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Development and Proposal of an Institutional Safety Program in the Operation of Laser Systems

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ABSTRACT

Laser radiation can cause undesirable biological effects on living beings; although it is not ionizing, this type of radiation can cause burns to the skin and cornea, even cataracts, depending on the wavelength and intensity of the laser radiation. Due to the wide growth of laser applications in several areas, such as research and development, services, and industry, the occupational risks concerning this non-ionizing radiation have increased considerably worldwide. Several countries have normative documents and regulatory bodies or agencies that approach occupational safety and quality regarding laser application, equipment, and machines. In Brazil, there is a lacking of laser safety documents published by a national regulatory council. Therefore, large technological centers and educational institutions, such as SENAI Institute for Innovation in Laser Manufacturing and Processing Systems (ISI-Joinville) and the Federal Technological University of Paraná (UTFPR), do not have an institutional safety program for laser operations, and to adapt to the most modern international recommendations they look for international documents and models from other institutions. The main objective of this work was to develop and propose an institutional program following Brazilian regulatory documents from the Ministry of Labor and Social Security and the most modern international standard about laser safety from the American National Standards Institute (ANSI-Z 136-1: 2014). The developed safety program was applied to ISI-Joinville, but a model was adapted to be implemented at any research center and university.

Keywords: **Laser security program, laser radiation, occupational safety, non-ionizing radiation.**

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1. INTRODUCTION

With the advancement of laser-based technologies, occupational hazards from exposure to laser radiation have increased proportionately in academia and industry. However, there is a lack of regulations and legislation regarding occupational laser safety in the Brazilian scenario. Some important research and technology organizations, such as the SENAI Institute of Innovation in world Manufacturing and Processing Systems (ISI-Joinville), the SENAI Institute of Welding Technology (Rio de Janeiro), as well as the Federal Technological University of Paraná (UTFPR) (Curitiba), do not have an established institutional laser safety program, despite knowledge of the primary risks when dealing with laser radiation.

The interactions of laser radiation on living beings can lead to several biological effects, including harmful and deleterious effects. The most significant risks from laser radiation are associated with eye and skin exposures. Acute eye exposure to lasers with specific wavelengths and power can cause corneal and retinal burns. The risk of skin exposure to UV lasers is more significant than other wavelengths. Chronic exposure to UV wavelengths (290-320 nm) can result in carcinogenesis [1].

The main international normative document concerning laser safety nowadays is the American standard from the American National Standards Institute (ANSI): ANSI Z-136-1:2014 - American national standard for the safe use of lasers [2]. This standard guides the safe use of lasers and laser systems by defining control measures for each of the seven laser hazard classifications. In addition, it describes the appropriate controls and technical information about measurements, calculations, and biological effects.

The ANSI Z-136-1:2014 standard classifies lasers according to wavelength and hazard [2]. Class 1 lasers are low-power lasers and laser systems that do not emit radiation levels greater than the Maximum Permissible Exposure (MPE). These lasers are incapable of causing damage to the eyes and are exempt from control measures. The Class 1M lasers are incapable of producing hazardous exposures in normal use unless the beam is viewed with an optical instrument (collection optics). These lasers are exempt from control measures. Class 2 covers the low-power lasers or systems operating in the visible spectrum (400-700 nm); those are incapable of causing damage to the eye due to the aversion response (0.25 seconds). Class 2M differs from Class 2 because it embraces the low-power lasers or laser systems that operate in the visible spectrum that, although incapable of causing eye damage due to the aversion response (0.25 seconds), if viewed with certain optical aids, are potentially dangerous. The medium power lasers and laser systems capable of causing eye damage with a short duration (<0.25 seconds) when exposed to direct or specular reflection viewing conditions are in Class 3. This class is subdivided into 3R and 3B lasers. Class 3R are lasers or laser systems that can be dangerous under some specular and direct reflection viewing conditions if the eye is focused and stable, but the likelihood of eye injury is small. These lasers pose no fire or stray reflection hazard. Class 3B includes the medium-power lasers or laser systems operating in visible or non-visible regions that may be hazardous under intravascular reflection (direct) or specular (mirror-like) viewing conditions. Finally, Class 4 are high-powered lasers and laser systems capable of causing acute eye and skin damage with a short-term duration (<0.25 seconds) from direct, specular, or diffuse reflection exposures. They are capable of igniting certain materials and fuels, even with diffuse reflections. These lasers can produce airborne contaminants generated by laser-induced processes.

