# DEVELOPMENT OF AN ITALIAN FIRE PREVENTION TECHNICAL RULE FOR HYDROGEN PIPELINES

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**ABSTRACT**

This paper summarizes the current results of the theoretical and experimental activity carried out by the Italian Working Group on the fire prevention safety issues in the field of the hydrogen transport in pipelines. From the theoretical point of view a draft document has been produced beginning from the regulations in force on the natural gas pipelines; these have been reviewed, corrected and integrated with the instructions suitable to the use of hydrogen. From the experimental point of view an apparatus has been designed and installed at the University of Pisa; this apparatus has allowed the simulation of hydrogen releases from a pipeline with and without ignition of hydrogen-air mixture. The experimental data have helped the completion of the above-mentioned draft document with the instructions about the safety distances. The document has been improved, for example pipelines above ground (not buried) are allowed due to the knowledge acquired by means of the experimental campaign. The safety distances related to this kind of piping has been chosen on the base of risk analysis.

The work on the text contents is concluded and the document is currently under discussion with the Italian stakeholders involved in the hydrogen applications.

## 1.0 INTRODUCTION

### 1.1 Hydrogen as an energy carrier

The use of hydrogen as an energy carrier is foreseen as the key element for the development of a worldwide sustainable energy system. In fact hydrogen can significantly reduce the production of air pollutants due to the combustion of hydrocarbon fuels, in particular if it is produced by means of renewable energy sources.

Moreover hydrogen can be added to natural gas with significant improvement in performances of engines, so that an easy way to introduce an hydrogen based economy could start from the employment of hydrogen-methane gas mixtures. This explains the great interest on the regulation of hydrogen pipelines and safety issues.

Currently hydrogen distribution by pipeline is quite limited worldwide and it is quite completely confined into industrial plants. Recently the hydrogen pipeline network has reached about 1450 km of extension in the USA and 1800 km in Europe and many companies are working for extending their own plants. The comparison with 1.8 Mkm of the European natural gas pipeline network is the best way to underline how limited is the hydrogen pipeline network and how much interest industrial companies can show. This does not mean that hydrogen pipelines are a real new technology because industrial application, limited to pipes internal to industrial plants, have been used since decades ago, so that the specific knowledge is not lacking but it is only available to few people.

It is a matter of fact that in Italy it is not available a law or a technical rule to follow in order to install a pipeline intended for hydrogen compressed gas. As Italian companies have large experience in the field of the natural gas transport in pipelines, some of them install their own hydrogen pipelines with reference to the requirements pertaining to the natural gas pipelines. However, the unique physical and chemical properties of hydrogen require specific and additional measures, e.g. the choice of suitable materials in order to avoid hydrogen embrittlement. These issues are even more important for civil installations.

Starting from this considerations, the Italian Working Group on fire prevention [1] has decided to draw up a technical rule for the hydrogen pipelines. The Group has produced a specific draft of technical rule which is intended to help the installation of hydrogen pipelines with the use of well-defined minimum safety standards and without high disadvantages for this technology.

## 2.0 REGULATION IN FORCE

The great experience gained in natural gas pipelines has suggested to base the development of the hydrogen technical rule on the knowledge acquired which implies to take under account not only the most recently published laws [2,3] but also hydrogen peculiar properties and behaviour. Moreover it cannot be forgotten that European laws already cover many aspects involved in the design, the building and safety issues, e.g. PED (DIRECTIVE 97/23/EC [4]). Hence the main concern becomes the correct definition of safety distances once the pressure and dimension of the pipe is chosen.

Moreover, as it is common practice to bury pipelines, it is important to establish if a part of a pipe can be allowed in free air when a burying cannot be accomplished and consequently which should be the correct safety distance. In the latter case it is possible to choose the same values that the regulation requires for methane, as the regulation itself suggests, but this way it is not possible to be sure that the same distance prevents from the same risk. Not to mention that there is no evidence of leakage frequencies, dimension of release hole or kind of dangerous phenomena (consequent to release) taken into account.

## 3.0 EXPERIMENTAL TEST

In order to better assess the specific behaviour characterizing hydrogen releases from a pipeline, the Group has decided to support its theoretical work with a suitable experimental activity. For this purpose, a proper apparatus has been installed at the University of Pisa, Department of Mechanical, Nuclear and Production Engineering, named H.P.B.T. (Hydrogen Pipe Break Test). The plant has been used to simulate hydrogen release, its ignition and development of combustion. Thanks to the experimental activity, data have been acquired about the diffusivity of the gas, the size of release jet and jet-fire as function of internal pressure and release hole diameter. The information obtained by the experimental activity has been the basis for the development of a specific fire prevention rule applied to hydrogen. This experimental activity has also provided useful information in order to validate the calculation models currently used for a hydrogen release from pipelines.

