Safety aspects of usage of flammable and toxic gases in high power laser accelerator experiments

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Abstract

High power laser accelerators are promising technologies that can effectively decrease the space and potentially cost of the particle acceleration experiments. For many of them there is a technical demand to use flammable and toxic gases as targets for lasers or for accelerated particles. Their usage, however, brings many challenges for design of the technology and safety management system of the facility. This paper provides basic overview of design and operational safety measures and challenges that must be overcome to be able to start the operation. There is a set of activities from the implementation of system safety rules and safety configuration management to control the design and project activities to the installation of additional systems (e.g. continuous alarm monitoring) or implementation of numerous set of administrative controls (e.g. respiratory protection or trainings). When launching the operation it is necessary to pay a special attention because this is the most critical point in the facility lifecycle. It have to be ensured that all addressed controls were implemented and the personnel is prepared for the operation (are trained, have appropriate PPEs, and work with technology in the most suitable conditions).

Key words: flammable gas, toxic gas, gas safety, high power lasers, particle acceleration, hydrogen, explosion, respiratory protection.

I. INTRODUCTION

Using high power lasers in experiments is relatively novel attitude of research and there is a lot of existing or under construction laser driven experimental facilities around the world (e.g. ELI Beamlines in the Czech Republic, LLNL in California, Rutherford Appleton Laboratory in UK and many others). These facilities provide a variety of applications in physics, material science, energetics, medicine, biological sciences, and chemistry.

Flammable and toxic gases are essential for some types of laser driven acceleration experiments and thus the high level of safety must be established. There are several aspects connected to the usage of these gases where some influence the design not only of the gas supply technology but also the design of the facility. There are more combined hazards in the laser driven accelerator facilities including high power lasers, ionizing radiation, electromagnetic pulses, cryogenics, or high voltage. Flammable and toxic gases are one of the most hazardous in the list of hazards. They act promptly and cause vast damage. Flammable gases like hydrogen or carbon monoxide can create explosive atmosphere that is easy to be ignited by the ignition source. We have to have in mind that there are a lot of ignition sources in these facilities. The list is not limited to ionizing radiation, electricity, possible fire (e.g. caused by focused laser beam), or indirectly electromagnetic pulse. On the other hand toxic gases which are used or are promising for the experiments can cause extensive health damage or immediate death. These gases can be for example hydrogen sulfide, hydrogen cyanide, or carbon monoxide.

It is necessary to pass through the whole safety design process properly to establish safety and effective system for operating the technology using the gases. This includes also the modification or improvement of other parts of the technology and facility. The main aim of this paper is to give an overview of safety aspects of designing of the technology and its operation. It provides the level of detail to address all the important points and fulfil the reader's expectation. It is not the aim of this paper to provide any design or ready-made technical solutions to be directly implemented. All sketches are illustrative and simplified for the purpose of the basic explanation.

II. USAGE OF GASES IN LASER DRIVEN EXPERIMENTS

One of the most explored usages of gases with laser driven experiments are high harmonics generation [1]. In this kind of experiments are mainly Helium and Neon gases. The more dangerous gas as Hydrogen is used in laser-plasma electron acceleration [2]. Laser interaction with Hydrogen gas (or other gasses used) creates plasma waves with enormous electric field where electrons can be accelerated towards the relativistic energies on a centimeter-scale [3], [4]. Accelerated electrons can be then focused by magnetic optics into the specific configuration of magnets called an undulator. Relativistic electrons starts to quiver in the path through the undulator and emits X-rays [5] with an energy proportional to the electron momentum. Such application is called X-ray Free-Electron Laser and its principle is visualized in Fig. 1.
Energy of photons generated via free-electron laser, higher harmonics or other high intensity laser-matter interaction processes can vary from few units of eV up to tens of keV energy level. Such variability in energy of photons enables various performances of their applications. Since higher photon energy can lead to the shorter pulses (down to attosecond scale), one can apply those pulses as a probe beam to visualize molecular dynamics [6] and more, to control them [7]. It is also possible to visualize large molecules or viruses before their atomization [8].

