Summer 2019

A Study To Determine How to Measure the Laser Safety Climate at Academic Institutions

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A STUDY TO DETERMINE HOW TO MEASURE THE LASER SAFETY CLIMATE AT ACADEMIC INSTITUTIONS

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A Research Study Presented to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirement for the Degree of

MASTER OF SCIENCE

OCCUPATION AND TECHNICAL STUDIES

OLD DOMINION UNIVERSITY

August 2019

Approved by:

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CHAPTER I

INTRODUCTION

The use of lasers in academic settings has increased over the last 20 years, resulting in increased student access to this technology in the academic setting. Students benefit from the increased access to lasers allowing the development of scientific skills, access to research, or work on cutting edge laser development, and testing. This expanded use of laser in academic institutions also has unique risks associated with the academic learning environment. According to the Laser Institute of America (2009), lasers are "used in universities, colleges, secondary, and primary schools for teaching, research, laboratory experiments, demonstrations, and projects/science fairs" (p. 11). These conditions result in laser safety risks that are unique to academia because "(m)any of those involved in the educational environment are first-time laser users who have no knowledge of laser safety" (Laser Institute of America, p. 11). The increasing access to lasers in the academic setting has increased the potential for laser injury to students and staff.

Lasers present unique safety hazards that must be managed using a risk management strategy to reduce related safety incidents in the academic environment. According to Holcomb (2012), educational facilities accounted for 23% of all laser accidents from 1986-2010. Some of the factors that account for this rate of injury in academia are the dramatic growth in the number of lasers at academic institutions. Holcomb outlined these factors as reduced cost, more variety, reduced laser size, and more applications that can use lasers. In many academic institutions, Environmental Health and Safety (EHS) is often charged with the overall risk management program, but the laser safety program is a collateral job rather than a dedicated supervisory position.

According to Spichiger, Zakiar, and Tabor (2013), the development and implementation of the laser safety program at Georgia Institute of Technology (Georgia Tech) required a decade to evolve from a collateral duty to a functional program. Before the establishment of Georgia Techs' laser safety program, the administration was not aware of the number of lasers on campus or how many departments used lasers for academic goals (Spichiger, Zakir, & Tabor). Holcomb (2012) and Garcia (2018) reported similar findings at the University of Texas at Austin and the University of Michigan. Although these institutions laser programs may be outliers, it is just as likely they are representative of scope or breadth of programs at large research universities.

Laser-related injuries at academic laser labs can have physical consequences to the user and economic costs to the institution. In 2004, a student who was not adequately supervised while studying in a university laser lab suffered a permanent loss of central vision from a laser strike (Lujan, 2004). Barat (2014), documented numerous cases of students receiving laser injuries in academic labs, which he attributed inadequate training and supervision. In one case, a student received a seven-figure settlement from a university despite violating multiple institutional laser and lab safety policies (Barat, 2006). More recent cases include a 2014 incident where the Department of Energy fined a major university $250,000 after several laser injuries. The notice of violation stated that the reduction in fee (fine) was due to a violation due to a lack of acceptable safety performance and a series of laser-related incidents and near misses at a university lab (Simonson, 2014). Many of these cases identified lax supervision or policy enforcement of sanding laser safety policy as a primary or contributing factor of the incident.

Zohar (1980) developed and validated the first safety climate questionnaire in the late 1970s to measure the safety climate in the industrial setting. His questionnaire includes 40 items and measures the safety climate in eight dimensions using a 5-point Likert scale. This questionnaire was used to measure the safety climate in industrial settings (Zohar). Cooper and Phillips (2004) found an empirical link between safety climate perceptions and behavior but qualified their results by stating that a safety climate "should only be viewed as key *if it predicts actual, or ongoing, safety performance in organizations*" (2004, p. 498). They pointed out "all organizations should regularly survey their prevailing safety climate to identify potential issues" (2004, p. 510), and a safety climate survey should include one of several measures used to understand an organizations safety climate. Policy enforcement issues are often discussed in the literature as a lagging indicator of an organization's 'safety culture' or 'safety climate' because this type of issue becomes the focus of post-incident investigations.

Wu, Liu, & Lu (2007) extended Zohar's work to study the safety climate in universities. Their study modified Zohar's instrument to measure the Taiwanese university's safety climate to better reflect the cultural differences unique to academia (Wu, Liu, & Lu). Gutiérrez (2011) found that the university safety climate in the United States had not been studied. She built on the work of Zohar and Wu to develop a 22-item university safety climate questionnaire, which was validated in her study of 971 respondents from five universities. The self-administered online questionnaire used a 5-point Likert style scale was able to measure five dimensions of a university's safety climate with high statistical confidence (Gutierrez). A similar instrument has not been found to measure the specialized laser safety climate in the academic environment. Additionally, no research has been located regarding what factors should be evaluated and measured to determine the laser safety climate of an academic institution.

The Committee on Establishing and Promoting a Culture of Safety in Academic Laboratory Research (2014), states safety climate has been measured as lagging indicators, including the numbers of accidents and lost-time injuries by most organizations. The report recommends collecting data on near misses and conducting hazard analysis “to change behavior and culture before an incident occurs, organizations may take advantage of leading indicators: before-the-fact data that can help identify risks and vulnerabilities ahead of time.” (p. 5).

Statement of Problem

The purpose of this study was to determine if the laser safety climate can be measured at academic institutions and what factors would provide valid measures of the laser safety climate at academic institutions. Specifically, the study attempted to answer the following questions:

Research Questions

RQ_1. Can laser safety climate be measured at academic institutions using a climate survey instrument?

RQ_2. What factors should be measured by a laser safety climate instrument?

RQ_3. What measures would provide actionable data for prescriptive intervention by laser safety professionals at academic institutions?

Background and Significance

The manufacture, specifications, and regulations of lasers are regulated by the Code of Federal Regulations (CFR) 21 § 1040.10 (2018) which assigns the Food and Drug Administration (FDA) as the regulatory organization for lasers. All lasers are classified based on a laser’s power, beam characteristics, and ability to cause injury or damage to a person with a Class I laser being the least likely to cause harm and while a Class IV laser is the most likely to cause injury. The differences between each laser classification is outlined in Table *1***Error! Reference source not found.** (U.S. Food and Drug Adminstration, 2018). Although the legal framework for the manufacture and regulation is defined by the CFR, the primary reference for laser safety is the *American National Standard for Safe Use of Lasers* (Laser Institute of

America, 2014) which is often discussed in the literature by the shorthand name ANSI Z136.1-2014.

Table 1.

Comparison of FDA and ANSI Laser Classification Systems

FDA	ANSI-Z136.1	Safety Requirements by Class	Definition
Class I	Class 1	Not Required	Any laser or laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injury during normal operation. This does not apply to service periods requiring access to Class 1 enclosures containing higher-class lasers
NA	Class 1M	CM[a], TNG[a], LSO[a], EC[a]	Considered incapable of producing hazardous exposure unless viewed with collecting optics
Class II	Class 2	Not Required	Visible lasers considered incapable of emitting laser radiation at levels that are known to cause skin or eye injury within the time period of the human eye aversion response (0.25 seconds).
Class IIa	NA	Not Addressed	Visible lasers that are not intended for viewing and cannot produce any known eye or skin injury during operation based on a maximum exposure time of 1000 seconds
NA	2M	CM[a], TNG[a], LSO[a], EC[a]	Emits in the visible portion of the spectrum, and is potentially hazardous if viewed with collecting optics.
Class IIIa	NA	Not Addressed	Lasers similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam
NA	Class 3R	Not Required[b]	A laser system that is potentially hazardous under some direct and specular reflection viewing condition if the eye is appropriately focused and stable

Class IIIb	Class 3B	CM, TNG, LSO, EC	Medium-powered lasers (visible or invisible regions) that present a potential eye hazard for intrabeam (direct) or specular (mirror-like) conditions. Class 3B lasers do not present a diffuse (scatter) hazard or significant skin hazard except for higher-powered 3B lasers operating at specific wavelength regions
Class IV	Class4	CM, TNG, LSO, EC	High-powered lasers (visible or invisible) considered to present a potential acute hazard to the eye and skin for both direct (intrabeam) and scatter (diffused) conditions. Also, have potential hazard considerations for fire (ignition) and byproduct emissions from target or process material

NOTE: summary of data in from multiple sources all definitions quoted from ANSI Z136.1 table J2

[a] Application dependent requirements.

[b] Not required except for intentional beam exposure

The classification schema used by ANSI Z136.1-2014 uses slightly different definitions than the FDA as well as using Arabic numbers and upper-case letters instead of the Roman numerals and lower-case lettering used in federal regulations. The ANSI Z136.1-2014 classification system defines all lasers as falling into Class 1, Class1M, Class 2, Class 2M, 3R, 3B and Class 4 lasers (Laser Institute of America, 2014, pp. 244-245). The ability of the laser to damage a person determines the precautions that must be used with a laser. These precautions are Control Measure (CM), Training (TNG), Laser Safety Officer (LSO), and Engineering controls (EC). Table *1* also includes a comparison of the laser classification systems used by the FDA and the ANSI Z136.1.

The ANSI Z136.1-2014 classification system is closely aligned to the international system of laser classification. In January of 2018, the FDA announced the intention to align their classification schema to the international standard (U.S. FDA Laser Notice No. 56, 2018). This study will use the ANSI Z136.1-2014 system when referring to lasers.

Zohar (1980) discussed the safety climate as the shared perception of the sum value of safety, stating that an organization's safety climate could change over time. He posited that a positive safety climate would result in a lower organizational accident and injury rate. Zohar developed a 40-item questionnaire to measure safety climate, and subsequent research has resulted in safety scales for various industries (Zohar, 2009). However, until Wu et al. (2007) conducted a study of Taiwanese universities, the campus safety climate had not been studied. A study of the laser safety climate in the academic institutions has not been located.

A safety culture requires a high-level internalization of cognitive and affective aspects of the value of safety by organizational leadership. Lundell and Marcham (2018) asserted that organizational safety culture is a critical function of leadership. They stated the leader should "specify safety objectives; distribute responsibility for safety; and plan, organize and control the organizational environment according to safety objectives and precautions" (Lundell & Marcham, 2018, p. 37). A positive laser safety culture requires the active integration of academic leadership to establish administrative controls, Standard Operating Procedures (SOPs), and rigorous operator qualification standards, to reduce the risk of injury or death to operators and bystanders.

Limitations

Researchers have emphasized limitations of the Delphi research technique. Woudenbuer (1991) cited potential reduced accuracy and reliability of the results. However, anonymity, careful selection of experts, following an iterative process, and the inclusion of feedback to the panelists can be used to mitigate these issues. In more recent research, Wakefield and Robinson (2014) pointed to the selection of experts, participation of panlists throughout a study, and use of closed-ended items during the first round of the Delphi as structural issues that often reduce the effectiveness of this method. The panel was also selected based on information that was publicly available or was self-reported by the participants, so the accuracy of such information was assumed to be true.

Assumptions

It was assumed the selection criteria for the experts on the panel was valid, and each member had the professional experience to provide a valid judgment of the issues under study. The selection criterion was defined in terms of professional experience relevant to laser safety, active employment as a certified laser safety officer (CLSO) used to identify the leading laser safety experts. These criteria align with the best practices identified by Rogers & Lopez (2002) as modified by Hallowell & Gambatese (2002). It is assumed the participants who joined and completed the Delphi were the best-qualified members of the pool of experts, and their ability to make a valid judgment of the items under study was unbiased.

It is assumed the panel of experts remained anonymous during the study, but it is possible the *maintenance of anonymity* was not achieved because of the prominence of many of the members of the study. Some reasons this could have occurred include preexisting professional relationships, attendance at meeting or conference, or conferring with experts outside of the panel, or a unique style of communication that other experts might recognize. Control measures that were adopted by the researcher avoid skewing the results due to any of these issues might have reduced the effectiveness of the study.

Procedures

A Delphi method uses an anonymous panel of independent experts to obtain their judgment on a topic by arriving at a group consensus (Hallowell & Gambatese, 2002). This method has been used to forecast events, make decisions, provide guidance for research on the correct course of action or direction for research (Rowe & Wright, 1999). Although initially used to discuss classified national defense issues at the RAND Corporation, the Delphi methodology has been applied to topics as diverse as construction engineering and management (Hallowell & Gambatese, 2002), career and technical education (Kosloski & Ritz, 2016), economics and business research (Ishikawa, Amagasa, Shiga, & Tomizawa, 1993; Einhorn, Hogarth, & Klempner, 1977), and midwifery research (Kennedy, 2003), to name a few, to develop qualitative data with a valid quantitative component. This study recruited a panel of laser safety experts to participate in a Delphi study to determine:

1. If the laser safety climate could be measured at academic institutions.
2. The factors that indicate the laser safety climate of an academic institution.
3. The measures to evaluate the laser safety climate.

Definition of Terms

The following terms, abbreviations, and acronyms are defined as related to this research. These items are derived from multiple sources:

- **Accident**. For the purpose of this study, the term accident will refer to an incident that results in equipment damage or destruction.
- **American National Standards Institute (ANSI)**. The American National Standards Institute is an organization that develops and distributes guidelines for business and industry.
- **Class 1 Laser**. A Class I laser is safe under all viewing conditions, and is exempt from control measures (Laser Institute of America, 2014).
- **Class 2 Laser**. A Class II laser emits visible light of at or below a defined power, and the natural reaction of the eye when it blinks is adequate eye protection. Class II lasers

have one subcategory referred to as the Class 2M laser, which meets the definition of a Class II laser unless viewed through magnifying optics (2014).

- **Class 3 Laser**. A Class 3 laser may be hazardous under direct and reflected viewing but are not normally a diffuse reflection or fire hazard. There are two subclasses of this type of laser called Class 3R and Class 3B. According to ANSI Z136.1-2014 Class 3B lasers always requires training, but Class 3R training is application dependent (2014).
- **Class 4 Laser**. A Class 4 laser is always a hazard to the eye or skin from the beam and can be a diffuse reflection or fire hazard. This type of laser can cause air contaminates and plasma radiation (2014).
- **Injury**. For the purpose of this study, the term "injury" will refer to an incident that results in harm or death to a human being.
- **LASER.** LASER is an acronym for Light Amplification by Stimulated Emission of Radiation.

