FIRE CORPS STANDARD OPERATING PROCEDURES WITH HYDROGEN RELEASES: HARMONISATION ISSUES

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ABSTRACT

This paper presents a study on the Standard Operating Procedures (S.O.P.s) for the operation of the Fire Corps squads in the event of accidents with a hydrogen release, fire or explosion. This study has been carried out by the Italian Working Group on the hydrogen fire prevention safety issues [1, 2] in collaboration with members from the American based Hydrogen Executive Leadership Panel (HELP) [3, 4]. The Standard Operating Procedures proved to be a basic tool in order to improve the effectiveness of the Fire Corps rescue activity. The unique physical and chemical properties of hydrogen, its use without odorization and its almost invisible flame require a review of the already codified approaches to the rescue operations where conventional gases are involved. Hydrogen procedures result those providing an overall structure for the management of gaseous fuel accidents. They are fixed on the basis of the possible scenarios relevant to the hydrogen releases. Technological supports are specified in order to ensure suitable performances in terms of reliability, detection swiftness and confidence. Significant parameters are investigated which can be useful in order to recognize a presence of hydrogen or hydrogen fire, e.g. by means of temperature changes.

NOMENCLATURE

F.T.: Fire Truck

P.P.E.: Personal Protective Equipment

S.O.P.: Standard Operating Procedure

U.N.I.: the Italian National Body for Standardization (Ente Nazionale Italiano di Unificazione)

W.T.T.: Water Tank Truck

1.0 INTRODUCTION

The person who receives help usually feels in trouble in comparison with the normal circumstances because he is experiencing an emergency situation which he is not used to deal with. The person who asks for help expects to receive the best help possible, by the best squad of an Organization and by means of the best equipment.

The Standard Operating Procedures (S.O.P.s) proved to be the most effective tool in order to achieve qualitative leaps which can be acknowledged even by those who ask for help. The Standard Operating Procedures are a group of organizing instructions intended to codify the course of the rescue operations and therefore optimize the performances of the rescue squads. They will avoid the waste of both theoretical and practical experience and competence achieved on the management of the rescue operations. Therefore they essentially put together the theoretical knowledge of the accidents and their scenarios with the means available to face them properly and to mitigate their consequences.

Figure 1 reports the scheme of work to be applied. The scheme is cyclic; this means the process is always under a continuous revision and therefore allows the continuous refining and improvement of the performances and the qualities of the operations. The best result is achieved when each Fire Corps Headquarters involved in the rescue operations organizes a system under continuous development and is able to personalize, refine and keep the procedures updated through periodic and systematic revisions.

