GUIDELINES FOR FIRE CORPS STANDARD OPERATING PROCEDURES IN THE EVENT OF HYDROGEN RELEASES

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ABSTRACT

This paper presents a study on the Standard Operating Procedures (P.O.S.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 fire prevention safety issues as one of its main objectives. 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 the 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. However, this is only the first step; a Standard Operating Procedure puts together both the theoretical and practical experience achieved on the management of the rescue operations; therefore its arrangement is a cyclic process by nature, always under continuous revision, updating and improvement.

NOMENCLATURE

A.B.P.: Autobotte Pompa (water tank truck)

A.P.S.: Autopompa Serbatoio (fire truck)

P.O.S.: Procedura Operativa Standard (Standard Operating Procedure)

P.P.E.: Personal Protective Equipment

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

1.0 INTRODUCTION

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 we use and they pose specific problems in the fire fighting and in the emergency management; it is better to anticipate and to deal with them as soon as possible, if we do not want to be unprepared in face of the hydrogen sector evolution.

This paper defines guidelines for the arrangement of fire brigade Standard Operating Procedures (P.O.S.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.

Different operating procedures have to be 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 fire the prevention safety issues [1] as one of the main objectives of its work. With reference to each scenario, the procedures specify the flowchart of the intervention, the number of the firemen involved, their work and personal protective equipment and finally their duties during the operations.

2.0 FIRE CORPS STANDARD OPERATING PROCEDURES: DEFINITION, OBJECTIVES, ADVANTAGES

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 (P.O.S.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 (here relevant to the hydrogen properties) with the means available to face them properly and to mitigate their consequences.

The structuring work of the Standard Operating Procedures has the following main objectives:

- to assemble a body of operating procedures for the rescue operations; it should be the state-of-the-art in the management and execution of the ordinary rescue operations and the civil defence operations

- to standardize the quality levels in the services supplying and in the meantime to allow the proper adjustment of the procedures depending on the local requirements

- to guarantee homogeneous and standard levels of safety and health for the firemen, the people and the other Bodies and Organisations involved

- to create a system of reference for the information, education and training activities

- to put in action an information exchange system among the members of the National Fire Corps

- to share experiences by means of a nimble, agile and effective tool

- to maintain updated the intervention procedures and techniques

A system of operating procedures results in the following advantages:

- clear, exhaustive, authorized and official operating instructions

- uniform conduct by the different squads in the answering to the same ask for help

- sharing of the knowledge and experience of each Fire Corps member through his involvement in the process of the procedure drawing up and its subsequent revision after the testing “on the field”

2.1 Characterization of the procedures

It is not correct to say that the interventions of the Fire Corps squads are different from each other. It is better to highlight that similar interventions share more common issues in comparison with their differences. It is also correct to observe that the intervention scenarios change every time. However, if each operator is provided with a set of good Standard Operating Procedures, he will have at his disposal suitable tools to make the best strategic, tactical and operational choices.

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. Fig. 1 reports the scheme of work to be applied.