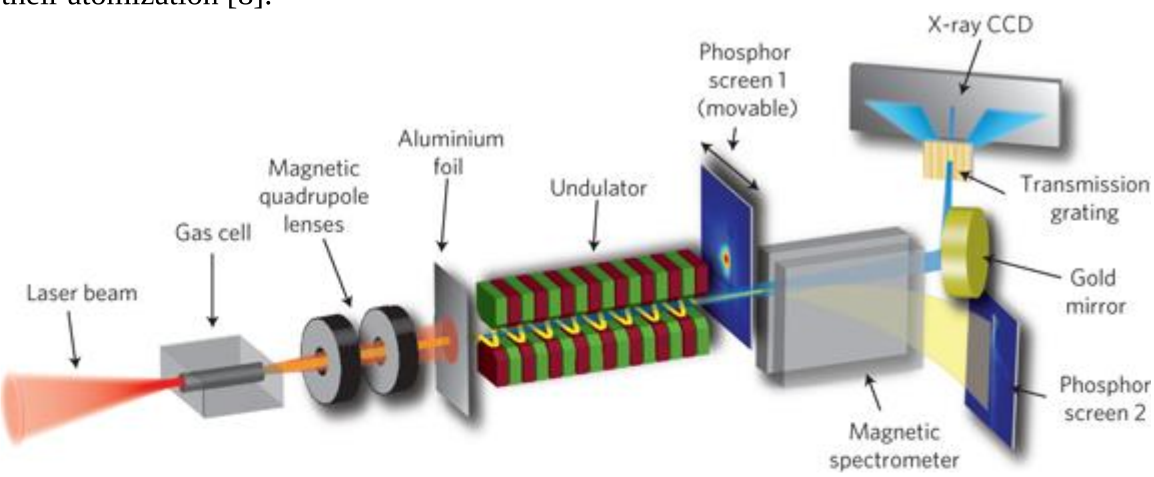

Fig. 1 Example of the experimental setup with gas cells [9].

Another field of laser-matter interaction study where it is possible to find flammable gasses and toxic materials is the inertial confinement fusion. Here the Deuterium and Tritium gases are used to create the cryogenic sphere for laser-fusion experiments [10]. What is more, in one of the possible configuration of the indirect drive scenario is to create an ablator from Beryllium [11]. Vacuum vessel of this target system is supposed to be a subject to decontamination when it will work with high repetition rate lasers. Beryllium and its compounds were developed as one of the possible stable ablator for laser-matter interaction [12], not only for fusion-related experiments.

The fusion-related experiments works with cryogenic target consisting of Deuterium and Tritium. Recently, there was proposed an experiment working with pressurized hydrogen to cool it down and solidify to grow a hydrogen ice on a tape for enhancement of laser-driven proton acceleration [13]. In this kind of experiment Hydrogen can be replaced by Deuterium or Deuterium with a certain ratio of Tritium to reach nuclear fusion reaction and generate fusion neutrons.
Another use of intense laser beams is for an *in situ* spectroscopy for continuous monitor of toxic metals [14]. Focused laser beam makes a spark on a surface of tested sample. Created spark is a plasma with short period of duration where all the elements are atomized and excited. From the spectra measurement of such spark one can obtain the results showing what kind of material the surface is made of.

III. CHEMICAL AND TOXICOLOGICAL PROPERTIES OF SELECTED GASES

As mentioned above several types of flammable and toxic gases are frequently used during the laser driven experiments. There are other gases like rare gases (helium, neon, xenon, argon etc.) or nitrogen used but these are not the topic of this paper. Those gases pose the risk of suffocation due to their oxygen depleting properties.
We will focus on the most characteristic flammable and toxic gases used for the laser driven experiments.

Hydrogen and its isotopes

Hydrogen (H_2) and its isotopes deuterium (D_2), tritium (T_2), mixture of HD and DT are flammable in gaseous phase and when released they create an explosive atmosphere. Hydrogen creates the explosive atmosphere with oxygen and air in wide concentration range. Its explosive atmosphere is within the concentration limits from 4% to 77% with air and 4% to 95% with oxygen saturated atmosphere. In addition, hydrogen explodes in contact with Platinum where Platinum acts as a catalyst. The mixtures of hydrogen with fluorine and chlorine are also explosive where ignition can be triggered only by light. The hydrogen is lighter than air and ascends to the ceiling when released.
Although hydrogen is not toxicologically interesting (does not have any toxicological effect), it can deplete oxygen in the atmosphere and cause suffocation. It acts as a simple asphyxiant, which means it depletes oxygen from atmosphere, and thus, can cause suffocation. Nevertheless this can happen in high hydrogen concentrations in atmosphere [15]. Deuterium evinces the same properties as hydrogen and tritium is more or less toxicologically interesting due to its radioactive properties [16], [17].

Hydrogen sulfide

Hydrogen sulfide (H_2S) is a toxic gas with significant odor of rotten eggs. In air, H_2S creates explosive atmosphere within the concentration limits from 4% to 45.5%. The autoignition temperature of H_2S is 260°C.
This compound is interesting from the perspective of its adverse health effect. In lower concentrations around 20 – 50 ppm it causes irritation of eyes, and concentration above 150 ppm irritates respiratory system. Inhalation of H_2S in concentration of 500 ppm for 30 minutes causes headache, dizziness, excitement, staggering, and gastroenteric disorders followed in some cases by bronchitis or bronchial pneumonia. Concentrations above 600 ppm can cause death in 30 minutes due to the respiratory paralyses [18]. The odor threshold of H_2S is 0.003 – 0.02 ppm [19]. There is one dangerous effect of H_2S on olfactory system. The olfactory fatigue occurs at the concentrations approximately from 150 ppm to 200 ppm, which

causes that the characteristic smell is no longer recognized [17]. The immediately dangerous to life or health concentration (IDLH) is 100 ppm.