Summary and Overview

The increasing access to lasers in academic settings has increased the risk that students or staff will be injured while using a laser in an academic setting. The laser safety climate at universities has not been studied. However, the general safety climate of academic institutions has been studied in several recent investigations. This study used the Delphi technique to determine if the laser safety climate could be measured at academic instructions and how such measurement might be accomplished.

Chapter II is a review of the literature of subject experts and researchers concerning the safety culture and climate, university safety climate, laser safety, and the Delphi method. Chapter III is a description of the method and procedures used in this research study. Chapter IV has the finding from the research. Chapter V is the summary and conclusions of the research study and includes recommendations for further research.

CHAPTER II

Review of Literature

The purpose of this study was to determine the factors of the laser safety climate that can be measured at academic institutions and how these factors can be used to improve laser safety at academic institutions. The literature review will identify factors of laser safety and safety climate measurement, and provide background and technical context to the study. The review includes sections covering safety culture and climate, university safety climate, laser safety, and laser safety in the academic environment.

Safety Culture and Safety Climate

The terms safety culture and safety climate are often used to describe an organization's performance. Although closely related, an organization's safety culture the describes how the individual and group interact regarding safety. The term originated in the nuclear power industry after the Chernobyl disaster and was defined as the "assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance (International Nuclear Safety Advisory Group, 1991, p. 1). This phrase has since entered the common vernacular and is often tied to the headline of high-profile accidents such as the 2013 train derailment in Lac-Megantic, Quebec, which resulted in the destruction of much of the town and the deaths of 47 people (George-Cash, 2018). The term 'safety culture' was returned 56 times in electronic searches of the *Wall Street Journal* and 59 times in the *New York Time*s between 2014 and 2018. In these searches, safety culture is used to describe contributing factors of high-profile accidents such as chemical accidents or transportation disasters.

Laser Safety culture has been defined by Barat (2014) as the belief that “laser safety is in the midst of, group responsibility over individual safety” (p. 1). He states that the adoption of group safety norms is a vital aspect of a culture of laser safety and rules enforcement. The group dynamics of the student experience, shared resources, the use of different classes of lasers in a single academic lab present multiple challenges to maintaining a positive laser safety culture in the university setting.

Zohar (1980) developed the first safety climate instrument in 1980. His study defined safety climate as the “summary of molar perceptions that employees share about their work environments” (p. 96) which provide a “psychological utility in serving as a frame of reference for guiding appropriate and adaptive task behaviors” (p. 96). Since the 40-item questionnaire was initially published in 1980, it has been widely used and modified by researchers to measure the safety climate of specific industries (Zohar, 2009). In a meta-analysis of 31 safety climate and safety performance studies, Clarke (2006) identified instruments for such diverse industries as chemical, construction, food service, energy production, military, retail, and service sectors. However, an instrument for the measurement of laser safety climate has not been identified in the literature.

Donald and Cantor (1994) identified six factors associated with workers developing safe practices at work that included “Management commitment, safety training, open communication, environmental control and management, a stable workforce and positive safety promotion policy” (p. 204), finding most important discriminator of a company’s safety culture is the “importance of safety training” (p. 204). Other factors affecting the safety climate included the “effects of the workplace, status of (the) safety committee, status of (the) safety officer, effect of safe conduct on promotion, level of risk at the workplace, management attitudes towards safety, effects of safe conduct on social status" (p. 204). These safety climate measurements can be used as either leading or lagging organizational indicators.

Flin, Mearns, O'Connor, and Bryden (2000) conducted a review of 18 published studies in high-reliability industries such as chemical, energy, and nuclear that analyzed the application of safety climate studies. They found a shift from using safety climate studies for lagging indicators of safety to leading indicators of safety. According to Flin et al., a lagging indicator provides retroactive accident data, such as lost time, accident rates, and incident data, which is used as feedback in a reactive leadership system. A proactive leadership style uses safety climate studies along with other proactive measures, such as safety audits and hazards analysis, to provide leading indicators of safety (Flin et al.). Gutierrez (2011) supported this view, stating the safety climate "is a leading indicator of injuries, is inversely linked to injuries, provides information not commonly measured, and regulatory agencies have recognized the value of institutions with strong safety climate" (p. 19).

In *Laser Safety Tools and Training*, the term "Safety Culture" (Barat, 2014, p. 1) is the first topic of discussion. The meaning of a safety culture is an ongoing theme of the text. Barat outlines how the failure to keep a safety culture results in laser accidents with an underlying series of case studies. This belief that a commitment to safety, good organizational leadership, and organizational learning results in the reduction of accidents and injuries. According to Sorenson (2002), this combination of indicators is associated with the term safety culture. He says a positive relationship is assumed to exist between safety culture, human performance, and reliability.

University Safety Climate

Wu et al. (2007) outlined a series of accidents from 1997 to 2004 in various Taiwanese university labs as an impetus for both regulatory action and their study. Wu et al. posited that Zohar's instruments were inadequate to measure the safety climate in academia due to the cultural differences between industry and academic institutions. They modified Zohar's instrument to focus and measure factors unique to the academic safety culture. This study of 100 Taiwanese universities found that organizational and individual factors affected the safety climate. These factors included organizational structure (public or private), safety management, demographics, accident experience, and safety training as affecting the university safety climate.

Gutierrez's (2011) research supported the conclusions of Wu et al. (2007), explaining how such studies could be used to prevent accidents and injuries. She said the safety climate "is a leading indicator of injuries, is inversely linked to injuries, provides information not commonly measured, and regulatory agencies have recognized the value of institutions with strong safety climate" (p. 19). Thus, a safety climate study might best be used in a prescriptive way to correct issues before an accident or injury.

According to the Laser Institute of America (2009), universities should establish an Educational Laser Safety Committee that "shall be responsible for the establishment and maintenance of adequate policies for the control of laser hazards and safety training for all laser users" (p. 26). The LIA emphasizes the importance of faculty and staff laser safety training to "understand and communicate the proper regard for laser safety" (p. 27) to students. This supports the discussion by Donald and Cantor (1994) of the importance of training as a critical safety culture factor.

Steward, Wilson, and Wang (2014) identified cultural factors between the academic and industrial settings affecting the safety climate in university labs. They pointed out that all university labs include a wide range of toxic hazards that may include chemical, biological, explosive, corrosive, and radiological material in the academic setting. They said the "relaxed approach toward safety makes academic laboratories more dangerous than those in industry" (p. 5) because the principal investigator is responsible for both setting and enforcing the safety requirements. The cumulative impact of these challenges is that "cross-discipline incubator projects" (p. 5) often stretch the qualifications of university faculty.

The National Academies of Science (2014) outlined a series of chemical accidents at university research facilities as the catalyst for the 2014 research project resulting in *Safe Science: Promoting a Culture of Safety in Academic Chemical Research* (Safe Science). The committee noted that although the focus of the work was limited to university chemistry research labs, "the same risks and hazards identified in this report exist under the same cultural constraints in other research communities within colleges and universities" (p. 95). The committee presented 16 findings in four broad categories that affect the safety climate resulting in nine recommendations to improve the academic safety cultures. The categories of findings and a summary of the recommendations are discussed in the following paragraphs.

The first category is *Institution-wide Dynamics and Resources*, which focused on the development of a positive university safety culture and the ability to sustain that climate over time. The committee recommended that academic institutions demonstrate safety as a core valued by administrative leadership. This commitment would include using safety as a criterion for promotion, tenure, and salary decisions. Using these performance-based data for professional advancement would demonstrate the commitment of university leadership to maintaining a safe academic research environment. When research is being planned, each laboratory should have a comprehensive risk management plan that includes prevention, mitigation, and emergency response plans. The decisions to proceed (or discontinue) with research should be dependent on available safety resources because the safe performance of research is critical to all parties (Committee on Establishing and Promoting a Culture of Safety in Academic Laboratory Research, 2014).

The second category is *Research Group Dynamics.* This topic came under scrutiny by the committee because of the power structure in university labs and the competitive environment of academic research. They recommended that departments should better utilize available safety resources to promote a safety culture. Support of these resources should be provided by department level mechanisms to create a collaborative environment between researchers, principal investigators, and the environmental health and safety personnel (Committee on Establishing and Promoting a Culture of Safety in Academic Laboratory Research, 2014).

The third category is *Data, Hazard Identification, and Analysis*, which was found to need improvement at most universities. The committee noted that safety performance is tied to the ability to recognize and act on hazardous situations, something many students are still developing while conducting academic research. The committee recommended that universities shift to leading indicators by developing an anonymous near-miss reporting system. This system would support the incorporation of lessons learned in subsequent research, and the data could be linked to scientific literature. They noted that researchers often do not have an appreciation of the risk related to their research due to their limited experience or background, thus may not be capable of performing a hazard analysis for the research. The committee recommended addressing this shortcoming by integrating hazard analysis as a mandatory design element of the principal investigator's research proposals, and the incorporation of the hazard analysis process into laboratory notebooks as research topic area (Committee on Establishing and Promoting a Culture of Safety in Academic Laboratory Research, 2014).

Fourth, *Training and Learning* was discussed as a keystone to safety by the committee. They found significant variability in the availability and quality of training at academic labs, noting a link between the quality of training and a positive safety culture. The committee recommended safety training should be a continuous process that includes initial, ongoing, periodic refresher training with a specific focus on protective measures, hazard identification, and mitigation (Committee on Establishing and Promoting a Culture of Safety in Academic Laboratory Research, 2014). Although *Safe Science* only discussed lasers as a tool in chemical research facilities, these recommendations may have general applicability to laser use in other lab research environments.

Laser Safety

American National Standard for Safe Use of Lasers (ANSI Z136.1-2014), is the foundational document on laser safety that provides laser safety guidelines for use by public and private educational institutions, industry, and the military. The standard provides laser classification information, laser-related definitions, hazard evaluation control measures, education and training requirements, medical examinations, non-beam hazards, the criteria for eye and skin exposure to laser light, technical information on laser measurement calculations, and the biological effects of a laser injury (Laser Institute of America, 2014). ANSI Z136.1 is the basis of all text located on laser safety (Barat, 2006; Barat, 2014; Winburn, 1990) and is listed as the primary reference for much, if not all, training documentation (George Washington

University Office of Laboratory Safety, 2017; Virginia Tech, n.d.; Zimmerman, Aldrich, Fraser, & Cosper, 2014).

The Laser Institute of America (2014) categorizes control measures as: "engineering, administrative (procedural), and personal protective equipment (PPE)" (p. 25). An engineering control measure is "designed or incorporated into the laser or laser system" (p. 9). One example of an engineering control is an interlock, which interrupts the operation of equipment when a door is opened, thus reducing an individual's risk to the laser. Administrative controls are the measures used to mitigate laser hazards such as training, safety approvals, operator qualification, and standard operating procedures (SOP). Personal protective equipment (PPE) are devices that are physical barrier worn on the body of a laser operator or observer to reduce or eliminate the laser-related dangers. Examples of PPE include laser eye protection, clothing, and respirators (2014).

The Laser Institute of America has developed two documents that provide supplemental information to ANSI Z136.1-2014 for the academic environment. The laser safety requirements of academic personnel and students below the graduate level is the topic of *American National Standard for Safe Use of Laser in Educational Institutions* ANSI Z136.5-2009 (Laser Institute of America, 2009). Faculty and students conducting research in laboratory environments should follow the guidance in the *American National Standard for Safe Use of Lasers in Research, Development, or Testing* (ANSI Z136.8-2012) for all test and research procedures. (Laser Institute of America, 2012).

The study of lasers for academic purposes has specific safety risks to both the staff and students. The *American National Standard for Safe Use of Lasers in Educational Institutions* (ANSI Z136.5-2009) discusses unique laser hazards in the academic setting, including:

- Large groups of students working in confined laboratory spaces.
- Laser labs as a shared resource of multiple departments.
- Different laser classes and wavelengths in a single laboratory.
- Increased risk of specular reflections from open and unrestricted beam paths.
- Many of the labs may have non-beam hazards (Laser Institute of America, 2009).

These unique problems indicate how practices that are considered indications of a safe workplace in business and industry may be more challenging to implement in an academic setting.

According to the Laser Institute of America (2012), when using lasers for research, development, and testing, the principal investigator (PI) and researchers should consult ANSI Z136.8 for supplementary guidance in the lab. The LIA points out that multiple standards may be necessary to develop a thorough laser hazard control program (Laser Institute of America, 2012). For example, if a university used a laser as a spotter when teaching an undergraduate astronomy class that includes fieldwork outside, three sources would be appropriate. In this situation, *Safe Use of Lasers* ANSI Z136.1-2014, *Safe Use of Lasers in Educational Institutions* ANSI Z136.5-2009, and *Safe Use of Lasers Outdoors* ANSI Z136.6-2018 should be consulted when developing a hazard analysis. A complete list of the ANSI guidance for specific laser applications is included in appendix A.

Laser Safety in the Academic and Research Environment

A university's laser safety climate is a microcosm of the overall safety climate, but there are specific issues that may be faced when developing a laser safety program. Spichiger, Zakiar, and Tabor (2013) outlined the challenges of setting up a university laser safety program at a large, technically focused university. Their program required a clear definition of scope, training for Environment Health & Safety staff, identification of external stakeholder (university, state and federal) requirements, and obtaining administrative and facility buy-in before implementation. It is noteworthy that the program required nearly a decade to mature from a collateral duty in 2003 to an integrated laser safety program by 2013. They remarked that until the first laser inventory was completed in 2009, Georgia Tech was only aware of about 11% of the 425 Class 3B or Class 4 lasers owned by 12 separate departments on campus (Spichiger, Zakir, & Tabor, 2013). Holcomb (2012) and Garcia (2018) found similar situations at their universities. Holcomb reported 300 students annually using over 425 lasers in 130 laser labs at the University of Texas at Austin (Holcomb, 2012), and Garcia (2018) found the University of Michigan was only aware of 77 of the over 600 Class 3B and Class 4 lasers used on campus when he became the LSO in 2014 (pp. 4-9).