### 3.1 Parameters to optimize for the evaluation of safety distances

According to the draft, pipelines are categorized as function of internal pressure and diameter, so these two parameters were taken as the referring values to identify the incidental scenario. This has allowed to define the dimension of the consequent jet fire. The purpose of the experimental campaign was the identification of a reasonable relation between a pipe category and the correct safety distance. The most credible accidental scenario has to be referred to an unintended release that is somehow ignited. This is the reason why hydrogen dispersion and jet fire have been chosen as the target of the experimental study.

The main concern was to chose the correct dimension of release hole and to correlate it to the pipeline category, so that the internal pressure would be defined as well. The Group decided to follow the Italian Guide for ATEX [5] which suggests that a pipeline with a diameter of 150 mm shows unintended releases due to bad installation or gasket failure approximately comparable with a release due to a hole area about 2.5 $mm^2$ large.

The hole area that comes out this way is referred to a very small release, that is hard to be found or detected and that is dangerous when allowing accumulation into confined spaces, in accordance with ATEX purposes. This value could not fit the needs of the research, because it does not cover those accidents involving a real damage to the pipe, so the Group has chosen to double the area. Finally, for a pipe with a diameter of 100 mm, the effect of three hole diameter were studied: 2.5, 5 and 11 mm (corresponding approximately to an area about 5, 20 and 100 $mm^2$).

### 3.2 Experimental apparatus

The experimental apparatus named HPBT (Hydrogen Pipe Break Test) was installed within the Laboratory “Scalbatraio” of DIMNP. Its layout is described in detail in [6], but briefly the apparatus can be divided into four ideal parts: (A) Hydrogen and nitrogen storage (two banks of twenty five cylinders with an initial pressure of 20 MPa); (B) Gas reservoir (test pressure) composed of four large storage tanks (3 $m^3$ each) with a maximum working pressure of 1 MPa; (C) a pipe of 4 inches (0.102 m) in diameter and 50 m long connects the gas reservoir to an automatic release system (ARS) where the hydrogen leakage takes place in an open field (the release was realized at 0.9 m above ground); (D) a vent line (Figure 1).

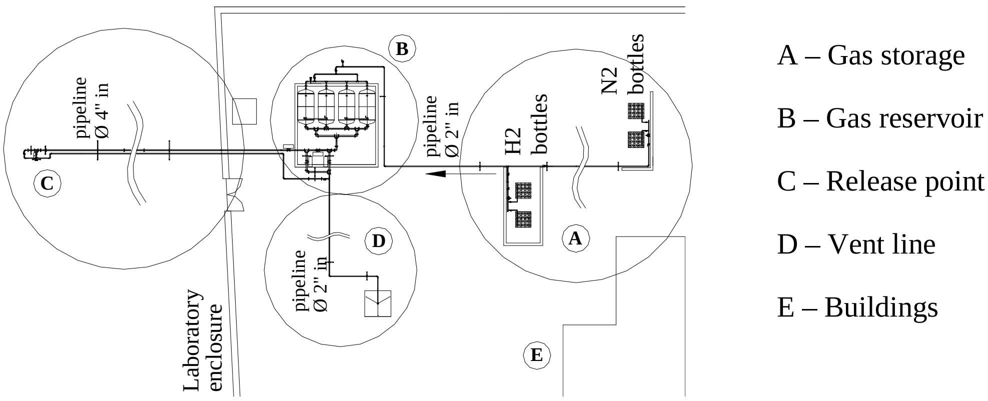


Figure 1. HPBT layout

The acquisition system is described in detail in [6] and [7]. During the tests wind was monitored at about 3 m from ground and far from obstacles that could create turbulence and data were acquired during all the day. This way it was possible to have data about wind not only at the moment of the test, but also before and after.

During the experimental series a total of 22 release tests were performed. The parameters changed during the tests were: hole diameter (2.5 mm, 5 mm and 11 mm) and internal pressure (from 2 to 10 bar). Hydrogen concentration was acquired in eight different points. Test points were chosen both in planar and spatial configuration to study, on one hand, jet shape and, on the other, wind influence. Monitor points are labeled from X4 to X12.

