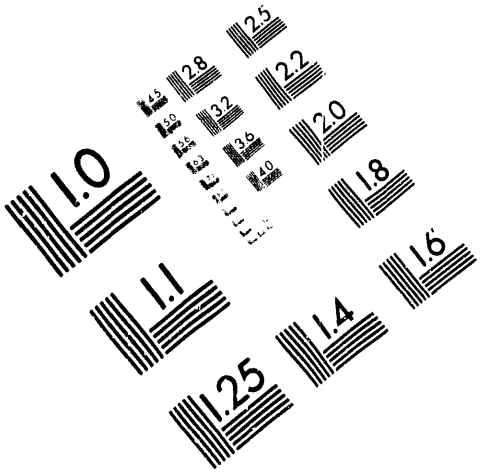

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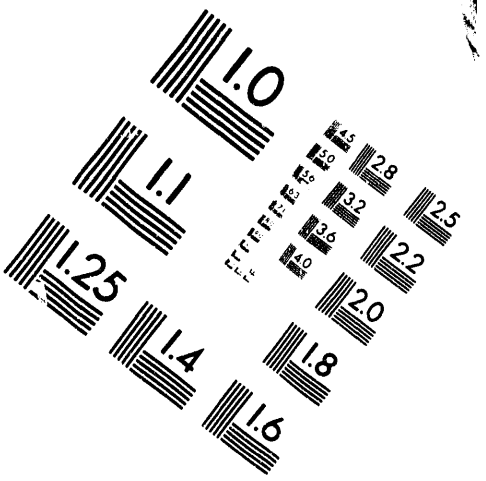

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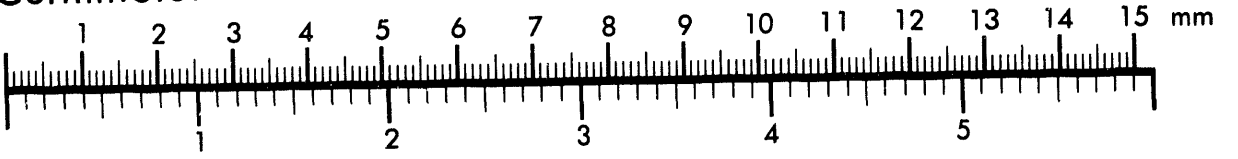

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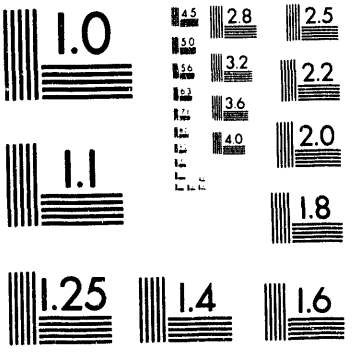

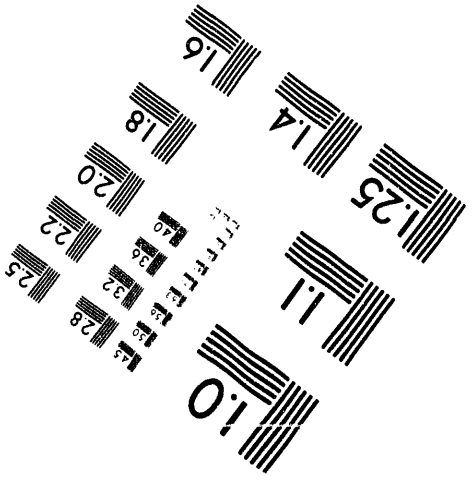

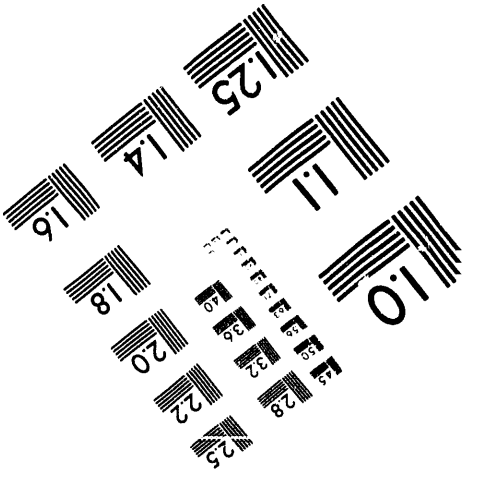

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Safety Approaches for High Power Modular Laser Operation

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Safety Approaches for High Power Modular Laser Operation

Abstract

Approximately 20 years ago, a program was initiated at the Lawrence Livermore National Laboratory (LLNL) to study the feasibility of using lasers to separate isotopes of uranium and other materials. Of particular interest has been the development of a uranium enrichment method for the production of commercial nuclear power reactor fuel to replace current more expensive methods. The Uranium Atomic Vapor Laser Isotope Separation (U-AVLIS) Program has progressed to the point where a plant-scale facility to demonstrate commercial feasibility has been built and is being tested. The U-AVLIS Program uses copper vapor lasers which pump frequency selective dye lasers to photoionize uranium vapor produced by an electron beam. The selectively ionized isotopes are electrostatically collected.