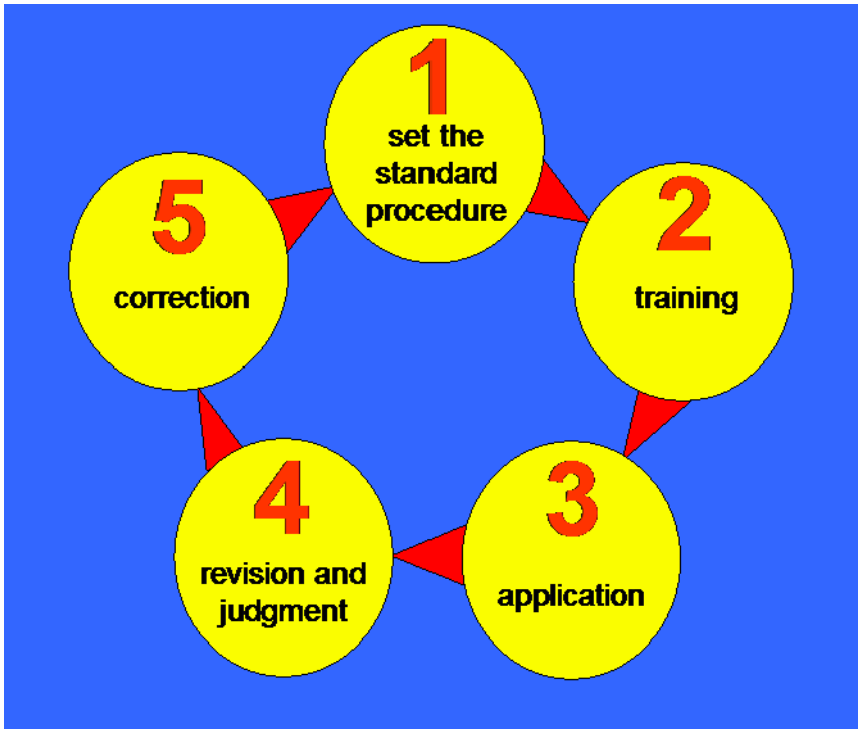


Figure 1. System for the P.O.S. development

Once the scheme of work has been started, it is cyclic; this means the process is always under a continuous revision. Therefore it allows the continuous refining and improvement of the performances and qualities of the operations. The process is explained in details below:

1. Set the Standard Operating Procedures

In order to start the process, a first model of the procedure has to be written, even roughly; this model reports what has been done up to now with regard to the specific intervention under consideration; or what would be done if the rescue squad should asked for help “just at that moment”.

2. Training

From the beginning, the training shall comply with the modalities fixed by the procedure, although it is still approximate. This will allow the squads to be ready for the procedure application and testing

since the first intervention.

3. Application

Although the diversity of the scenarios does not allow an early prevision of all the strategic and tactical options, the application of the procedure during the rescue operations is the moment when it is really tested. In this case its effectiveness will be evaluated immediately. When the procedure is still "in the embryo stage", there is surely enough room for suitable "working progress" adjustments.

4. Revision and judgment

The evaluation of the procedure effectiveness shall result in a collection of comments and remarks; they will be useful to the critical revision. The critical revision shall highlight in real terms which procedure issues have to be corrected, improved and integrated.

5. Correction

After the critical revision the procedure is corrected and issued (or reissued) officially. The cycle is now closed; the process is started and will be stopped no more.

2.2 General scheme for the structuring of a Standard Operating Procedure

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

There are different ways to draw up a procedure. The parameters affecting this choice can be relevant to the "logic succession of the operations", or relevant to the highlighting of the operator duties rather than those of the squad as a whole; or they are "organizing" or simple "graphical" parameters.

All the procedures shall allow the execution of the rescue operation in the shortest time, with the maximum optimization and synergy of the available resources, with the maximum level of effectiveness, accuracy and professionalism and finally with the maximum safety for all the people on the scene.

Furthermore, it is important that the part relevant to the general strategy for the intervention (the core of each procedure) is usually limited to two or three pages, four pages at most. Obviously, the less complex strategies can also be described on half a page while the more complex procedures require more pages (e.g. the procedures relevant to accidents with dangerous goods).

Table 1 reports the general model of the possible contents of a P.O.S..

Table 1. General model for the contents of a P.O.S..

Italian National Fire Corps	**STANDARD OPERATING PROCEDURE**	N. 0000/000
	Write TYPOLOGY OF INTERVENTION	Page
(city)	Approved:	Date

INTRODUCTION - WHEN AN INTERVENTION IS CLASSIFIED WITHIN THIS CATEGORY

This section lists a brief survey of the intervention typologies which may be classified and associated with this procedure, e.g. ask for help following a road accident with people within the vehicles; or ask for help following the presence of dangerous or radioactive goods.

INSTRUCTIONS OF REFERENCE

This section lists the legally binding instructions and also those instructions from which the specific mandatory issues of the procedure are drawn. This brief list is a suitable reference because it always has to take into account the existing instructions for the further revision and/or widening of the procedure.