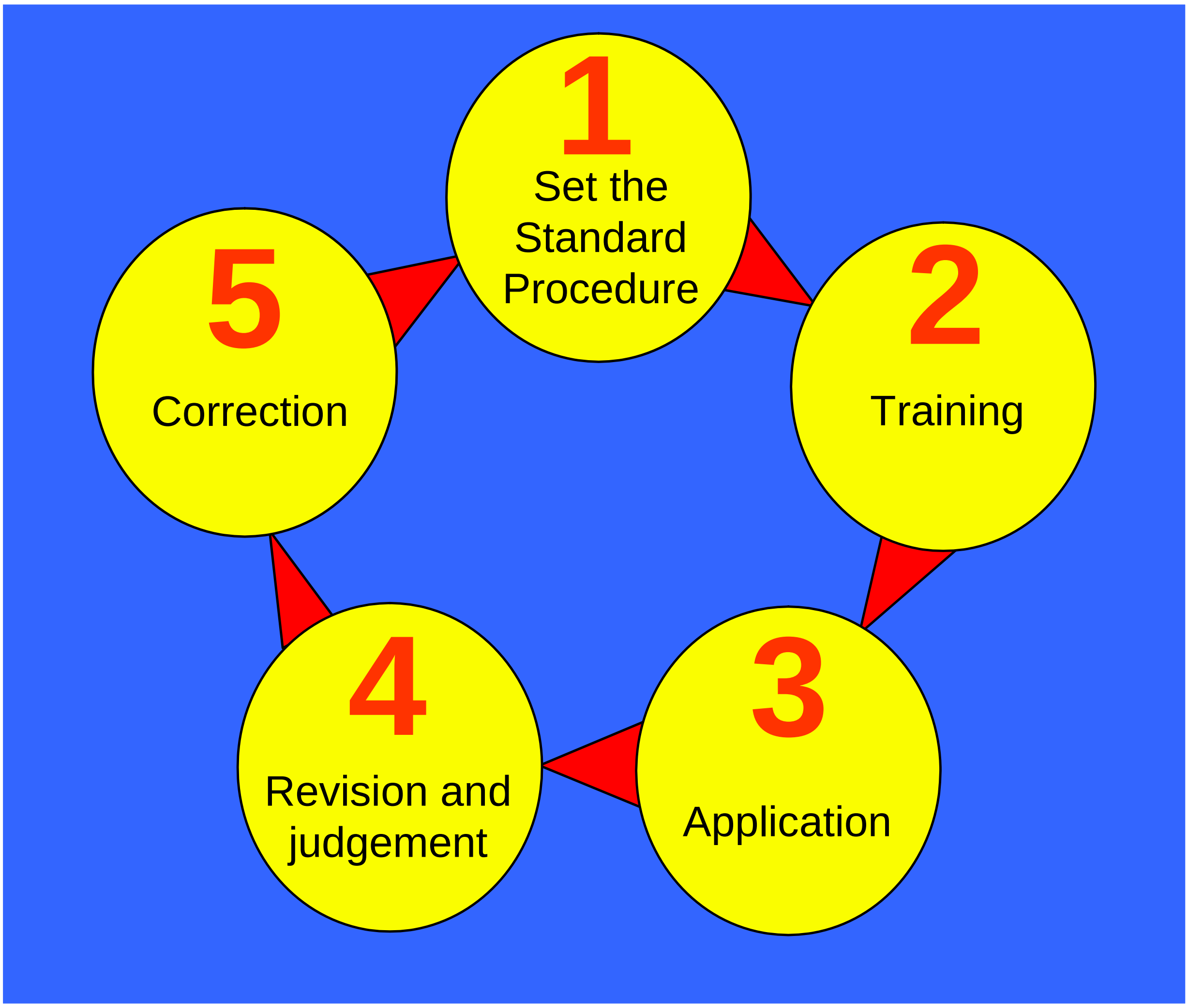


Figure 1. System for the S.O.P. development

This paper defines guidelines for the arrangement of fire brigade Standard Operating Procedures (S.O.P.s) during rescue operations involving hydrogen, e.g. in the event of a possible hydrogen release, fire or explosion. These procedures recommend the approach methods for fire brigade operation in the events above.

Hydrogen is colorless, odorless, tasteless and therefore not detectable by the human senses; hydrogen is flammable and burns in air with a very hot and almost invisible flame, which emits a very little radiant heat and therefore gives a limited warning of its presence. These features make hydrogen different from any common fuel and they pose specific problems in the fire fighting and in the emergency management.

Different operating procedures are here fixed depending on the scenarios relevant to the hydrogen releases. The hydrogen use without odorization and its almost invisible flame require a review of the already codified approaches to the rescue operations involving conventional gases. This peculiarity has to be held in due consideration throughout an intervention, both at the beginning stage, during the operations and at their conclusion. For example, at the end of the operations one must be sure that the possible sources of a hydrogen leakage have been removed: this can be performed exclusively by means of suitable equipment (e.g. explosive gas detectors, etc.), unlike the other gases, in view of their odorization.

This study has been carried out by the Italian Working Group on the hydrogen fire prevention safety issues [1, 2] in collaboration with members from the American based Hydrogen Executive Leadership Panel (HELP) [3, 4]. With reference to each scenario, the procedures specify the intervention flowchart, the number of the firemen involved, their work and personal protective equipment and finally their duties during the operations.