Moreover a series of jet fire tests has been accomplished. The internal pressure and dimension of release hole have been chosen identical to those adopted during simple release tests, so that the two phenomena could be related. Length and diameter of the flare were recorded on video by thermo-cameras and video-cameras.

An example of data acquired during simple release is shown in fig. 2 and an example of jet fire video frame caught on camera is shown in fig. 3.

All data acquired can be found in an internal report available at Department of Mechanical, Nuclear and Production Engineering, University of Pisa [8].

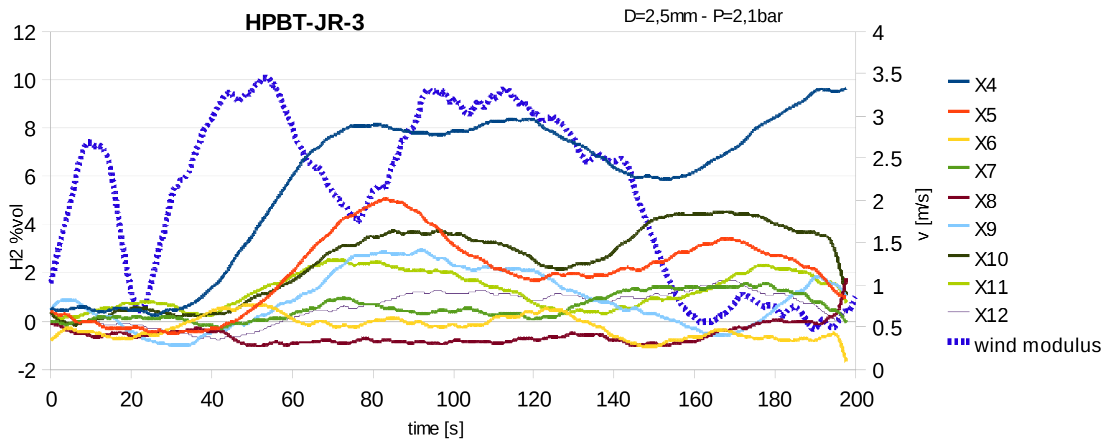


Figure 2. Hydrogen concentration and wind velocity vs. time [7]

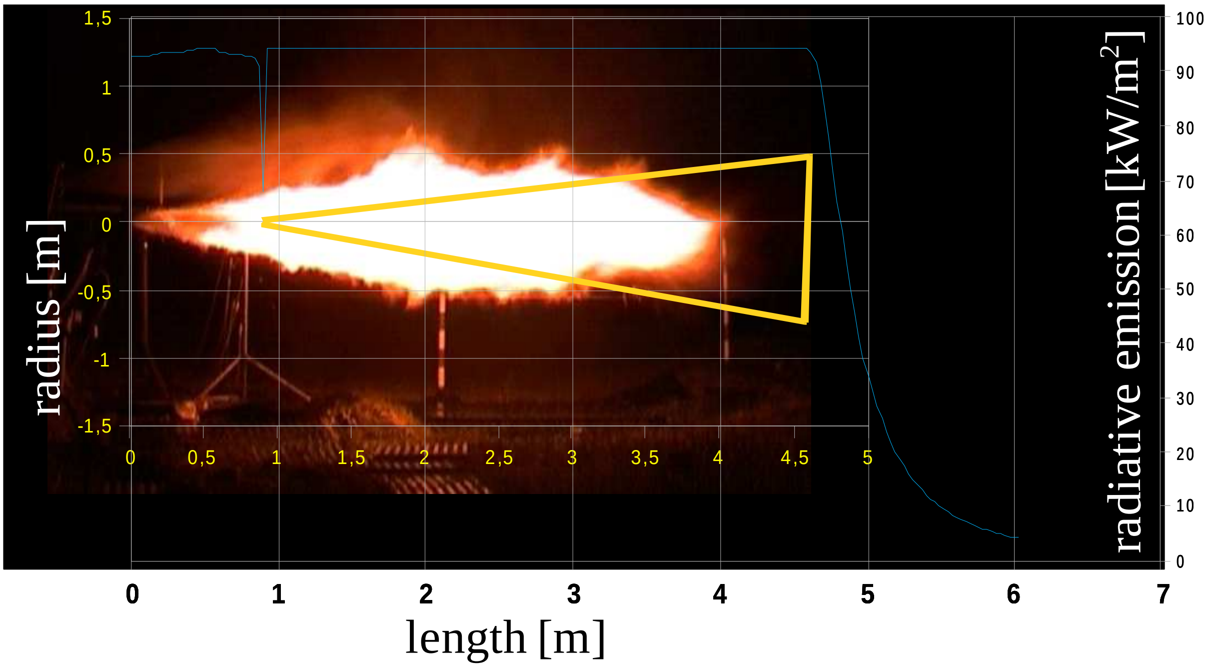


Figure 3. Jet fire dimension overlapped to EFFECTS simulated frustum and correlated radiation

