Laser Safety for diagnostic laser systems with multi-fibre outputs

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10th DOE EFCOG
LLNL

- **Introduction**
- **Fibre laser based diagnostics**
- **Typical laser specifications**
- **Risk based approach**
- **Risk assessment**
- **Summary**

Introduction to AWE

- ***Work at AWE covers the entire life cycle of nuclear warheads; from initial concept, assessment and design, through to component manufacture and assembly, in-service support, and decommissioning and disposal.***

- ***AWE is managed for the UK Ministry of Defence (MoD) through a Government Owned/Contractor Operated (GOCO) arrangement.***
  - ***AWE's sites and facilities remain in government ownership, but day-to-day management is contracted to a private company: AWE Management Ltd***
  - ***AWE ML is formed of three equal stakeholders: Serco, Lockheed Martin and Jacobs Engineering Group. AWE ML delegates the day-to-day management to AWE plc, the company which employs the workforce and holds the nuclear site licenses.***

- ***UK is signatory to the CTBT therefore relies on physics based models for certification of warhead supplemented by data from experiments on processes and material properties to validate the models***
  - ***science based stockpile stewardship***

Introduction to fibre laser based diagnostic systems

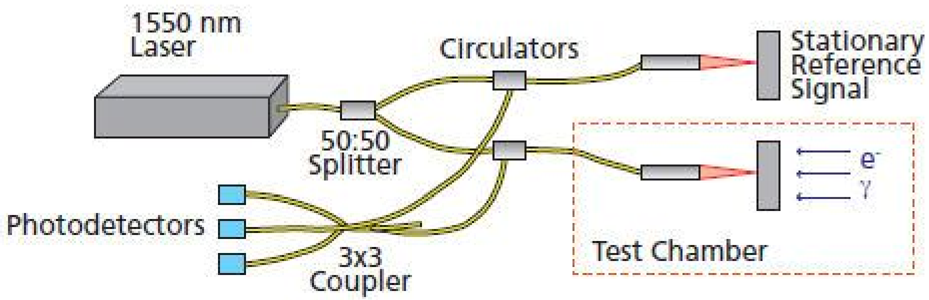
- ***In the absence of underground nuclear tests, confidence in the safety and performance of the nuclear stockpile is based on predictions from physics models, with experimental data being used for model validation.***

- ***Requirement***
  - ***to measure small displacements of surface induced from thermo-mechanical impulse driven by x-ray or electron deposition in ns timescale***
    - ***micron displacements and velocities in tens of metres/second***
  - ***to measure velocities of explosively driven surfaces***
    - ***shock driven velocities of order km/s***

- ***Optical systems offer***
  - ***non-contact/small probes – good working distance from surface***
  - ***ability to extract signals in high noise environment***
  - ***fibre systems offer simplicity, ease of alignment, lower risk from laser safety perspective***

Photonic Displacement Interferometer

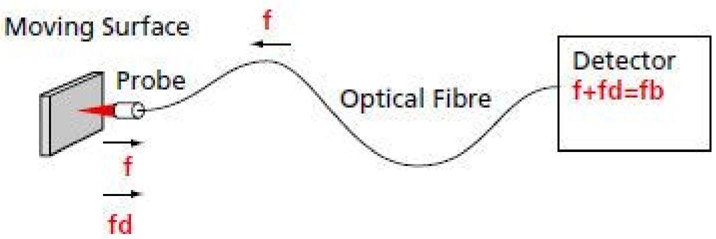
- *Measures small surface displacements (micron) induced by pressure waves driven from the thermo-mechanical impulse arising from deposition of keV x-rays or MeV electrons*