2.0 STANDARD OPERATING PROCEDURES IN THE EVENT OF HYDROGEN RELEASES

The drawing up of a Standard Operating Procedure shall take into account the following issues:

- scenarios of reference (intervention typology) and mandatory issues
- operational conditions, means of transport and equipment of each seat of services
- results and basic operational objectives
- state-of-the-art in the rescue techniques
- main and alternative modalities of intervention
- minimum safety and health standards for the operators and people on the scene
- replacing in service of the means of transport and equipment
- administrative accomplishments and police accomplishments

The possible contents of a S.O.P are the following:

1. Introduction - When an intervention is classified within this category
2. Instructions of reference
3. Management of the operating room
4. Means of transport and equipment suitable to the intervention
5. General procedure for the intervention
6. Techniques for the intervention
7. Safety (general safety, safety of the Fire Corps operators)
8. At the end of the intervention
9. Communications, administrative and police accomplishments
10. Maintenance of the means of transport and equipment
11. Safety and health of the operating personnel
12. Critical revision of the intervention and notes for the training

The specificities of the hydrogen releases are fulfilled in the characterization of the General procedure for the intervention at point 5. above. The other sections do not undergone considerable changes in comparison with those widely used by the National Fire Corps when different flammable gases are involved. In this context the main operating differences can be actually highlighted in comparison with the scenarios relevant to the releases of flammable gases.

The following scenarios are basic scenarios which require the intervention of a single squad. Whatever similar scenario occurs in the neighbourhood while this squad is operating, it will require the intervention of a different squad.

2.1 Definition of the scenarios

The arrangement of a Standard Operating Procedure requires the definition of the scenarios of reference which a rescue squad will have to face. These scenarios are summarized in the following three typologies of event:

1. release without ignition
2. release with immediate ignition and resulting jet fire
3. release with delayed ignition and resulting flash fire, UVCE (Unconfined Vapour Cloud Explosion) or CVCE (Confined Vapour Cloud Explosion)

2.2 Scenario n. 1: release without ignition

The main aim of the intervention is the leakage removal.

Unlike the interventions with conventional gases, two explosive gas detectors to measure gas concentration and one thermocamera shall be available:

- the first explosive gas detector is required to fix the physical boundaries of the zone within the flammability limits
- the second explosive gas detector allows the squad leader and the support operator to locate the leakage point with reference to the surrounding conditions
- the thermocamera is the equipment for the support operator; although the fire is absent, it allows him to locate the leakage point by taking advantage of the temperature change in the hydrogen release, especially in the presence of high pressure releases

The second explosive gas detector and the thermocamera are the additional equipment required to execute this intervention; in the conventional interventions auxiliary equipment is not required to locate the gas leakage (the first explosive gas detector is standard equipment).

Figure 2 reports the logic scheme of this intervention; Table 1 reports the list of the used symbols.

2.3 Scenario n. 2: release with immediate ignition and resulting jet fire

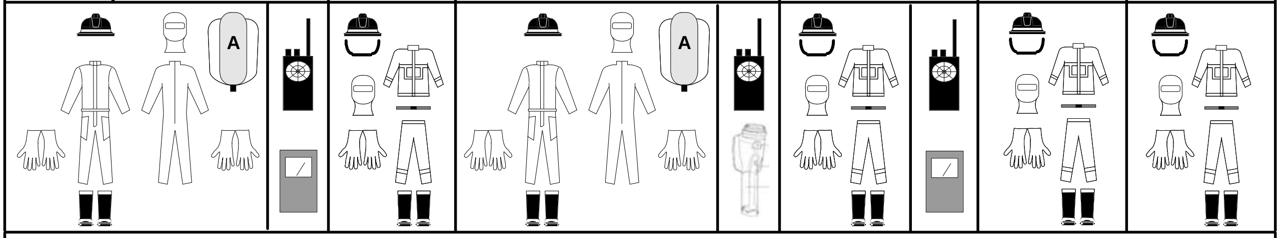
The main aim of the intervention is the fire removal by the leakage removal.

Unlike the interventions with conventional gases, one thermocamera shall be available besides the explosive gas detector usually required. The thermocamera allows the squad leader to locate the fire; it is the additional equipment required to execute the intervention; in the conventional interventions auxiliary equipment is not required to locate the fire.

