CONCLUSION

Italian regulation approach impose safety distances from an hydrogen fuelling station, taking into account the influence of mitigation that shield the target but not addressing the impact of mitigation aimed to reduce the frequency of a release of the fuelling station. In addition, safety distances are expressed irrespectively of the maximum hydrogen pressure. Results from calculation on worse case hydrogen release from hazardous sources of the plant shows that the damage thresholds may either overestimate or underestimate the imposed external safety distances. Exploiting the possibility given by the regulation to derogate from imposed safety distances, an approach has been proposed to calculate tailored distances following the engineering fire safety approach and using a simplified risk analysis method.

The simplified approach has been presented to help calculate external safety distances including the possibility select "reasonable scenarios" by the introduction in the evaluation process of mitigation measures that can reduce the frequency of occurrence of the undesired event.

The proposed approach allows to calculate external safety distances in derogation to the one imposed by the Italian regulation by taking into account the presence of safety related systems.

The proposed approach applied to a dispenser shows the possibility to use certified "safety instrumented function" as defined by the EN 61508 to exclude ruptures and other worst case scenarios events from the calculation of external safety distances.

An advantage of the presented approach is that reducing the frequency of occurrence of a rupture scenario by introducing a safety related system allows to shorten the safety distances but at the same time enhances the overall safety of the installation.

A critical step has been identified in the selection of the threshold frequency of occurrence that can allow to consider "not reasonable", a certain scenario.

Future steps of the present research will consist in a more extensive application of the proposed approach to the "hazardous sources" of the fuelling station.

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