Lectures on Medical Biophysics

Department of Biophysics, Medical Faculty,
Masaryk University in Brno

Occupational Safety When Using Medical Devices

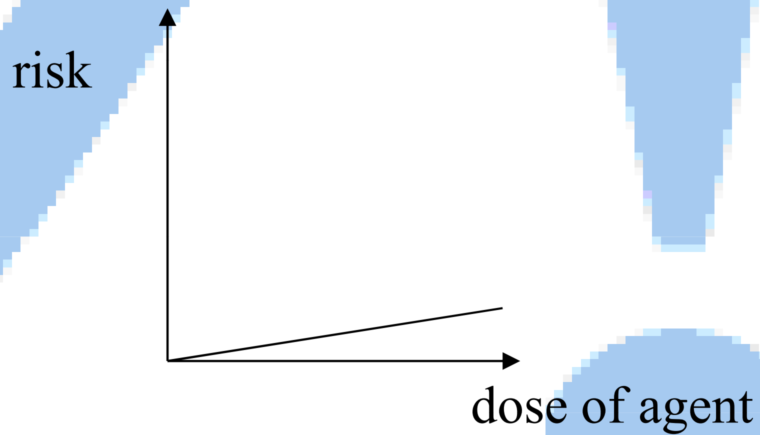
Carmel J Caruana, BioMedical Physics, Institute of Health Care, University of Malta

Risks in Medical Facilities

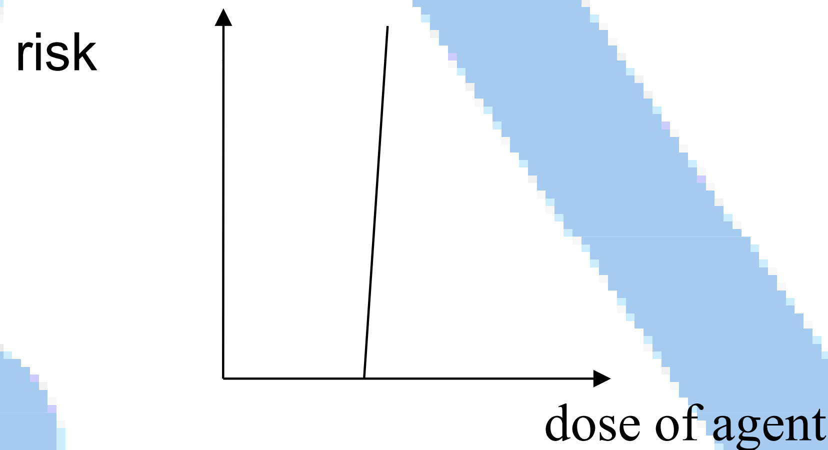
- Risks from Physical, Chemical and Biological 'agents'
- Somatic agents: ability to cause defects in an exposed individual
- Teratogenic agents: ability to cause defects in an exposed conceptus
- Mutagenic agents: can cause mutations in exposed sperm and ova
- Physical agents: mechanical, electrical, magnetic, ionising radiation

Characteristics of Biological Effects

- **Acute** (effects occur short-term) vs **Late** (effects occur long-term)
- **Deterministic** (existence of a threshold dose) vs **Stochastic** (no threshold, dose and risk proportional)



stochastic effects



deterministic effects

Mechanical

- Care in the presence of moving objects (centrifuges, X-ray systems etc.)
- When walking under hanging objects
- Slippery floors
- Back-pain (lifting heavy equipment, patients etc.)

Electrical Shock

- Conditions for a shock to be possible
  - TWO connections to the body across which there is a voltage (potential difference) are required for a shock to be possible (one often the earth).
  - Shocks are often the result of an ‘earth-seeking’ mains voltage.
- Factors affecting magnitude of effect on the body
  - type of electric energy source
  - the amount and duration of current flow
  - the parts of the body affected (depends on path of current through body)

Magnitude of Current

The human body has an internal resistance of about 500 ohms. Hands and feet have a minimal resistance of 1000 ohms. The resistance of dry skin varies from one individual to another but is often around 100,000 ohms. The resistance of any given contact will depend on the area of contact, pressure applied, the magnitude and duration of current flow, and moisture present. The resistance will vary with time as the skin is charred or perforated and as physiological reactions occur. When the current is large enough to cause tissue damage, skin resistance falls within 5 to 10 seconds.