MANAGEMENT OF THE OPERATING ROOM

This section lists the indispensable information which the Fire Corps switchboard operator shall get by asking those who ask for help some “key questions”. This section also lists the main operations to be executed in order to start the rescue squads belonging to Fire Corps and/or other Bodies or Organisations.

MEANS OF TRANSPORT AND EQUIPMENT SUITABLE TO THE INTERVENTION

This section contains a table with the means of transport and the possible specific equipment to be sent at once and those to be sent afterwards, if they are necessary; it depends on the gravity of the situation and/or the presence of specific circumstances.

GENERAL PROCEDURE FOR THE INTERVENTION

The general procedure contains the instructions which are common to all the interventions belonging to the same typology; they are indispensable to start the intervention, to manage it during the operating stages and to close it. This section is the “core” of the procedure because the objectives of the rescue activity are listed herein with the relevant strategies and tactics. The operations to be carried out are listed on the whole; they are listed according to the succession judged the most correct and with the most suitable equipment in view of the optimization of the human and material resources available on the scene.

TECHNIQUES FOR THE INTERVENTION

This section describes the specific techniques to be used in order to solve typical operating issues during the intervention. If it should be necessary, a series of techniques (even quite unlike each other) can be provided for specific variations of scenarios.

SAFETY

General safety

This section highlights all the general safety issues of the scene, although a part of them has been already anticipated in the description of the general procedure for the intervention. These issues include the safety of the present people as well as the continuous assessment of the site safety.

Safety of the Fire Corps operators

This section highlights all the safety issues concerning the Fire Corps operators, although a part of

these issues has been already anticipated in the description of the general procedure for the intervention.

AT THE END OF THE INTERVENTION

This section lists all the operations indispensable to make safe the scene, to collect the required data and to prepare a possible transfer to other Bodies. Furthermore, it lists the main controls to be executed on the scene before taking the service away and going back to the seat of services. All the administrative and police accomplishments to be carried out on the spot are also specified.

COMMUNICATIONS, ADMINISTRATIVE AND POLICE ACCOMPLISHMENTS

This section contains all the administrative, bureaucratic and police accomplishments which are carried out after the return of the squads to the seat of services.

MAINTENANCE OF THE MEANS OF TRANSPORT AND EQUIPMENT

This section lists all the actions indispensable for the full replacing in service of the means of transport and equipment.

SAFETY AND HEALTH OF THE OPERATING PERSONNEL

This section lists, if necessary, the possible medical checks to which the personnel has to be subjected in the event of an exposure to chemical products and/or combustion exhausts; this section also lists any other operating issue which is able to risk the operator's health. The data collection for the update of the health documents can be foreseen. The general health issues can also be highlighted (e.g. those relevant to the cleaning of the protective clothes).

CRITICAL REVISION OF THE INTERVENTION and NOTES FOR THE TRAINING

This section lists some key points in the intervention execution which have to be to revised and corrected on the basis of suitable schemes and/or packages. This critical revision is intended to allow the improvement (and the rewriting) of the procedures on the basis of the interventions carried out. The critical revision is one of the key stages in the drawing up of the Standard Operating Procedures.

The training following the critical revision is another key outcome. The training notes also contain everything which cannot be putted in the procedure text for reasons of simplicity. A lot of key information can be suitably highlighted only during the training stage; in this section they can be collected and organized.

3.0 STANDARD OPERATING PROCEDURES IN THE EVENT OF HYDROGEN REALEASES

The specificities of the hydrogen releases are fulfilled in the characterization of the above-mentioned general procedure for the intervention. The other sections of the Standard Operating Procedure 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 requires the intervention of a single squad. Whatever similar scenario occurs in the neighbourhood while this squad is operating, it will requires the intervention of a different squad.

3.1 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 Vapor Cloud Explosion) or CVCE (Confined Vapor Cloud Explosion)

While in the latter scenario the approach to the event mitigation could be led back to already codified intervention typologies (e.g. natural gas explosions), in the former two scenarios it is necessary to carry out strategies aimed at overcoming the difficulties resulting from the absence of the lighting flame and gas smell. This means to recommend actions which can make the flame visible with the naked eye and actions which can allow the leak source location. Therefore, these actions are the connection tool between these two types of event (to be codified) and the operating procedures for the already codified events.