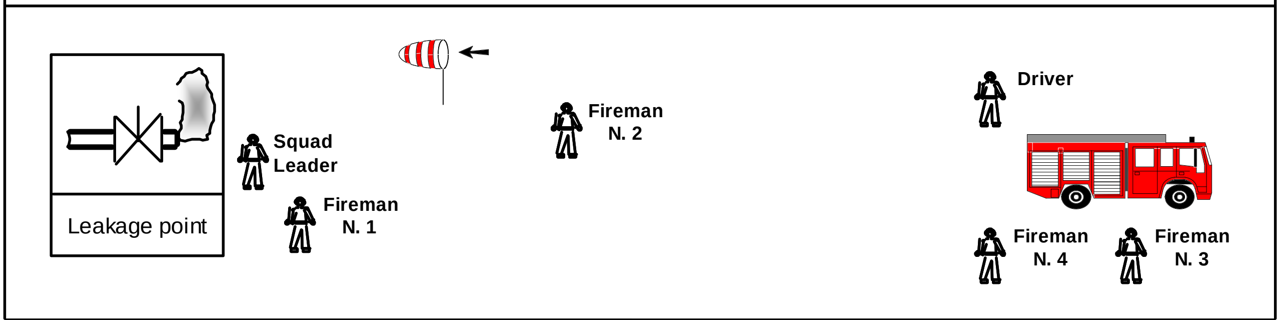
The use of dry-chemical fire extinguishers is a solution alternative to the thermocamera; the extinguishing substance is sprayed and allows the fire visibility and then its location.

Figure 3 reports the logic scheme of this intervention.

MEN	WORK AND PERSONAL PROTECTIVE EQUIPMENT					
Squad Leader	Driver	Fireman N.1	Fireman N.2	Fireman N.3	Fireman N.4	



ARRANGEMENT OF MEN, MEANS OF TRANSPORT AND HYDRAULIC CIRCUIT



F.T.	Duties
Squad leader	He coordinates the operations for the approach and positioning of the means of transport and equipment in order to make the moving away as quick as possible. He provides himself with an explosive gas detector and a portable explosion-proof radio. He performs the approach operations to execute the leak closing or plugging, if it is possible. By means of the explosive gas detector he moves in the direction of the maximum concentration in order to locate the position of the gas leakage.
Driver	He puts himself at the Squad Leader's disposal.
Fireman N. 1	He follows the Squad Leader in the approach operation. He provides himself with a thermocamera and a portable explosion-proof radio.
Fireman N. 2	He provides himself with an explosive gas detector and a portable explosion-proof radio. He performs a continuous monitoring to fix the boundaries of the zone within the flammability limits.
Fireman N. 3	He puts himself at the Squad Leader's disposal.
Fireman N. 4	He puts himself at the Squad Leader's disposal.