Effect on Various Tissue Types

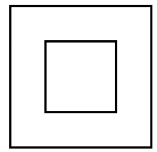
- Tissues differ in their resistance to the passage of electric current. Nervous tissue is the least resistant, followed by blood vessels, muscle, skin, tendons, fat, and bones. The actual passage of current through the body will depend on the resistance of the various tissues. This explains why nervous tissues are so often damaged by electric shock while other tissues are relatively intact.

Current Thresholds for Physiological Effects

- 1 mA: threshold of feeling
- 5 mA: max ‘harmless’ current
- 10 – 20 mA: sustained muscular contraction (‘can’t let go’)
- 50 mA: pain, fainting
- 100 – 300 mA: Heart - ventricular fibrillation (uncoordinated ventricular contractions) leading to very low blood supply to brain etc. - usual cause of death by electric shock.

To Improve Electrical Safety

- Handle devices with care.
- Protect cords from heat, alcohol, traffic pathways.
- Use 3-pin plugs (unless using doubly insulated devices).



- Do not use damaged plugs, frayed wires or outlets that do not hold the plug firmly.
- Never remove a plug by pulling on the cord.
- Discontinue using and report any device that emits a shock or tingle.
- Never plug in devices whilst touching pathways to earth (e.g. patient metal bedrails, plumbing etc).
- Do not touch two electrical devices simultaneously.
- Avoid moist hands, being barefoot, wet floors.
- Do not touch any part of patient, bedrail, gelled areas during defibrillation or cardioversion, check for cracks in the defibrillator paddle.
- Devices should be checked for safety at regular intervals.