3.2 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 release point

- the thermocamera is the support equipment for the support operator; although the fire is absent, it allows him to locate the release point by taking advantage of the heating effect 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 release (the first explosive gas detector is standard equipment). Fig. 2 reports the logic scheme of this intervention; Table 2 reports the list of the used symbols.

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

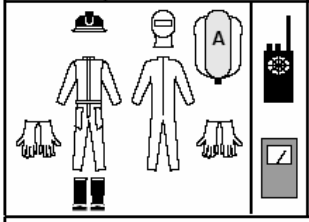
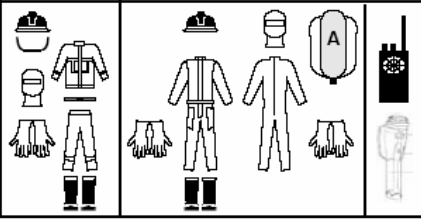
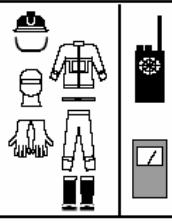
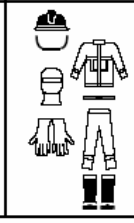
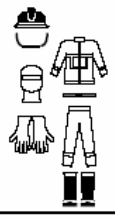
The main aim of the intervention is the fire removal by the leakage removal.

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. Fig. 3 reports the logic scheme of this intervention.

3.4 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.

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

A.P.S.	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.