PROCEDURE FLOWCHART

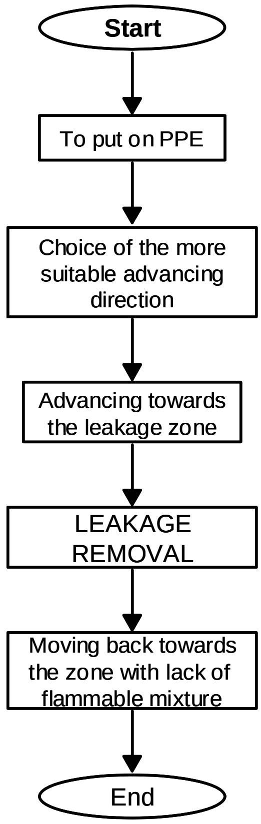
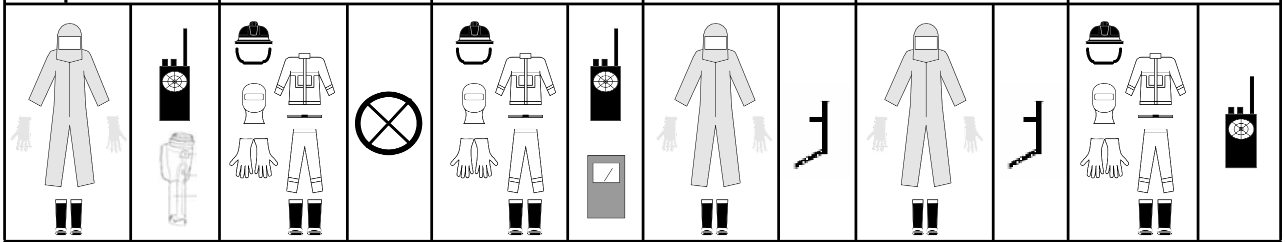
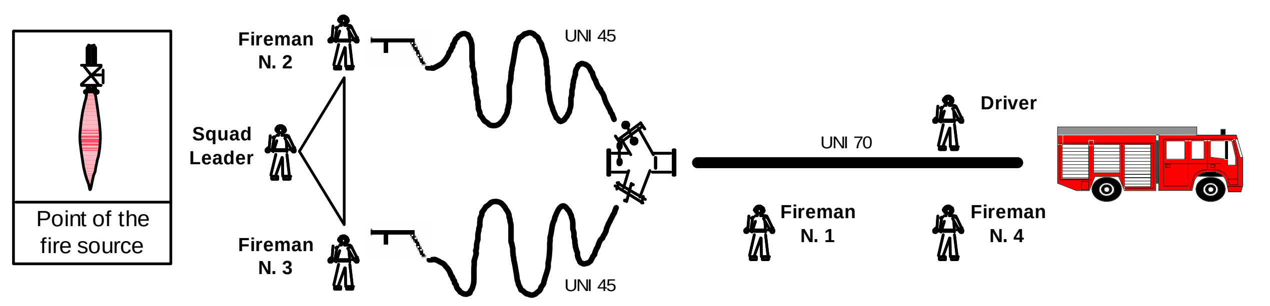


Figure 2. Approach procedure in the event of a LEAKAGE

MEN	WORK AND PERSONAL PROTECTIVE EQUIPMENT				
Squad Leader	Driver	Fireman N.1	Fireman N.2	Fireman N.3	Fireman N.4



ARRANGEMENT OF MEN, MEANS OF TRANSPORT AND HYDRAULIC CIRCUIT



F.T.	Duties
Squad Leader	He coordinates the operations for the approach. He puts on the suit for the approach and approaches the fire to intercept it while he hides himself behind a shield of water. He provides himself with a thermocamera and a portable explosion-proof radio.
Driver	He puts himself at the Squad Leader's disposal. He operates the pump.
Fireman N. 1	He spreads the hydraulic circuit for the cooling operations. He provides himself with an explosive gas detector and a portable explosion-proof radio.
Fireman N. 2	He spreads the hydraulic circuit. He puts on the suit for the approach. He protects the fireman assigned to the leakage removal by means of a fire hose with a jet of pulverized water. He keeps at a distance from the fireman assigned to the leakage removal in proportion to the jet and the radiation he is subjected.
Fireman N. 3	He spreads the hydraulic circuit. He puts on the suit for the approach. He protects the fireman assigned to the leakage removal by means of a fire hose with a jet of pulverized water. He keeps at a distance from the fireman assigned to the leakage removal in proportion to the jet and the radiation he is subjected.
Fireman N. 4	He spreads the hydraulic circuit for the cooling operations. He provides himself with a portable explosion-proof radio.

W.T.T.	Duties
Driver	He puts himself at the F.T. Driver's disposal. He attends to the continuous water supply.
Fireman N. 1	He carries out the hydraulic connections with the F.T. for the water transfer.