Spichiger, Zakiar, and Tabor (2013) also discuss the necessity of developing stakeholder buy-in, and the discovery of "anecdotal information regarding injuries and property damage … communicated to the LSO" (Spichiger, Zakir, & Tabor, 2013, p. 16) during the development of the program. These discussions include an interesting undercurrent of how a laser safety climate can improve over time by addressing stakeholders concerns early and often in the development process. The necessity of developing administrative buy-in to the program is emphasized throughout the discussion, so the program becomes less confrontational.

Winburn's *Practical Laser Safety* (1990) provides practical application information on the previous revisions of ANSI Z136.1, Z136.2, and Z136.3 laser standards. He states that the cause of all accidents could be traced to unsafe acts or conditions. Thus, the goal of the laser safety program is to train the individual users in the principles of laser safety and Laser Safety Officer (LSO) to establish controls for the working environment. He outlines the fundamental concepts of laser safety in a format with a focus toward practical information; his topics include control measures, hazard reduction, practical advice on user training, and the selection and use of laser eye protection, supported by 10 case studies of laser eye injuries (Winburn, 1990).

Laser Safety Management by Barat (2006) is also focused on the management of laser hazards but includes a detailed discussion of the development and documentation of laser safety training. He discusses specific types of user training, including awareness training, on the job safety training, and lesson learned, which he states should each be part of a continuum of competency-based training (Barat). This point aligns with the concept of developing a positive safety culture using proactive measures to improve the laser safety climate.

Delphi Method Research

Delphi Method is defined by Anderson (2010) as an iterative group judgment process to reach a consensus of an expert panel using the following steps. First, survey a panel of experts anonymously about on a topic. Second, collect and summarize the responses. Third, provide a summary of responses to the panel members and ask if they want to revise their response. Fourth, conduct multiple iterations of the process to reach a consensus. Fifth, report the group response. She noted the advantage of the technique is a collection of data from a team of experts, but the integration of the data may be difficult, and the study requires a high commitment of time to complete (Anderson, 2010).

Woudenberg (1991) and Rowe and Wright (1999) identified the critical characteristics of a Delphi study as anonymity, iteration, feedback, and statistical aggregation of the response set. According to Hallowell and Gambatese, (2002) these features are mitigations for the negative bias in the group judgment such as the dominance of a few panel members who skew the outcome away from the mean, or the collective unconscious where minority voices suppress their genuine opinion to allow a consensus to develop (Hallowell & Gambatese).

Hallowell and Gambatese (2002) provided a suggested procedure to conduct a Delphi study (see Figure 1). Their process discussed identification and qualification of experts, recommendations about the panel size and number of rounds, relevant statistics for each round of feedback, mitigation for eight types of bias, and measuring consensus in Delphi method study.

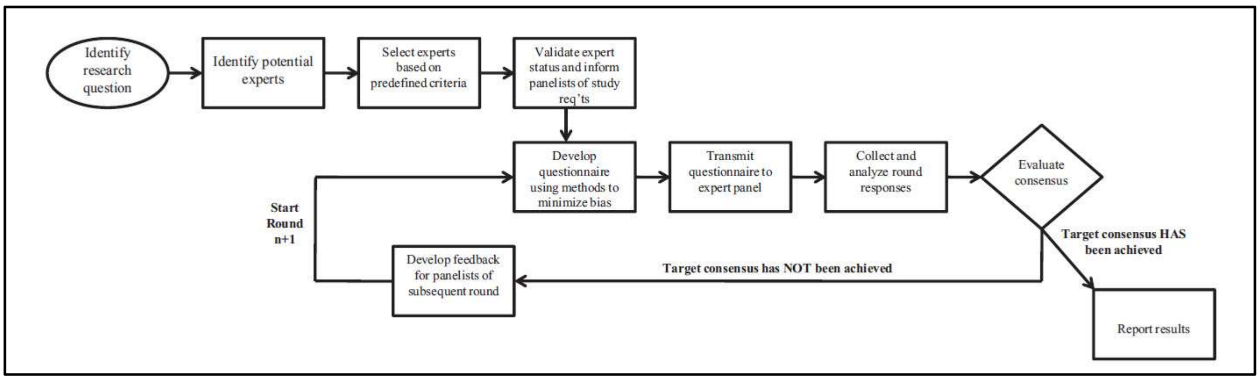

Figure 1. Hallowell and Gambatese Delphi Procedure (Hallowell & Gambatese, p. 102).

Woudenbeg (1991) questioned the quality of judgment (which he defined as a combination true score and error component) that emerged from the Delphi process, stating Delphi studies are no more accurate than other judgment methods. He further stated the inherent "person and situation-specific bias" (p. 134) effectively made each round of a Delphi study a new measuring instrument, impacting the accuracy, reliability, validation, and standardization of the method (Woudenberg, 1991).

Hallowell and Gambatese (2002) defined judgment as a decision-making skill that is a combination of diagnostic, inductive, and interpretive reasoning. They state the key to success when using the Delphi method is to mitigate issues that contribute to biased judgment. They analyzed the sources of "judgment-based bias" (p. 104) that can negatively skew the results of studies. According to Hallowell and Gambatese, the eight sources of bias are; collective unconscious, contrast effect, neglect of probability, Von Restorff effect, myside bias, recency effect, primacy effect, and dominance. They suggest six controls to reduce these bias (see Table *2*) (Hallowell & Gambatese, 2002).

Table 2

Controls to Mitigate Bias

Control	Description	Bias issue
Randomize survey questions	Vary the order of items between members	Primacy
Provide feedback justification	Provide justifications for an item's rating	Collective unconscious
Conduct multiple survey rounds	Used to achieve a high degree of consensus among the panel	Reduces dominance issues on the panel.
Measure probability and severity separately	Avoids issues of neglecting the probability of an event	Neglect of probability
Report median ranges rather than means	The mean is more susceptible to biased responses	Reduces neglect of probability
Monitor/remove members who have recent experience with the topic.	Recent experience with an issue may skew the results	Reduces the effect of recent events

The qualification of the experts has received considerable commentary in the literature. Woudenberg (1991) found that in some studies, the level of expertise was suboptimal due to selection criteria and membership attrition. Although skeptical of the expert selection process, he provided no advice on how to improve a panel. Because the community of laser safety experts is relatively small, the panelists may have recognized issues that are advocated by a specific individual. Kennedy (2003) observed the level of expertise in studies ranged from a subject specialist (Ph.D.), to subject matter expert (SME; BA/MA), to a knowledgeable practitioner of the subject (secondary job function; Kennedy). Kennedy’s point may be especially relevant at smaller institutions where the LSO is a collateral duty.

The recruitment of highly qualified panel affects the outcome of a Delphi study because the process depends on participants' judgment skills. Rodgers and Lopez (2002) stated that expertise should be measured by competencies, which they defined as that each panelist meeting a combination of professional criteria. They required their panelist to meet a minimum of two professional indicators of achievement in the field under study, which could include "publications, presentations, extended work experience, relevant committee work, relevant faculty experience" (p. 123) to qualify expertise. Howell and Gambatese (2002) required their panel members to meet four of eight criteria which they stated would provide a "balance of academic and professional experience and ensures that panelists have distinguished themselves as experts on the topic" (p. 103).

Recent studies have continued to emphasize the necessity for rigorous examination of the panel members expertise. Wakefield and Watson (2014) suggested five criteria for the selection of experts including knowledge in the area under investigation, performance record, objective and judgment, availability to complete the study, and commitment to participate in the process (p. 580).

According to Kennedy (2002), the Delphi method is "a constructive effort in building knowledge by all who share in the process" (p. 505). This constructive aspect of a Delphi is accomplished by providing an iterative forum for a panel of experts to exchange opinions anonymously, evaluate the augments of others, then modify their position after considering the opinion of other experts, resulting in reaching a consensus in an environment where individual reputation is not at risk (Kennedy). Because of the competitive aspect of the academic research environment, the Delphi methodology provides a safe platform to exchange information on laser safety practices that work in the academic environment.

Summary

Facilities using lasers can expect the safety outcomes to be a reflection of their laser safety culture and climate. The review discussed the safety, university safety climate, laser safety, laser safety culture, and climate in the academic environment, and the Delphi research method. Although there is limited literature on laser safety culture, a significant body of research supports the necessity of measuring an organizational safety climate. This review of the literature supports the importance of measuring an institutions laser safety culture, which can then be used to provide leading indicators in a timely manner that can be acted on prior to an injury or accident. Using the Delphi technique can be an effective method to survey expert knowledge and develop a consensus of the if academic laser safety climate can be measured, what factors would affect laser safety and what measures would indicate either a positive or negative laser safety climate. These data can then be used to design a valid proactive leading safety climate instrument.

Chapter III discuss the methods and procedures used to complete the research study. It will discuss the surveyed population. Provide a detailed outline of research procedures along with a discussion of the data collection process. Finally, it has information about the methods of statistical analysis used in the research study.

CHAPTER III

Methods and Procedures

The purpose of this study was to determine if the laser safety climate can be measured at academic institutions. The researcher attempted to identify factors that indicate the state of the laser safety climate, and to suggest a set of measures which provide data to support prescriptive measures by laser safety professionals to improve laser safety at academic institutions. It is believed that a favorable laser safety climate would result in a safe learning environment, leading to fewer near-miss incidents, less equipment damage, and a low rate of laser injuries.

This chapter discusses the methods and procedures used in this study to collect and analyze data focused on determining what factors could be measured by such an instrument and how they might be applied to reduce the rate of laser injuries at academic institutions. The discussion will include an overview of the population studied, the research variables, the instrument used for data collection, a description of the data collected and how the data were analyzed, and a summary of the chapter.

Population

A survey consisting of extant literature, university safety websites and, conference proceedings identified a population of 365 potential laser safety professionals with a broad range of expertise and interests. The evaluation criteria were defined in terms of professional experience relevant to laser safety; thus, active employment as a certified laser safety officer (CLSO) used to identify the leading laser safety experts.

The qualification standards for the panel aligned with the recommendations of Rodgers and Lopez (2002), Hallowell and Gambatese (2002), and Wakefield (2014) to provide a diversity of backgrounds and relevant professional experience. Hallowell and Gambatese (2002) suggested a guideline for qualifying construction engineering and management Delphi panelist. The following list was adapted from their list to identify highly qualified laser safety experts. To be considered highly a qualified laser safety expert, each panelist was examined for a combination of professional achievements that included at least two of the following criteria:

- Primary or secondary writer, peer-reviewed laser safety journal articles.
- Invited conference speaker at a laser safety conference.
- Member or chair of a nationally recognized laser safety committee.
- At least five years of professional experience as a laser safety officer.
- Laser or photonics faculty member at an accredited institution of higher learning.
- Writer or editor of a book or book chapter on the topic of laser safety, or laser risk management.
- Advanced degree in the field of the laser, photonics fields.
- Professional registration, such as a certified laser safety officer (CLSO).
- Certified Safety Professional (CSP) Laser or Photonics Risk.

A summary of the population of the experts' backgrounds and key leaders in the field is contained in Table *3*.

Research Variables

The design of a Delphi study makes the variable of the study somewhat emergent. Okoli and Pawlowski (2004) characterized one of the strengths of the Delphi method as providing a team of experts to help the researcher determine and prioritize variables for research. They felt this would provide a basis for subsequent research that will have higher generalizability due to the quality expertise shaping the findings. According to Wakefield and Watson (2014), the open-ended initial questions of a Delphi study are critical because they provide the basis "to lead the study into different subcategories and variables through their responses” (p. 581). This aspect of the Delphi was essential to this study because of the goals to derive a set of quantifiable variables that can be used to measure the academic institution’s laser safety climate.

Table 3

Summary of the Expert Population Background.

Type of Institution	Number	Laser Safety Task Group	Z136.1 Committee
Academic	201	5	4
Secondary	1		
Technical School	1		
Community College	19		
University	178	5	
Government	19	3	1
Research Lab	43	25	
Hospital	2		
Military	10		4
Commercial	63		1
Total	336	37	10

The qualification, selection, and size of panel members were critical dependent variables of the study. One common critique of the Delphi is the selection and ranking process of experts as Woudenberg (1991), Rogers and Lopez, (2002), Hallowell and Gambatese, (2002), each discussed in their studies. The goal of the Delphi technique is to leverage expert information of the panel. According to Okoli and Pawlowski (2004), in many Delphi studies, the screening and selection of ‘experts’ is problematic, thus limiting the generalizability of the results.

Rowe and Wright (1999) conducted a systematic review of the effectiveness of the Delphi method finding the common independent variables were technique, the number of rounds, and the type of feedback. They identified dependent variables as accuracy, opinion change, confidence, the use of self-rated instead of objective expertise, and participant attrition during subsequent rounds.

Procedures and Data Collection

Data were collected from a panel of experts using email and commercial survey software in three phases. The Delphi was conducted using a commercial survey software package that distributed an instrument and collected all responses from the participants. The recruitment email provided the background of the researcher, the purpose of the Delphi Panel, and the background and importance of safety climate instruments. This phase also included the informed consent procedure. Those who accepted the invitation were sent Round 1 of the study.

Delphi Round 1

In Round 1, each participant was asked the following questions regarding laser safety at academic institutions during recruitment:

1. Can the laser safety climate be measured? The available responses were Yes, No, and Unsure. Each respondent was also asked to include a short explanation of their answer.

2. What do you consider the three most important factors that indicate a positive laser safety climate? Are there specific measures/indicators an LSO should collect related to these factors?

3. What are the three most important factors that indicate a negative laser safety climate? Are there specific measures/indicators an LSO should collect related to these factors?

Finally, during this phase, the respondents were asked to volunteer professional expertise and experience data to support the selection criteria for the Delphi panel.