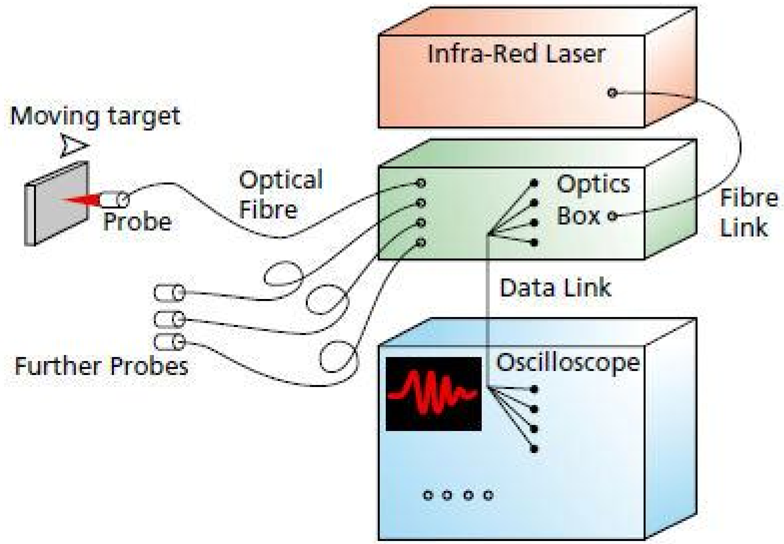
PDI schematic.

PDV - Photon Doppler Velocimetry aka Het V Heterodyne Velocimetry

- ***Used for investigation of explosively driven metal surfaces***
- ***Interferes Doppler shifted light from moving surface with reference unshifted light***
- ***Measures beat frequency on oscilloscope***



Creating a beat frequency



A schematic of the heterodyne velocimetry system

Laser source

- *1550nm Erbium doped fibre lasers*
- *several Watts cw output – Class 4 laser*
- *Standards specify controls required for Class 4 laser installation*
  - *Laser controlled area*
  - *Interlocks etc*

But

output pigtailed into several fibres
individual beam output AEL – typically equivalent to Class 1M

so user view is NO further controls needed……….

…………………………….resolve with **risk assessment**
(mandatory requirement under European Legislation)

Health & Safety Basics

- **Definition of a Hazard?**
  - ***"Anything that can cause harm"***

- **Definition of Risk?**
  - **"Likelihood of hazard causing harm"**
    - ***Very likely***
    - ***Possible*** **Probability**
    - ***Improbable***
  - &
  - **Severity of harm caused**
    - ***Major***
    - ***Moderate*** **Consequence**
    - ***Minor***

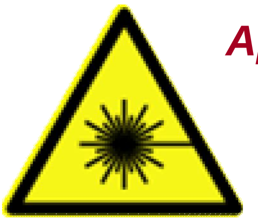
Risk assessment used to define controls required to minimise risk ….
can be qualitative or quantitive

Hierarchy of Risk Controls

- **Eliminate the hazard**
- **Reduce the hazard**
- **Remove person from hazard**
- **Contain hazard by enclosure**
- **Reduce employee exposure**
- **Implement Safe Systems of work**
- **Personal protective equipment (PPE)**