## 4.0 INTERPRETATION OF EXPERIMENTAL RESULTS

Usually the Italian Fire Brigade use EFFECTS 7.6 (a common computer program that can calculate the effects of an accidental event), when a permission for a new installation is asked. For this reason the results of the experimental tests have been compared to those obtained by computer simulation.

As it was shown in a previous work [7] EFFECTS 7.6 overestimates the dimension of the jet if compared both to experimental values and to CFD calculated values (as shown in fig. 4 in a comparison with FLACS v9.0 [7]). So if EFFECTS 7.6 is used to evaluate the dimension of a release, it can be assumed that the distance calculated can be seen as a conservative safety distance.

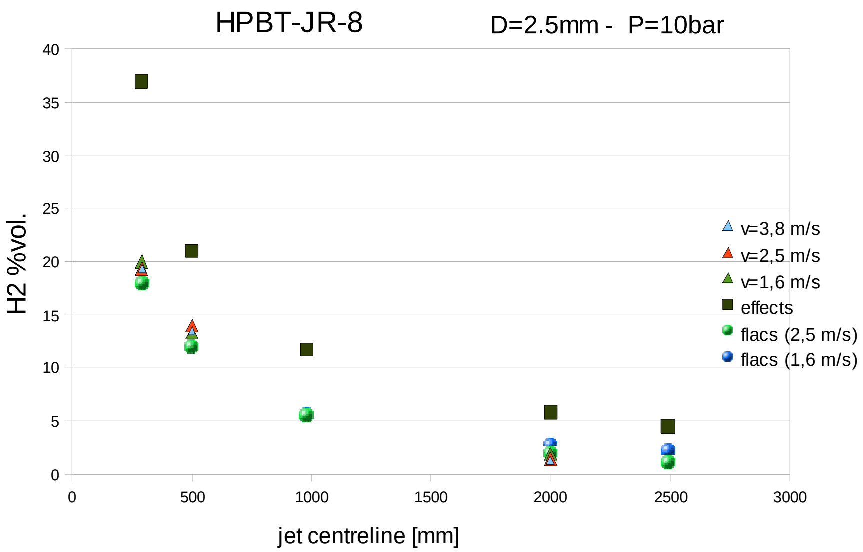


Figure 4. Hydrogen concentration along release centreline measured by experimental test and calculated by EFFECTS 7.6 and by CFD code [7]

Following this approach the safety distance correlated to the technical rule have been chosen as the distance beyond which the thermal radiation due to the jet fire felt down to less then a defined value. This distance is obviously referred to pipelines built over the ground, whereas buried ones need smaller distances.

An interesting note deals with the energy release due to a methane pipe and to a hydrogen one, if pressure and hole release area are equal. It is well known that hydrogen density is very small in comparison to methane one

$$\frac{\rho_{H2}}{\rho_{CH4}} = 0.125$$

and the opposite can be said of the heating value

$$\frac{Q_{H2}}{Q_{CH4}} = 2.4\,,$$

so a kind of compensation takes place and the energy flow is really similar.

Hydrogen energy flow can be evaluated as 85% of methane one. So there is no surprise if safety distances are smaller for hydrogen than for methane. Or, looking at the same phenomenon from another point of view, it can be said that in order to have the same energy flow, either the pressure inside the pipe is the same and hydrogen release hole is bigger or vice versa.

Once the dimension of the release has been defined (by means of hole area and internal pressure) it is possible to evaluate the maximum distance at which the thermal radiation reaches a limit value. This happens when the jet axis is horizontal and that is why the experimental tests have been conducted in order to ignite an horizontal jet. The limit value of thermal radiation (3 $kW/m^2$) has been chosen in agreement with the Italian laws (D.M. 9 Maggio 2001 [9]): according to the law it is possible for a person to be exposed to such a radiation, produced by a stationary fire, undergoing to no more than reversible injuries.