FLOWCHART OF THE PROCEDURE

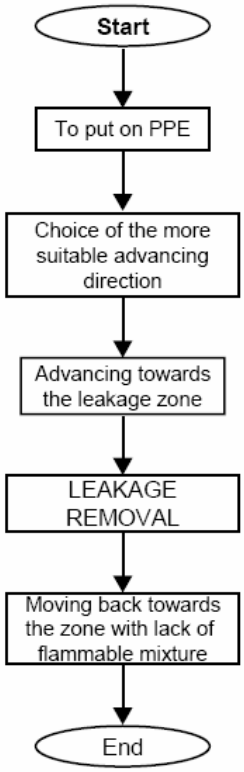


Figure 2. Approach procedure in the event of a LEAKAGE

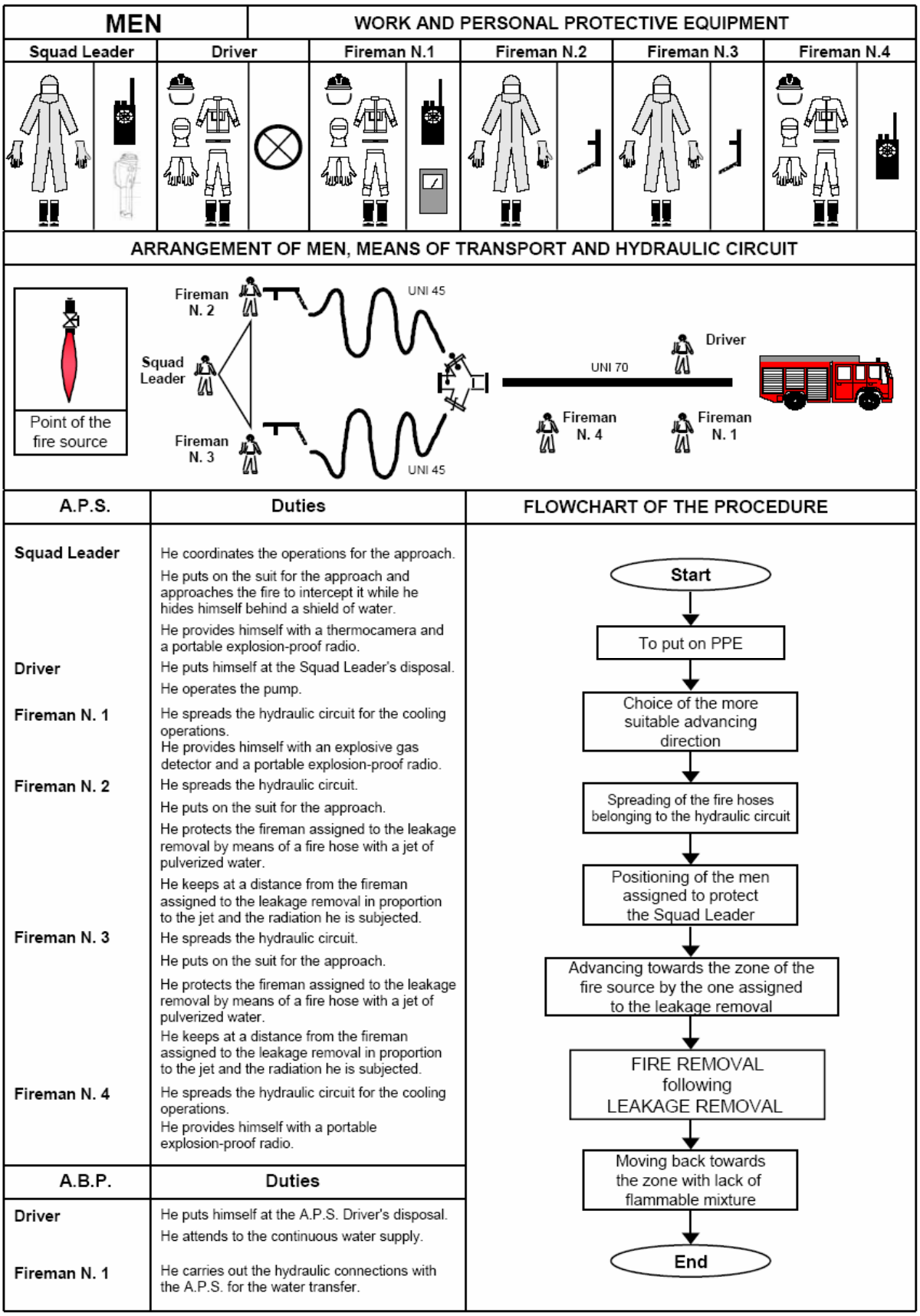
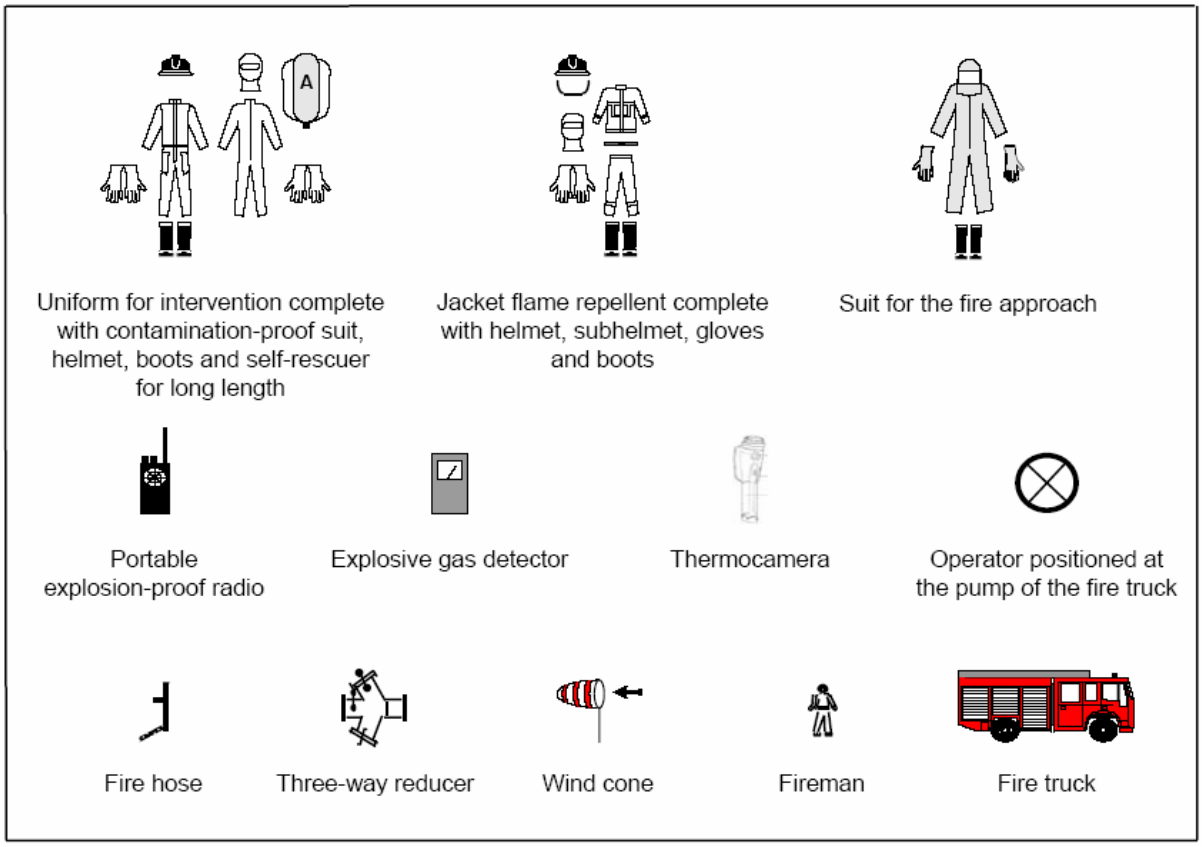