• Eliminate
• Reduce
• Isolate
• Control
•PPE
•Discipline

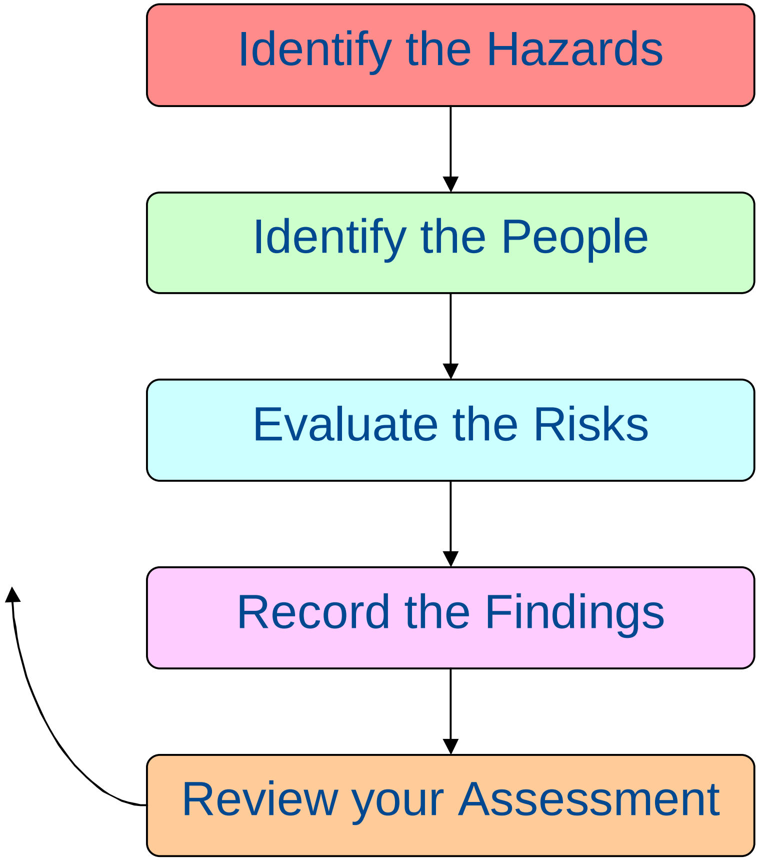
ERICPD



Apply the risk control hierarchy for your system
(work from top to bottom)

HSE 5-Steps to Risk Assessment

- 5-Steps Process



Identify what the hazards are and how people might be harmed

Decide who might be harmed and under what circumstances

Evaluate the risks and decide on the precautions and controls needed

Record and Implement your findings

Review and update your assessment as necessary

- **Record Your Findings & Implement**
  - *Report your findings*
    - *Senior management*
    - *Health & Safety Committee*
    - ***All personnel with access!***

- **Review Your Assessment**
    - *After a set period (e.g. annually)*
    - *As defined in the risk assessment report*
    - *Random audit (not popular)*
    - *After an accident or a near-miss incident*
    - *As soon as the work procedure or process changes*

UK HSE Risk Assessment Template

Company name:	Date of risk assessment:

Step 1
What are the hazards?

Spot hazards by:

- walking around your workplace;
- asking your employees what they think;
- visiting the *Your industry* areas of the HSE website;
- checking manufacturers' instructions;
- contacting your trade association.

Don't forget long-term health hazards.

Step 2
Who might be harmed and how?

Identify groups of people. Remember:

- some workers have particular needs;
- people who may not be in the workplace all the time;
- members of the public;
- if you share your workplace think about how your work affects others present.

Say how the hazard could cause harm.

Step 3
What are you already doing?

List what is already in place to reduce the likelihood of harm or make any harm less serious.

What further action is necessary?

You need to make sure that you have reduced risks 'so far as is reasonably practicable'. An easy way of doing this is to compare what you are already doing with good practice. If there is a difference, list what needs to be done.

Step 4
How will you put the assessment into action?

Remember to prioritise. Deal with those hazards that are high-risk and have serious consequences first.

Step 1	Step 2	Step 3	Further action	Action by whom	Action by when	Done

Five steps to risk assessment

Step 5 Review date:

- Review your assessment to make sure you are still improving, or at least not sliding back.
- If there is a significant change in your workplace, remember to check your risk assessment and where necessary, amend it.

Example of quantitative assessment

This Methodology derived from BSEN 61508 for assessing Safety Integrity Level for an electronic protection system

Evaluate the risks –

- ***C - consequence of hazardous event***
- ***F - frequency of and length of exposure to the hazard***
- ***P - probability of avoiding the hazard***
- ***W - demand rate of exposure to the hazard***

Consequence C		Frequency of exposure F		Probability of Hazard Avoidance if the Protection P System Fails	
1	Severe Injury	1	< 0.01		
2	Death of 1 person	2	0.01 – 0.1	1	Possible
3	Death of > 1 person	3	0.1 – 1.0	2	Almost Impossible

HC = 1 + 3 + 1 = 5

		Hazard Class HC						
Demand Rate W		<=4	5	6	7	8	9	10
A	< 0.1/yr			**1**	**2**	**3**	**4**	
B	01. – 1.0 /yr		**1**	**2**	**3**	**4**		
C	1.0 – 10/yr	**1**	**2**	**3**	**4**			