The copper lasers are arranged in oscillator/amplifier chains. The current configuration consists of 12 chains, each with a nominal output of 800 W for a system output in excess of 9 kW. The system requirements are for continuous operation (24 h a day, 7 days a week) and high availability. To meet these requirements, the lasers are designed in a modular form allowing for rapid change-out of the lasers requiring maintenance. Since beginning operation in early 1985, the copper lasers have accumulated over 2 million unit hours at a >90% availability. The dye laser system provides approximately 2.5 kW average power in the visible wavelength range.

This large-scale laser system has many safety considerations, including high-power laser beams, high voltage, and large quantities (~3000 gal) of ethanol dye solutions. The Laboratory's safety policy requires that safety controls be designed into any process, equipment, or apparatus in the form of engineering controls. Administrative controls further reduce the risk to an acceptable level. Selected examples of engineering and administrative controls currently being used in the U-AVLIS Program are described.

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Introduction

Laser safety standards[1,2] utilize an alpha-numeric hazard classification scheme for laser systems and products. The established classes are 1, 2, 2a, 3a, 3b, and 4. Each class includes those laser radiation parameters with similar hazard potential. Class 1 is considered non-hazardous and Class 4 poses an acute potential hazard both from direct and scattered laser radiation. The hazard associated with each of the remaining classes falls between those two extremes. Engineering, labeling, and administrative control requirements are determined by the level of laser radiation accessible at various times. The overall classification of a particular laser system depends on the level of laser radiation being produced by the system, along with two other considerations. The first is the concept of "human access" or "accessible radiation" which is essentially the ability to intercept laser radiation with a part of the body. In addition, classification is based on access during "operation" only. Operation is distinct from "maintenance" and "service" procedures (as defined in the standards), and human access during such procedures does not affect the overall system classification. It is, therefore, possible, and quite common, for a laser system to contain higher internal levels of laser radiation than the overall system class designation. The laser radiation is enclosed, contained, or reduced in intensity within the device or structure and is, therefore, not accessible. Every-day examples include compact disc (CD) players and laser printers which are Class 1 systems because there is no human access above Class 1 levels during their intended modes of operation.

The copper and dye laser systems used in the U-AVLIS Program are Class 1 systems. In addition, wherever possible, maintenance and service procedures are also accomplished under Class 1 conditions. This philosophy extends to other hazards as well. Several of the engineering and administrative controls used are described below.

Worker Qualifications

Only properly qualified and trained personnel are permitted unescorted entry into these controlled areas. Lead Experimenters/Responsible Individuals (LE/RI) are designated for each portion of an operation, and these first line managers are responsible for assuring that all personnel under their supervision have the necessary classroom and on-the-job training which allows safe performance of each assigned task. Minimum training requirements are developed from regulatory requirements, LLNL training policies, Laser Programs training policies, and LE/RI-developed requirements. Necessary training is described in a Facility Safety Procedures (FSP)[3] manual which authorizes specific activities and establishes the basic safety controls for a facility

complex. A list of training requirements and proof of completion are maintained in a Laboratory Safety Notebook which is available in the work area.

Workplace Entry Control

Entry control panels ensure that only properly qualified personnel enter laboratories and/or the large industrial size systems. A status panel indicates the level of laser activity within the area and includes a cipher keypad for entry of access codes issued through a central office. Only adequately trained personnel thoroughly knowledgeable of the hazards and the specific operation taking place in that area are issued these codes.

These panels are primarily an administrative control measure but may be part of an engineering control when a safety interlock is also tied into the system. When a safety interlock is tied in, in accordance with the LLNL Health and Safety Manual[4], the interlock may only be bypassed by an authorized individual if there is no laser radiation present at the point of entry/exit, required protective devices are worn by personnel entering the area, and a 15-second clock designed into the interlock control circuit will automatically reactivate the interlock chain. The entry control interlock must also be tied to the cipher lock, and there may be no hazards other than the laser radiation. In the case of an emergency, an override is provided which will unlock the door. Use of this bypass when exposed laser levels are above 15 mW will cause the lasers to be shuttered in a safe configuration or shut down by other means.

Laser System Interlocks

Laser system interlocks are an example of an engineering control measure used to prevent human access and, in conjunction with protective housings, to ensure that many systems containing high levels of laser radiation can be classified as Class 1 lasers. The interlocks used in the U-AVLIS systems activate shutters which are designed to close in a fraction of a second. For example, the copper laser oscillator uses a fail-safe, air operated piston which forces a metal slide across the output aperture of each laser tube. Moreover, when one interlock is opened, all shutters in a chain close to prevent spontaneous emissions from any part of the chain.