Hydrogen cyanide
Hydrogen cyanide (HCN) is a toxic and flammable gas evincing bitter and almond-like odor. The odor threshold is at the concentration approximately from 2 ppm to 10 ppm. But the odor threshold can vary. That is why one should never rely on odor alone to determine the presence of HCN in air. Inhalation of the gaseous HCN can be rapidly fatal. Higher doses can cause rapid loss of consciousness and affected person stops breathing and dies. Lower doses of HCN, the affected person can experience weakness, headache, confusion, nausea, and vomiting [20]. HCN creates an explosive atmosphere in the concentration limits from 5.4% to 46%. The autoignition temperature is 538°C.

Carbon monoxide
Carbon monoxide (CO) is odorless toxic and flammable gas with density higher than air. It means that it falls to the floor when released. CO binds to the hemoglobin and causes suffocation. At the concentration from 35 ppm to 400 ppm it causes the headache and above this concentration other symptoms and signs occurs. Those are dizziness, nausea, tachycardia or convulsions. The concentration approximately 6,400 ppm for 20 minutes leads to the death and concentration 12,800 ppm leads to unconsciousness after 2 to 3 breaths. It results in death after several minutes. The explosive limits of CO are 10.9 – 74%. The autoignition temperature is 607°C.

IV. TYPICAL SETUP

Typically, the system consists of several parts connected to each other. The experiment is based on the laser interaction with gas or plasma created from the gas. This requires sealed experimental chamber which is under vacuum during the experiment. The quality of the vacuum differs but anyway vacuum assures that the gas is not ignited. The gas pumped into the system using the gas jets or gas cells which are connected with the outer gas supply system. Fig. 2 shows the typical engineering setup of the gas supply system.

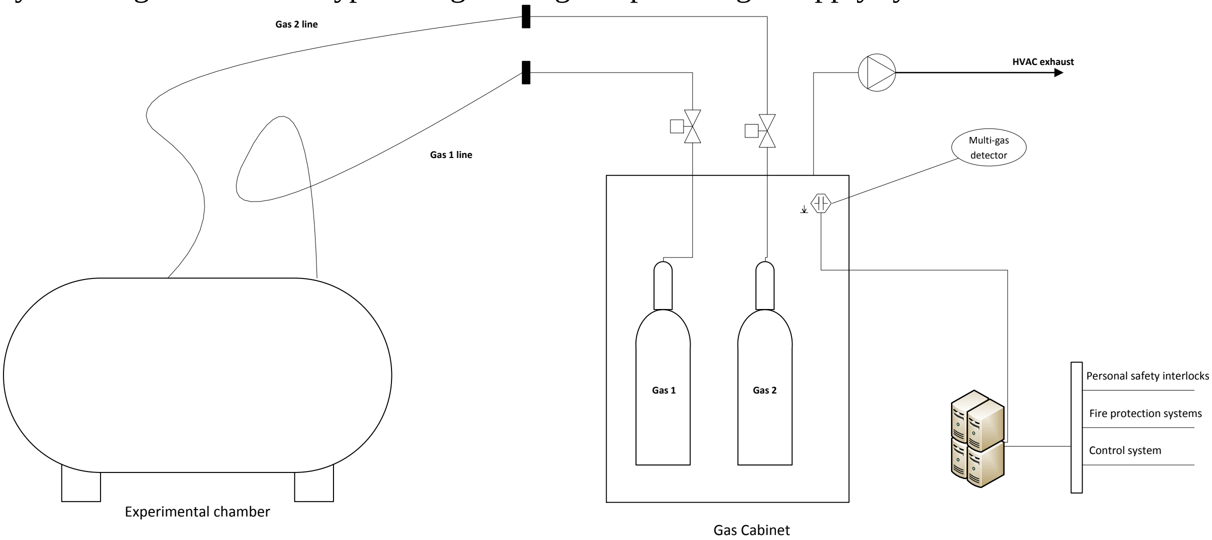

Fig. 2 Typical design of the gas supply system.

The gas is supplied either from the pressurized gas cylinders or from the storage tanks outside the experimental area (mostly even outside of the building). The storage area must be restricted and protected against the fire. The gas cylinders should be placed to the storage cabinets with certain fire resistance to avoid the fire or heat spread into the cabinet. The cylinders are connected to the fixed pipes through automated valves. Manual valves can be also used but after that there is no control and automatic shutdown in the case of a system failure.

The pipes lead to the gas supply panels. The experiments differ one from the other and various types of experimental chambers can be used for different types of experiments. Therefore, it is not practical to install fixed pipes from the panel to the chamber. For such purpose the flexible piping is used.

Inside the experimental chamber the gas is injected and serves as a target for the laser beam. Whole system in the experimental chamber is under vacuum and typically it is connected either to the central vacuum system or it has its own vacuum loop in the room.

The gas cabinet is connected to the HVAC system and permanently vented. There must be a gas monitor connected to other safety critical systems such as personal safety interlocks, fire alarm systems etc. Based on the type of used gas, proper measuring device must be installed. Because the experiments can differ and there can be more than one type of gas connected in the cabinet, it is typical to use the multi-gas detector. Data obtained from the detection system are sent to the programmable logic controller which gives the information to other systems like personal protection interlocks, process control system, and fire alarm systems.