Electric Shock
1. DANGER
If you suspect someone has received an electric shock you must ensure all power sources are isolated before you can treat the casualty.
HIGH VOLTAGE
Overhead power cables are an example of a power source generating high voltage electricity. High voltage electricity has the ability to 'jump' or 'arc' up to distances of 18 metres or over. If faced with a casualty resulting from high voltage electricity:
DO NOT APPROACH. Stay at least 25 metres away from the casualty until the power has been switched off by an official agency i.e. Electricity Board.
LOW VOLTAGE
If faced with a casualty who is in the process of receiving an electric shock you should:
Attempt to turn the power off at the mains.
Remove any cables/power tools etc., still in contact with the casualty.
ACTION TO TAKE FOR LOW VOLTAGE
Insulate yourself from the ground with books, newspapers or rubber matting.
Use an electric shock rescue hook or object of low conductivity i.e. a wooden broom or rolled up newspaper, to push away the power source from the casualty.
2. RESPONSE
To give the casualty the optimum chances of survival you must quickly assess the levels of response. A rapid assessment will allow effective treatment to be administered and will also allow for accurate information to be passed on to the ambulance service.
CHECK WHETHER THE CASUALTY IS CONSCIOUS
01. Ask "Open your eyes if you can hear me" and call their name if known.
02. Ask in both the casualty's ears to open their eyes.
03. Offer a mild stimulus by shaking casualty's shoulders.
04. DO NOT move the casualty unless the environment or situation is dangerous.
3. GETTING HELP
CALL FOR HELP
If alone call for help. If someone responds to your call ask them to stay with you whilst you assess the Airway and Breathing. One of you should wait with the casualty whilst the other calls the emergency medical services (EMS).
NB If no-one responds, do not leave the casualty but go on to assess the airway and breathing.
CALLING THE EMERGENCY MEDICAL SERVICES
01. Lift the receiver and wait for a dialling tone.
02. Dial 999 / 112.
03. The operator will ask you which service you require. Once you have stated "ambulance" you will be connected to ambulance control. The operator will ask you a set of questions.
DO NOT hang up at any stage of the conversation. The operator will terminate the call when appropriate.
Isolate or cordon off the exposed, damaged or faulty electrical source
Calling Emergency
As soon as possible after the casualty has been taken to hospital report the incident to the local supervisor. Give all information you can as an IRF needs to be completed for all accidents and incidents.
Leave details about yourself so that you can be contacted should the need arise. Report defective equipment that caused the shock (if applicable) so that repairs can be made.
RIDDOR (Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 2013).
4. AIRWAY & BREATHING
FOR AN UNRESPONSIVE CASUALTY
OPEN THE AIRWAY
01. Look in the mouth to ensure there are no obvious obstructions.
02. Open the airway by lifting the chin and tilting the head back. This will free the tongue from the back of the throat.
03. If neck/spinal injury is suspected, put one hand on the stomach to feel if it rises and falls. This indicates normal breathing.
ASSESS FOR BREATHING
01. LOOK for the rise and fall of the chest and beyond.
02. LISTEN for sounds of breathing near to the face.
03. FEEL for breathe on your cheek near to the face.
04. Carry this out for up to 10 seconds.
BREATHING NORMALLY
If normal breathing is present go straight to the Unconscious - Breathing section. (See box 7)
NOT BREATHING NORMALLY
If the casualty is not breathing normally, call for the Emergency Medical Services (EMS) or ask for people nearby to call, when calling ask for a defibrillator if it is available - commence full Cardio Pulmonary Resuscitation (CPR).
6. DEFIBRILLATION
Use an AED (Automated External Defibrillator) if available and follow prompts.
5. UNCONSCIOUS - NOT BREATHING
TO COMMENCE CPR:
FOR AN UNRESPONSIVE CASUALTY
01. Ensure the casualty is on a firm, flat surface.
02. Place your hands one on top of the other in the centre of the casualty's chest. (Fig. 1)
03. Compress the chest (up to a maximum depth of approximately 5-6cm) 30 times at a rate of 100-120 compressions per minute. The compressions and releases should take an equal amount of time.
04. After 30 compressions, open the airway again using head tilt/chin lift.
05. Seal the nostrils with your thumb and forefinger. (Fig. 2)
06. Blow steadily into the mouth until you see the chest rise, take about a second to make the chest rise, 2 effective rescue breaths in total (Blow in for 1 second, 2 breaths within 5 seconds). (Fig. 2)
07. Remove your mouth to the side and let chest fall. Inhale some fresh air, when breathing for the casualty.
08. Repeat so you have given 2 effective rescue breaths in total within 5 seconds.
09. If chest does not rise after the second breath, go back to 30 compressions then try again with 2 breaths.
10. Return your hands to the correct position on the chest and give a further 30 chest compressions.
Fig. 1
Fig. 2
CONTINUE WITH CPR UNTIL
The casualty shows signs of recovery.
Emergency services arrive.
You become exhausted and unable to continue.
The situation changes and you are now in immediate danger.
7. UNCONSCIOUS - BREATHING
IF THE CASUALTY IS BREATHING NORMALLY, TURN INTO THE RECOVERY POSITION
01. Check for any other obvious injuries.
02. Remove sharp objects from pockets.
03. Turn the casualty into the recovery position.
04. Place the nearest arm at a right angle to the body. (Fig. 1)
05. Draw the furthest arm across the chest and place the back of the hand across the cheek. (Fig. 2)
06. Keep this here whilst you raise the furthest leg by grasping the top of the knee. (Fig. 3)
07. Gently pull on the knee so that the casualty pivots over onto their side facing you. (Fig. 3)
08. The casualty should be fully over and stable.
09. Re-check the airway, breathing and circulation.
10. Draw up the leg at a 90 degree angle. (Fig. 4)
11. Check for continued breathing.
12. Send someone to ring 999 / 112 or if you are alone, leave the casualty and call 999 / 112.
Fig. 1
Fig. 2
Fig. 3
Fig. 4
8. BURNS
BURNS
Exposure to electricity can cause burns to the skin and, in severe cases, internal organs. In such cases the electricity may, for example, enter via a hand and leave via the foot causing 'entry' and 'exit' burns.
CONSCIOUS CASUALTIES
01. Burns should be immersed in cold running water for a minimum of 10 minutes (any constricting items such as watches should be removed). (Fig. 1)
02. Once cooled the burn should be covered with a sterile dressing (non-fluffy). (Fig. 2)
UNCONSCIOUS CASUALTIES
Cool the burn with wet dressings after placing them in the recovery position.
DO NOT:
Burst any blisters.
Apply adhesive dressings.
Remove damaged skin.
Apply ointments or creams.
Cover with 'fluffy' dressings.
Affix dressing too tightly.
Apply butter, fats or margarine.
Remove damaged clothing.
Apply ice.
Fig. 1
Fig. 2
9. OTHER INJURIES
MUSCLE SPASM / SEIZURES
These may be present for some time after the exposure to electricity and indicate a seriously ill casualty.
ACTION IN THE EVENT OF A MAJOR SEIZURE
The casualty will almost definitely collapse during a major seizure. Try to control the fall.
Ensure the safety of the casualty by removing any objects that may cause injury if they are struck.
Place padding under the head of the casualty. Improvise if necessary by using clothing.
DO NOT place anything in the casualty's mouth.
Loosen any clothing that may restrict the airway.
Time the seizure.
When the seizure has subsided:
Check the casualty's Airway, Breathing and Circulation (ABC).
If unconscious and breathing normally or semi-conscious, place the casualty in the recovery position (see opposite). Perform CPR if not breathing.
Place a blanket over casualty to preserve modesty.
Reassure the casualty whilst continuing to monitor the ABC and any other injuries.
CASUALTIES WITH NO APPARENT INJURY
If no injury is present and the casualty appears well, it is still advisable to take the casualty to a hospital or medical facility for a check up, as certain organs/systems within the body may be affected several hours after a shock.
© Safety First Aid Group Ltd 2016
The information contained in the poster is for guidance only and should not be used as a substitute for recognised training.
A601 (REV:01/16)