PROCEDURE FLOWCHART

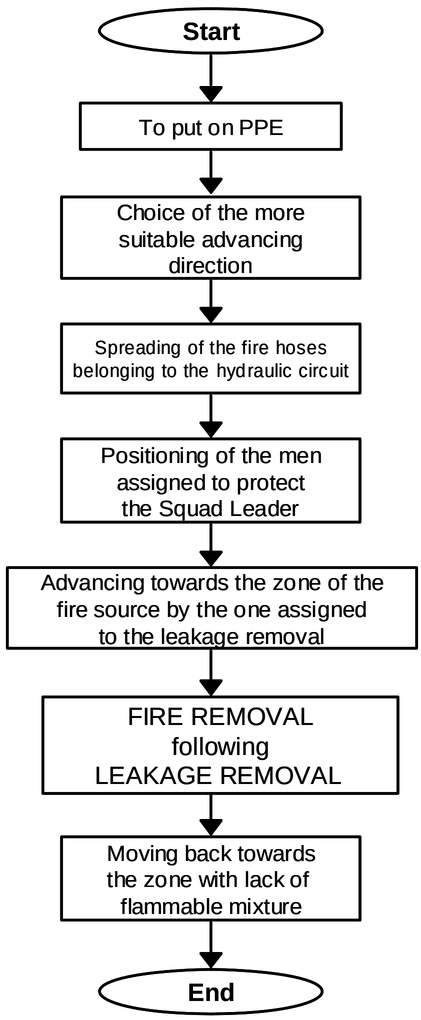
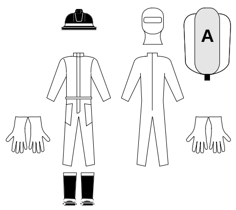
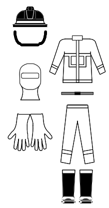
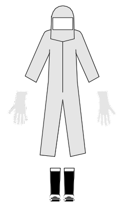
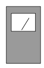
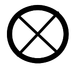
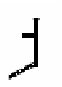
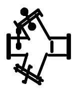
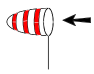
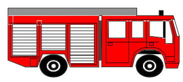


Figure 3. Approach procedure in the event of a FIRE

Table 1. List of Symbols

Symbol	Description
	Uniform for intervention complete with contamination-proof suit, helmet, boots and self-rescuer for long length
	Jacket flame repellent complete with helmet, subhelmet, gloves and boots
	Suit for the fire approach
	Portable explosion-proof radio
	Explosive gas detector
	Thermocamera
	Operator positioned at the pump of the fire truck
	Fire hose
	Three-way reducer
	Wind cone
	Fireman
	Fire truck

2.4 Scenario 3: release with delayed ignition

The main aim of the intervention is the help and rescue of the people involved and the location of the release point, if it is still present.

As regards the people rescue, this scenario is a conventional scenario; therefore there are well-established operating procedures for the intervention. As regards the location of the release point, this scenario is led again to the previous scenarios.

3.0 SUPPORT EQUIPMENT

The equipment required during the interventions is the following:

a) Detection and monitoring systems (Figure 4)

These systems are intended to confine the release area by determining the boundaries of a "red zone"; within this "red zone" there is a high risk of ignition because of the gas concentration; it is the zone with direct hazards for the rescue squads. These systems can also allow the squad leaders to locate the leakage point in the event of a release without ignition.

It is possible to use explosive gas detectors located at fixed points in order to evaluate the gas concentration locally; the location of the gas detectors should be fixed depending on the environmental conditions and the release area. Radio devices connect the gas detectors to a general control system located inside the Local Control Unity, where the emergency is managed. It is possible to use a monitoring system with up to ten explosive gas detectors; over ten detectors the time for the positioning, installation and connection with the main system is usually too long in comparison with the emergency time.

Figure 4. Example of an explosive gas detector

b) Visual systems (Figure 5)

Portable infrared imaging devices (thermocameras) are widely used to keep the emergency under control in the event of accidents with a release and subsequent ignition. These devices mainly allow the fire location but they can also help the location of a simple gas release. As their main advantage, they allow the rescue squads to assess the accident conditions without entering into the “red zone.”

These devices also allow the squads to assess the state of neighbouring elements such as tanks, pipes, supports or other pressure equipment in view of possible domino effects. It is possible to assess the temperature of the systems and then to make a quick evaluation of the possible failure time due to the simultaneous thermal and pressure stresses. Furthermore, the thermocameras allow the squads to assess the developments of the ductile or brittle fractures and then to fix indirectly the safety distances for the squads themselves.