The setup can differ in details but in general the description given above is valid for most of the experimental setups.

V. RISK ANALYSIS

The technology used as a gas supply for the experiments shall be a subject of the risk analysis before the design is ready. For the design safety purposes the weak points must be identified and measures applied to the technology design. The measures to be applied should not be limited only to the gas supply technology but also for the devices connected to and surrounding the environment. It is important to keep in mind that significant hazards are handled. All processes and work steps must be identified, described and assessed to address appropriate engineering and control measures for the operation.

There are several methods suitable for the risk analysis such as HAZOP or FMECA. The risk analysis process must cover both the gas supply technology and other devices and surrounding environment. All routine and non-routine steps must be identified and assessed. Modus operandi is one of the most important inputs because it will affect the design of engineering and administrative controls.

First, the hazards must be identified. In our case there are following combined hazards:

- Explosives,
- Toxic substances,
- High voltage and other electrical devices (capacitors for laser and experimental technology),
- Ionizing radiation (accelerated particles and neutrons),
- Laser radiation,
- possibly Electromagnetic pulses– EMP (for interaction of high power lasers with matter it is very probable and it can cause local sparks on the surface of the conductive objects),
- Cryogenics (coolants for the technology like magnets etc.).

In the case of flammable gases, we need to identify all potential sources for explosive

atmosphere and ignition sources. The ignition sources here are electricity, ionizing radiation, lasers, and EMP. Another ignition source which must be taken into account is a fire or heat generated with the improper function of the cooling system.
There are also other hazards and risks which are not related to the combustion or poisoning but will influence the nature of the controls and emergency response. The typical example of such hazard is ionizing radiation. The fact that the radiation occupies the room disables us to enter the area and react on the emergency situation. So the system must be fully automatic without any demand any physical action in the room (e.g. manual closing of the valve etc.). That is why it is very important to take into account also other hazards when designing the technology.

VI. HANDLING WITH THE GAS IN THE SYSTEM

It is crucial to have the knowledge of safe handling with flammable and toxic gases to prevent any accident. The gases must be stored in the sealed gas cabinets with some fire resistance to prevent the heating if the fire in the room starts. The gas cabinets must be permanently vented or must have automatic emergency venting system which trigger is based on the reaching of defined concentration level. It is very important to separate the incompatible gases and store them in different cabinets. Those gases are flammable gases and oxygen. The explosive limits of the gases extend when the atmosphere is saturated with oxygen. Also the exhaust ducts of the venting system must be separated for flammable gases and oxygen.
The experimental chambers are under vacuum and after the experimental campaign the air is pumped into to be able to open it and prepare another experiment. The chamber contains the flammable gas which can create the explosive atmosphere in contact with air. During the experiment the air containing the flammable gas is pumped out of the chamber with vacuum system to maintain the vacuum conditions. Vacuum pumps are possible ignition source and must be either constructed with the explosion protection or must be intertied with nitrogen or other suitable gas like carbon dioxide [21]. Special attention should be paid when the vacuum in the chamber is being broken. The reason is that the air pumping into the chamber can result in explosive atmosphere creation. Due to this fact the chamber is also intertied with nitrogen and the atmosphere in the chamber is slowly diluted to prevent the explosion.
Gases are used as targets for lasers to accelerate the particles. During the experiment the interaction chamber is under vacuum. Despite the fact that laser is an ignition source it is not possible to ignite the flammable gas in vacuum level below 10^{-4} Pa. All laser beam paths must be covered and shooting must be avoided when there is a potential explosive atmosphere.

VII. ENGINEERING CONTROLS AND SYSTEMS

Safety design is one of the most important aspects of gas supply technologies for high power laser experiments. Because of the more combined hazards it is necessary to take into account all of them and create effective layers of protection. These have an effect to the design of the gas supply but also to the design of the room and finally whole facility.
We mentioned above that there is ionizing radiation in the room during the experiment (it is the nature of the experiment) which does not allow any personnel to enter the area. Due to this fact it is essential that the gas supply is fully automatic. It means that it is controlled with an automation system reacting on all emergency situation and failures. This system must be connected to all important building and technology systems which can affect its operation. In practice it means that if there is any problem for example with vacuum, the system gives this information to the gas supply automation system and it terminates the process (closes the valves). Also, it must be possible to operate the gas supply remotely from the control room to

shut down the system in the case of any doubts.

There are two systems which are typical for laser and accelerator facilities and are part of the facility level safety system. These are monitoring system (MS) and personal safety interlocks (PSI). These systems are connected to other important building systems and control the operation in the whole facility.

Monitoring system

The monitoring system controls the concentration levels at selected places to detect the creation of explosive or toxic atmosphere. It is beneficial for the laser and accelerator facilities to integrate this system along with the monitoring system (MS) for ionizing radiation. This integration brings not only financial benefits but also operational advantage. The possible setup of the gas monitoring system (GMS) is shown in Fig. 3.