According to the American standard ANSI Z-136-1:2014, to manage the risks associated with lasers, the employer must implement a program with the following provisions:

a) Designation of a professional or individual as a Laser Safety Officer (LSO) with responsibility for carrying out the assessment and control of laser hazards;

b) Training of authorized personnel (LSO, laser machine operators, and others);

c) Application of adequate control measures to mitigate laser risks;

d) Incident investigation, with the preparation of action plans for the prevention of future claims following a known or suspected incident;

e) Appropriate medical examinations;

f) Formation of a Laser Safety Committee (LSC) when the number, risks, complexity and/or diversity of laser activities warrant it.

However, inside the academic world or research centers are knowledge about laser safety and isolated actions of safety, for example, the use of individual protection; in Brazil, there is no requirement to harmonize with international standards or national legislation focused on managing the risks associated with laser radiation. Indeed Brazilian regulatory documents have requirements focused on machine safety, but not specific to laser radiation [3].

Considering occupational laser safety and non-ionizing radiation effects, the present work developed and proposed an institutional laser safety program for the operation of machines or lasers, following the safety requirements of the current Regulatory Norm nº 12 (NR12 - Safety at Work in Machines and Equipment) [3] and the most modern recommendations currently available, such as the ANSI-Z 136-1: 2014, which is widely used in the United States of America and adopted by other countries. To exemplify the proposal, the program was developed based on the infrastructure and laser machines of the ISI-Joinville. Still, this model can be adapted to be used for any institution.

2. MATERIALS AND METHODS

To start developing the safety program, we chose to construct the model of the program at ISI, Joinville –SC. This institute is dedicated to advanced manufacturing processes and laser processing. Currently, the ISI has eight laser processing machines divided into three laboratories: the additive manufacturing laboratory, the laser metal deposition laboratory, and the surface texturing laboratory.

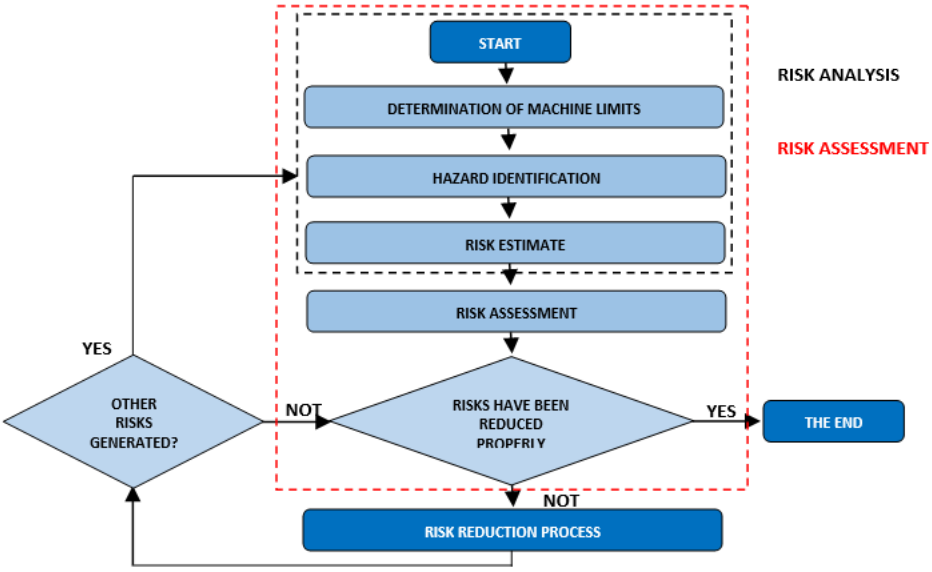
Specific steps are followed to develop the program. First, we started evaluating the perception of safety from the perspective of professionals and users of ISI laser machines. After that, we developed the documents for safety training for machine operators to comply with national and international standards based on one of the eight ISI laser machines. The laser safety program for ISI was designed to be a document with a governance structure - functions and responsibilities, which required monitoring and updates following a model of continuous improvement.