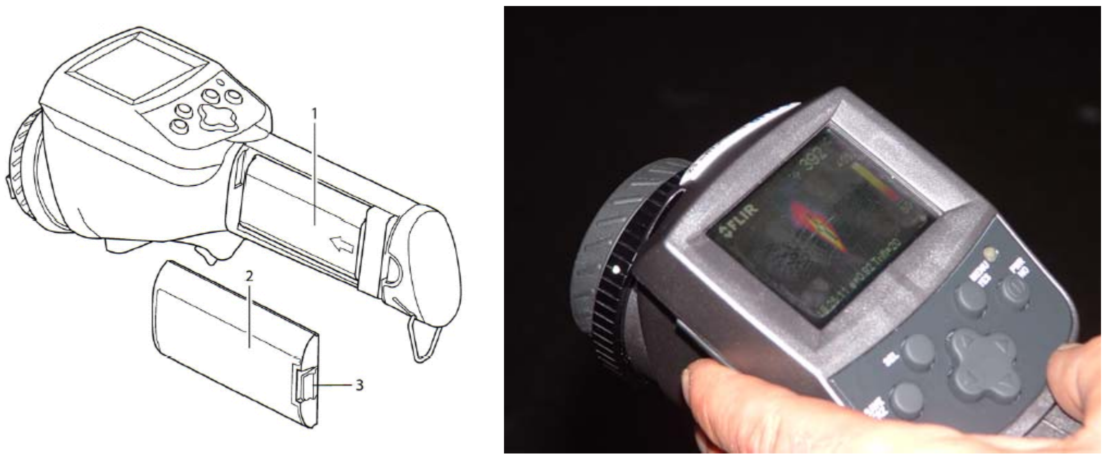


Figure 5. Example of a thermocamera

4.0 THERMOCAMERA USE FOR A LEAKAGE LOCATION

The thermocamera setting in the event of a hydrogen release with ignition is quite easy; data on the hydrogen fire temperature are readily available [5]: it is up to about 2200 °C. In the event of a hydrogen release without ignition the expected temperature change has to be theoretically evaluated to have an order of magnitude to set the thermocamera.

The following hypotheses have been here assumed:

- hydrogen is supposed as a perfect gas for the sake of simplicity

- a hydrogen leakage is supposed as an adiabatic expansion to the atmospheric pressure; this hypothesis is consistent with the intention of assessing the temperature change close to the gas leakage in order to locate the leakage itself

The pressure-temperature relation is then:

$$T \cdot p^{\frac{1-k}{k}} = const \,, \qquad (1)$$

where T - temperature, K; p - pressure, Pa; k - specific heat ratio (for hydrogen k=1.41).

Figure 6 plots a diagram with the percentage in the temperature change versus the system pressure. The temperature change is negative and it is about 60-70% with a pressure up to about 10 MPa, and until 85% with a pressure up to 70 MPa.