Magnetic

- Magnetic Resonance Imaging (MRI): people cannot enter room:
  - with iron objects (they become projectiles)
  - if have metal implants
  - or heart-pacemaker/defibrillator/cardioverter

Ionising Radiation

Carmel J Caruana, BioMedical Physics, Institute of Health Care, University of Malta

Basics

- Definition: particles or photons of electromagnetic radiation (f > 3×10^{15} Hz i.e., UV, X and γ) which have enough energy to ionise body atoms.
- These ions can lead to the formation of FREE RADICALS (H·, OH· from water) and other highly chemically reactive compounds e.g., H_2O_2 which may bring about changes in biologically important molecules e.g., DNA hence producing serious biological effects e.g., carcinogenesis, mutagenesis.
- The unit of RADIATION 'DOSE' is the Sievert (Sv). Doses in practice are of the order of mSv. A certain risk of serious biological effect is associated with each Sv e.g., a risk of 2 per million per mSv for leukaemia.

Uses of Ionising Radiation in Hospitals

- Radiodiagnostics (XRI)
- Nuclear medicine
- Radiotherapy
- bone-densitometry
- research

Interaction of Radiation with Tissue

- Particles: The kinetic energy of the particle is totally absorbed by the tissue.
- Photons: The energy of the photon is either totally absorbed by the body or partially absorbed (during scatter).
- The higher the number of particles / photons absorbed by the body and the higher the energy of each particle / photon, the higher the number of free radicals etc produced, the higher the dose, the higher the risk.

Some Radiation Hazards

- Stochastic
  - Carcinogenesis : induction of cancer (increased risk of dying of cancer at a future date is increased by 0.005% per mSv)
  - Mutagenesis (change in a gene in gametes)
- Deterministic
  - Eye-lens cataracts
  - Skin injuries
  - Effect on conceptus in the uterus (relevant to pregnant workers)

Effects of Radiation on Cells

- Cells are most vulnerable during mitosis (cell division)
- Possible effects of radiation on cells:
  - Cell death prior to or after mitosis
  - Delayed or prolonged mitosis
  - Abnormal mitosis followed by repair
  - **Abnormal mitosis followed by replication** - this is the major problem as damage is replicated in daughter cells; e.g., changes in cell control mechanism leads to carcinogenesis.