So the safety distances have been defined, as shown below, as a function of the dimension of the flow area and the internal pressure. Hole release diameter is 2.5% of pipe diameter or, which is the same, hole flow area is about 0.06% of pipe flow area, as shown in Tab. 1. The safety distances defined for the categories A, B and D are usually smaller than those of category E because they refers to buried pipelines which means to a different incidental scenario (for the definition of categories see paragraph 5.2). As they must be consistent with those of methane, just because at the moment hydrogen pipelines is regulated by methane regulation, it can happen that safety distances for buried pipeline result bigger than those for pipeline above the ground. The Group is working to solve this problem which has no scientific motivation, but only legal and bureaucratic involvements. So for example to pipe with internal diameter equal to 100 mm would correspond a 2.5 diameter release hole, that can origin jet fire that can cover from 2.5 to 3.5 m with radiation higher than 3 $kW/m^2$ depending on internal pressure.

Table 1. Safety distances.

| Gauge Pressure allowed inside pipe [MPa] | 1° Type 2.4 < P ≤ 6 | | | | 2° Type 1.2 < P ≤ 2.4 | | | | 3° Type 0.5 < P ≤ 1.2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Categories | A | B | D | E | A | B | D | E | A | B | D | E |
| Pipe Diameter [mm] | Safety Distance [m] | | | | | | | | | | | |
| ≤ 100 | 3,5 | 2,5 | 1,5 | 3,5 | 3,5 | 2,5 | 1,5 | 3,0 | 2,5 | 1,5 | 1,0 | 2,5 |
| 125 | 4,5 | 3,0 | 2,0 | 4,0 | 3,5 | 2,5 | 1,5 | 4,0 | 2,5 | 1,5 | 1,0 | 3,0 |
| 150 | 5,5 | 4,0 | 2,5 | 5,0 | 4,5 | 3,0 | 2,0 | 4,5 | 3,5 | 2,5 | 1,5 | 3,5 |
| 175 | 7,0 | 4,5 | 3,0 | 5,5 | 4,5 | 3,0 | 2,0 | 5,0 | 3,5 | 2,5 | 1,5 | 4,0 |
| 200 | 7,0 | 4,5 | 3,0 | 6,0 | 5,5 | 4,0 | 2,5 | 6,0 | 3,5 | 2,5 | 1,5 | 4,5 |
| 225 | 8,0 | 5,5 | 3,5 | 7,0 | 7,0 | 4,5 | 3,0 | 6,5 | 3,5 | 2,5 | 1,5 | 5,0 |
| 250 | 9,0 | 6,0 | 4,0 | 7,5 | 7,0 | 4,5 | 3,0 | 7,0 | 3,5 | 2,5 | 1,5 | 5,5 |
| 300 | 10,0 | 7,0 | 4,5 | 9,0 | 8,0 | 5,5 | 3,5 | 8,5 | 3,5 | 2,5 | 1,5 | 6,0 |
| 350 | 12,5 | 8,5 | 5,5 | 10,5 | 9,0 | 6,0 | 4,0 | 9,5 | 4,5 | 3,0 | 2,0 | 7,0 |
| 400 | 14,5 | 10,0 | 6,5 | 12,0 | 11,5 | 7,5 | 5,0 | 11,0 | 5,5 | 4,0 | 2,5 | 8,0 |
| 450 | 16,0 | 10,5 | 7,0 | 13,5 | 11,5 | 7,5 | 5,0 | 12,0 | 7,0 | 4,5 | 3,0 | 9,0 |
| > 500 | 18,0 | 12,0 | 8,0 | 15,0 | 12,5 | 8,5 | 5,5 | 13,5 | 7,0 | 4,5 | 3,0 | 10,0 |

### 4.1 Comparison to international approach

Once the results of the experimental activity were achieved, two documents referring to the same subject were available by two international organization: Sandia National Laboratories and ISO. The Sandia Report SAND2009-0874 [10] and ISO/DIS 20100 [11] cover a larger range of pressure and deal with more complex plants than a simple pipeline; moreover none of them refers to simple pipelines. Nonetheless if applied to the scenario under study, both the methodologies can be used to establish the dimension of the release hole that can be the most probable as function of pipe diameter.

The release frequency analysis of both Sandia and ISO suggests that the more probable diameter are comparable to those chosen by the Italian Working Group. Anyway a simple comparison is hard to be done because of the different plant considered. In fact unintended releases have to be expected more frequently from more complex apparatus than from a pipe, e.g. from compressor. A more detailed argumentation about this facet can be found in the paper "*Safety distances: comparison of the methodologies for their determination*" by Vanuzzo et al. submitted at this conference [12].