The daily operations performed at the ISI were observed in the development of the laser safety program. Looking at ISI laser manufacturing processes and related labs, we verified that all laser machines are Class 1 from their original equipment manufacturers, even though the laser sources are Class 4. In addition, all laser labs already had warning signs and lights to alert the public about the presence of laser radiation.

Interviews, observations of the process, and a questionnaire were carried out to understand the safety perception of the risks associated with the laser by the ISI team. The questionnaire was made available to participants in the ISI WhatsApp group through a link generated by Google Forms. The questionnaire did not collect any information from employees or users, aiming that the answers were not biased. Ten workers that effectively operated the machines in the ISI laboratories participated in this questionnaire. In all, 15 employees interact with the laser machines in some way, and of these 15, 5 are always accompanied by others with more experience in the processes.

Subsequently, existing international and national standards on occupational hazards with laser radiation was carried out to identify control measures and appropriate training. The standards used in this step were the national standard NR-12 and the international standard ANSI-Z 136-1: 2014. In addition, the program development stages also included elaborating a risk assessment on one of the ISI laser machines, as determined by national standard NR-12 and based on the technical standard ABNT NBR 12100 [5]. Figure 1 presents the risk assessment stages that must be applied to ISI laboratories laser machines.

Figure 1: Stages of Risk Assessment according to ABNT NBR 12100



Source: Adapted ABNT NBR 12100 [5]

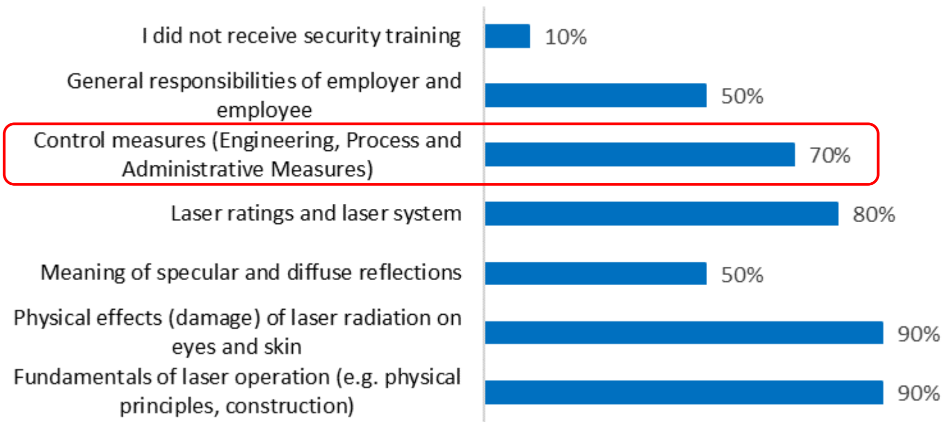
Finally, the Institutional Program for Safety in the Operation of Laser Systems (*Programa Institucional de Segurança em Operação de Sistemas a Laser* - PISOSL) of ISI was designed based on the American standard ANSI Z-136-1:2014, as well as other successfully implemented programs, such as the Institute's Laser Safety Program of National Health (USA) [4] and the Ohio University Laser Safety Program (USA) [1]. Thus, the common minimum requirements, recommendations and procedures present in these documents have been carefully adapted to the ISI.

The governance structure specifies how duties and responsibilities are distributed among different stakeholders. It also regulates the rules and procedures for making decisions in corporate matters and, in this specific case, will determine the rules and procedures related to the institutional program for safety in the operation of laser systems. With basis on both standards, the ANSI Z-136-1:2014 and the NR-12, the PISOSL follows the responsibilities assigned to each member involved in a laser safety program, such as the coordinator and laboratory leaders, representing the employer, the laser user, who is a collaborator/employee and the LSO and LSC, professional collaborators/employees who look for to comply with legal regulations as well as looking to mitigate risks in the work environment.