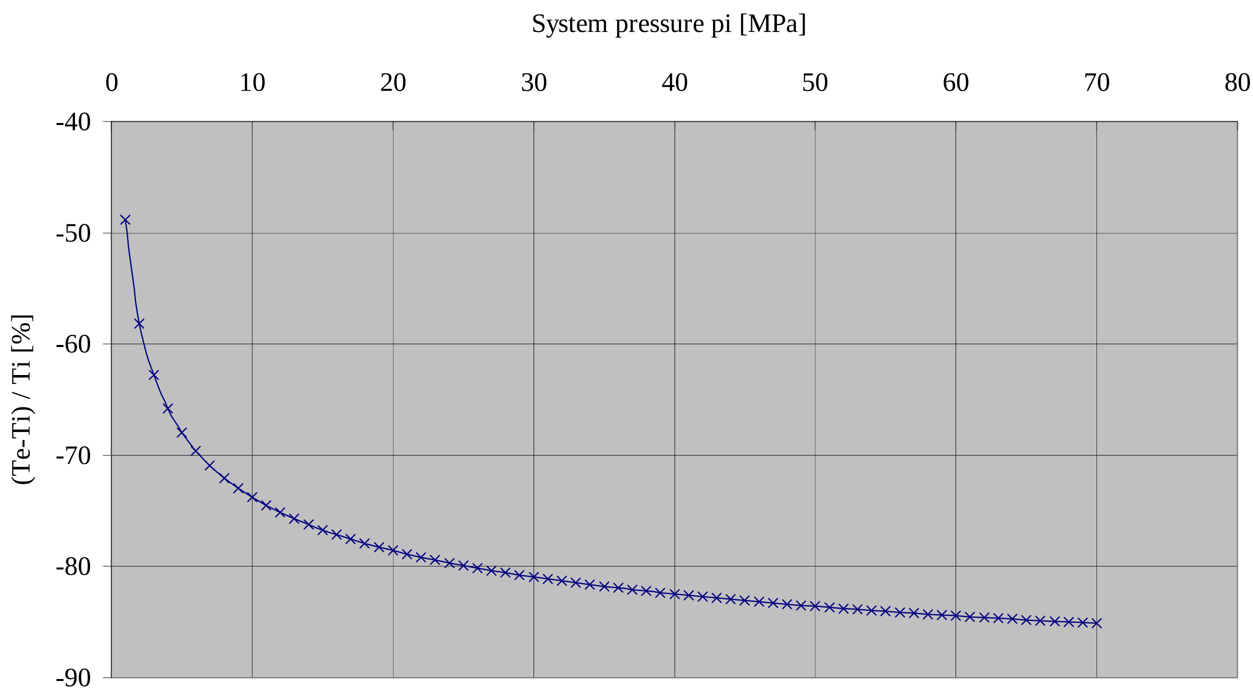


Figure 6. Percentage in the temperature change versus the system pressure in the event of a hydrogen release without ignition

From this result the following approach can be supposed with reference to the specific event involving a hydrogen release without ignition:

1. after the squad arrival, a measurement of the possible system temperature (by means of a thermocamera) and knowledge about the system pressure

2. the thermocamera setting with reference to the temperature previously measured and the pressure

3. the leakage location

5.0 CONCLUSIONS

This paper discussed a study on the Standard Operating Procedures (S.O.P.s) for the Fire Corps intervention in the event of accidents with a hydrogen release. The expected diffusion of the hydrogen applications over the next few years requires the capability to operate effectively in the possible scenarios. The characterization of these procedures leaves out of consideration the specific use of gaseous hydrogen.

The possible scenarios do not differ from those in the rescue operations involving a release of conventional gases and the main aim is always the leakage removal. It is necessary to carry out strategies intended to overcome the difficulties resulting from the absence of the lighting flame and gas smell. This imply recommending actions (use of gas detection systems and visual systems) which can make the flame visible with the naked eye and which can allow the leakage location. These actions are the connection tool between the hydrogen scenarios and the operating procedures for the already codified scenarios. Therefore it is possible to exploit the existing background and knowledge, the conceptual approach should not be revised and the operating procedures are not completely reinvented. Furthermore, the solution for the specific problems coming from the hydrogen makes the hydrogen procedures applicable and correct for all the gaseous fuels. Then the hydrogen procedures become a suitable revision tool of the procedures for the conventional gases.

These procedures are a first scheme intended to allow each brigade to fit the intervention modalities on its own needs and circumstances. Therefore the S.O.P.s are lively tools under continuous development. It has to be borne in mind that only the starting of the process for a procedure structuring needs several months of continuous work intended to fix the requirements, the operational issues and the problems, and their solutions.

REFERENCES

[1] Grasso, N., Ciannelli, N., Pilo, F., Carcassi, M. and Ceccherini, F., Fire prevention technical rule for gaseous hydrogen refuelling stations, Proceedings of the International Conference on Hydrogen Safety, 8-10 September 2005, Pisa (Italy), Paper 420064.

[2] Grasso, N., Ciannelli, N., Hydrogen Release/Fire Standard Operating Procedures, HELP Fall 2007 Meeting, 6-7 November 2007, Arlington, VA.

[3] Hydrogen Executive Leadership Panel (HELP). <http://www.nasfmhydrogen.com/>. Website last accessed on 28/04/2008.

[4] Chernicoff, W. P., McCullough, R., Postel, F., The Hydrogen Executive Leadership Panel (HELP) Initiative for Emergency Responder Training, Proceedings of the 2nd International Conference on Hydrogen Safety, 11-13 September 2007, San Sebastian (Spain), Paper 1.5.130.

[5] Supporti didattici per lo svolgimento dell'attività formativa alle Aziende da parte dei Comandi Provinciali dei Vigili del Fuoco. Ministry of the Interior. Prot. no. IFP 1153, 13/02/1997.