Radiosensitivity of Cells

- Law of Bergonie and Tribondeau: radiosensitivity of cells is proportional to rate of cell division (mitotic frequency) and inversely prop. to the level of cell specialisation (aka cell ‘differentiation’). Some exceptions e.g., mature lymphocytes are very radiosensitive
- High sensitivity: bone marrow, spermatogonia, granulosa cells surrounding the ovum
- Medium sensitivity: liver, thyroid, connective tissue, vascular endothelium
- Low sensitivity: nerve cells, sense organs
- Radiosensitivity increases the lower the age

Radiosensitivity: Tissue Weighting Factor

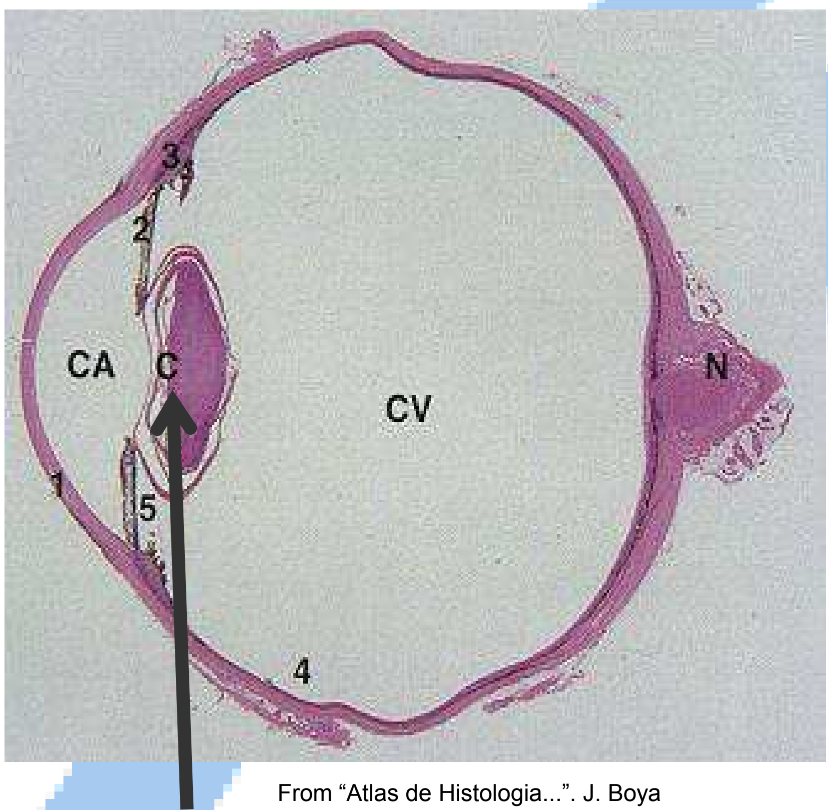
Tissue or organ	Tissue weighting factors, w_T
Gonads	0,20
Bone marrow (red)	0,12
Colon	0,12
Lung	0,12
Stomach	0,12
Bladder	0,05
Breast	0,05
Liver	0,05
Oesophagus	0,05
Thyroid	0,05
Skin	0,01
Bone surface	0,01
Remainder	0,05 (**) (***)

(**) For the purposes of calculation, the remainder is composed of the following additional tissues and organs: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus and uterus. The list includes organs which

(Ref. 96/29/Euratom)