3. RESULTS AND DISCUSSION

When we evaluated the ISI-Joinville team's safety perceptions of laser-associated risks, it became evident the need to implement a safety program that standardizes minimal concepts and procedures on laser radiation. Considering those involved in laser materials processing who answered form questions, 10% of the survey participants revealed that they had not received any training on laser radiation safety, 50% were unaware of the responsibilities of employers and employees, and 30% were unaware of the laser machine's safety control measures (Figure 2).

Figure 2: Question: Have you received safety training to operate a laser machine? If the answer is yes, was this training addressed which of the topics mentioned above?



Regarding the development of the menu for safety training for laser machine operators, in addition to the fundamentals of safety and laser risks, a report called risk assessment was prepared, which served as material for the assembly of the safety training of machines and equipment. Table 1 presents the training menu defined for the ISI-Joinville, which applies to any teaching and research institution that operates laser machines.

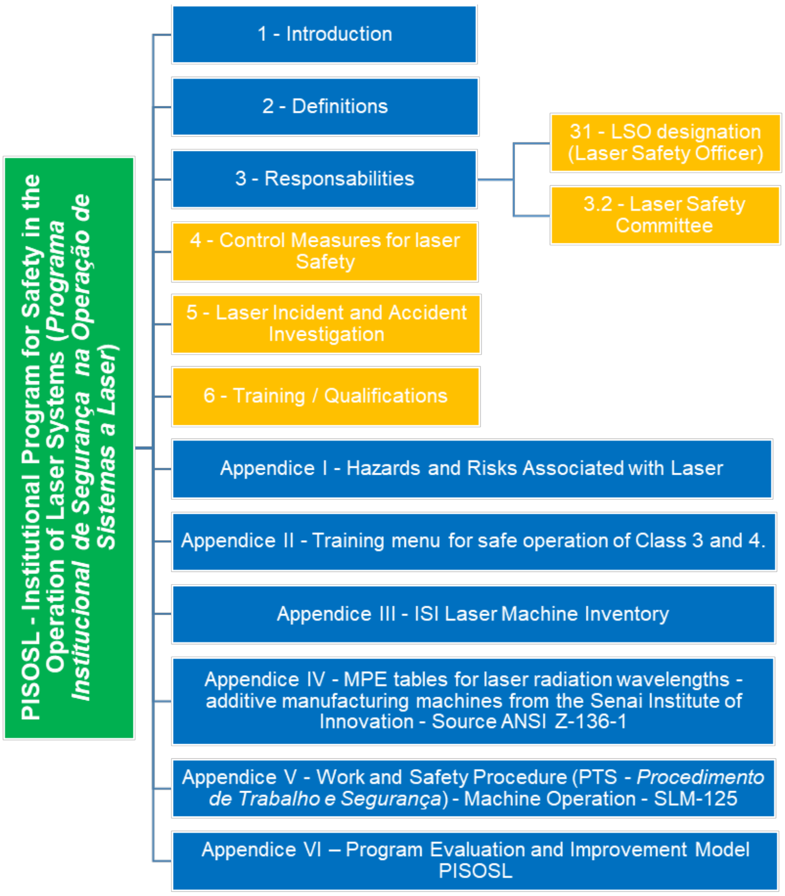
Table 1: Training course for the safe operation of Classes 3B and 4 laser machines.