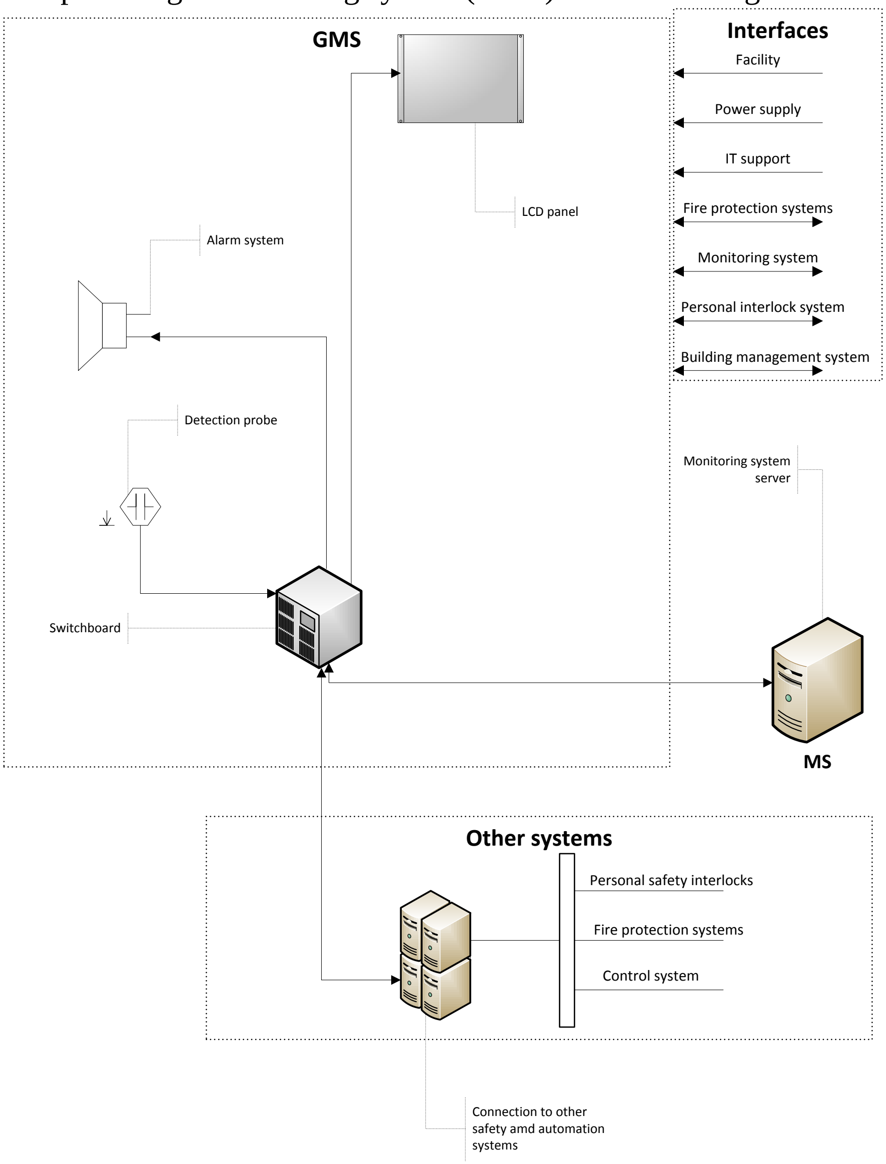

Fig. 3 Possible setup of the monitoring system.

The GMS consist of several autonomous parts and parts which are components of the MS. The GMS is connected to the MS via IT network. MS also includes ionizing radiation monitoring system (IRMS) which is other autonomous system. GMS can be functionally divided into flammable, toxic and oxygen depleting gases monitoring. The system consists of measuring probes, switchboard, wiring and IT infrastructure, and LCD panel and alarm system. The measuring probes differ based on the monitored gas type. The location of the probes is based on the location of possible hazard occurrence. The location should be chosen carefully with respect to the nature of the hazards and their behavior in environment. E.g. the probes for hydrogen should be installed above the source of leakage where probes for CO should be located below the level of the release source.

When leaked, the flammable gases can create explosive atmosphere. It is then characterized by the lower and upper explosive limits (LEL and UEL). Within these concentrations the explosive atmosphere is present. The explosive atmosphere can be ignited by the ignition source. The probe measures the concentration of the flammable gases in the environment around the potential source of its creation (connections, valves, or other weak places). There can be several levels of detection, alarm and action. For the simplistic explanation we use two levels: 10% of LEL and 20% of LEL. The system reacts differently based on the level. In both cases the GMS also sends the information to the MS to process and store the information.

When 10% of LEL is reached, the probe sends signal to the switchboard about the created situation. Switchboard gives command to the alarm system to start alarming. The alarm is acoustic and visual. The visual signal means that the beacon light is turned on and LCD panel in the control room shows the alarm. No other automated actions are required.