Figure 3. Approach procedure in the event of a FIRE

Table 2. List of Symbols.



4.0 SUPPORT EQUIPMENT

The equipment required during the interventions is the following:

a) detection and monitoring systems (Fig. 4)

Figure 4. Example of explosive gas detector

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 also allow the squad leaders to locate the release 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.

b) visual systems (Fig. 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, these systems 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 (Fig. 6) and then to fix indirectly the safety distances for the squads themselves.

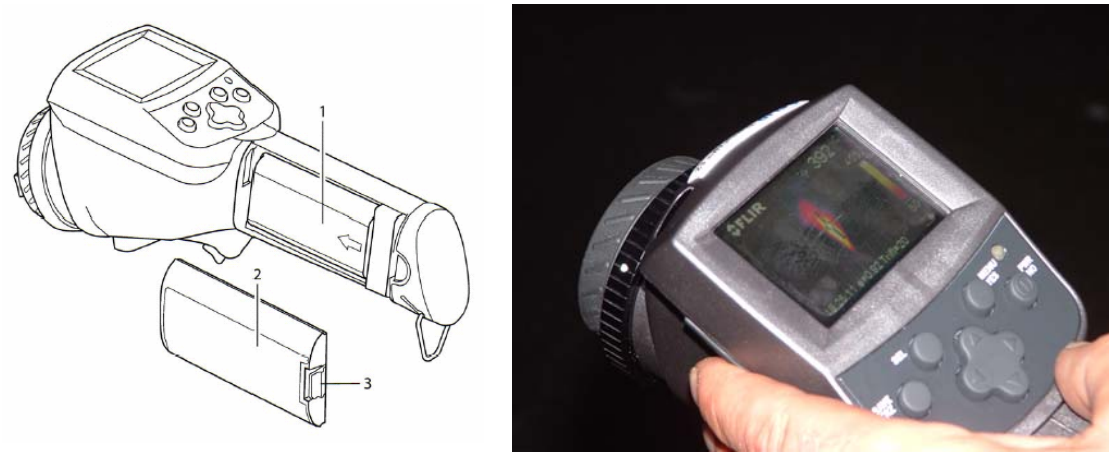


Figure 5. Example of thermocamera

Figure 6. Hydrogen tanks involved in a fire with jet. Brittle fracture of the blanket

5.0 CONCLUSIONS

This paper discussed a study on the Standard Operating Procedures (P.O.S.s) for the Fire Corps intervention in the event of accidents with hydrogen releases. 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 hydrogen (delivery network, storage on board vehicle involved in road accidents, compressed gas or liquid storage).

These procedures are a first scheme intended to allow each brigade to fit the intervention modalities on its own needs and circumstances. Therefore the P.O.S.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.

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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, Paper 420064.