

THE PERSONNEL SAFETY SYSTEM OF ELI-ALPS*

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Abstract

ELI-ALPS will be the first large-scale attosecond facility accessible to the international scientific community and its user groups. The facility-wide Personnel Safety System (PSS) has been successfully developed and commissioned for the majority of the laboratories. The system has three major goals.

First, it provides safe and automatic sensing and interlocking engineering measures as well as monitoring and controlling interfaces for all laboratories in Building A: emergency stop buttons, interlock and enabling signals, door and roller blind sensors, and entrance control.

Second, it integrates and monitors the research technology equipment delivered by external parties as black-box systems (all laser systems, and some others). Third, it includes the PSS subsystems of research technology equipment developed on site by in-house and external experts (some of the secondary sources).

The gradual development of the system is based on the relevant standards and best practices of functional safety as well as on an iterative and systematic lifecycle incorporating several internal and external reviews. The system is implemented with an easily maintainable network of safety PLCs.

INTRODUCTION

ELI's long-term objective is to become the world's leading user facility utilizing the power of state of the art lasers for the advancement of science and applications in many areas of societal relevance [1]. The main objective of the ELI Attosecond Light Pulse Source (ELI-ALPS) pillar is the establishment of a unique attosecond facility that provides ultrashort light pulses with high repetition rates.

The Personnel Safety System (abbreviated as PSS) of ELI-ALPS is responsible to prevent or reduce any laser related harm or risk to the persons working in the facility. This system is one of the several protection layers aiming to prevent persons from getting life-threatening exposure, injury or damage potentially caused by laser radiation.

The PSS provides safe and automatic sensing and interlocking engineering measures as well as monitoring and controlling interfaces for all non-ionizing Laser- and Low-shielded Target Areas. The system consists of highly reliable sensors and actuators (collectively called field devices), and logic solvers which maintains the data link between the field devices.

* The ELI-ALPS project (GINOP-2.3.6-15-2015-00001) is supported by the European Union and co-financed by the European Regional Development Fund

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The PSS is complemented by other engineering controls: entrance control, mobile laser shielding walls, curtains, organizational and administrative controls (e.g. safety signs, safety trainings) and personal protective equipment (e.g. laser safety goggles).

The PSS communicates and integrates several other safety systems delivered by external parties: the PSS subsystem of the laser source systems, the fire safety system, the Safety Access Control System (Saf-ACS) as well as the Radiation Monitoring System in the future. For the block diagram of the PSS, see Fig. 1.

The system has been developed by following the relevant international standards and recommendations with particular reference to the IEC61511, as well as considering the experiences of similar projects [2-5].

SAFETY REQUIREMENTS

The completely independent Environmental, Health and Safety Division systematically surveyed and still continuously monitors the hazards and risks of the facility with a special focus on research technology related ones. The engineers and scientists are heavily and regularly involved in this work in order to identify and mitigate as risks as possible.

These hazard and risk assessments target all kinds of hazards from fire, electrical to laser radiation and so on. The results of the assessments are the allocation of safety functions to different kind of protection layers, with a special focus on laser safety and safety instrumented systems: requirements against external suppliers (e.g. companies delivering laser systems) as well as requirements against the facility-wide PSS. An important measure related to the PSS systems is the regular training (including exams) of all personnel working in the lab, especially the area managers responsible for the proper and safe operation of the respective laboratories.

RESEARCH TECHNOLOGY EQUIPMENT

The general architecture of ELI-ALPS' research technology includes three major parts. *Laser Source (LaSo)* systems provide the necessary laser beam to the experiments. They arrived as black box systems satisfying the prescribed PSS requirements (internal states, interface). *Beam transport systems* transfer the laser beam to the Secondary Sources. Developed in-house as a white box system. *Secondary Source (SeSo) Systems* are the equipment in which the attosecond pulses are generated. Developed in a collaboration of domain-experts as grey box systems from PSS point of view.