The responses to the first round of questions were collected, analyzed, and statistically summarized for the second phase of the study. The percentage of positive and negative responses to the question 'Can the laser safety climate be measured?' was calculated. For the remaining questions, responses were aggregated to eliminate duplications. Each factor and measure the panel proposed was summarized and tabulated by the researcher to develop the survey questions for the second round of the Delphi panel.

Delphi Round 2

During the second round of the Delphi study, the panel was provided a list of laser safety factors and measures resulting from the aggregated responses from the first round. They were asked to examine the list of factors that affect laser safety in the academic setting. The panel was then asked to evaluate whether or not the list of factors was complete. If a panelist felt that the list was complete, they needed to take no additional action other than to agree with the list. If a panelist felt that an item or items were missing from the aggregated list, they then had the opportunity to provide additional laser safety factors to the list. Any additional responses would again be aggregated and added to the list prior to submitting Round 3 to the panelists.

Delphi Round 3

In the third round of the Delphi study, the panel was provided with the list of factors and measures and asked to evaluate the relative value of each factor and measure on a Likert-type scale. The options were: 1 = Not at all important, 2 = Slightly important, 3 = Moderately important, 4 = Very important, and 5 = Extremely important. The design of the scale provided the panelists an interactive method of providing their opinion of the relative value of each factor or measure, allowing panelists to select their response on a sliding scale that included partial numbers. This option provided quantitive measurement data that could be statically analyzed to determine precise means, standard deviations, and variances of each item. The design of the scale allowed a higher level of discrimination by each panelist than would have been available on a Likert-type scale that only permitted the selection of whole numbers. An example of this scale is provided in Figure *2*.

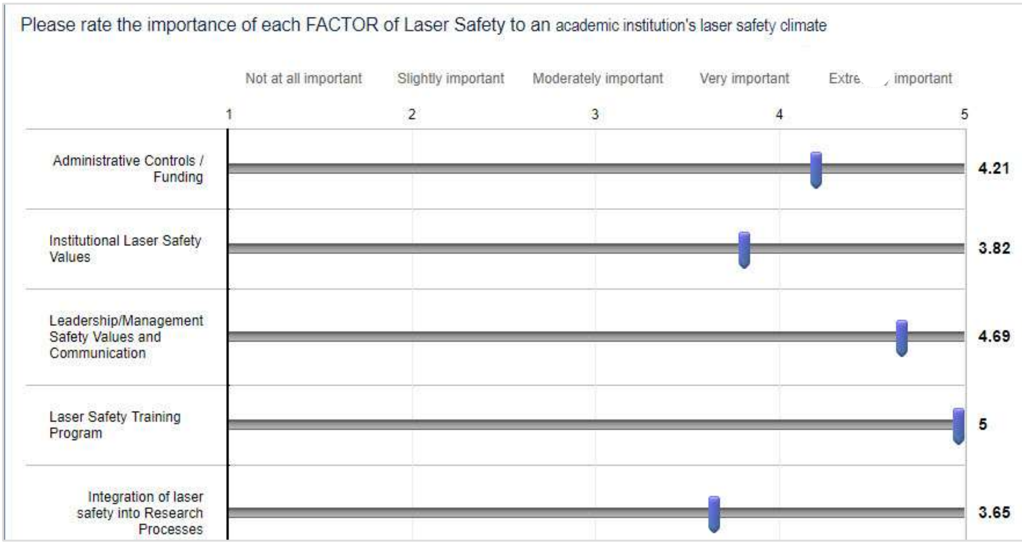

Figure 2. *Example of an Interactive Likert-Type Scale.*

Statistical Analysis

This study used a variety of statistics including, totals, means, standard deviations, and variances to determine relevance and degree of consensus of each factor and measure. Because the intent of the study was to develop a comprehensive list of factors and measures, the researcher intentionally did not utilize cut scores, but rather provided a comprehensive list which indicated relevance and consensus. One outcome of this study is a validated list of factors and measures that can be used for a future laser safety climate study by academic institutions.

Summary

This chapter discussed the methods, population, research variables, instrument and data collections procedures, and the data analysis process of the study. The population of the study was a panel of laser safety experts. The responses were a combination of open-ended questions and Likert-type items that were delivered and compiled electronically during the collection period. The next section reports the finding of the research study and provides statistical analysis of the results.

CHAPTER IV

Findings

The purpose of this study was to determine if the laser safety climate can be measured at academic institutions. If the laser safety climate can be measured at academic institutions, which factors indicate the state of the laser safety climate. Finally, the study will suggest a set of measures to provide data to support prescriptive measures by laser safety professionals to improve laser safety at academic institutions. It is believed that a favorable laser safety climate would result in a safe learning environment, leading to fewer near-miss incidents, less equipment damage, and a low rate of laser injuries.

This chapter discusses the population of the Delphi panel and the findings of each phase of the study. During the recruitment phase of the laser safety Delphi study, 56 experts who met eligibility criteria were contacted and asked to participate in a three-round study to determine if the laser safety climate of an institution could be measured. The response rate for the this phase was 32% ($n = 22$). Of the 22 experts who agreed to join the Delphi panel in the recruitment phase, two were lost to attrition in the final round. Some of the panelists who completed each round did not necessarily answer every question on every round. Because the goal of the study was to develop a comprehensive list of laser safety factor and measures, each measure includes the mean, standard deviation, variance and the number of experts who responded to each item.

Population Analysis

The goal of using a Delphi panel was to leverage the expertise of a broad range of laser safety professionals. This study used a purposive sample of academic LSOs and laser safety experts to achieve this goal. Items related to expertise and experience were optional and included to support the validity of the sample selection and panel expertise. Although four members of the panel chose not to provide these data, the researcher made the assumption, based on the recruitment data, that all met the eligibility requirements for participation in the study. Subsequently, the expertise and experience data for the other panelists further supported the requirement that the panelists in this study were qualified experts and can achieve reliable findings.

The panel included university, government, and research lab LSOs. The average laser safety experience on the panel was 11.63 years. The panel included four LSOs who were primary or secondary journal authors, eight invited speakers at laser safety conferences, nine members of nationally recognized laser safety committees, six book authors or editors of books, seven members that held advanced degrees in the laser or photonics fields, 10 members who were certified laser safety officers (CLSO), and two members who were Certified Medical Laser Safety Officers (CMSLO).

Findings

Round 1

Each respondent was asked (1) If an academic institution's laser safety climate can be measured? (2) What do you consider the three most important factors that indicate a positive laser safety climate? (3) What are the three most important factors that indicate a negative laser safety climate? (4) Are there specific measures/indicators an LSO should collect related to these factors?

Can the laser safety climate be measured?

The panel was divided with 45.5% (n = 10) responding Yes, 0% responding No, and 54.5% (n = 12) responding Unsure.

What do you consider the three most important factors that indicate a positive laser safety climate?

The panel provided 88 responses that were compiled, decomposed into each element, and coded for commonality using a multi-pass data encoding method. These responses were grouped into 10 laser safety factor categories. These factors are reported in Table *4*:

Table 4

List of Laser Safety Factors in the Academic Environment

Laser Safety Factor
Administrative Controls
Institutional Laser Safety Values
Leadership/Management Safety Values
Laser Safety Training Program
Integration of Laser Safety Officer into the Research Processes
Near Miss Program
Laser Safety Hazard Awareness/Risk Analysis Program
Personal Safety Values
Compliance Measurement
Engineering Controls

Are there specific measures/indicators an LSO should collect related to these factors that indicate a negative laser safety climate?

The panel was also asked to discuss factors and measures that indicate a negative laser safety climate. These questions provided validation and were incorporated into the analysis of laser safety factors and measures. The panel provided 83 safety measures that were analyzed and aggregated into measurement categories that supported the factors identified in Table 4. Findings summarizing these measures are reported in Tables 5 to 8.

Table 5

Measures Supporting Factors of Laser Safety Leadership and Management

Laser Safety Measures
Institutional Laser Safety Values (factor)
LSO Staffing Level
Fiscal Support for Laser Safety
Explicit Safety Budget in Experimental Proposals
Laser Safety Compliance as a Criterion of Tenure
Leadership/Management Safety Values (factor)
Principle Investigator Oversight of Researchers
Advance Laser Operation Planning
Laser Safety Compliance as a Criterion of Proposal Review
Administrative Controls (factor)
LSO Audits
Annual Program Audits

Table 6

Measures Supporting Factors of Laser Administrative Control

Laser Safety Measures
Administrative Controls (factor)
External Review of Experimental Processes
Laser Access Control
Compliance Check Measures (factor) /
Frequency of Lab Audits
Frequency of Unannounced Lab Visits
Laser Safety Training Program (factor) / Personal Safety Values (factor)
Use and Selection of Proper Laser Eye Protection (LEP)
Use and selection of Proper Personal Protective Equipment (PPE)
Use of Standard Operating Procedures
Use of laser Operation Checklist.
Compliance Measurement (factor)
Verification Rates - Laser Safety Training
Verification Rates - Laser Safety Checklist
Verification Rates - Laser Operation Log
Verification Rates - Preventative Maintenance
Rate of Corrective Actions Due to Lab Inspections
Laser Program Documentation Measures
Quality Standard Operating Procedures
Accurate Laser Inventory
Repeatable Experimental Protocols
Leadership/Management Safety Values (factor)
Accident Reporting
Injury Reporting
Near Miss Reporting
Integration of Laser Safety Officer into the Research Processes (factor)
Advance Laser Operation Planning Time

Table 7

Measures Supporting Factors of Programmatic Measures

Laser Safety Measures
Integration of Laser Safety Officer into the Research Processes (factor)
LSO Collateral or Primary Responsibility
LSO to User Communication
Documentation Measures
Laser Access Control
Quality Standard Operating Procedures
Accurate Laser Inventory
Hazard Mitigation / Response Plan
Accurate User Reported Incident History
List of Class 3B and 4 Users on Campus
Evaluation of Compliance Measure (factor)
Availability/quality of Standard Operating Procedures (SOP) and laser checklist
Conducting Compliance Checks
Research integration of LSO
Completion Rate of Annual Laser Facility Inspections
Effectiveness of Laser Safety Training Program (factor)
Laser Injury rate
Laser Accident Rate
Laser Near Miss Rate
User assessment scores on training
Personal safety Values (factor)
Use and Selection of Proper Laser Eye Protection (LEP) and other Personal Protective Equipment (PPE)
Use of Standard Operating Procedures and Operations checklist
User-Initiated Communication to LSO
Hazard Awareness/Risk Assessment Program (factor)
Risk / Hazard analysis plan for each laser
Annual Laser Facility Inspections
Hazard Mitigation / Response Plan
Continuous Hazard Awareness Procedure
Hazard Awareness / Risk Assessment Included in Lab Notebooks
Engineering Control Measures (factor)
Availability and use of barriers
Laser operation lights
Use of warning devices and signs

Table 8

Measures Supporting Factors of Programmatic Effectiveness

Laser Safety Measures
Laser Safety Training Program (factor)
Compliance Rate of Laser Safety Training
Laser Safety Checklist
Laser Operation Log
Preventative Maintenance
LSO Audits
Risk / Hazard Analysis
Annual Laser Facility Inspections
Near Miss Program (factor)
Near Miss
Active Near Miss Program
Lessons Learned Program
Lessons Learned / Near Miss Discussion in Lab Notebooks
Completion of Near-Miss Assessment by Researchers

Round 2

The results of Round 1 of the study were aggregated, summarized, and provided to the Delphi panel during Round 2 of the study. During this phase of the study, the panel was asked if the list of factors and measures were complete, and if additional items should be added to the list.

Please evaluate if the list of laser safety FACTORS is complete.

The panel was divided with 75% responding Yes (n = 15) and 25% responding No (n = 5). The panel proposed nine additional items as factors. These findings were compiled, decomposed into each element, and coded for commonality using the same multi-pass data encoding method used during Round 1 of the study. These responses were integrated into the final list of laser safety factors which are reported in

Table 9.

Next, the panel was asked, "Please evaluate if the list of Laser Safety (category/groups of measures) is complete. Each question included the same stem and each item from the list paired with the category or group of safety measured derived in phase one of the study and summarized in Tables 5 through 8. Thus, a panelist was presented an item that read “Please evaluate if the list of Laser Safety Leadership / Management MEASURES are complete” along with the list of related proposed measures. If a panelist responded the list of measures was incomplete, space was provided to propose additional items to the list of measures. The response percentage is rounded to the nearest whole number.

The next question was presented to all panelist to provide the opportunity to propose additional measures for the final round of the Delphi study.

Please include any additional Laser Safety Measures that should be included in the list of measures.

Table *10* is a summary of the responses to these items.

Table 9

Additional Factors or Measures Proposed in Phase Two of the Delphi Study

Factors
Management must be financially committed to providing support to the laser safety program in terms of purchasing controls, software, training.
Lessons learned program.
Active rather than a passive program.
Laser Safety Newsletter to the user community.
If calling out admin and engineering controls separately also need to include PPE controls. Documenting roles/responsibilities for laser workers and laser supervisors is needed; + having them accept these responsibilities.
Faculty-led compliance oversight committee.
Laser program can be folded into an existent committee such as the Radiation Safety Committee.
Periodic peer or independent audit.
Emergency Response SOP.
Occupational Health enrollment (check individual health before work).
On the job training (may be included in the training program). This seems like a list for a large organization, maybe not as relevant to a mom-and-pop shop that has lasers.

Factors
JC Laser Competency - may be included in a training program, Policies and Procedures, Procedural Controls, Authorization to use Lasers & Physician Privileging.

The next question was presented to all panelist to provide the opportunity to propose additional measures for the final round of the Delphi study.

Please include any additional Laser Safety Measures that should be included in the list of measures.