When 20% of LEL is reached, the probe sends signal to the switchboard about the created situation. Switchboard gives command to the alarm system to start alarming. The alarm is acoustic and visual. The visual signal means that the beacon light is turned on and LCD panel in the office or control room shows the alarm. Switchboard sends the information to the PSI with warning of the hazard. PSI shall terminate the operation of the technology and start shutdown procedure. Switchboard sends the information to the fire detection system which shall start another alarm and shall react according to its procedure (unblocking the doors, venting the area, potentially evacuation procedure for vacuum chamber etc.). Switchboard gives the command to the control system of the gas supply system to close the valves and terminate the pumping of the gas to the system. The operation is terminated in the room.

The situation is different in the case of toxic gases. The toxic gases (HCN, H_2S, CO etc.) are also characterized with Threshold limit value (TVA) and Occupational exposure limit (OEL). TVA is a lower detection limit which shall not be exceeded during the working shift where OEL is the upper limit on the acceptable concentration (this shall be never exceeded). These limits can be taken as a detection levels.

When TVA is reached, the probe sends the information to the switchboard about the situation. The switchboard gives command to the alarm system to start alarming. The alarm is acoustic and visual. The visual signal means that the beacon light is turned on and LCD panel in the office or control room shows the alarm. No other automated actions are required.

When OEL is reached, the probe sends signal to the switchboard about the created situation. Switchboard gives command to the alarm system to start alarming. The alarm is acoustic and visual. The visual signal means that the beacon light is turned on and LCD panel in the office or control room shows the alarm. Switchboard sends the information to the PSI with warning of the hazard. PSI shall take into account additional hazard in the room. Switchboard sends the information to the building management system and it turns on the emergency ventilation. Switchboard gives the command to the control system of the gas supply system to close the valves and terminate the pumping of the gas to the system. The operation is terminated in the room.

The MS must be properly designed to be able to cooperate with other systems in the facility and to cover the hazards precisely at the place of their locations.

Personal safety interlocks (PSI)

PSI is a facility level safety system which prevents the hazards to "escape" the room and controls that the process runs within the limits. There are two systems with similar function: PSI and machine safety interlock (MSI). These should be integrated because the failure of the technology can affect both personnel and machine. In addition there can be a situation occurred when the damage of the machine or improper shutdown can generate the hazard for personnel.

PSI is an autonomous system to which the standards on functional safety are applied. The devices of the PSI (PLCs – controllers, door locks, sensors etc.) are classified as SIL2 or SIL3. This is based on the SIL classification and risk assessment. The classification depends also on the modus operandi. It blocks the entrances to the hazardous area or allows access only to authorized people (above the access control system) and overtakes the control under defined safety related devices like shutters in the beam path.

Due to the fact that PSI is connected to the laser and experimental technology it can terminate their operation when it obtains information from GMS about the emergency situation. GMS cannot have such function because it would be high risk for the operation of the facility. In the areas where there is not PSI the process must be controlled with the control system of the technology based on the information from GMS. PSI is one of the main important safety systems in accelerator facilities and the operation cannot be launched without it [22], [23], [24].

VIII. ADMINISTRATIVE CONTROLS

Besides the engineering controls there are a lot of administrative ones which act as additional layers of protection. Those are represented with trainings and drills, personal protective equipment (PPEs), or documentation.

Training

Each person performing the work related tasks in the rooms must be trained on several safety topics. Besides the training on laser safety, radiation protection, chemical safety and others, the person must undergo the gas safety training and emergency response. Because the usage of PPEs for some types of works is mandatory, the personnel using them must be trained on how to use them properly. Gases are stored in the pressurized cylinders which are connected to the gas supply system. All steps leading to the connection of the cylinders must be done carefully and can be done only by trained personnel.

There are several specialized trainings on gas safety. Good example can be e.g. OSHA training on H_2S or some commercially available training on explosives and toxic gases. The facility can also have an internal or external certified specialist who trains the operational personnel on demand. The training must be performed prior to the job assignment and then on the regular basis. For example, according to OSHA 29 CFR 1910.120(e)(8), the personnel exposed to the hazardous substances shall obtain 8-hours annual refresh training. This training should be conducted by qualified training providers [25]. The training must be properly documented and records archived. It is crucial to develop suitable curriculum for the initial and refresh training to cover (if possible) all activities and hazards.

The operational personnel must be prepared on the emergency situations which can come to pass and thus the emergency response drills must be carried out. These can be included in the exercises and drills on the emergency response on other situations in the room (e.g. cryogenic gas leakage, injury caused by laser, or fire). Nevertheless the personnel handling with the gas cylinders should obtain special emergency response drill above the standard level of knowledge.

PPEs

Respirators are typical PPE for toxic gases manipulation. Those must be used when connecting and disconnecting of the cylinder is performed. It is crucial to assign appropriate respirator which covers the handled hazards and provides appropriate assignment protection level (APF). During the connecting and disconnecting of the cylinders the respirator should be worn for the case of any emergency. For emergency situations it depends on the concentration of toxic gases in the air. In the most of the cases the concentration is measured with the GMS and there is an overview about the situation but there can be a situation when the concentration is not known or can be at the IDLH level. For such cases the respirators with APF = 10,000 should be selected.