Effects on the Eyes

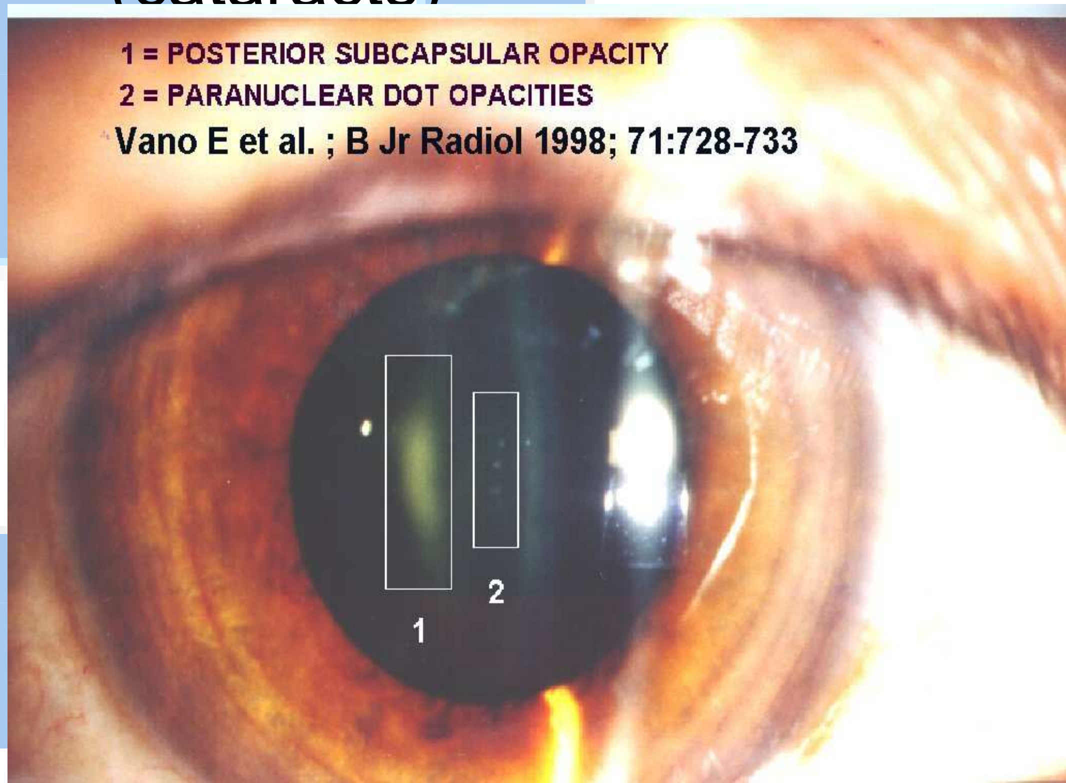
Sagittal section of eye:



From "Atlas de Histologia...". J. Boya

Eye lens is highly RS, moreover, it is surrounded by highly RS cuboid cells.

- lens opacities leading to visual impairment (cataracts)



Occupational Dose Limits (Legal Permissible Max Doses)

- Set by the ICRP (Intern Commission for Radiological Protection)
- Deterministic effects: dose limits are set below thresholds to avoid deterministic effects.
- Probabilistic effects: cannot be zero! The occupational dose limits are set in a way that the risk is comparable to that found in other socially acceptable occupations / situations.
- *Dose limits are NOT safe limits and ALARA (As Low As Reasonably Achievable) must be practiced even when doses are below these limits*.

Minimising Doses from External Sources

- Avoid ionising radiation when possible.
- Never put yourself in path of beam.
- Minimise source strengths.
- Minimise particle energies and maximise photon energies.
- Minimise exposure time (free!!).
- Maximise distance (inverse square law) (free!!).
- If all else fails introduce Pb shielding, however shielding is the *most expensive option*.

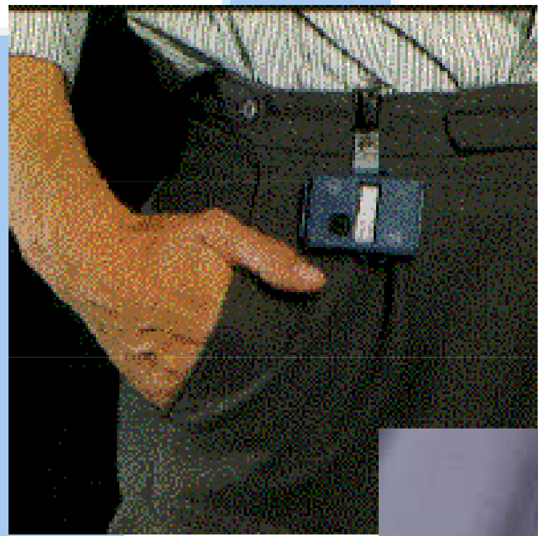
Minimising Doses from Internal Radiation

