Laser Safety at AWE highlighting arrangements for the ORION High Power Laser

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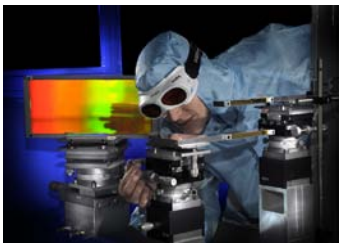
Introduction



This paper looks at the general laser safety management arrangements at AWE, highlighting the specific arrangements for the Orion high power laser facility. It includes background on four laser safety training videos sponsored by AWE and produced through the UK National Physics Laboratory, NPL for use in the AWE laser safety training programme.

AWE

AWE is the centre for research and production of the UK nuclear deterrent. It operates as a GoCo, Government owned, Contractor operated site run on behalf of the UK Ministry of Defence by AWEML, the management company formed from Lockheed Martin, Serco and Jacobs Engineering. There are over 9000 staff and contractors on site. Three main directorates make use of lasers in their missions. The Science and Technology Directorate are the biggest users of lasers owning the Orion facility, several custom systems for diagnostics of physics experiments and in Materials Science analytical instruments with embedded Class 3B lasers. The Production Directorate owns several high power machining lasers and the Systems Engineering Directorate own a laser additive manufacturing system, scanning systems and develop their own bespoke systems. These lasers are often used in novel ways, combining conventional laser hazards with other, sometimes, non conventional hazards.

The major laser facility at AWE is the Orion facility dedicated to high energy density physics research combining ten nano-second long beams at 500J at 351nm with two half pico-second beams at 1 PW peak power at 1054nm. The facility was completed in December 2010 with the subsequent commissioning of the ten long pulse and two short pulse beams completed in December 2011. The facility is currently midway through the first demonstration that the simultaneous high temperature high density conditions required for its mission can be generated and the target systems are fully commissioned

AWE Laser Safety Management Arrangements:

AWE has a comprehensive and robust safety management system for control of risk from hazards. This comprises a set of higher level Company Safety Instructions outlining the policy and management organisation and Company Safety Procedures providing more detailed arrangements for control of the hazards.
AWE Laser safety policy is defined in a Company Safety Instruction that defines the company requirements and responsibilities to ensure compliance with BS EN 60825 (current issue) the Safety of Laser Products - and other relevant legislation concerning their safe use, operation, service and maintenance, throughout their lifecycle at AWE.
In addition, a Company Safety Procedure outlines the AWE Laser Safety Code applying to all lasers under AWE control or used at AWE premises. The purpose of this laser safety code is to identify the minimum safety standards to be applied, as well as good practise and technical solutions that have been developed. The prime audience are Laser Safety Officers, Supervisors, Workers, Facility Managers and Workplace Supervisors. This code builds on the British Standard series BS EN 60825.

Class 1 Enclosure for 8 kW Trumpf Trudisk Laser.

AWE Laser Safety Organisation

The CSI and CSP describe the roles and responsibilities of the AWE laser safety organisation including the function of the AWE Laser Safety Authority, a committee run by the AWE Senior Laser Authority and comprising representatives viz. qualified Laser Safety Officers, from all directorates employing lasers on-site. The main roles within the organisation are:

Senior Laser Authority (SLA)

The competent person appointed by the Company Director responsible for Safety and the Company Director responsible for Research. The SLA approves and authorises the appointments of Laser Safety Officers (LSO) and has responsibility for laser safety standards and practice throughout the company.

The SLA ensures that:

(i) the Company complies with the requirements of BS EN 60825.
(ii) competent persons are appointed as LSOs and terms of reference and the boundary of responsibility for each LSO are agreed.

The SLA also provides advice on all aspects of laser safety including:

(i) Best practice.

(ii) Proposed legislation.

(iii) The technical requirements of systems and procedures.

(iv) The establishment and maintenance of high standards of competency and work, concerning the installation, commissioning and use of lasers.

(v) The adequacy of the methods established by the Company for determining and ensuring the suitability of laser safety equipment.

(vi) The suitability of professional and safety training associated with laser matters.

Laser Safety Officer (LSO)

A person nominated by their Director and authorised for appointment by the SLA as being competent after successful completion of recognised training and a formal assessment interview. . LSOs duties may include

(i)) evaluate and control laser hazards, within their boundary of responsibility, by risk assessment and application of risk reduction measures.