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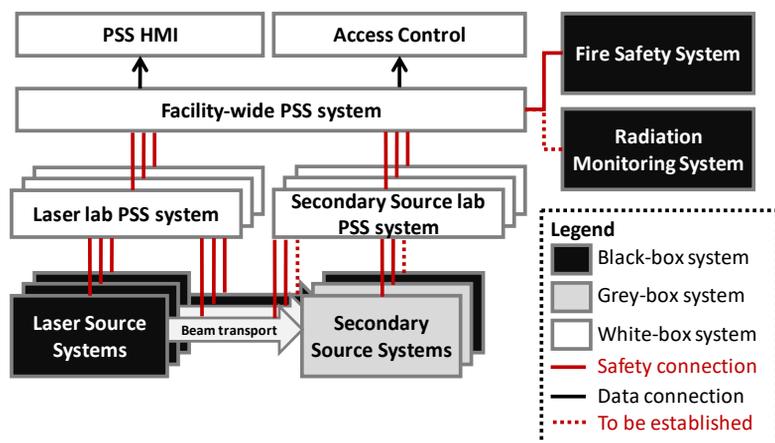


Figure 1: PSS Block diagram.

The PSS is implemented on three levels (see Fig. 1):

- research technology equipment’s (laser or secondary source) PSS: either delivered by an external party (black-box systems) or developed fully (white) or partly (grey) by ELI-ALPS
- laser and/or secondary source lab PSS, covering the two ends of beam transport (white-box, developed by ELI-ALPS)
- facility-wide PSS for integration (white-box)

The high-power laser systems have been developed by external parties. Already during the development phase of these the safety requirements, including operation states and interfaces towards the facility-wide PSS have been prescribed and communicated. Therefore, all high-power laser system has similar safety features and able to cooperate with the facility-wide PSS. The laser systems (as well as the secondary sources) have four well distinguishable operation states:

- **“OFF” state:** the system is not running; it is ready for “maintenance” or “normal” operation. Associated color: green
- **“NORMAL” state:** the system is working properly; status is achieved either after “OFF” or “maintenance” states. Associated color: yellow
- **“MAINT” state:** this mode corresponds to a state where certain interlocks are disabled. Only trained people can operate the equipment in this mode. The maintenance mode is accessible from the “OFF” and “normal” state. Associated color: red
- **“INTERLOCK TRIPPED” state:** at least the light emission from the system has to be stopped due to an external or internal interlock fault (e.g. cover switch or entrance door), but not necessarily means the total electric shutdown of the system. In that state, the system has to be recovered into the “OFF” state. Associated color: green-yellow-red.

The safe operations (“OFF”, “normal”, “interlock tripped”) are defined such that the design of the system inherently avoids any laser light above safe level to escape the enclosures of the system (besides the normal output point).

That is, in “interlock tripped” state using the implemented safety systems the emission of laser radiation above safe measure in any part of the system shall be avoided (e.g. blocked by a beam dump, stopped by turning off the electric drive systems, stopping pump laser operations by disabling triggering signals, etc.).

In “maintenance” mode the same operation is expected in terms of output light parameters as in “normal” mode, but in this mode the system is accessible for experts for tuning, that is, certain parts of the interlock (like covers) are disabled, while others are still active and may cause an “interlock tripped” state (like not allowed roller blind opening).

LABORATORY SAFETY STATES

In the case of laser controlled areas different lab safety states must be distinguished depending on the operation mode of the laser equipment and the hazards present in the laboratory. The laboratories might be in one of the following safety states:

- **Class1:** Maximum Class1 laser radiation can be present in the lab. Indicated by green lights and by sign “No laser hazard” on the Information Panels.
- **Class 2/3R:** Maximum Class3R laser radiation can be present in the lab. Indicated by yellow lights and by sign “Caution! Low power laser ON” on the Information Panels.
- **Class 3B/4:** Class 4 laser radiation can be present in the lab. Indicated by red lights and by sign “Danger! High power laser ON” on the Information Panel

The state of the laboratory determined by the facility-wide PSS according the status of all the laser and/or secondary source equipment inside as well as the field devices.

ACCESS CONTROL

A Security Access Control System (Sec-ACS) was delivered together with the Building Infrastructure for handling access to offices, workshops and partly to laboratory areas. The Safety Access Control System (Saf-ACS) de-

signed and developed to cover all laboratory areas in Building “A” together with a proper integration towards the Sec-ACS, as well as in an integrated manner with the facility-wide PSS at the same time.

Access to certain laboratories happens through dedicated airlock rooms (changing rooms). The entrance of the airlocks is managed by the Sec-ACS, while the entrance of the laboratories is managed by the Saf-ACS: the two access control systems communicate with each other in order to (a) fulfill the requirement of having maximum one door open momentarily, (b) operate with the same access cards in order to make them transparent for the personnel.