Take Demand Rate C

SIL2

Laser risk assessment for example PDI system

- **Laser source**
  - ***1550nm cw seed laser with amplifier in enclosure***
- **Delivery system**
  - ***optical fibre; probe: freespace propagation: focussing lens***
- **Application**
  - ***Diagnostics***
- **People**
  - ***Laboratory staff***
  - ***Cleaners, visitors, contractors, facility maintenance workers in vicinity***
  - ***Servicing and maintenance personnel***
- **Environment**
  - ***Laboratory, experiment hall***
  - ***Accessibility of work points***
  - ***Any working at height***
  - ***Clean room environment etc***
  - ***Any trip hazards, noise etc***
  - ***Location of laser relative to user point – same room?***
  - ***Control of bulkhead connectors***

Risk assessment approach under these headings pioneered by Health Protection Agency and Loughborough University

Laser source

- *1550nm   cw*
- *amplified 25mW seed laser to 2.4W max output*

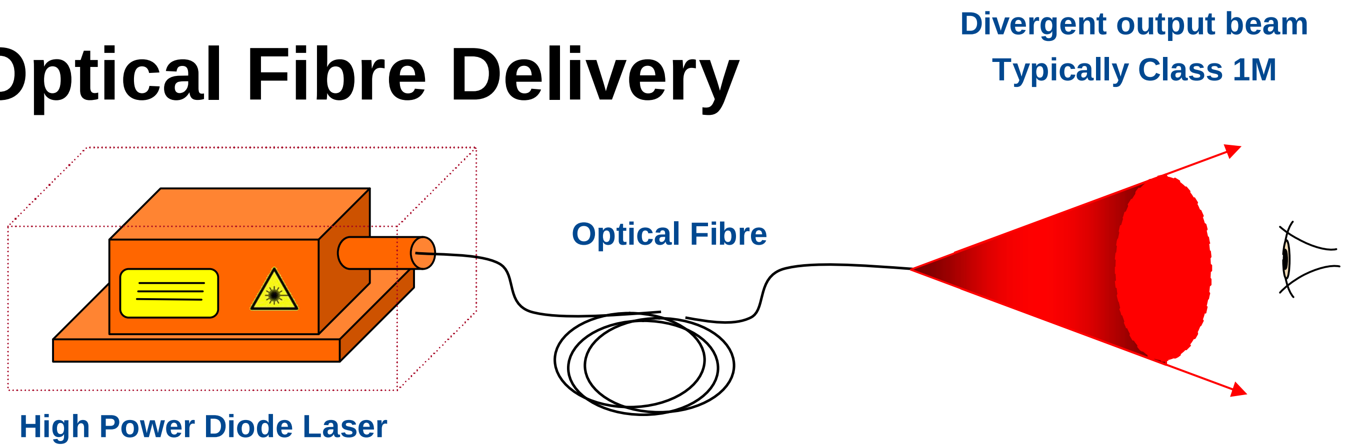
- *Class 4 Laser from Test Condition 2 (Diverging Beam)*

- *Limiting aperture (eye and skin)   3.5 mm*
- *MPE (eye and skin)   1000 W/m²*

Exposure Hazard Value (EHV) = Irradiance/MPE

EHV=250

Optical Fibre Delivery



- *Flexible means of delivery*
- *Very good safety properties*
  - *Enclosed beam; Divergent exit cone*
- *Robust design*
  - *Cable Ruggedisation as needed*
  - *Robust launch optics*

BUT

Is the laser source in the same room as the output probe?

Is it delivered through bulkhead connections that can be uncoupled and expose the beam?

Laser output pig-tailed into 10 single mode fibre outputs with mode field diameter d_{63}=11μm

Full power 240mW down one fibre — *NOHD 0.138m*

Laser Class Test Conditions

Condition 3 – unaided eye viewing
Limiting aperture 3.5mm at 100m
AE = 0.018 W

Condition 2 – diverging beam
Limiting aperture 7mm at 70mm
AE = 0.11 W

Individual Fibre output hazard level equivalent to Class 3B

Reduced amp gain to get power <136mW per fibre — *NOHD 0.10m*

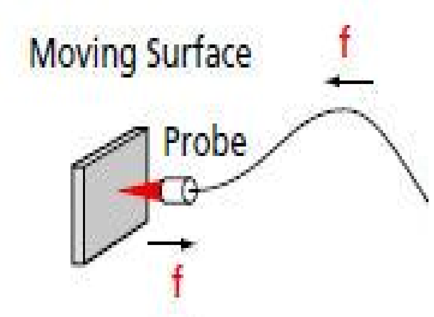
Condition 3 – unaided eye viewing
AE = 0.010 W

Condition 2 – diverging beam
AE = 0.063 W

Individual Fibre output hazard level now equivalent to Class 1M

BUT………...Relying on administrative controls to reduce power
How can you make sure that ensure that fibres can't be bundled together with beams propagating from ends?