- Arise from **open** sources (powders, liquids, gases)
- Minimise source activities and energies
- Appropriate procedures: no mouth pipetting, spillages immediately cleaned up, throwaway tissues, containment using splashtrays
- Personal hygiene: appropriate clothing (labcoats, overshoes, gloves, masks), washing and monitoring of hands, clothes and shoes
- Appropriate lab design: non-absorbent surfaces, special basins, bins for radioactive waste, adequate ventilation, availability of washbasins and showers, laminar flow cabinets, glove boxes, installed dose and contamination monitors

Installed Dosemeters

Portable Dosemeters (contamination monitors)

Personal Dosemeters



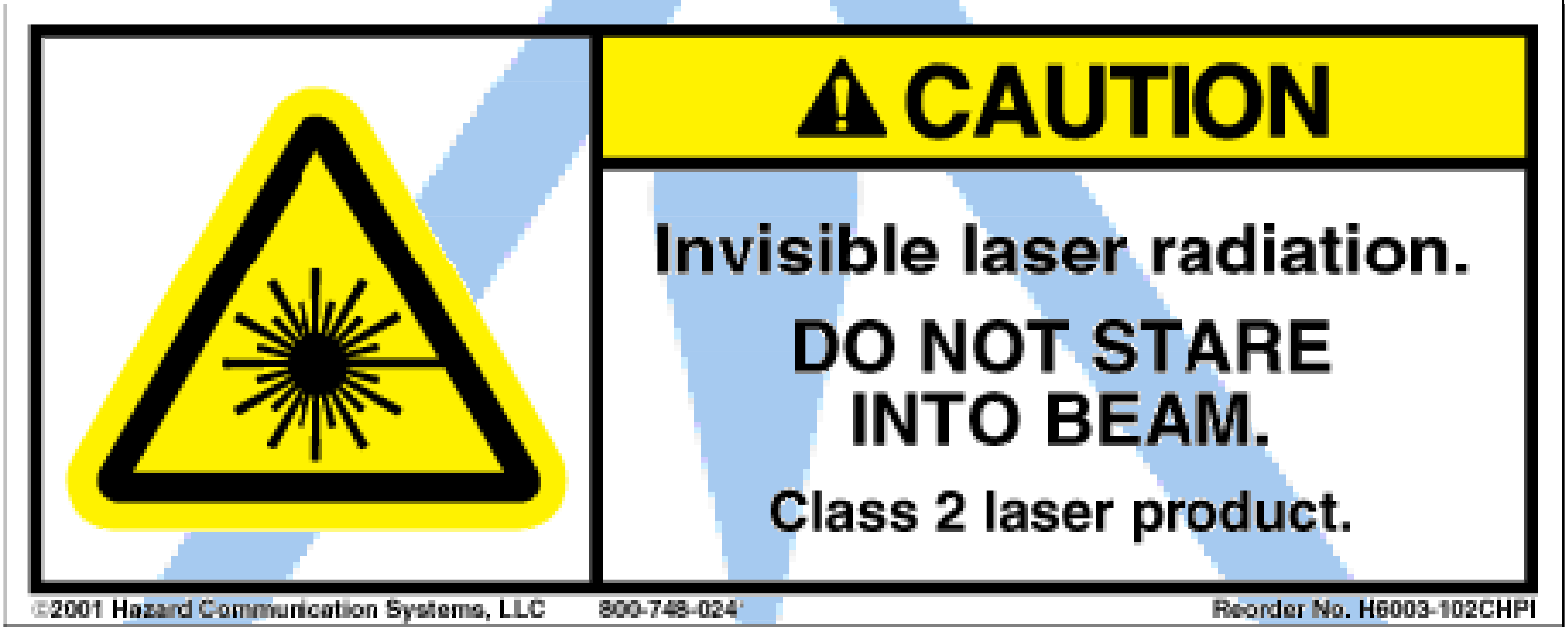
Radiation Notices

Non-Ionising Radiations

- laser
- ultrasound (other lecture)
- ultraviolet
- radio-frequencies (RF – other lecture)
  – microwaves
  – short-waves