(ii) evaluate and endorse the purchase of all new lasers and laser equipment for use in their area. providing technical, managerial and safety advice on the safe use of lasers and laser products. Monitor and advise on compliance with the requirements of the AWE Laser Safety Code and facility safety functional requirements and advise on the requirements for laser controlled areas.

(iii) maintain records of all potentially-hazardous lasers (Class 4, 3B and 3R) and maintain a register of laser eyewear and undertake a yearly inspection of the eyewear in addition to user checks
(iv) undertake laser risk assessments including perform laser safety calculations, select suitable laser eye wear and advise laser operators and other workers in the area of suitable laser PPE.
(v) advise and deliver appropriate training requirements for laser LSA, Laser Operators (LO) and Laser Workers (LW) in their area and appoint suitable trained and competent LSA, LO and LW's.
(vi) investigate (or participate) in laser related Assurance Events as required by the Senior Laser Authority or Facility Manager.
(vii) be an active member of the AWE Laser Safety Authority and promote laser safety.

Laser Safety Advisor (LSA)

These are persons nominated by the LSO. The LSA are persons experienced in laser technology with sufficient knowledge, ability, training and experience to support safe laser installation, use and operation within their boundary of responsibility. The LSA is the owner of a particular laser/system within a room/lab. They are

generally involved in specifying the system for its functionality and will have the detailed knowledge of the laser parameters to advise the LSO who will work with the LSA to carry out supporting calculations to assess the risk, specify control measures including PPE and produce the safe system of work. The LSA has local responsibility to ensure that his laser is run to the procedures developed with the LSO.

Laser Operator

A laser operator is an individual who has been trained to operate a laser device within specified boundaries. Laser Operators (LO) are persons who have been authorized by the LSO to use free-standing or embedded lasers of Class 3R, 3B and Class 4 in open beam mode when necessary (e.g. to perform alignment checks or maintenance activities). These roles are filled with persons generally who have more practical skills rather than academic qualifications. Experience gained from 30 years of operating the HELEN Laser has shown that this is an effective approach.

Laser Worker

A laser worker is an individual who may be present in an area in which a laser is operating but is not necessarily involved in the process but should be aware of the hazards.

Laser Safety Training Arrangements

The Senior Laser Authority appoints LSO's. Prior to appointment an LSO must undertake an external Laser Safety Management training course in the UK run jointly by the UK Health Protection Agency and Loughborough University. An LSO would then be interviewed by the Senior Laser Authority to establish they are suitably qualified and experienced to take on the role and following a successful SQEP interview they are formally appointed for a three year period. Refresher training is organised bi-annually through a custom designed course put together by AWE/NPL with an external consultant laser safety trainer, Blueside Photonics.

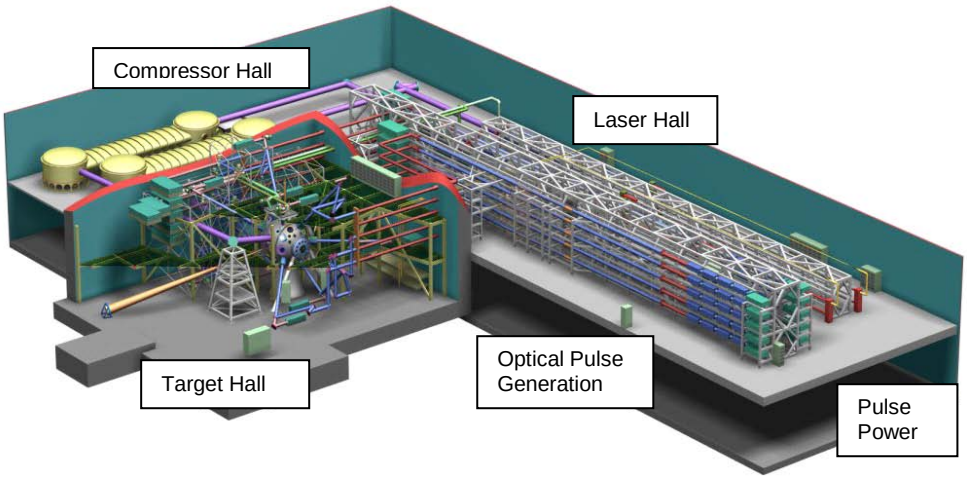
Laser safety Advisors are given a sub-set of the LSO training and are appointed by the LSO who ensures they have the required competence regarding the laser system under their ownership. Their training is refreshed every two years. A custom designed safety course has been developed through our external laser safety training collaborators NPL and Blueside Photonics.