## 5.0 THE DRAFT OF THE TECHNICAL RULE

### 5.1 General overview

It has already been said that the draft document follows the model of the fire prevention regulations for natural gas pipelines ([2, 3]); anyway the peculiar proprieties of hydrogen have been taken into account and specific regulations covers this aspect.

The text is divided into the following Sections:

Section 1: General instructions

Section 2: Pipelines operating with maximum pressure greater than 0.5 MPa (gauge pressure)

Section 3: Pipelines operating with maximum pressure up to and including 0.5 MPa (gauge pressure)

Section 4: Compression facilities

Section 5: Pressure reduction facilities

Section 6: Installations within the industrial areas

Section 7: Setting up of construction site (placing of the pipeline)

Section 8: Pipeline operation.

The pipelines have been divided into 7 Classes to be consistent with existing laws as shown in Tab. 2:

Pipes, valves, curves, fittings and other special components used in the hydrogen pipelines shall be designed, constructed and tested in accordance with the requirements of the Pressure Equipment Directive (PED) 97/23/EC [4]. Furthermore, the hydrogen pipelines shall be marked so that it will be possible to easily identify the gas which flows inside, its direction of flow and its maximum operating pressure.

Table 2. definition of duct types as function of internal gauge pressure.

| class | duct type | maximun gauge pressure allowed (less than) [MPa] | minimum gauge pressure allowed (equal to) [MPa] |
|---|---|---|---|
| a) | 1° | 6 | 2.4 |
| b) | 2° | 2.4 | 1.2 |
| c) | 3° | 1.2 | 0.5 |
| d) | 4° | 0.5 | 0.15 |
| e) | 5° | 0.15 | 0.05 |
| f) | 6° | 0.05 | 0.004 |
| g) | 7° | 0.004 | 0 |

It goes without saying that higher pressure pipelines (Class 1) are used for gas transportation and that lower pressure pipelines (Classes 4, 5, 6 and 7) are used to create a network able to deliver the gas to the user's equipment. Classes 2 and 3 connect the transportation ducts to the distribution network.

Following Italian Regulation [1] systems operating at pressure lower than 0.5 MPa are not subjected to the fire prevention procedure, so they shall comply only with the instructions of the draft under development.

General requirements regardless of the Class deal with:

- use of suitable materials in order to avoid hydrogen embrittlement;
- connections of the components to reduce unintended releases;
- dissections that divide a long pipeline in smaller parts so that a release would remain contained and a suitable discharging devices would allow its dispersion in air;
- operating pressure control that is a safety device that grant not to exceed the maximum operating pressure;
- operating flow rate control which avoids the exceeding of the maximum operating flow rate
- depth of the burial and parallelisms and crossings taking into account the kind of ground and the specific requirements related to crossing of roads, watercourse etc.;
- Safety distances from buildings and maximum operating pressure;
- Pipeline testing in order to be sure that a fluid under defined pressure won't spill out;
- Protection against corrosion.

**5.2 Pipe-laying conditions**

The practice of methane pipe laying describes the burying of the pipes following three Categories: A, B, D. All the Categories (described below) have been reported in the draft document and a Category E has been added for those part of the pipeline that will be over the ground. This addiction has been accepted because of the experimental data that have shown that it is possible to define an adequate safety distance. In fact, the safety distances have been evaluated following the experimental testing performed with the H.P.B.T. apparatus described above both for buried pipeline and for those above the ground.

- Category A: pipeline sections buried in soil which has an impermeable surface layer;
- Category B: pipeline sections buried in soil without an impermeable surface layer;
- Category D: pipeline sections laid inside other pipes or special systems and provided with spaced diaphragms and vent devices;
- Category E: pipeline sections built above the ground over proper backing.

## 6.0 CONCLUSION

The Italian Working Group on fire prevention has drawn up a technical rule for the hydrogen pipelines. The Group has produced a specific draft of technical rule which is intended to help the installation of hydrogen pipelines with the use of well-defined minimum safety standards and without high disadvantages for this technology.

In order to better assess the specific behaviour characterizing the hydrogen releases from a pipeline, the Group has supported its theoretical work with a suitable experimental activity. For this purpose a proper apparatus has been installed at the University of Pisa: this apparatus is named H.P.B.T. (Hydrogen Pipe Break Test). The plant has been used to simulate hydrogen release, its ignition and development of combustion.

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