Lasers

- devices: CT, MRI, radiotherapy systems, laser surgery, eye-lens corrections, DVDs etc
- bioeffects: thermal and photochemical damage to skin, retina as eye-lens can focus laser to a very intense point on the retina, corneal burn
- Laser Protection Adviser (LPA) and Laser Protection Supervisors
- laser controlled areas
- local rules
- appropriate training
- protective eye-wear
- Maximum Permissible Exposure levels


CAUTION
Invisible laser radiation.
DO NOT STARE
INTO BEAM.
Class 2 laser product.
©2001 Hazard Communication Systems, LLC
800-748-024
Reorder No. H6003-102CHPI

Laser Classes

- classes 1 - 4 in increasing power
- Class 1: Inherently safe (max permitted limit cannot be exceeded) because laser is very low power or housed in an enclosure that does not allow harmful levels of exposure (e.g. laser printer, CD drive)
- Class 2: low power where safety is afforded by blink mechanism of eye (e.g. laser lecturing pointer)
- Class 3A and 3B: direct beam viewing could be hazardous
- Class 4: high power devices. Direct beam and **reflections** hazardous.

UV

- devices: spectrophotometers, photo-therapy, suntan machines, photocopiers etc.
- careful as non-visible
- UVA, UVB, UVC increasing frequency
- bioeffects: skin cancer, erythema, premature aging of skin, cataracts

Personal Protective Equipment (PPE)

- Any device or appliance designed to be worn or held by an individual for protection against one or more health hazards
- Directive 89/686/EEC

Additional Information for Radiation Workers

Radiation Quantities and Units 1

- External sources: ABSORBED DOSE – the amount of energy absorbed per unit mass of tissue. Units $J \cdot Kg^{-1}$ (Gray Gy). The higher the absorbed dose the higher the number of ions produced and the higher the risk.
- Internal sources: COMMITTED ABSORBED DOSE amount of energy absorbed per unit mass of tissue over a period of 50 years (70 years for children).

$$D_{T,R} = \frac{energy\ absorbed}{m}$$

Radiation Quantities and Units 2

Effective Dose and Committed Effective Dose (units Sv):

$$E = \Sigma w_T \; w_R \; D_{T,R}$$

$$w_R \;=\; \textit{radiation weighting factor}$$

$$w_T \;=\; \textit{tissue weighting factor}$$

The radiation weighting factor is necessary because certain radiations are more risky than others. γ and X (ext/int) 1, a (internal) 20.

The tissue weighting factor is necessary because different tissues have different *radiosensitivity*.

The effective dose is often referred to simply as the *dose*.

Units of H are Sievert Sv (usually mSv used).

Shielding

- α no shielding required since stopped by skin
- β usually 1cm of perspex is enough
- X / gamma radiation require shielding (usually Pb)

$$t = \frac{1}{\mu} \ln \frac{E_I}{E_T}$$

μ = linear energy attenuation coefficient of the shielding material

t = thickness of shielding required to reduce effective dose from E_I to E_T

Half Value Layer (HVL) = 0.693 / μ

Tenth Value Layer (TVL) = 2.303 / μ

Old Units

- 1 RAD = 0.01Gy
- 1 REM = 0.01 Sv
- Quality factor = radiation weighting factor
- Roentgen (R): measure of radiation exposure used for X and g only.

(Exposure: In a small volume of the air, it is the quotient *q/m*, where *q* is total negative (or positive) electric charge produced in the air volume with mass *m*. The exposure unit is coulomb per kilogram ($C{\cdot}kg^{-1}$). An older unit of exposure is roentgen (R):

$$\mathbf{1\ R = 2.58 \cdot 10^{-4}\ C.kg^{-1}}$$)

Websites for additional information on radiation sources and effects

European Commission (radiological protection pages): **europa.eu**

International Commission on Radiological Protection: **www.icrp.org**

World Health Organization: **www.who.int**

International Atomic Energy Agency: **www.iaea.org**

United Nations Scientific Committee on the Effects of Atomic Radiation: **www.unscear.org**

Author:

Carmel J. Caruana

Graphic design and content collaboration:

Vojtěch Mornstein

Last revision: December 2018