Laser operators/workers are given basic laser safety awareness training usually by the LSO, refreshed every three years.

Orion Laser Facility

The ORION laser at AWE provides the UK with a unique facility to enable the study of high-energy-density physics through focusing the output of a large laser onto a sub-mm scale target in a vacuum chamber. ORION is a flashlamp pumped Nd doped glass laser with ten long-pulse beams delivering 5kJ of light at 351nm in 1 nano-second, and two short-pulse beams each with a power of 1 Peta-Watt in 0.5 pico-second at 1054nm. These enable us to compress material to many times solid density with the long-pulse beams, and then, with the short-pulse beams, instantaneously heat it to temperatures of millions of degrees to study matter in extreme conditions. Construction started mid 2006. The project completed in December 2010 with all equipment installed and two laser beams demonstrated. A two year facility commissioning period will culminate in the first experiment leading to a full operating capability in 2013.

Fig. 1: ORION Laser System



The long-pulse and short-pulse beams are directed into the concrete shielded target hall then focused into a 4 m diameter aluminium target chamber which can be evacuated to a pressure of 10^{-5} mbar. Primary target diagnostics are geared to look in the x-ray region providing high resolution time integrated and time

resolved spatial and spectral information. A suite of active and passive optical diagnostics provides information on surface motion. A further set of diagnostics studies particle emission from the target i.e electrons, protons and neutrons. The internal arrangement of the facility is shown in Fig. 1. The building has a footprint of approx. 100m by 60m with an overall height of 27m. To preserve the sensitive optics used to process & deliver the beams, the laser is housed in a series of interconnected, and very large, class 10000 clean rooms in which the environment is maintained at 19 C (+/- 0.5 C) with a relative humidity of 46%.

Laser Safety on Orion

The primary laser hazard is the firing of the system but this is confined to four laboratories that comprise the laser controlled area and therefore the main system can be considered as Class 1 in that there is no access at shot time. However, the laser/target interaction generates significant other hazards viz prompt high energy x rays constituting a radiation dose, electro-magnetic pulse and activated material. To guard against exposure a layered safety system is in place. The first layer of defence comprises engineering controls and a complex Safety Interlock System comprising independent mechanical trapped keys coupled to an electronic system using solid state relay logic ensures no personnel can be present when the laser is fired to target.

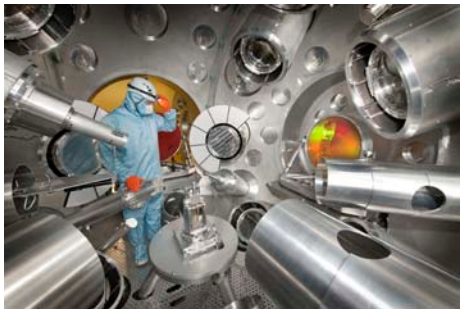
However, there are times when it is necessary for personnel to be present in the LCA when alignment lasers are being used, presenting numerous challenges with regard to laser safety. During the concept stage a number of safety requirements for laser safety within Orion were established. Of these requirements there are two key ones pertaining to laser safety, the first entails the use of engineered enclosures and the second refers to the use of the laser PPE

(i) All laser beams shall be enclosed by beam tubes or equivalent features that prevent exposure to hazardous laser light. (All exposed beams shall be below the MPE).

Accessibility of the main alignment components in the extended facility, particularly those at height on the spaceframe support structure requires full remote alignment and beam viewing systems. In excess of 1200 separately controllable axis (mirrors bids etc) and 280 cameras have been fitted to the system. This enabled beam containment, thus removing the operator from the hazard. The alignment system is currently working extremely well with very little intervention into the beam containment required by operators. Beam containment has been achieved by either containing the beam with tubes, hard enclosures or behind large soft enclosures. In some instances free space propagation of beams has been allowed, however the beams are expanded sufficiently such that the accessible exposure is below the MPE.
Despite there being no exposed beams under normal use because of the extended nature of the system and the potential for an enclosure to be opened, when beams are propagating all personnel within laser controlled areas are still required to wear eyewear at all times as an ALARP (as low as reasonably practicable) measure, however as more operational experience is gained this requirement may be reviewed.