Table 10

Evaluation of the Comprehensiveness of the Laser Safety Measures

Measure Category	**Yes**	**No**	**Number**
Leadership / Management MEASURES	74%	26%	19
Administrative Control MEASURES	79%	21%	19
Training MEASURES	85%	15%	19
Programmatic MEASURES	79%	21%	19
Programmatic - Effectiveness MEASURES	95%	5%	19

The Delphi panel provided 11 additional responses to the proposed measures, which were compiled, decomposed into each element and coded for commonality using the same multi-pass data encoding method used during the first phase of the study. These responses were integrated into the final list of laser safety measures that were presented to the panel to rank in the third phase of the study.

Round 3

During Round 3 of the Delphi, the panel was presented the compiled list of factors and measures. Two of the panelists did not respond and were lost due to attrition. A sliding scale variant of a five-point Likert-type scale was used to allow the panel to provide their professional judgment of the relative value of each item. This scale scored responses to one-hundredth of a point. The responses are provided in Tables 11 to 16.

Table 11

Responses to Please rate the importance of each FACTOR of Laser Safety to an academic institution's laser safety climate.

Factor	**M**	**SD**	**σ2**	**Count**
Administrative Controls / Funding	4.47	0.66	0.44	19
Institutional Laser Safety Values	4.36	0.76	0.58	19
Leadership/Management Safety Values and Communication	4.23	0.64	0.42	19
Laser Safety Training Program	4.56	0.48	0.23	19
Integration of laser safety into Research Processes	4.11	1.00	1.00	19
Near Miss and Lessons Learned Program	3.91	0.90	0.81	19
Laser Safety Hazard Awareness/Risk Analysis Program	4.06	0.84	0.71	19
Personal Safety Values	4.34	0.73	0.53	19
Compliance Oversight / PPE Measurement and Audits	3.84	0.77	0.59	19
Engineering Controls	4.43	0.66	0.44	19

Table 12.

Responses to the item Please rate each group of Laser Safety Laser Leadership Management MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Measure	**M**	**SD**	**σ2**	**Count**
Oversight of Researchers by the Principle Investigator	3.90	0.92	0.86	19
LSO Staffing	3.87	0.98	0.97	18
Frequency of Lab Audits / Visits	3.29	0.80	0.64	19

Measure	M	SD	σ2	Count
Fiscal Support of Laser Safety Program	4.20	0.72	0.52	17
Explicit Safety Budget in Experimental Proposals	3.88	1.04	1.08	18
Annual Program Audits	3.86	0.80	0.63	18
Advance Laser Operation Planning	3.87	0.98	0.96	19
Laser Safety Compliance as a Tenure/Proposal Criterion	3.27	1.34	1.79	17
Compliance Oversight Program	4.02	0.67	0.46	19
Explicit Safety Budget in Experimental Proposals	3.76	1.05	1.09	18

Table 13

Responses to the item Please rate each group of Laser Safety Laser Administrative Control MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Measure	**M**	**SD**	**σ2**	**Count**
Compliance Check -Use and Selection of Proper Laser Eye Protection (LEP)	4.53	0.70	0.49	19
Compliance Check - Personal protective equipment (PPE),	4.34	0.79	0.62	18
Compliance Check -Use of Standard Operating Procedures	4.26	0.77	0.59	19
Compliance Check -Laser Operations Checklist	3.93	0.99	0.99	19
Experimental Protocols - Repeatable Experimental Protocols	3.71	1.07	1.14	18
Experimental Protocols - Advance Laser Operation Planning Time	3.94	0.88	0.78	18
Experimental Protocols - External Review of Processes	3.31	1.09	1.20	18
Experimental Protocols - Average Level of Laser Experience.	3.44	0.96	0.93	18
Verification / Rate of - Laser Safety Training	4.07	0.83	0.68	19
Verification / Rate of - Laser Safety Checklist	3.75	0.72	0.52	19
Verification / Rate of - Laser Operation Log	3.30	1.08	1.16	19
Verification / Rate of - Preventative Maintenance	3.44	1.16	1.34	19
Verification / Rate of - LSO Audits	3.65	0.94	0.89	18
Verification / Rate of - Annual Laser Facility Inspections	3.88	0.98	0.95	19
Verification / Rate of - Corrective Actions Due to Lab Inspections	4.11	1.00	0.99	18
Documentation - Laser Access Control	3.89	1.01	1.03	18
Documentation - Quality Standard Operating Procedures	4.03	0.76	0.58	19
Documentation - Accurate Laser Inventory	3.74	1.12	1.25	19
Documentation - Accident Reporting	4.48	0.72	0.51	19
Documentation - Injury Reporting	4.50	0.72	0.51	19
Documentation - Near Miss Reporting	4.07	0.98	0.96	19
Documentation- Laser Manuals Available	3.47	1.21	1.48	18

Table 14

Responses to the item Please rate each group of Laser Safety Laser Training MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Measure	M	SD	σ2	Count
Quality Measures of –Initial Training	4.47	0.56	0.31	19
Quality Measures of –On the Job Training (OJT)	4.49	0.73	0.53	19
Quality Measures of –Periodic Training	3.74	0.99	0.98	19
Quality Measures of –Tailored (Visitor, LSO, Professional Development)	3.57	1.10	1.22	19
Quality Measures of –Sufficient OJT Training Time	4.09	0.89	0.79	19
Quality Measures of –Hazard Analysis Training	3.74	1.09	1.18	19
Quality Measures of –Laser Safety Communications	4.14	0.88	0.78	19
Quality Measures of –User Feedback of Training Effectiveness	3.70	1.40	1.95	19
Quality Measures of –User Assessment Scores on Training	3.17	1.23	1.52	19
Documentation Measures - Periodic Training	3.78	1.05	1.10	19
Documentation Measures - Tailored (Visitor, LSO, Professional Development)	3.42	1.06	1.12	19
Documentation Measures - Performance on Periodic Refresher Training	3.41	1.22	1.49	18
Documentation Measures - Number of Hours of Required Laser Safety Training	2.84	1.16	1.34	18
Inclusion of – Lessons learned Training	3.92	1.18	1.39	19
Inclusion of – Hands-On Practical Alignment Training	4.12	1.22	1.48	19
Inclusion of – Training Measurement Should Include Correlating Incidents and Close Calls.	3.96	0.91	0.82	18
Inclusion of – User-Focused Accident Response in Case of Accidental Exposure	4.11	0.97	0.95	19

Table 15

Responses to the item Please rate each group of Laser Safety Laser Programmatic MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Measure	M	SD	σ2	Count
Documentation Measures - Laser Access Control	3.91	1.00	0.99	20
Documentation Measures - Quality Standard Operating Procedures	4.17	0.57	0.33	20
Documentation Measures - Accurate Laser Inventory	3.62	1.13	1.28	20
Documentation Measures - Hazard Mitigation /Response Plan	4.17	0.85	0.72	20
Documentation Measures - Accurate User Reported Incident History	3.86	1.06	1.11	20
Availability/Quality of Standard Operating Procedures (SOP) and Laser Checklist	4.29	0.62	0.39	20
Evaluation Measures - Use of Sops and Checklist	4.20	0.77	0.59	20
Evaluation Measures - Research Integration of LSO	3.39	1.13	1.28	19
Evaluation Measures - User Assessment Scores on Training	3.32	1.07	1.15	19
Evaluation Measures - Accident Rate	3.59	1.25	1.57	20
Evaluation Measures - Injury Rate	3.61	1.26	1.59	20
Evaluation Measures - Near Miss Rate	3.61	1.15	1.33	20
Evaluation Measures - Completion of Annual Laser Facility Inspections	3.74	0.97	0.94	20
Evaluation Measures - LSO To User Communication	4.37	0.65	0.43	20
Evaluation Measures - LSO Collateral or Primary Responsibility	3.37	1.33	1.76	20
Evaluation Measures - User-Initiated Communication to LSO	3.93	1.26	1.59	20
Evaluation Measures - List of Class 3B and 4 Users on Campus	3.93	1.11	1.24	19
Compliance Measures – Conducting Compliance Checks	3.96	0.93	0.86	20
Compliance Measures – Use and Selection of Proper Laser Eye Protection (LEP) And Other Personal Protective Equipment (PPE)	4.55	0.60	0.36	20
Compliance Measures – Use of Standard Operating Procedures and Operations Checklist	3.96	0.79	0.63	20

Measure	M	SD	σ2	Count
Measures of – Risk / Hazard Analysis Plan for Each Laser	3.98	0.86	0.74	19
Measures of – Annual Laser Facility Inspections	3.68	1.01	1.02	20
Measures of – Hazard Mitigation / Response Plan	3.57	1.13	1.27	20
Measures of – Continuous Hazard Awareness Procedure	3.62	0.98	0.95	20
Measures of – Hazard Awareness / Risk Assessment Included in Lab Notebooks	3.24	1.18	1.38	19
Engineering Control Measures – Availability and Use of Barriers	4.36	0.95	0.91	20
Engineering Control Measures – Laser Operation Lights	4.08	0.97	0.94	19
Engineering Control Measures – Use of Warning Devices and Signs	4.30	0.75	0.57	20
Risk Assessment Measures - Hazard Awareness / Risk Assessment Included in Lab Notebooks	3.32	1.31	1.70	19
Risk Assessment Measures - Hazard Mitigation /Response Plan	4.03	0.89	0.80	20

Table 16

Responses to the item Please rate each group of Laser Safety Laser Programmatic Effectiveness MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Measure	M	SD	σ2	Count
Compliance Rate - Laser Safety Training	4.31	0.52	0.27	20
Compliance Rate - Laser Safety Checklist	3.68	0.77	0.59	20
Compliance Rate - Laser Operation Log	3.08	1.45	2.10	20
Compliance Rate - Preventative Maintenance	3.21	1.40	1.96	20
Compliance Rate - LSO Audits	3.74	1.18	1.39	20
Compliance Rate - Risk / Hazard Analysis	3.76	0.95	0.90	20
Compliance Rate - Annual Laser Facility Inspections	3.95	0.76	0.57	20
Near Miss - Active Near Miss Program	3.48	1.25	1.57	20
Near Miss - Lessons Learned Program	3.56	1.27	1.60	20
Near Miss - Lessons Learned/Near Miss Discussion in Lab Notebooks	2.52	1.71	2.92	19

Measure	M	SD	σ2	Count
Near Miss - Completion of Near-Miss Assessment by Researchers	3.00	1.64	2.69	19
Evaluation Measures – Availability/Quality of Standard Operating Procedures (SOP) And Laser Checklist	3.88	0.91	0.83	20
Evaluation Measures – Use of SOPS and Checklist	3.98	0.85	0.72	20
Evaluation Measures – Research Integration of LSO	2.93	1.49	2.22	19
Evaluation Measures – User Assessment Scores on Training	3.26	1.38	1.90	19
Evaluation Measures – Accident Rate	3.42	1.38	1.92	20
Evaluation Measures – Injury Rate	3.53	1.42	2.02	20
Evaluation Measures – Near Miss Rate	3.30	1.56	2.43	20
Evaluation Measures – Completion of Annual Laser Facility Inspections	3.72	1.07	1.14	20
Evaluation Measures – LSO to User Communication	4.10	0.87	0.75	19
Evaluation Measures – LSO Collateral or Primary Responsibility	3.12	1.29	1.66	20
Evaluation Measures – User-Initiated Communication to LSO	3.80	1.02	1.04	20
Evaluation Measures – List of Class 3B and 4 Users on Campus	3.89	1.09	1.19	20
Compliance Measures - Conducting Compliance Checks	3.64	1.09	1.18	20
Compliance Measures - Use and Selection of Proper Laser Eye Protection (LEP) and Other Personal Protective Equipment (PPE)	4.55	0.46	0.21	20
Compliance Measures - Use of Standard Operating Procedures and Operations Checklist	4.03	0.66	0.43	20
Engineering Control Measures - Availability and Use of Barriers	4.30	0.65	0.42	20
Engineering Control Measures - Laser Operation Lights	3.92	1.15	1.32	19
Engineering Control Measures - Use of Warning Devices and Signs	4.22	0.78	0.60	20

Summary

This chapter presented the results of each phase of the Delphi research study. During phase one of the study, a panel of twenty-two experts evaluated if the laser safety climate of an academic institution could be measured. The panel of experts then proposed several factors or indications of an institution's laser safety climate. The Delphi panel proposed measures that could be used to evaluate the factors of laser safety. During phase two, all twenty-two experts responded to the survey. Each panelist was presented a list of factors and measures from the first phase and was asked if the list was complete. Each member was provided the ability to propose additional factor or measures as necessary. The findings from the prior phases were organized into groups of factors and measures and presented to the panel to evaluate the relative value of each factor and measure in phase three of the study. During this phase, 19 members of the panel responded to the survey. The panelists provided a numerical rating of each item using a sliding Likert type scale. The findings were compiled and developed into summary tables of factors and measures. Chapter V will summarize the report and draw conclusions based on the data collected.

CHAPTER V

Summary, Conclusions, and Recommendations

The purpose of this study was to determine if the laser safety climate can be measured at academic institutions. If the laser safety climate can be measured at academic institutions, which factors indicate the state of the laser safety climate. Finally, the study will suggest a set of measures to provide data to support prescriptive measures by laser safety professionals to improve laser safety at academic institutions. It is believed that a favorable laser safety climate would result in a safe learning environment, leading to fewer near-miss incidents, less equipment damage, and a low rate of laser injuries. This chapter will summarize the research, discuss the conclusions based on the findings, and provide recommendations for additional studies.

Summary

The purpose of this study was to determine if the laser safety climate can be measured at academic institutions and what factors would provide valid measures of the laser safety climate at academic institutions. The research questions developed before data collection were:

RQ_1. Can laser safety climate be measured at academic institutions using a climate survey instrument?

RQ_2. What factors should be measured by a laser safety climate instrument?

RQ_3. What measures would provide actionable data for prescriptive intervention by laser safety professionals at academic institutions?

The limitations of the study were as follows:

1. Although the Delphi research technique is recognized as a practical technique to anonymously facilitate expert discussion (Kennedy, 2003), obtain qualitative guidance and consensus about complex domains (Wakefield & Watson, 2014), and obtain reliable survey data

from experts (Hallowell & Gambatese, 2002), the methodology may have reduced accuracy, and reliability of the results (Woudenberg, 1991).