In order to facilitate dynamic access of personnel, depending on the state of the laboratory, the *Access level* is defined. It determines in which state a person can enter a given lab. The access levels are: *Class1*, *Class2/3R*, *Class3B/4*, *Security* according to the columns of Table 1.

Table 1: Saf-ACS Decision Table

	Undefined	Class 1	Class2/3R	Class3B/4	Security
Class 1	NO	YES	YES	YES	YES
Class2/3R	NO	NO	YES	YES	YES
Class3B/4	NO	NO	NO	YES	YES

Access rules are stored in a database local to the Saf-ACS. The Security staff can enter the lab in any mode, but their access causes and immediate interlock in Class3B/4.

One key element of the access control is the different kind of entrances as well as how the facility-wide PSS relates to these:

- **Dedicated entrances:** The door through which people enter or leave the laboratory in normal cases. They are equipped with card reader operated by the Saf-ACS, but electromagnetic lock, sensor, visual signs, information panels are operated by the facility-wide PSS.

- **Non-passage doors:** Doors, which does not serve as a dedicated entrance, permanently locked by mechanical means and not connected to Saf-ACS, but supervised by the facility-wide PSS.
- **Transport doors:** Non-passage doors, which can be opened for transportation. during formerly planned and approved transportation periods.

SAFETY INSTRUMENTED FUNCTIONS

Interlocks

The following kind of interlocks are distinguished according to Fig. 2.

- **Facility Interlock (FI):** Provided by the facility-wide PSS, on the basis of an alarm from an interconnected facility-wide safety system, e.g. Fire Safety System, Signals from the Fire Safety System are connected to a dedicated central PLC, which transfers these signals in the internal network of the system, see Fig. 3. Later on, the Radiation Safety System will also be connected to the facility-wide PSS.

- **Laboratory Interlock (LI):** Provided by the facility-wide PSS, on the basis of a signal from a safety device. The Laboratory Interlock only affects the laboratory it occurs in. If an equipment in another lab is also affected (e.g. unauthorized opening a common door), the lab PLC transfers this interlock signal as a Facility Interlock towards the other PLC.

- **Equipment Interlock (EI):** Provided by the equipment’s internal PSS. Equipment Interlock signals received by the local unit of the facility-wide PSS, which uses it to determine the safety state of the laboratory and trigger further interlocks if needed, depending on the situation.

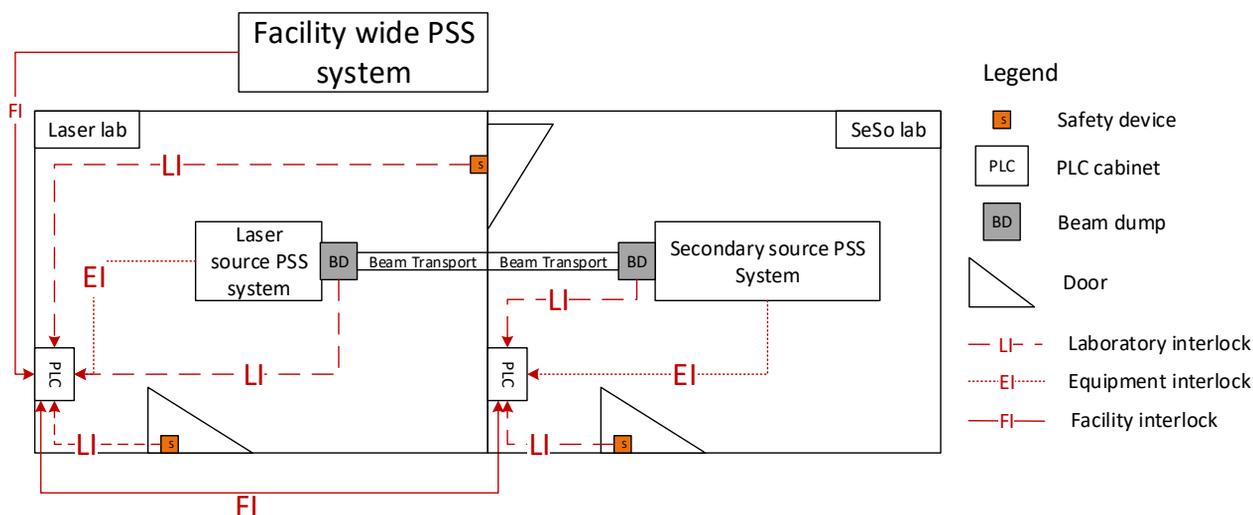


Figure 2: Types and propagation of interlocks.