Laser output propagated from end of fibre to probe which focuses light onto moving surface and picks up return signal



Typical probe characteristics

Lens aperture	*5mm*
Focal length	*25mm*
Divergence	*0.12rad*

Worst case – specularly reflected beam is not picked up by probe

NOHD ~ 0.5m

Is the probe breakout enclosed?
If not, could somebody encroach within this distance during set-up/alignment?
Can lower power be used for initial set-up?

People

- ***Are all operators trained and competent?***
- ***Any other workers around not involved with the work?***

Environment

- ***Accessibility of work points***
- ***Any working at height?***
- ***Clean room environment etc***
- ***Any trip hazards, noise etc?***
- ***Location of laser relative to user point – same room?***
- ***Can bulkhead connectors be disconnected with laser on?***

Hazard *Laser radiation*

Who or what could be harmed, what happens, and how?

Eye / skin damage from exposure to laser radiation to persons in proximity to work

There is a greater probability of a fibre end being held closer to skin than to an eye. MPE is same for eyes and skin, therefore this poses a higher risk than eye damage.

Exposure possible if laser propagated down fibre with fibre not coupled to bulkhead connector/probe.

MPE levels are exceeded if the laser for a distance up to 100mm for a 136mW beam in a single fibre.

If multiple fibres are bundled together the nominal ocular hazard distance will be greater as beams overlap.

Control measures *needed* to reduce the risk to ALARP?

- ***The source laser system must deactivate if opened.***
- ***Laser output shall be fibre coupled.***
- ***Probe output contained within an enclosure or barrier to prevent encroachment within NOHD***
- ***Key control on laser.***
- ***Fibres must be connected to bulkhead multi-fibre feed-throughs before any lasers are activated with key.***
- ***The laser system should be producing a laser power ALARP to meet the interferometry requirements at a maximum, class 1M equivalent laser radiation/per channel.***
- ***Initial alignment done in low power mode with seed laser only***
- ***Indication that laser is on should be provided at remote operation point***
- ***Only competent people to operate the system.***
- ***Persons in laboratories not involved with work must be made aware of this risk assessment***

Control measures *already* in place

- ***No operator access to internal parts of the source laser system. The enclosure is interlocked and will be only accessed by the vendor.***
- ***All 10 enclosure outputs are fibre coupled and laser delivered to point of use with fibre.***
- ***The probe focussing optics are only coupled to fibres within an optically sealed vessel.***
- ***The laser is NOT to be activated before the system is inspected to be fault and damage free, bulkhead connectors all made. Key control with designated operator.***
- ***Bulkhead multi-fibre connectors are NOT to be uncoupled during laser operation.***
- ***Laser output power controlled to be minimum required for application and less than 136 mW per channel.***
- ***Laser output is indicated by a light on the laser front panel. A fibre-coupled laser power meter measures the power by the point of use indicating laser on and power level verified to meet requirement.***
- ***The laser is only to be operated by authorised personnel who are competent***
- ***Keys to operate laser are held by operators who are laser safety trained.***
- ***Operation of the laser system shall not deviate from the experiment plan.***

Further control measures to meet ALARP

- ***Install engineering controls such that fibres can only be released from a bulkhead connector by using a laser key that must be removed from the laser, thereby switching laser off.***
- ***Pigtail more fibres to reduce output per fibre to 1M hazard level w/o administrative control to turn down output***

Summary

- *Described fibre based optical diagnostic systems that enable measurements of displacement and velocity*
- *Demonstrated a laser risk assessment for use with one example of these systems*
- *Shown how risk assessment provides a powerful tool that allows use of high power lasers in a safe way without necessarily putting in place all the controls defined within the standard.*

Questions?