ITEM	PROGRAM CONTENT	REFERENCE
1	Description and identification of the risks associated with each machine and the specific protections against each of them;	• Risk Assessment of each ISI machine.
2	Fundamentals of laser operation (e.g., physical principles, construction);	• HENDERSON, Roy.; SCHULMEISTER, Karl. Laser Safety. New York, NY 2004.
3	Biological effects of laser radiation on eyes and skin;	• AMERICAN NATIONAL STANDARDS INSTITUTE ANSI Z-136.1. Protective Equipment. USA. 2014.
4	Meaning of specular and diffuse reflections;	• HENDERSON, Roy.; SCHULMEISTER, Karl. Laser Safety. New York, NY 2004.
5	Beamless laser hazards (Additional Hazards);	• HENDERSON, Roy.; SCHULMEISTER, Karl. Laser Safety. New York, NY 2004. • AMERICAN NATIONAL STANDARDS INSTITUTE **ANSI Z-136.1**. Protective Equipment. USA. 2014.
6	Laser and laser system ratings;	• AMERICAN NATIONAL STANDARDS INSTITUTE ANSI Z-136.1. Protective Equipment. USA. 2014.
7	Control measures;	• Risk Assessment of each ISI machine and Manufacturer's Manuals. • HENDERSON, Roy.; SCHULMEISTER, Karl. Laser Safety. New York, NY 2004.
8	Functioning of protections, how and why they should be used;	• NR-12 - Machinery and Equipment Safety
9	How and under what circumstances a protection can be removed, and by whom;	• NR-12 - Machinery and Equipment Safety
10	What to do if a protection has been damaged or has lost its function;	• NR-12 - Machinery and Equipment Safety
11	What are the safety principles when using the machine or equipment;	• NR-12 - Machinery and Equipment Safety
12	Safety for mechanical, electrical and other relevant risks;	• NR-12 - Machinery and Equipment Safety
13	Safe working method;	• NR-12 - Machinery and Equipment Safety
14	Locking system during inspection, cleaning, lubrication and maintenance operations;	• NR-12 - Machinery and Equipment Safety
15	General management and employee responsibilities;	• NR-12 - Machinery and Equipment Safety
16	CPR for maintenance personnel or working on lasers with high exposed voltages.	• https://cpr.heart.org/-/media/CPR-Files/CPR-Guidelines-Files/Highlights/Hghlghts_2020ECCGuidelines_Portuguese.pdf

With the application of this menu, ISI-Joinville will comply with the NR-12 legislation in the training requirement established in Annex II of the same standard and with the laser training specifications by the ANSI Z-136-1:2014 standard.

Figure 3 shows the structure of the PISOSL with six chapters and six appendices; the chapters were divided into definitions, responsibilities, risk control measures associated with laser machines, procedures for incident and accident investigations, and training guidelines. In addition, this document proposes the procedure for certifying and appointing a Laser Safety Officer (OSL) and creating a Laser Safety Committee (CSL). The program's appendices are hazards and risks associated with the laser, training menu, inventory of laser machines, tables with the permissible exposure limits (MPE) for the characteristics of the ISI lasers, work and safety procedure and evaluation model and program improvement.

Figure 3: Structure of the PISOSL.



To control occupational risks related to laser radiation, consequently not exceeding the MPE, the program establishes the control measures provided in Chapter 4 - Control Measures for laser safety. These measures are engineering measures, process measures and individual protection measures. Figures 4 and 5 illustrate engineering and individual protection measures, respectively.

Figure 4: Examples of engineering measures: the left (a) and center image (b) correspond to the service access panel and the right (c) correspond to a door interlock device.

Figure 5: Examples of individual protection measures: laser protective glasses

Laser eye protection (goggles) should be worn whenever there is potential for exposure to lasers of Classes 3B or 4. When specifying eyewear suitable for laser use, visible light transmission (VLT) must be considered. Eye protection must have a VLT of at least 20% while maintaining adequate OD (Optical Density).

The process measures are related to work and safety procedures. At PISOSL, we developed the process measures for one of the machines in the additive manufacturing laboratory: the SLM-125 machine.

The ISI already has a well-established guideline for the flowchart of registration activities and actions when an accident or an incident occurs on the institute's premises. The Federation of Industries of Santa Catarina (FIESC), which ISI is a part of, has a tool called “Communique”, which is a digital form accessed through a banner on the intranet home screen at the address: https://intranet.sesisc.org.br/intranet/montagem.php?login=sim&, where any employee can report an accident at work, using a cell phone or tablet from inside or outside the unit, without missing the legal deadline. The process is described in Chapter 5 of PISOSL.

Within the PISOSL, we added an annex that deals with the hazards and risks associated with laser radiation, mainly exposures to eyes and skin highlighted (Table 2), which may occur in the event of incidents in the operation of laser machines.