There are specific recommendations for respirator types for H_2S and those differ based on the concentration in air or the nature of the work. According to NIOSH, for concentrations up to 100 ppm of H_2S in air, it is recommended to use from any powered air-purifying respirator with cartridges (APF = 25) to self-contain breathing apparatus with a full facepiece (APF = 50) [26]. In the case of emergency or when there is an entry to unknown concentration planned, the self-contained breathing apparatus with a full facepiece and operated in pressure-demand or other positive-pressure mode or full facepiece supplied-air respirator with an auxiliary self-contained positive-pressure breathing apparatus are recommended [26]. For HCN (where IDHL is 50 ppm), there is any supplied-air respirator (APF = 10) recommended for concentration up to 47 ppm. When the concentration reached IDLH level, there are any supplied-air respirator in a continuous-flow mode (APF = 25) to any self-contained breathing apparatus or supplied-air respirator with a full facepiece (APF = 50) [27]. For entering the area with unknown concentration or above the level of IDLH, there is the same recommendation as for H_2S [27]. Due to the fact that CO has much higher level of exposure limits and IDHL than H_2S or HCN the recommendations for respirators differs in the term of various concentration limits exposure. For concentration up to 350 ppm there is any supplied-air respirator (APF = 10) recommended. There is other concentration level (875 ppm) where any supplied-air respirator with continuous flow operation (APF = 25) is suitable. For concentrations up to 1,200 ppm, there is recommendation to use from any full facepiece air-purifying respirator to any full facepiece supplied-air respirator or self-contained breathing apparatus (all APF = 50). The recommendation for respirators is the same as for previous ones for the case of entering the area with unknown concentration or on or above the level of IDLH [28].

According to OSHA 29 CFR 1910.134(c), there must be a written respiratory protection program implemented. It shall contain procedures for selecting of the respirators, medical evaluations of employees wearing the respirators, fit testing procedures, procedures for proper use of the respirators (both for routine and non-routine or emergency situations), procedures and plans for respirators maintenance, procedures for verification of the air quality, trainings (including the hazards and use of the respirators), and procedures for evaluation of the program effectiveness.

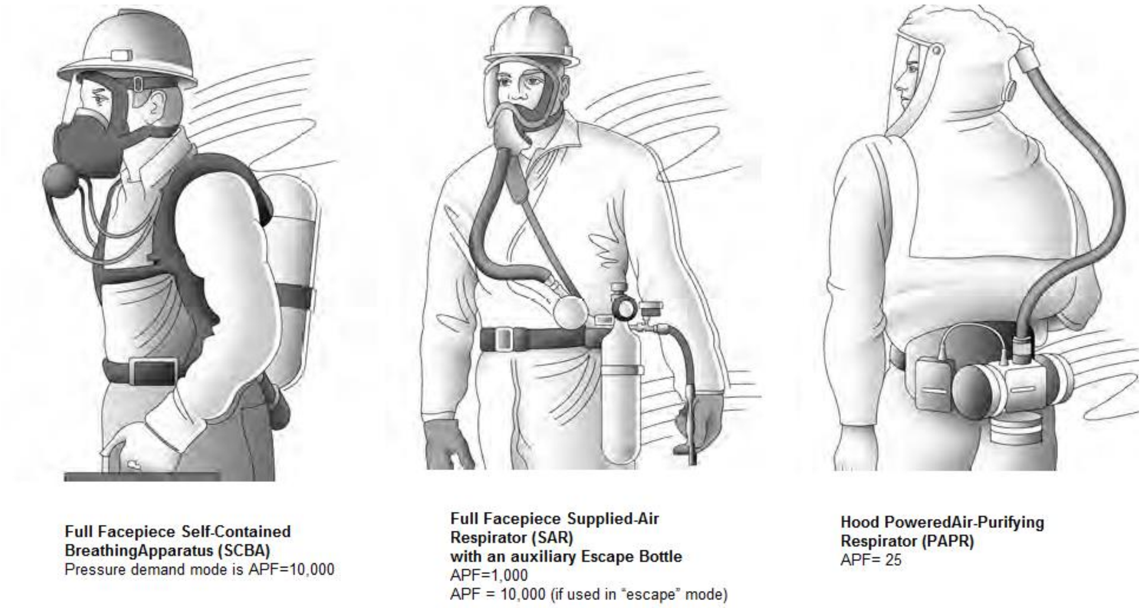

Fig. 4 Examples of the respirators [29].

Documentation and inspections

To ensure safety and prove the compliance it is necessary to document all safety relevant activities. Besides the training and PPEs related documentation which was described above there must be standard operational and safety procedures adopted for routine and non-routine works. There must be hazardous substances and energies inventory created and regularly updated. Based on the inventory and inputs from the risk assessment the safety procedures and instructions are implemented. In the case of laser driven accelerator these are represented by and not limited to:

- Radiation safety program,
- Laser safety manual,
- Chemical safety manual,
- Instructions for works in the particular experimental and technological rooms (there can be different hazards and risks, and controls in the rooms),
- Non-ionizing radiation safety manual (covering EMP, magnetic field etc.),
- Respiratory protection program,
- Fire protection manual,
- Compressed gas safety manual (including handling with the cylinders),
- Electrical safety procedure and many others.