(ii) Only one laser eyewear filter type is to be used within Orion.

This requirement could only be satisfied if suitable eyewear, certified to the correct level could be found. Initially eyewear was not available so in conjuction with Laser Vision a potential suitable eyewear was identified, however the eyewear was not certified to the required protection level. Working with Laser Vision and a certification body eyewear performance tests were conducted with a re-configured laser system at AWE. The end result being we are able to use a single eyewear to protect against all lasers sources used in the facility.



Orion Laser Safety Management and Training Arrangements

The responsibility for ensuring laser safety, and that only trained and competent persons are allowed to use and operate lasers within the Orion Facility, resides with the Facility Manager (FM). The FM delegates this responsibility to the LSO. The LSO is responsible for the implementation of the Orion laser safety programme in accordance with company requirements.

Training & Developing Competence

The Orion facility uses four times more beams than the HELEN laser that it replaces but more effective methods of working, primarily involving remote operations, enables operation without a pro-rata scaling of the number of operators. However, a significant uplift in staff was still required. Experience has shown that it can take several years to develop the skilled operators required to maintain and operate such a facility. We have built on a skilled core team who transferred onto Orion following the HELEN closure, supplemented by limited early recruitment. A continuing programme of recruitment at low level is planned for the next three years. Staff have different levels of competence dependent on their position within the training programme

Laser training on Orion is based on the Corporate system but extended. It is divided into three elements.

Firstly, formal half day laser safety training is delivered and administered by the LSO. This requires a pass mark on the related test as a prerequisite to achieving Laser Worker status for all staff who are required to enter a Laser Controlled Area.

In support of this training and in anticipation of the requirement to recruit new laser operations support technicians a suite of laser training videos were commissioned The initial objective was to provide some interactive capability though use of a virtual reality software tool (2nd Life) The interactive element was too difficult to achieve within budget so the tool was used to generate video sequences only, and the interaction dropped.

Topics for the videos produced:

(i) General laboratory laser safety.
(ii) Laser classification.
(iii) Laser protective eyewear.
(iv) Laser alignment.

Within Orion the videos are used as part of a regular programme of training for new staff and refresher training for all laser staff. The videos have been based on laser safety arrangements at AWE however the underlying principles have much broader application. The videos are widely used within AWE and have been offered to UK universities, for use at no cost, with the aim of improving laser safety awareness of undergraduates, some of whom may take up employment at AWE. To date the uptake on this has been excellent.

The second element of the training is technical training is delivered by an LSA. This training consists of a number of technical presentations and assessments on the following Orion specific beam line topics:

(i) Lasers
(ii) Laser Optical Systems
(iii) Polarisation
(iv) Laser Components
(v) Nonlinear Optics
(vi) Orion Long Pulse Beam Lines
(vii) Orion Short Pulse Beam Lines
(viii) Orion Optical Pulse Generation
(ix) Orion PAM and SPRA systems
(x) Orion Probe Beam

Finally, the third element is Hands on Training:

The initial alignment of the beam lines required hands on laser alignment activities and we had to rely on the experienced laser scientists and laser operators from the HELEN laser to undertake this work. As commissioning progressed the requirement for this hand's on work decreased as the remote beam alignment and beam viewing systems became operational. Currently there is little call on the laser operators to perform any local hands on beam alignment as full alignment can be achieved from the control room. To gain and maintain laser operator competence a laser training lab has been established in which a series of alignment exercises can be conducted to help maintain hands on competency. The exercises have been arranged so that they mimic operations which, in the event of equipment failure, may have to be undertaken on the main beam

lines. In order to maintain competency these exercises are required to retaken quarterly. The exercises are supervised by a Laser Safety Advisor (LSA). The current exercises are:

(i) Gaussian beam point and centre
(ii) Beam Expansion and Serrated Aperture
(iii) Image Relaying and Removal of the Serrations
(iv) Centring and pointing larger beams
(v) Polarises and Brewster's angle
(vi) Faraday rotators and Isolators
(vii) Using Polarisation as a switch
(viii) Pockels Cell and Z-Cut Rotator
(ix) Alignment task Multi-pass systems
(x) Alignment task output diagnostics
(xi) Alignment task Regenerative Amplifier layout
(xii) Wave front error
(xiii) Alignment of frequency conversion and auto-correlation systems

In addition to these training lab based exercises candidates are required to undertake a series of beam line on the job training exercises under the supervision of a LSA. These on the job training exercises are undertaken against approved task books.