2. The effectiveness of the Delphi method may be subject to structural limitations based on the selection of experts, participation of panelists throughout a study, and the use of closed-ended items during some phases of the study.

3. The panel was selected based on information that was publicly available or was volunteered by the participants. It is possible that the selection criteria were too narrow or too broad, which could affect the quality of the study results.

4. Because the panel was actively recruited from the field of laser safety experts, the results may have been influenced by inadequate bias mitigations or a bias that was not identified.

This study used a purposive sample of 22 academic LSOs and laser safety experts, all of which participated in the study. The goal of assembling a panel of experts was supported by the expertise and experience data provided by 18 of 22 members of the study. The panel included representatives of a variety of academic institutions including university, government, and research lab LSOs. The average laser safety experience on the panel was 11.63 years. The panel included four LSOs who were primary or secondary journal authors, eight indicated they were invited speakers at laser safety conferences, nine members of nationally recognized laser safety committees, six book authors or editors of books on laser safety, seven members that held advanced degrees in the laser or photonics fields, and ten members who were certified laser safety officer (CLSO), and two members who were Certified Medical Laser Safety Officers (CMSLO).

Conclusions

The following conclusions were made to the research questions:

RQ_1. Can laser safety climate be measured at academic institutions using a climate survey instrument?

Based on the data collected from the Delphi panel, a consensus was reached that laser safety can be measured in the academic setting using a combination of the suggested measures to provide evidence that will support action by the laser safety specialist in specific areas of the academic climate.

When initially surveyed the panel, a slight majority of the panel indicated they were unsure if the laser safety climate of an academic institution could be measured. The panel developed a consensus on 10 laser safety factors (M = 4.23, SD = .744, $\sigma 2$ = .575), that should be monitored by an academic institutions LSO. Additionally, the panel suggested 79 potential diagnostic measures (M = 3.85, SD = .97, $\sigma 2$ = .99) that could be used to provide leading indications of an institution's status related to the identified laser safety factors. Although Delphi panels often use a cut score to determine the relevance of an item and indicate consensus, the overarching goal of this study was to develop a comprehensive list of laser safety factors and measures for future research. Had a cut score been set at 3.50 (Kosloski & Ritz), 63 of the 79 items would have been considered highly relevant to understanding an academic institutions laser safety climate.

RQ_2. What factors should be measured by a laser safety climate instrument?

The population of the study deemed the 10 laser safety factors as critical to identifying and reducing unsafe laser practices in the academic environment. The panel identified the following factors as leading indicators of laser safety:

- Laser Safety Training Program (M = 4.56, SD = 0.48, $\sigma 2$ = .23).
- Administrative Controls / Funding (M = 4.47, SD = 0.66, $\sigma 2$ = .44).

- Engineering Controls (*M* =4.43, *SD* = 0.66, σ2 = .44).
- Institutional Laser Safety Values (*M* = 4.36, *SD* = 0.76, σ2 = .58).
- Personal Safety Values (*M* = 4.34, *SD* = 0.73, σ2 = .53).
- Leadership/Management Safety Values and Communication (*M* = 4.23, *SD* = 0.64, σ2 = .42).
- Integration of laser safety into Research Processes (*M* = 4.11, *SD* = 1.00, σ2 = 1.00).
- Laser Safety Hazard Awareness/Risk Analysis Program (*M* = 4.06, *SD* = 0.84 σ2 = .71).
- Near Miss and Lessons Learned Program (*M* = 3.91, *SD* = 0.9, σ2 = .81).
- Compliance Oversight / PPE Measurement and Audits (*M* = 3.84, *SD* = 0.77, σ2 = .59).

The factors identified by the panel have a strong correlation to earlier work in the field such as the safety climate work of Zohar (1980, 2009) in the industrial setting, the work of Wu et al. (2007), and Gutierrez (2011) on the safety climate in the academic setting. However, the panel proposed measuring additional factors that are not currently part of safety climate instruments. The Delphi panel proposed that a safety climate instruments measure (1) the level of integration of into the research processes of an academic institution's laser safety officers, (2) the effectiveness of an institution's 'Near Miss and Lessons Learned Program', and (3) the effectiveness of an institution's 'Laser Safety Hazard Awareness/Risk Analysis Programs'. These additional safety climate factors would provide objective quality evidence (OQE) of leading indicators that could be used by institutional leadership for prescriptive intervention to reduce the rate of laser injuries and accidents in the academic setting. However, the panel was somewhat split regarding the value of these less-traditional factors, scoring them moderately lower than the median of the well understood items. The rating of the new factors and measures may reflect the level of familiarity of the panel as a whole with the concepts and theory related to these items.

RQ_3. What measures would provide actionable data for prescriptive intervention by laser safety professionals at academic institutions?

The Delphi approach was used to identify potential measures that could be used by an academic institution as leading indicators of the laser safety climate. Furthermore, the panel evaluated the relative value of each measure, arriving at a high level of consensus about the relative value of each measure. Although many Delphi studies use cutoff scores to indicate consensus, the goal of this study was the development of a comprehensive list of potential laser safety climate diagnostic measures. As such, the panel scored each potential laser safety measure based on the value of the measure as a diagnostic tool. The panel of experts identified 79 significant laser safety measures that could be used at academic institutions (see Tables 12 - Table 16). One widely accepted indication of consensus of an item when using the Delphi methodology is the use of a cutoff threshold, such as 3.50 on a 5.0 point Likert scale (Kosloski & Ritz). Had this standard been applied to this study, 79% of the measures would have exceeded this threshold, indicating a high level of relevance and consensus among the Delphi panel members about the value of the perposed set of digonostic measures.

The complete list of laser safety diagnostic measures was statically analyzed to determine the mean score, standard deviation, and variance among panel members. Means were utilized to indicate relevance, while standard deviation and variance were used to indicate consensus. Table

17 is the complete list of laser safety diagnostic measures the proposed by the panel arranged from the highest to lowest mean score.

Table 17.

List of Laser Safety Diagnostic Measures

Measure	*M*	*SD*	σ2
Compliance Measures – Use and Selection of Proper Laser Eye Protection (LEP) And Other Personal Protective Equipment (PPE)	4.55	0.60	0.36
Compliance Check -Use and Selection of Proper Laser Eye Protection (LEP)	4.53	0.70	0.49
Documentation - Injury Reporting	4.50	0.72	0.51
Quality Measures of –On the Job Training (OJT)	4.49	0.73	0.53
Documentation - Accident Reporting	4.48	0.72	0.51
Quality Measures of –Initial Training	4.47	0.56	0.31
Evaluation Measures - LSO To User Communication	4.37	0.65	0.43
Engineering Control Measures – Availability and Use of Barriers	4.36	0.95	0.91
Compliance Check - Personal protective equipment (PPE),	4.34	0.79	0.62
Engineering Control Measures – Use of Warning Devices and Signs	4.30	0.75	0.57
Availability/Quality of Standard Operating Procedures (SOP) and Laser Checklist	4.29	0.62	0.39
Compliance Check -Use of Standard Operating Procedures	4.26	0.77	0.59
Fiscal Support of Laser Safety Program	4.20	0.72	0.52
Evaluation Measures - Use of Sops and Checklist	4.20	0.77	0.59
Documentation Measures - Quality Standard Operating Procedures	4.17	0.57	0.33
Documentation Measures - Hazard Mitigation /Response Plan	4.17	0.85	0.72
Quality Measures of –Laser Safety Communications	4.14	0.88	0.78
Inclusion of – Hands-On Practical Alignment Training	4.12	1.22	1.48
Verification / Rate of - Corrective Actions Due to Lab Inspections	4.11	1.00	0.99
Inclusion of – User-Focused Accident Response in Case of Accidental Exposure	4.11	0.97	0.95
Quality Measures of –Sufficient OJT Training Time	4.09	0.89	0.79
Engineering Control Measures – Laser Operation Lights	4.08	0.97	0.94
Verification / Rate of - Laser Safety Training	4.07	0.83	0.68
Documentation - Near Miss Reporting	4.07	0.98	0.96
Documentation - Quality Standard Operating Procedures	4.03	0.76	0.58
Risk Assessment Measures - Hazard Mitigation /Response Plan	4.03	0.89	0.8
Compliance Oversight Program	4.02	0.67	0.46
Measures of – Risk / Hazard Analysis Plan for Each Laser	3.98	0.86	0.74
Inclusion of – Training Measurement Should Include Correlating Incidents and Close Calls.	3.96	0.91	0.82
Compliance Measures – Conducting Compliance Checks	3.96	0.93	0.86
Compliance Measures – Use of Standard Operating Procedures and Operations Checklist	3.96	0.79	0.63

Measure	*M*	*SD*	σ2
Experimental Protocols - Advance Laser Operation Planning Time	3.94	0.88	0.78
Compliance Check -Laser Operations Checklist	3.93	0.99	0.99
Evaluation Measures - User-Initiated Communication to LSO	3.93	1.26	1.59
Evaluation Measures - List of Class 3B and 4 Users on Campus	3.93	1.11	1.24
Inclusion of – Lessons learned Training	3.92	1.18	1.39
Documentation Measures - Laser Access Control	3.91	1.00	0.99
Oversight of Researchers by the Principle Investigator	3.90	0.92	0.86
Documentation - Laser Access Control	3.89	1.01	1.03
Explicit Safety Budget in Experimental Proposals	3.88	1.04	1.08
Verification / Rate of - Annual Laser Facility Inspections	3.88	0.98	0.95
LSO Staffing	3.87	0.98	0.97
Advance Laser Operation Planning	3.87	0.98	0.96
Annual Program Audits	3.86	0.8	0.63
Documentation Measures - Accurate User Reported Incident History	3.86	1.06	1.11
Documentation Measures - Periodic Training	3.78	1.05	1.1
Explicit Safety Budget in Experimental Proposals	3.76	1.05	1.09
Verification / Rate of - Laser Safety Checklist	3.75	0.72	0.52
Documentation - Accurate Laser Inventory	3.74	1.12	1.25
Quality Measures of –Periodic Training	3.74	0.99	0.98
Quality Measures of –Hazard Analysis Training	3.74	1.09	1.18
Evaluation Measures - Completion of Annual Laser Facility Inspections	3.74	0.97	0.94
Experimental Protocols - Repeatable Experimental Protocols,	3.71	1.07	1.14
Quality Measures of –User Feedback of Training Effectiveness	3.7	1.4	1.95
Measures of – Annual Laser Facility Inspections	3.68	1.01	1.02
Verification / Rate of - LSO Audits	3.65	0.94	0.89
Documentation Measures - Accurate Laser Inventory	3.62	1.13	1.28
Measures of – Continuous Hazard Awareness Procedure	3.62	0.98	0.95
Evaluation Measures - Injury Rate	3.61	1.26	1.59
Evaluation Measures - Near Miss Rate	3.61	1.15	1.33
Evaluation Measures - Accident Rate	3.59	1.25	1.57
Quality Measures of –Tailored (Visitor, LSO, Professional Development)	3.57	1.1	1.22
Measures of – Hazard Mitigation / Response Plan	3.57	1.13	1.27
Documentation- Laser Manuals Available	3.47	1.21	1.48
Experimental Protocols - Average Level of Laser Experience.	3.44	0.96	0.93
Verification / Rate of - Preventative Maintenance	3.44	1.16	1.34
Documentation Measures - Tailored (Visitor, LSO, Professional Development)	3.42	1.06	1.12
Documentation Measures - Performance on Periodic Refresher Training	3.41	1.22	1.49
Evaluation Measures - Research Integration of LSO	3.39	1.13	1.28
Evaluation Measures - LSO Collateral or Primary Responsibility	3.37	1.33	1.76
Evaluation Measures - User Assessment Scores on Training	3.32	1.07	1.15

Measure	*M*	*SD*	σ2
Risk Assessment Measures - Hazard Awareness / Risk Assessment Included in Lab Notebooks	3.32	1.31	1.70
Experimental Protocols - External Review of Processes	3.31	1.09	1.20
Verification / Rate of - Laser Operation Log	3.30	1.08	1.16
Frequency of Lab Audits / Visits	3.29	0.80	0.64
Laser Safety Compliance as a Tenure/Proposal Criterion	3.27	1.34	1.79
Measures of – Hazard Awareness / Risk Assessment Included in Lab Notebooks	3.24	1.18	1.38
Quality Measures of –User Assessment Scores on Training	3.17	1.23	1.52
Documentation Measures - Number of Hours of Required Laser Safety Training	2.84	1.16	1.34

Recommendations

The use of safety climate surveys has a long history in industry (Zhoar 1980, 2009) and the pedigree of safety climate instruments in the academic setting is more recent (Gutierrez, 2011; Wu et al., 2007). A laser safety climate survey would be an extension of these more established applications to provide the leading indicator of the laser safety climate in academic institutions. The development and validation of a proactive measurement instrument will provide objective quality evidence (OQE) that can be used as leading rather than lagging indicators of laser safety. This OQE will support the ability of laser safety professionals to prevent laser accidents or injuries at academic institutions by better understanding their laser safety climate, allowing for effective intervention.

Finally, this panel of experts proposed the addition of several innovative safety factors and measures to the more conventional safety climate survey format. The near miss and lessons learned, and hazard awareness factors could have a high level of generalizability to other settings lab and academic setting. Additional research should be conducted to determine if these factors and measures could be used in other settings to improve operational, manufacturing as well as laser safety procedures.

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APPENDIX A

List of Some of the Relevant ANSI Z136 Series Standards

1. *American National Standard for Safe Use of Optical Fiber Communication Systems Utilizing Laser Diodes and LED Sources* (ANSI Z136.2)
2. *American National Standard for Safe Use of in Health Care Facilities* (ANSI Z136.3)
3. *American National Standard for Safe Use of in Educational Institutions* (ANSI Z136.3)
4. *American National Standard for Safe Use of Lasers Outdoors* (ANSI Z136.6)
5. *American National Standard for Safe Use of Lasers in Research, Development, or Testing* (ANSI Z136.8)
6. *American National Standard for Safe Use of Lasers in Manufacturing Environments* (ANSI Z136.9)

APPENDIX B

Delphi Round 1 Survey Instrument

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Int

Introduction.