The personnel entering the area and performing the works must be trained on these procedures within the extent of the nature of their work. In addition, the laser driven accelerator facilities provide some beam time for external users from academic and also commercial sector and these people must be trained within adequate extent.

Above all the manuals and procedures which cover the operation there should be also a system safety management (SSM) implemented. Due to the fact that the laser driven facilities continuously upgrade the technology, there must be a system in place to address the safety measures already in the initial phase of the project. The facility should adopt the system safety program (SSP) which defines the requirements on each technology and research project in the facility. SSM is then closely connected to the safety configuration management (SCM) which helps the engineers and designers to integrate the device or technology in the existing system, defines safety measures and verifies that safety requirement were implemented. All these

activities must be properly documented and archived.
The workplace and especially the gas supply system must be regularly inspected. According to OSHA 29 CFR 1910.101(a) the compressed gas cylinders must be inspected in accordance with Compressed Gas Association Pamphlets C-6-1968 and C-8-1962. There are various types of inspection from visual check to the functional tests of the cylinder and the devices of the gas supply system (valves etc.). The functional inspections must be performed by qualified person. The basic visual operational inspection of the gas cylinders are done internally by trained employee according to the checklist. All checks and inspections must be properly documented and this documentation is an inseparable part of the gas supply device during its whole lifecycle.

IX. INTERFACES WITH OTHER SYSTEMS

The gas supply system has many interfaces with other systems based on its complexity and function. Typically there is an interface with GMS which continuously measures the concentration levels of flammable and toxic gases and based on the detection or alarm levels it terminates the gas supply to the experimental chamber. This system must be connected to the fire protection system, PSI, control system, and building management system. As described in chapter "Monitoring system", there are some actions performed based on the detection of exceeding the defined limits. That is why GMS must be able to send the information not only to the operator but also to these systems to provide the response automatically.
The interfaces with other systems and facilities must be clearly identified and carefully described already in the initial phase of the gas supply system design. Definition of the interfaces are one of the main activates of SSM and when the device is integrated into the system are subject of SCM.

X. SUMMARY

Usage of the hazardous substances like flammable and toxic gases is essential for some laser driven experiments. That is why it is necessary to establish effective safety system to cover these hazards and ensure safety. There should be good safety and communication culture in the facility that will guarantee that all relevant information are passed to the safety specialists which can provide the expertise for design, installation and operation. As soon as the intention to build and use flammable and toxic gases is expressed, the risk analysis must be started. There must be possible places of explosive atmosphere creation and ignition sources identified. Based on this safety controls are addressed and implemented. The outputs from the risk analysis are essential for the design of both the gas supply and experimental technology. It must be verified that the intent to use these gases fits to the mission profile and design of the facility. The rooms must be suitable for the installation and usage of such device and there must be dedicated area for handling with the gas cylinders and their storage. Facility management must allocate financial resources for all design, installation and operational activities.
The gases can be either stored in the tanks or then filled to the pressurized gas cylinders or can be directly used in the gas cylinders. For the filling to the gas cylinders there must be filling station with all applicable safety measures installed. Another point is the amount of the gases that are to be used in the rooms. If stored and used in larger amount one has to be sure that this is in compliance with the fire protection concept of the rooms. Typically the gas cylinders are stored in the cabinets which serve for separation of the fire areas and provide the fixation of cylinders. It is necessary to assign appropriate measuring devices to monitor the

concentration of the gases in air for the case of any leakage. We have to keep in mind that various gases have different density and behave differently when released to atmosphere. For example hydrogen is lighter than air and moves up from the place of release where CO is heavier than air and falls down to the floor. This is important information for right installation of the measuring probes. Because the room is closed and "secured" with PSI during the experiment it is beneficial to have all gas supply processes automated to avoid the delays in response to the emergency situation. Thus the GMS must be interfaced with other operational and safety systems in the facility (PSI, control system, building management system, fire protection systems etc.).

Handling especially with flammable gases has a certain design demands in the term of protection and operational procedures. One of the most crucial points is an explosion protection of electrical devices. There must not be any unprotected electrical device installed near the place of possible leakage. When entered the vacuum system the flammable gas can create explosive atmosphere with air either in the vacuum system or in its exhaust. Therefore it is common practice to develop the procedures for breaking the vacuum which include inertization with e.g. nitrogen or carbon dioxide. This prevents the explosive atmosphere to be created.

Handling with flammable and toxic gases requires certain administrative measures that include wearing proper respiratory protection, regular inspections and checks of the workplace and the device, detail and practical oriented trainings and drills and effective documentation of all safety related actions. As mentioned above it is important to create, implement and sustain good safety culture in the facility to educate the personnel how to work safely in the hazardous area. Near miss reporting should be standard practice as well as all incident reporting. Facility management should be focused on the improvement of safety awareness to achieve high level of safety system.

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