Table 2: Risks associated with laser radiation

Wavelength	**Eye**	**Skin**
UV-C (100 - 280nm)	Photokeratitis photochemical cataract	Erythema (sunburn) Skin cancer
UV-B (280 - 320nm)		Accelerated skin aging Skin cancer
UV-A (320 - 400nm)		Pigment darkening Photosensitive reactions skin burn
Visible (400 - 700nm)	Photochemical Retinal thermal injury	Photosensitive reactions skin burn
IR-A (700 - 1400nm)	Retinal burns Cataract	Skin burn
IR-B (1400 - 3000nm)	Corneal burn Watery flame Cataract	Skin burn
IR-C (3000 – 10^6 nm)	Corneal burn only	Skin burn

Remembering that the risks depend on the intensity of the laser and the time of exposure.

In Appendices III of PISOSL, we included an inventory of laser machines to understand and knowledge of the readers about laser machines. The information contained in the inventory is technical characteristics of the laser source, wavelength, and type of process, among others. Figure 6 shows an additive manufacturing machine with its technical characteristics presented in PISOSL.

Figure 6: Example of the technical description provided at PISOSL (Appendices III) in the inventory of laser machines.

This information, contained in the machinery inventory, serves as a parameter for the use of Appendices IV of PISOSL, which determine the limits of maximum permissible exposures (MPE), according to ANSI Z-136-1/2014, in such a way that occupational diseases do not occur as a result of exposure to laser radiation during activities, whether in normal operations or maintenance service exposures.

Table 3 of Appendices IV of PISOSL presents the MPE for eye exposures in the wavelength range between 700 and 1200 nm. This is an example, considering the wavelength range of most ISI machines today. This type of information contributes to ISI users knowing the risk associated with operating a laser machine, contributing to a safety culture at ISI. In Appendices IV of PISOSL is given all MPE exposure to other parts of the human body that can be exposed to laser radiation. The parameters C_A and C_C are correction factors presented at PISOSL given by ANSI Z-136-1:2014.

Table 3: MPE for a point source ocular exposure (retina)

Wavelength λ (nm)	Exposure duration t(s)	MPE	
		J.cm^{-2}	**W.cm^{-2}**
700 a 1050	10^{-13} a 10^{-11}	1.0×10^{-7}	-
	10^{-11} a 5×10^{-6}	$2.0\ C_A\ 10^{-7}$	-
	5×10^{-6} a 10	$1.8\ C_A\ t^{0.75} \times 10^{-3}$	-
	10 a 30,000	-	$C_A \times 10^{-3}$
1050 a 1200	10^{-13} a 10^{-11}	$1.0\ C_C \times 10^{-7}$	
	10^{-11} a 13×10^{-6}	$2.0\ C_C \times 10^{-6}$	
	13×10^{-6} a 10	$9.0\ Cc\ t^{0.75} \times 10^{-3}$	
	10 a 30,000	-	$5.0\ C_C \times 10^{-3}$

Note: C_A – Correction factor that increases the MPE in the near-infrared (IR-A) spectral band (700nm to 1400nm) based upon reduced absorption properties of melanin pigment granules found in the skin and in the retinal pigment epithelium [2]. Cc - Correction factor that increases the MPE for ocular exposure because of pre-retinal absorption of radiant energy in the spectral region between 1150nm and 1400nm [2].

Finally, considering the improvement and updates required at PISOSL over time, and to facilitate the management, we proposed the Appendices VI of PISOSL (Table 4). This is a model of evaluation and improvement of the program to maintain the system of continuous improvement and to guide the managers of the ISI, as well as the LSC, on how to deploy it and monitor its deployment.

In the “Requirement” column, all activities necessary to comply with national and international standards aimed at occupational safety and meet the requirements of the proposed program are listed. In the “Period” column, the verification frequency of each activity in the “Requirement” column is defined. The “Not Implemented” column must be filled in when the “Requirement” has not been met/executed. The column “Partially Implemented” must be filled in when the “Requirement” has been partially completed, and if the “Requirement has been fully met, the column “Fully Implemented” must be filled in.