Laboratory Interlocks

Laser OFF There are several Laser OFF buttons in every laboratory, within a reasonable distance from the equipment, according to the applicable safety regulations as well as the results of the risk assessment. The personnel can stop all laser radiation by pressing one of them. Pressing will generate a Laboratory Interlock event in the PSS.

Doors The entrant has a limited time (10 seconds) to open the door after the PSS released the door lock. After opening, he or she shall close it within 30 seconds. If an unauthorized access happens, or the door has been open too long, a Laboratory Interlock will be tripped.

Roller blinds In laboratories with windows, roller blinds are equipped with the same sensor as the doors and shall be closed during Class 3B/4 state. If any of them is opened while the laboratory is in the abovementioned safety state, a Laboratory Interlock will be tripped.

Discrepancy interlock Where SIL certified sensors are used, the signals of their contacts shall arrive to the PLC at the same time. If the delay between the two signals is too long the PLC will detect it as a discrepancy error, which causes a Laboratory Interlock immediately. This interlock can only be acknowledged by the responsible engineer, after detailed investigation of the failure.

Beam dumps There will be motorized linear stages installed in each laboratory, which will move a mirror into the way of the laser beam to drive it into a beam absorbing device. This set along with its control button is referred as beam dump (abbreviated as BD) in the following. All linear stages have two strictly defined end positions (opened and closed), in which it shall be normally positioned at during normal operation. If the BD is out of position for too long, a Laboratory Interlock shall be tripped. All beam dumps are equipped with SIL graded safety sensors to detect which position they are, as well as illuminated operation and close buttons and an emergency button.

The position of each BD shall be taken into account by the laboratory PSS to determine the safety state of the laboratory.

Mode Enabling

Alignment mode When Class2/3R auxiliary lasers are used in the lab, which usually do not have status feedback, the lab shall be switched into Class2/3R state manually. For this purpose, a dedicated Alignment switch is installed in every lab.

Maintenance mode To enable switching the equipment into Maintenance mode, a dedicated laboratory Maintenance switch is installed in every lab. This switch sets the laboratory into Class3B/4 mode immediately, while the PSS prohibits the equipment to change its state to Maintenance mode when the laboratory Maintenance switch is OFF.

Transport mode To disable the interlock of the transport doors (see above), there is a key-operated switch installed next to every one of them. This switch is only effective in Class 1 and Class 2/3R mode. In Class 3B/4

mode opening a transport door cause an immediate interlock, regardless the state of the transport switch.

Information

Besides safe sensing and interlocking, the other main task of the PSS is to provide all the necessary information to the personnel working in the labs. The modes of transferring the information are the followings:

Audible signs The most important safety events are expressed by audible signs. When the lab goes into Class 3B/4 mode (by opening a BD or switching the Maintenance switch on) a short continuous signal is given, while the open status of a door is indicated by a pulsed signal.

Lamps At every entrance, a three colors LED lamp reflects the state of the laboratory. Meanwhile, every equipment has its own three colors signal tower reflecting its state.

Information panels At every entrance there is an Information panel that provides all the necessary information needed for the entrant, such as safety state of the lab, area manager contact information, necessary laser protective glasses (if relevant) and dynamic information on the denial or approval of the entrance request. Inside the lab there is another panel that contains all relevant information, such as the state of the followings: lab, all equipment inside, the doors and roller blinds. It also provides information about the interlocks. The cleared interlocks can be acknowledged here as well as the type of the necessary protective glass can be selected.

PSS monitoring software The PSS has an OPC UA interface towards the high-level control and monitoring software of the infrastructure. All the necessary information is transferred, such as the state of the labs, the equipment, the doors and roller blinds, laser OFF buttons, interlocks. The events are logged. The authorized employees (e.g. the Laser Safety Officer) have access to this information, but remote manipulation of the PSS is not possible as this is a one-way connection. The OPC UA interface is separated from the safety code in the PLC and programmed in such a way that it can not accept commands from the high level interface, just monitoring requests.

DESIGN AND IMPLEMENTATION

The driving force behind the choice of the controller was to be able to handle the complexity of logics easily as well as the requirement of having a modular system prepared for further extensions in the future. Therefore, the PSS system is based on PLCs. The PLCs are extended with proper Digital Input (DI), and Digital Output (DO) modules to provide the necessary amount of connection points towards the devices. The block diagram of a sample laboratory is shown on Fig. 3.