The interlock systems are in operation at all times except during very specific and limited maintenance or service procedures. In those few cases where access to higher levels of laser radiation is unavoidable, and this engineering control measure must be bypassed, appropriate administrative control measures are implemented to ensure continued safety. This includes the use of portable laser barriers to limit unnecessary access and potential exposure as required by the American National Standards Institute (ANSI) Z136.1[1] standard. Where these procedures are known to be a frequently recurring situation, permanent sliding accordion doors made of laser resistant materials and equipped with interlocks have been installed at appropriate points. Temporary controlled area warning

signs as required by ANSI Z136.1 are also posted for all barriers. In addition, only authorized personnel are permitted in the corridor and they are in direct communication by radio with the system operator located in a central control room. The interlock system can only be over-ridden when everyone confirms that conditions necessary for the safe accomplishment of the procedure are in place.

The copper laser hardware currently being built also utilizes light emitting diode (LED) interlock status indicators as part of each interlock. These status lights give visual confirmation that each interlock is in place and functioning. As a further protection, these new systems require the operators in the laser corridor to re-activate the interlock system from their location. The lasers will not operate unless all interlocks are closed and the reset feature activated.

Dye Laser Safety

The U-AVLIS dye laser system utilizes several dye circulation loops, the largest of which contain 691 gal (2616 L) of ethanol with typically a 10^{-4}M concentration of R4 or R6G dye solution. The total dye solution is approximately 3000 gal (11,356 L). In terms of safety specific to these systems, two areas immediately become apparent:

The dyes are being used and their solvent.

A discussion of the industrial hygiene concerns of laser dyes used at LLNL was presented at the 1990 International Laser Safety Conference.[5] The dyes used in the system have been tested and found to be non-mutagenic and non-carcinogenic; however, they are handled as moderately toxic materials. In addition, all personnel with potential for exposure to dye and/or dye solutions are required to attend periodic safety classes on dye/solvent hazards.

Crystalline dye is only handled during mixing with ethanol solvent. Typically, 1 to 4 gal (4 to 15 L) of heated, concentrated dye solution are prepared in a ventilated hood. Personnel are required to wear lab coats, chemically resistant gloves, and face shields. The concentrated dye solution is transferred to the dye pump/filter building for further dilution in specially designed mixing tanks and subsequent injection into the dye flow system.

A number of detection systems also monitor the environment, operation, and condition of the dye flow system. Ethanol detectors are installed which will shut down the system on detection of either vapor or liquid. Ventilation to remove any vapors assures that a fire does not occur by either shutting down the dye flow system or removing the vapors. The dye flow system will also automatically shut down on indication of a possible leak or break in the circulation line. The sensors include dye loop reservoir level sensors, pressure sensors, and a seismic sensor set at 0.05 G in any of three axes. All sensors and alarm systems are checked and calibrated on a routine basis as part of a formal program. All results are recorded and retained for inspection and audit.

Electrical Safety

Lockout/tagout procedures, in accordance with Occupational Safety and Health Administration (OSHA) requirements, are implemented in all areas. In addition, electrical safety is designed into the lasers. An example is a 480 V connector which connects the laser package to the primary power. This connector adds at least two levels of additional protection over the previous design by using a grounded fixed socket, an internal plug, and a 2 pin interlock for a relay system, in addition to the locked and tagged breaker panel.

The 480 V connector receptacle has a rotating dust cover which exposes a socket with 4 connections. The pins internal to the laser system housing are of different lengths such that the first pin to engage is the ground, next the 3 pins for the 480 V, and finally the internal relay interlock. Once the laser package is in position, a wrench is used to elevate the socket into the body of the laser where contact with the pins and activation of the relay interlock takes place. In this way, a connection can occur only within the protective housing. The lockout/tagout procedure is then reversed for activation of the 480 V to the laser.

Laser Subsystem Testing and Preparation

As mentioned above, the copper lasers are designed as a modular system. Replacement copper laser oscillators and amplifiers are operated and fully tested, prior to installation in a chain, using a safety engineered test bed which includes all necessary utilities and diagnostic connections. In addition to the lockout/tagout procedure, all electrical connections are in an interlocked cabinet such that no power can be applied until all connections have been made and the interlocks closed. One aspect of this testing includes examining the plasma discharge of the laser tube. This is done remotely and safely using a TV camera which allows the operator to observe the plasma discharge on a TV monitor. The laser parameters can then be adjusted with no access to either plasma or laser radiation.

Conclusion

The administrative and engineering controls described above are only a few of the many considerations needed to safely operate such a large laser facility. They have evolved as the result of a management emphasis on safety from the earliest design phase to a continuing commitment to implement new, safer designs as they are developed. Safety must be an ongoing, dynamic effort constantly seeking to improve the methods used to protect personnel.

References

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5 Miller, G.; Industrial Hygiene Concerns of Dye Lasers, Proceedings, International Laser Safety Conference, November 1990, pages 3-97 through 3-103, LIA.

6 Title 29 Code of Federal Regulations, Section 1910.147, The Control of Hazardous Energy (lockout/tagout), U.S. Government Printing Office (1991).

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