Table 4: Program evaluation and improvement model (PISOSL)

Requirement	Period	Not Implemented	Partially Deployed		Fully Deployed		Evidence of Implementation	Suggested Improvements
1- Preparation/updating of the	Annual			5%		10%		

Machine Inventory								
2- Risk assessment in laser machines	Upon acquisition of the machine or when physical or process changes occur			5%		10%		
3 - Suitability of machines according to risk assessments	Upon acquisition of the machine or when physical or process changes occur			2,5%		5%		
4 - Safety signs in the Portuguese language	Whenever the risk assessment indicates			2,5%		5%		
5 - Preparation of operation PTS for each of the machines	Upon acquisition of the machine or when physical or process changes occur			2,5%		5%		
6 - Operators have PPEs appropriate to the risks exposed	Whenever the risk assessment indicates			2,5%		5%		
7 - Formation of the Laser Safety Committee	Biennial – may be repeated for another period			5%		10%		
8 - Periodic CSL meetings				2,5%		5%		
9 - Laser Safety Officer (LSO)	Permanent			5%		10%		
10 - LSO training	Biennial			2,5%		5%		
11 - Laser User Training	When starting activities			2,5%		5%		
12 - Laser Machine Operation Training (using PTS)	When starting activities and when there are changes in the PTS			2,5%		5%		
13 - Workers are involved in all Program review activities	Constantly			1,5%		2,5%		
14 - The program is modified as necessary to correct deficiencies	At CSL meetings			2,5%		5%		
15 - Performance indicators are used to monitor the Program's improvements	At CSL meetings			1%		2,5%		
16 - Performance is monitored by leaders through indicators	After CSL meetings			1%		2,5%		
17 - Performance data is analyzed and shared with workers	After CSL meetings			1,5%		2,5%		
18 - Management reviews the Program to ensure that it is fully implemented and functioning as planned	Annual			2,5%		5%		
PROGRAM IMPLEMENTATION PERCENTAGE							**TOTAL (%)**	
RESPONSIBLE FOR THE ASSESSMENT							**DATE**	

4. CONCLUSION

This work aimed to develop a model and structure of a laser safety program considering the Brazilian research centers and universities. For this, we started with the biggest advanced manufacturing processes and laser processing center in Brazil: ISI – Joinville. At this center, it was identified that 90% of those involved in the ISI laser processing laboratories stated that they needed training in safety in operations with laser machines, 50% were unaware of the responsibilities of employers and employees and 30% were unaware of the safety control measures of the laser machines where they are located. This demonstrates the great opportunity to advance in programs aimed at standardizing processes, such as work procedures, policies and occupational safety guidelines. In the same survey, in the last question of the questionnaire, with open answers, the largest number of suggestions made is related to the need for training in the safety of these non-ionizing radiations.

During the elaboration of the ISI security program, it was also found that in the current training, the minimum requirements established in the national standard NR-12 were not addressed and fulfilled, leaving the ISI institution at risk of notification in a possible inspection by the Ministry of Labor and Welfare. This reinforces the importance of having an institutional document that brings the minimum security requirements, procedures and responsibilities.

One of the reasons found at the ISI for not meeting the safety training criteria for laser machines was that they did not prepare risk assessment reports on these machines. Because according to NR-12, employees who work on machines and equipment must know the hazards and control measures existing in the machines they work on. With the risk assessment model elaborated on the SLM 125 machine, this work established the bases for elaborating safety training material on machines belonging to laser processing laboratories.

From the program developed for the ISI, a Model Program was created that can be used by other institutions that have machines with laser radiation in their processes, contemplating national security requirements such as NR-12 regarding good practices and recommendations of the American standard ANSI Z-136-1: 2014. This document can be accessed at database https://repositorio.utfpr.edu.br/jspui/ searching for *Desenvolvimento e Proposta de um programa institucional de Segurança na operação de sistemas a laser*.

With the development and implementation of the proposed institutional safety program in operations in laser systems, the ISI starts to follow a standardization in its manufacturing and laser processing processes, standardization of safety training in operations, in addition to complying with the regulations national companies in machinery and equipment safety, seeking to align with what is currently the most complete in laser safety internationally.

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