My name is John Settlemyer, and I am a graduate student at Old Dominion University researching the Laser Safety Climate at academic institutions. I have identified you as a leading laser safety professional by conducting an exhaustive review of the literature, conference proceedings, and academic information. I would appreciate your assistance determining if the Laser Safety Climate in the academic settings can be accurately and reliably measured by joining a team of experts in a Delphi study.

My background includes twenty years in the U.S. Navy, work as Technical Laser Safety Officer (TLSO) on the Navy's Long-Range Ocular Interrupter (LORI) and the Laser Weapon System (LAWS) projects, training development, and delivery and work as an Operations Engineer for the Littoral Combat Systems Program.

Request for Participation in a Laser Safety Delphi study

A Delphi is an anonymous panel of independent experts to obtain their judgment on a topic by arriving at a group consensus. This study will use the Delphi technique to determine if the laser safety climate can be measured, identify critical laser safety factors, and determine appropriate measures of the academic laser safety climate.

If you agree to join this study, it will be limited to three rounds, with subsequent rounds using a commercial survey software package to distribute and collect responses electronically. During these rounds, you will be provided descriptive statistics of the previous round's items with summary feedback discussing the reasoning of each choice. The survey will be a combination of Likert-like scales and open-ended items to measure the panel opinion and rank order of each item, reach consensus on the research questions. This process will allow you the opportunity to evaluate the entire panel's reasoning and reevaluate prior responses. Should the panel reach consensus on the questions prior to the third round, the study will be concluded.

Background and Importance.

Occupational Health and Safety Professionals are regularly asked to quantify the effectiveness of their campus safety programs. One gap in this knowledge is no method for professionals to measure and analyze your institution's laser safety climate. This lack of a validated instrument reduces the prescriptive measures available to diagnose issues and prevent a laser accident or injury in a lab or classroom.

The unique factors related to laser safety in the academic setting has been emphasized by the Laser Safety Institute of America in the 2012revision to the *American National Standards for Safe Use of Lasers in the Educational Institutions*, various subject related books and in professional presentations. Some sources indicate that academia may account for as much as 23% of all laser accidents and injuries. However, no scientifically validated survey tool has been developed to measure the laser safety climate of an academic institution. The goal of this study is to develop a list of factors and measures that will be used in such an instrument. The tool will provide safety professionals with a tool for proactive laser safety actions.

Informed Consent

INFORMED CONSENT DOCUMENT

OLD DOMINION UNIVERSITY

PROJECT TITLE: A Study to Determine How to Measure the Laser Safety Climate at Academic Institutions

INTRODUCTION

The purposes of this form are to give you information that may affect your decision whether to say YES or NO to participation in this research, A Study to Determine How to Measure the Laser Safety Climate at Academic Institutions, and to record the consent of those who say YES.

RESEARCHERS

Michael F. Kosloski, Ph.D. in Occupational and Technical Studies, Education, STEM Education & Professional Studies
John M. Settlemyer, MS candidate, Occupational and Technical Studies.

DESCRIPTION OF RESEARCH STUDY

Several studies have been conducted looking into the subject of university employee safety climate. None of them have described the unique cultural factors between the academic and industrial settings affecting the laser safety climate in academic labs. Some of the factors that may affect university laser safety include institutional dynamics and resources, research group dynamics, laser hazard identification and risk analysis, and operator training and qualification.

If you decide to participate, then you will join a study involving research of the safety academic laser safety climate. This research will collect information using the Delphi method which will include email and up to two online surveys. If you say YES, then your participation will last for about thirty minutes during each contact electronic contact. Approximately 15-30 of laser safety experts will be participating in this study.

EXCLUSIONARY CRITERIA
To participate in a Delphi study you should be a highly a qualified expert in laser safety. Each potential panelist has been approached because the researcher found that a combination of professional achievement to indicate your professional standing. You should be considered highly a qualified expert, each panelist was examined for a combination of professional achievement that include at least two of the following criteria:

- Primary or secondary writer peer-reviewed laser safety journal articles.
- Invited conference speaker at a laser safety conference.
- Member or chair of a nationally recognized laser safety committee.
- At least 5 years of professional experience as a laser safety officer.
- Laser or photonics faculty member at an accredited institution of higher learning.
- Writer or editor of a book or book chapter on the topic of laser safety, or laser risk management.
- Advanced degree in the field of the laser, photonics fields.
- Professional registration such as a certified laser safety officer (CLSO).
- Certified Safety Professional (CSP) Laser or Photonics

To the best of your knowledge, you should not have any exclusionary criteria that would keep you from participating in this study and bias your judgment about laser safety climate in the academic environment such as having recently suffered a laser accident.

RISKS AND BENEFITS
RISKS: If you decide to participate in this study, then you may face a risk of loss of confidentiality. The researcher tried to reduce these risks by collecting your responses and removing all PII to protect your identity, analyzing and presenting data in aggregate and storing all data on encrypted removable media. However, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS: You may receive no direct benefit or harm from completing the study. Others may benefit by in improved laser safety on our campus and others applications in the future.

COSTS AND PAYMENTS

The researchers are unable to give you any payment for participating in this study.

NEW INFORMATION
If the researchers find new information during this study that would reasonably change your decision about participating, then they will give it to you.

CONFIDENTIALITY
The researchers will take reasonable steps to keep private information, such as questionnaire and responses, confidential, The researcher will remove identifiers from the information, destroy tapes, store information in a locked filing cabinet prior to its processing. The results of this study may be used in reports, presentations, and publications; but the researcher will not identify you. Of course, your records may be subpoenaed by court order or inspected by government bodies with oversight authority.

WITHDRAWAL PRIVILEGE

It is OK for you to say NO. Even if you say YES now, you are free to say NO later, and walk away or withdraw from the study -- at any time. Your decision will not affect your relationship with Old Dominion University, or otherwise cause a loss of benefits to which you might otherwise be entitled.

COMPENSATION FOR ILLNESS AND INJURY
If you say YES, then your consent in this document does not waive any of your legal rights. However, in the event of, harm, injury or illness arising from this study, neither Old Dominion University nor the researchers are able to give you any money, insurance coverage, free medical care, or any other compensation for such injury. In the event that you suffer injury as a result of participation in any research project, you may contact Michael F. Kosloski at (757) 683-3314 or John M. Settlemyer at (804) 878-6386, Dr. Laura Chezan, the current IRB chair at 757-683-7055 at Old Dominion University, or the Old Dominion University Office of Research at 757-683-3460 who will be glad to review the matter with you.

VOLUNTARY CONSENT
By signing this form, you are saying several things. You are saying that you have read this form or have had it read to you, that you are satisfied that you understand this form, the research study, and its risks and benefits. The researchers should have answered any questions you may have had about the research. If you have any questions later on, then the researchers should be able to answer them:

Dr. Michael F. Kosloski at (757) 683-3314 or John M. Settlemyer at (804) 878-6386.

If at any time you feel pressured to participate, or if you have any questions about your rights or this form, then you should call Dr. Dr. Laura Chezan, the current IRB chair at 757-683-7055, or the Old Dominion University Office of Research, at 757-683-3460.

And importantly, by signing below, you are telling the researcher YES, that you agree to participate in this study. The researcher should give you a copy of this form for your records.

Subject's Printed Name & Signature	Date
Parent / Legally Authorized Representative's Printed Name & Signature (If applicable)	Date
Witness' Printed Name & Signature (If Applicable)	Date

INVESTIGATOR'S STATEMENT

I certify that I have explained to this subject the nature and purpose of this research, including benefits, risks, costs, and any experimental procedures. I have described the rights and protections afforded to human subjects and have done nothing to pressure, coerce, or falsely entice this subject into participating. I am aware of my obligations under state and federal laws, and promise compliance. I have answered the subject's questions and have encouraged him/her to ask additional questions at any time during the course of this study. I have witnessed the above signature(s) on this consent form.

- Grant Consent
- Deny Consent

Section 1 - First Round Questions.

Can the laser safety climate be measured?

- Yes
- No
- Unsure

Please include a short discussion of your answer?

What do you consider the three most important factors that indicate a positive laser safety climate?

Are there specific measures/indicators an LSO should collect related to these factors?

What are the three most important factors that indicate a negative laser safety climate?

Are there specific measures/indicators an LSO should collect related to these factors?

SECTION 5 - GENERAL INFORMATION

The following demographic information is voluntary but will assist the researcher to validate the results of the study.

The critical characteristics of a Delphi study have been identified by experts as the selection of expert panelist, anonymity, iteration, feedback, and the statistical aggregation of the response set. Each potential panelist has been approached because the researcher found that a combination of characteristics using publicly available data to indicate professional achievement standing as an expert. The following demographic information will be used by the researcher to validate the selection process of the panelist when the findings are reported.

Primary or secondary writer peer-reviewed laser

safety journal articles	
Invited conference speaker at a laser safety conference.	
Member or chair of a nationally recognized laser safety committee	
Years of professional experience as a laser safety officer	
Laser or photonics faculty member at an accredited institution of higher learning	
Writer or editor of a book or book chapter on the topic of laser safety, or laser risk management	
Advanced degree in the field of the laser, photonics field.	
Professional registration such as a certified laser safety officer (CLSO)	
Certified Safety Professional (CSP) Laser or Photonics	

What to expect in the next phase of the Delphi study.

The results of this phase will be compiled and released to the panel within thirty days after the Delphi is convened. The second and third phases should require about thirty minutes of your time consider the results of the prior phase, evaluate and rank the proposed laser safety factors, and measures. The third round of the Delphi will provide you with a chance to consider the panel's response to each factor item. You will be asked to rank the order of each item's value to provide prescriptive data to the academic institution's laser safety officer. Should you need additional space for any response please email directly at jsett006@odu.edu.

I appreciate your help in shaping this important research by joining this Delphi study.

Best Regards,

John

John Settlemyer
804.878.6386
Jsett006@odu.edu

APPENDIX C

Delphi Round 2 Survey Instrument

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Thank you for participating in round two of the Delphi study. The results of the first phase have been compiled and should require less than 5 minutes of your time consider the results.

Please review our informed consent form before proceeding.

Odu informed consent document laser safety climate Delphi

- Grant Consent
- Deny Consent

Section 1 - Second Round Questions.

The panel identified list factors and measures of a positive laser safety climate in the first phase of the study. During this phase of the Delphi study, we ask that you evaluate if the list of proposed laser safety factors and measure is is complete and propose any additional factors or measures that should be included in the data set of the final Delphi round.

Please evaluate if the list of laser safety FACTORS is complete.

- Administrative Controls
- Institutional Laser Safety Values
- Leadership/Management Safety Values
- Laser Safety Training Program
- Integration of Laser Safety Officer into the Research Processes
- Near Miss Program
- Laser Safety Hazard Awareness/Risk Analysis Program
- Personal safety Values
- Compliance Measurement
- Engineering Controls

- Agree, the List is Complete
- Disagree List of Factors is incomplete

(Optional) Please propose any additional Laser Safety Factors that should be included in the list.

The Delphi panel proposed 83 safety measures that were compiled, decomposed into each element and coded for commonality using a multi-pass data encoding process. Responses were grouped into measurement categories thus some measures are included multiple factors and will appear in more than one section.

To propose additional measures, please include those items in the final open-ended question.

Please evaluate if the list of Laser Safety Leadership / Management MEASURES is complete.

- Principle Investigator Oversight of Researchers
- LSO Staffing Level
- The Frequency of Lab Audits
- The Frequency of Unannounced Lab Visits
- Annual Program Audits
- Fascial Support of Laser Safety.
- Explicit Safety Budget in Experimental Proposals.
- Advance Laser Operation Planning.
- Laser Safety Compliance as a Criterion of Tenure
- Laser Safety Compliance as a Criterion of Proposal Review

- Agree, the List is Complete

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Disagree; the Leadership / Management List is Incomplete

Please evaluate if the list of Laser Safety Laser Administrative Control MEASURES is complete.

Compliance Check Measures

- Use and Selection of Proper Laser Eye Protection (LEP)
- Use and selection of Proper Personal Protective Equipment (PPE)
- Use of Standard Operating Procedures
- Use of laser Operation Checklist.

Experimental protocols Measures

- Repeatable Experimental Protocols
- Advance Laser Operation Planning Time
- External Review of Experimental Processes
- Average Level of Laser Experience

Verification Rates

- Laser Safety Training
- Laser Safety Checklist
- Laser Operation Log
- Preventative Maintenance
- LSO Audits
- Annual Laser Facility Inspections

Laser Program Documentation Measures

- Laser Access Control,
- Quality Standard Operating Procedures,
- Accurate Laser Inventory, the
- The Rate of Corrective Actions Due to Lab Inspections,
- Accident Reporting,
- Injury Reporting,
- Near Miss Reporting.

Agree, the List is Complete

Disagree; the Administrative Control List is Incomplete

Please evaluate if the list of Laser Safety Training MEASURES is complete.

Documentation Measures

- Initial Laser Safety Training
- On the job training (OJT)
- Periodic Laser Safety Training
- Tailored Training (visitor, LSO, professional development))
- Performance on Periodic Refresher Training
- Number of Hours (Depth and Breadth) of Required Laser Safety Training

Evaluation Measures

- Initial Laser Safety Training
- On the Job Training (OJT)
- Periodic Laser Safety Training
- Tailored Training (visitor, LSO, professional development))
- Sufficient OJT Training Time
- Hazard analysis training
- Laser Safety Communications
- User feedback of Training Effectiveness
- User Assessment Scores on Training

Agree, the List is Complete

Disagree; the Laser Safety Training List is Incomplete

Please evaluate if the list of Laser Safety Programmatic MEASURES is complete.