The safety PLCs are connected to each other, forming a safety network. Highly reliable industrial switches are installed next to every PLC for interconnecting them through a deterministic Ethernet network. The info panels also use these switches to connect to the PLCs. On this network, the PLCs can exchange information and spread interlock signals (fire alarm, facility level interlock) among each other.

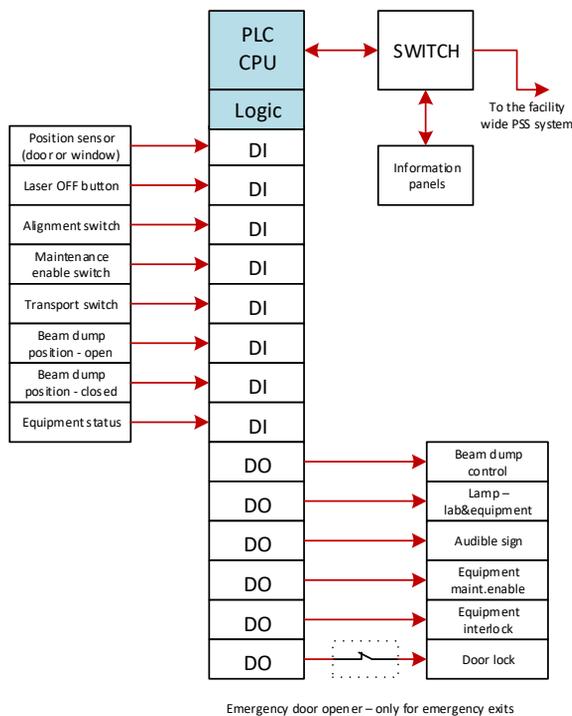


Figure 3: PSS architecture – laboratory.

Every laboratory has its own dedicated safety PLC, which is installed in a wall mounted metal cabinet along with all the necessary accessories. The cabinets are fed from the UPS power supply to ensure that all the labs are in safe state in case of electrical blackout.

The field devices have 24VDC Safety Extra Low Voltage supply from the cabinet.

Field devices that are mounted on the wall, their position were determined according to the guidance of the area manager and the laser safety officer. Some laser off buttons and the BD control buttons are placed on the optical table, within reasonable distance of the working area.

Mechanical parts work in positive action. All safety devices (laser off buttons, door sensors) shall be in “closed” state to form a safety loop. If this loop brakes, the interlock of all the related equipment shall be tripped immediately.

The PLC is also able to execute safety and non-safety functions as well, so the field devices are divided into two groups:

- **Safety devices:** Their malfunction may immediately cause dangerous situations, so they need to be highly reliable and fail-safe. The chosen products comply with the IEC 61508 standard. These devices are the PLC itself, the laser OFF buttons, the door and roller blind sensors, the BD position sensors and the emergency door opener.
- **Non-safety devices:** Their malfunction can cause inconvenience in the laboratory but not endanger the health of the resident personnel. These devices are the audible and visual signs, the information panels, the Alignment, Maintenance and transport switches.

To ensure that the PSS fulfills its specification a comprehensive functional test shall be conducted before the system is commissioned:

- The first step is a general I/O test to ensure if all Inputs and Outputs of the safety PLC work properly by using a software developed for this purpose. This test was conducted on every cabinet, after assembling, but before installation.
- Second step is to check if the complete system works according to the specification and test plans, which are validated by an independent engineer as well as by the Laser Safety Officer. After the PSS is commissioned, this type of test shall be conducted after every modification.

SUMMARY

Now the PSS is functional in ten labs and all the Laser Sources are partially (lasers under commissioning) or fully integrated into the system.

The PSS is continuously developing as new equipment arrive in the facility but thanks to the thorough documentation of requirements and the modular designs, no fundamental modifications were needed.

During the next years, the PSS will be expanded to the ionizing areas, on the basis of the experience gained in the non-ionizing areas, complemented with additional risk assessments and safety functions such as search protocol and integration with the Radiation Monitoring system.

ACKNOWLEDGMENTS

We would like to thank all the feedbacks, remarks and mind-opening questions from all of our colleagues and external partners who this way contributed to the development of the PSS system. We would like to especially thank the precious advices and reviews we received from the ELETTRA team led by Marco Lonza. We would like to especially thank the supportive and continuous help we get from our electrical workshop colleagues.

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