On completion of training and following a suitable period of accompanied beam line working, an assessment of each candidate is carried out by the LSO & the individual's Line Manager to ensure they are a Suitably Qualified & Experienced Person (SQEP) to hold the role. If successful a formal Letter of Appointment is issued.

Laser Safety Issues Arising

As part of our strategy to prevent access to all beams above the MPE, in addition to conventional beam-tubes, we have used large areas of commercially available laser curtain material to enclose substantial portions of the laser superstructure in custom designed frames. The material supplier worked with us to specially design the frames and hanging arrangements in the first ever use in the UK of such material over such a large area. We have also installed laser protective glass over our viewing gallery windows in the Laser Hall and Target Hall so that visitors can safely observe the preparations and alignment before the areas are closed up for the target laser shot. The amount of visitors to this type of facility is not to be under estimated, experience is showing that a considerable amount of time can be lost if this issue is not organised efficiently.

Because of the hazard of material or tools potentially being dropped from height, workers in the Laser, Compressor and Target Halls must wear hard hats, in addition to their normal clean-room clothing and, when lasers are propagating, laser goggles. One issue we have found arising from this PPE policy is that hard hats can interfere with correct wearing of laser goggles. Several staff have reported that the plastic protective straps and/or the hat brim can push down on the laser goggles causing them to pull away from the wearer's face, potentially allowing a stray beam a path into the eye. To alleviate this problem we have made a concession for staff to wear the more compact "rock climber's hat". We have also purchased several sets of tethered tools (tools are attached by a lanyard to a waist-belt) for use in the laser areas.

The eye hazard is not the only one to consider and we must also be aware of the potential for the alignment & other lasers to cause skin damage. We have been unable to find CE-marked hand protection for the range of lasers used in Orion so have had to take a pragmatic approach in selecting hand PPE. We tested several commercially available samples in our off-line laboratories and selected those that gave several seconds warning of "warming-up" before burning through.
A perennial problem for users of laser protective eyewear is the "fogging" of laser goggles after a period of use, particularly in the climate controlled large clean-rooms. When this occurs, normal practice is to leave the LCA and clean the goggles at a suitable cleaning station. In Orion there are long distances to travel to leave the area so, to avoid the temptation for wearers to try and clean their goggles in-situ (and expose themselves to a laser

hazard), we have built light-proof cleaning booths inside the LCAs. These are similar to small telephone booths and provide a safe, screened environment in which to remove laser goggles for cleaning – inside the LCA.

During commissioning of the first two beams, the LSO was on duty with the commissioning team every evening to gain a first-hand understanding of the laser safety issues experienced by the team and provide practical & pragmatic advice, in order to allow decisions to be made quickly and maintain project progress.

Review, Learn and Improve

Overall the laser commissioning has been a success with only one laser related incident (person entered laser hall without laser eyewear- no injury occurred). This successful commissioning of the laser was in no small part due to the experience gained by the same team in commissioning the CPA upgrade to the outgoing HELEN Laser some years previously.

A structured laser safety programme is essential.

The intention of producing interactive training material proved too challenging and more time should have been spent researching the delivery platform for its suitability rather than the technical content.

The decision to remain with the more practical and less academic laser operators has proven very successful.

Close involvement of the LSO was critical in the early stages of commissioning.

It is important to maintain a constant watch for laser related incidents reported by other establishments and to identify learning opportunities to be incorporated into our laser safety programme.

Finally we have benchmarked our operations with similar facilities world-wide and taken best practice into AWE. We have also taken input from previous ILSC's (my thanks to M. Woods (SLAC) for the idea of the laser training lab). We also maintain a regular involvement with the Health Protection Agency Laser Safety Forum in the UK.