Documentation Measures

- Laser Access Control

- Quality Standard Operating Procedures
- Accurate Laser Inventory
- Hazard Mitigation / Response Plan
- Accurate User Reported Incident History

Evaluation Measures

- Availability/quality of Standard Operating Procedures (SOP) and laser checklist
- Use of SOPs and checklist
- Research integration of LSO
- User assessment scores on training
- Laser Accident Rate
- Laser Injury rate
- Laser Near Miss Rate
- Completion of Annual Laser Facility Inspections
- LSO to User Communication
- LSO Collateral or Primary Responsibility
- User-Initiated Communication to LSO
- List of Class 3B and 4 Users on Campus

Compliance Measure Progam

- Conducting Compliance Checks
- Use and Selection of Proper Laser Eye Protection (LEP) and other Personal Protective Equipment (PPE),
- Use of Standard Operating Procedures and Operations checklist

Hazard Awareness/Risk Assessment Measures

- Risk / Hazard analysis plan for each laser,
- Annual Laser Facility Inspections
- Hazard Mitigation / Response Plan,
- Continuous Hazard Awareness Procedure
- Hazard Awareness / Risk Assessment Included in Lab Notebooks

Engineering Control Measures

- Availability and use of barriers
- Laser operation lights
- Use of warning devices and signs

○ Agree, the List is Complete

○ Disagree; the Programmatic List is Incomplete

Please evaluate if the list of Laser Safety Programmatic - Effectiveness MEASURES is complete.

Compliance Rate

- Laser Safety Training
- laser Safety Checklist
- Laser Operation Log
- Preventative Maintenance,
- LSO Audits,
- Risk / Hazard Analysis,
- Annual Laser Facility Inspections

Near Miss

- Active near miss program
- Lessons Learned Program
- Lessons Learned / Near Miss Discussion in Lab Notebooks
- Completion of Near-Miss Assessment by Researchers

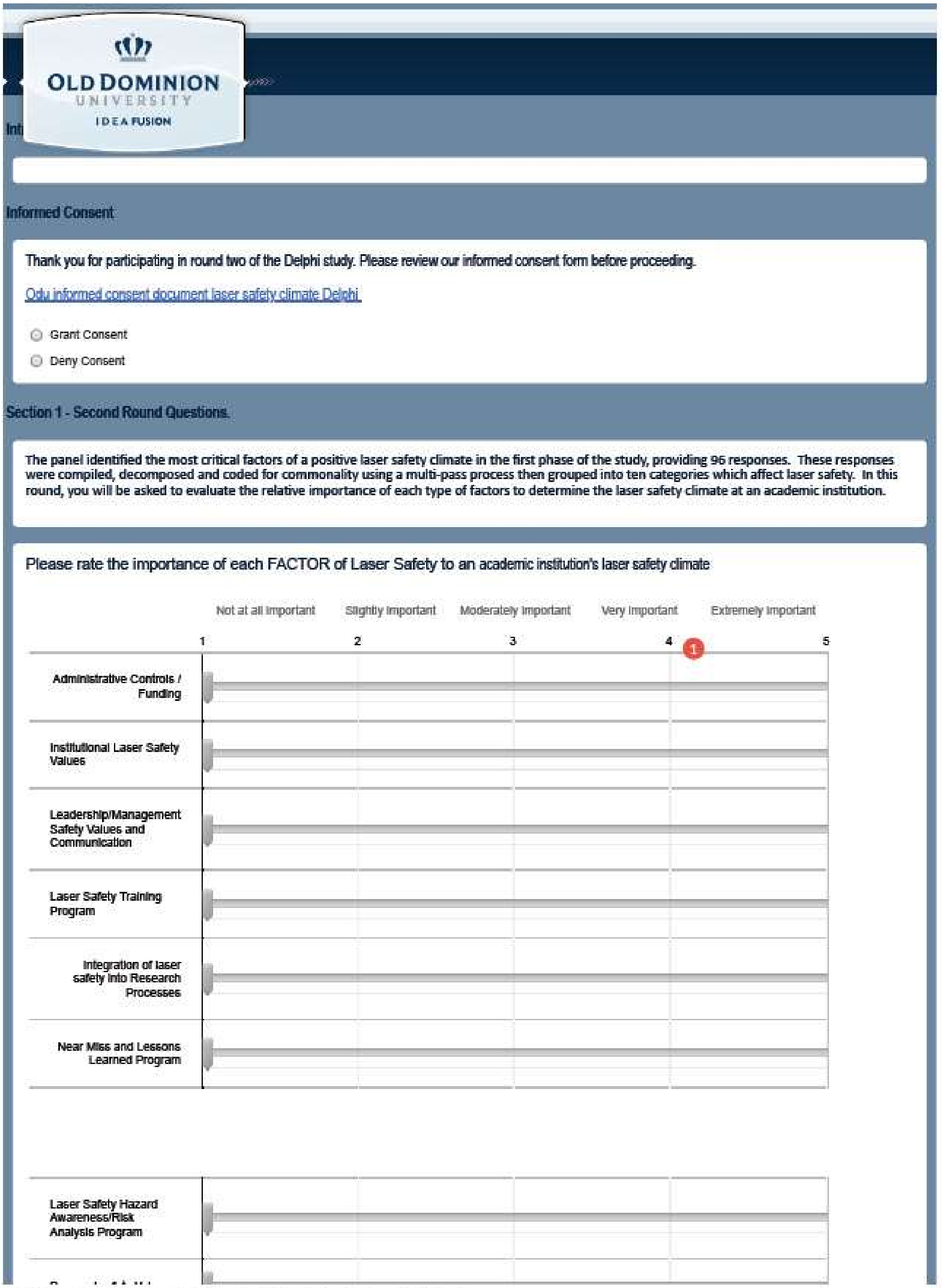
○ Agree, the List is Complete

○ Disagree; the Programmatic Effectiveness List is Incomplete

(Optional) Please include any additional Laser Safety Measures that should be included in the list.

APPENDIX D

Delphi Round 3 Survey Instrument



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Informed Consent

Thank you for participating in round two of the Delphi study. Please review our informed consent form before proceeding.

Odu informed consent document laser safety climate Delphi

- Grant Consent
- Deny Consent

Section 1 - Second Round Questions

The panel identified the most critical factors of a positive laser safety climate in the first phase of the study, providing 96 responses. These responses were compiled, decomposed and coded for commonality using a multi-pass process then grouped into ten categories which affect laser safety. In this round, you will be asked to evaluate the relative importance of each type of factors to determine the laser safety climate at an academic institution.

Please rate the importance of each FACTOR of Laser Safety to an academic institution's laser safety climate

	Not at all important (1)	Slightly important (2)	Moderately important (3)	Very important (4)	Extremely important (5)
Administrative Controls / Funding					
Institutional Laser Safety Values					
Leadership/Management Safety Values and Communication					
Laser Safety Training Program					
Integration of laser safety into Research Processes					
Near Miss and Lessons Learned Program					
Laser Safety Hazard Awareness/Risk Analysis Program					

Personal safety values

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Compliance Oversight / PPE Measurement and Audits					
Engineering Controls					

The panel provided 83 safety measures that were compiled, decomposed into each element and coded for commonality using a multi-pass data encoding. These responses were grouped into fourteen measurement categories. In round 2 the Delphi will be asked to evaluate and score the relative value of each group of measurements:

Please rate each group of Laser Safety Laser Leadership Management MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Oversight of Researchers by the Principle Investigator					
LSO Staffing					
Frequency of Lab Audits / Visits					
Fiscal Support of Laser Safety Program					
Explicit Safety Budget in Experimental Proposals					
Annual Program Audits					
Advance Laser Operation Planning					
Laser Safety Compliance as a Tenure/Proposal Criterion					
Compliance Oversight Program					
Explicit Safety Budget in Experimental Proposals					

Please rate each group of Laser Safety Laser Administrative Control MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

	Not at all Important 1	Slightly Important 2	Moderately Important 3	Very Important 4	Extremely Important 5
Compliance Check - Use and Selection of Proper Laser Eye Protection (LEP)					
Compliance Check - Personal protective equipment (PPE),					
Compliance Check - Use of Standard Operating Procedures					
Compliance Check - Laser Operations Checklist					
Experimental Protocols- Repeatable Experimental Protocols,					
Experimental Protocols- Advance Laser Operation Planning Time					
Experimental Protocols- External Review of Processes					
Experimental Protocols- Average Level of Laser Experience.					
Verification / Rate of - Laser Safety Training					
Verification / Rate of - Laser Safety Checklist					
Verification / Rate of - Laser Operation Log					
Verification / Rate of - Preventative Maintenance					
Verification / Rate of - LSO Audits					
Verification / Rate of -					

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Annual Laser Facility Inspections					
Verification / Rate of - Corrective Actions Due to Lab Inspections					
Documentation - Laser Access Control					
Documentation - Quality Standard Operating Procedures					
Documentation - Accurate Laser Inventory					
Documentation - Accident Reporting					
Documentation - Injury Reporting					
Documentation - Near Miss Reporting					
Documentation- Laser Manuals Available					

Please rate each group of Laser Safety Laser Training MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Quality Measures of – Initial Training					
Quality Measures of – On the Job Training (OJT)					
Quality Measures of – Periodic Training					
Quality Measures of – Tailored (Visitor, LSO, Professional Development)					
Quality Measures of – Sufficient OJT Training Time					

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Quality Measures of – Hazard Analysis Training					
Quality Measures of – Laser Safety Communications					
Quality Measures of – User Feedback of Training Effectiveness					
Quality Measures of – User Assessment Scores on Training					
Documentation Measures - Periodic Training					
Documentation Measures - Tailored (Visitor, LSO, Professional Development)					
Documentation Measures - Performance on Periodic Refresher Training					
Documentation Measures - Number of Hours Of Required Laser Safety Training					
Inclusion of – Lessons learned Training					
Inclusion of – Hands-On Practical Alignment Training					
Inclusion of – Training Measurement Should Include Correlating Incidents and Close Calls.					
Inclusion of – User Focused Accident Response In Case of Accidental Exposure					

Please rate each group of Laser Safety Laser Programmatic MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	1	2	3	4	5
Documentation Measures - Laser Access Control					
Documentation Measures - Quality Standard Operating Procedures					
Documentation Measures - Accurate Laser Inventory					
Documentation Measures - Hazard Mitigation /Response Plan					
Documentation Measures - Accurate User Reported Incident History					
Availability/Quality of Standard Operating Procedures (SOP) And Laser Checklist					
Evaluation Measures - Use of Sops and Checklist					
Evaluation Measures - Research Integration of LSO					
Evaluation Measures - User Assessment Scores on Training					
Evaluation Measures - Accident Rate					
Evaluation Measures - Injury Rate					
Evaluation Measures - Near Miss Rate					
Evaluation Measures - Completion of Annual Laser Facility Inspections					
Evaluation Measures - LSO To User Communication					

	1 Not at all important	2 Slightly important	3 Moderately important	4 Very important	5 Extremely important
Evaluation Measures - LSO Collateral or Primary Responsibility					
Evaluation Measures - User-Initiated Communication to LSO					
Evaluation Measures - List of Class 3B and 4 Users on Campus					
Compliance Measures – Conducting Compliance Checks					
Compliance Measures – Use and Selection of Proper Laser Eye Protection (LEP) And Other Personal Protective Equipment (PPE)					
Compliance Measures – Use of Standard Operating Procedures and Operations Checklist					
Measures of – Risk / Hazard Analysis Plan for Each Laser					
Measures of – Annual Laser Facility Inspections					
Measures of – Hazard Mitigation / Response Plan					
Measures of – Continuous Hazard Awareness Procedure					
Measures of – Hazard Awareness / Risk Assessment Included in Lab Notebooks					
Engineering Control Measures – Availability and Use of Barriers					
Engineering Control Measures – Laser Operation Lights					

Engineering Control Measures – Use of Warning Devices and Signs

Not at all important | Slightly important | Moderately important | Very important | Extremely important

1 2 3 4 5

Risk Assessment Measures - Hazard Awareness / Risk Assessment Included in Lab Notebooks

Risk Assessment Measures - Hazard Mitigation /Response Plan

Please rate each group of Laser Safety Laser Programmatic Effectiveness MEASURES on a scale of Importance to determine the laser safety climate at an academic institution.

Not at all important | Slightly important | Moderately important | Very important | Extremely important

0 1 2 3 4 5

Compliance Rate - Laser Safety Training

Compliance Rate - Laser Safety Checklist

Compliance Rate - Laser Operation Log

Compliance Rate - Preventative Maintenance

Compliance Rate - LSO Audits

Compliance Rate - Risk / Hazard Analysis

Compliance Rate - Annual Laser Facility Inspections

Near Miss - Active Near Miss Program

Near Miss - Lessons Learned Program

Near Miss - Lessons Learned/Near Miss Discussion in Lab Notebooks

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	0 1	2	3	4	5
Near Miss - Completion of Near-Miss Assessment by Researchers					
Evaluation Measures – Availability/Quality of Standard Operating Procedures (SOP) And Laser Checklist					
Evaluation Measures – Use of SOPS and Checklist					
Evaluation Measures – Research Integration of LSO					
Evaluation Measures – User Assessment Scores on Training					
Evaluation Measures – Accident Rate					
Evaluation Measures – Injury Rate					
Evaluation Measures – Near Miss Rate					
Evaluation Measures – Completion of Annual Laser Facility Inspections					
Evaluation Measures – LSO to User Communication					
Evaluation Measures – LSO Collateral or Primary Responsibility					
Evaluation Measures – User-Initiated Communication to LSO					
Evaluation Measures – List of Class 3B and 4 Users on Campus					

Compliance Measures - Conducting Compliance Checks					

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
	0 1	2	3	4	5
Compliance Measures - Use and Selection of Proper Laser Eye Protection (LEP) and Other Personal Protective Equipment (PPE)					
Compliance Measures - Use of Standard Operating Procedures and Operations Checklist					
Engineering Control Measures - Availability and Use of Barriers					
Engineering Control Measures - Laser Operation Lights					
Engineering Control Measures - Use of Warning Devices and Signs					