External Dosimetry

Professional Training Programs

Oak Ridge Associated Universities

Objectives

- Review the dose quantities used in external dosimetry.
- Discuss dosimeter types and wearing locations for workers in various situations.
- Review the regulations about monitoring workers.
- Review the essential elements of an external dosimetry program.
- Discuss frequently encountered problems in dosimetry programs.

Dose Equivalent

External doses are evaluated at various depths depending on where the tissue at risk is located.

Dose Equivalent Type	Abbreviation	Measurement Depth for External Sources (cm)
Deep dose equivalent	DDE	1
Lens of eye dose equivalent	LDE	0.3
Shallow dose equivalent, skin or any extremity	SDE	0.007

Dose Quantities

- NRC defines the whole body as the head, neck, trunk of the body, arms above the elbows, and legs above the knee.

- The extremities are the hands, elbows, arms below the elbow, and feet, knees, legs below the knee.

Dose Quantities

- DOE defines the whole body as the head, trunk of the body, arms above and including the elbows, and legs above and including the knee.

- The extremities are the hands, arms below the elbow, feet, and legs below the knee.

Dose Quantities

- The total risk of radiation exposure includes the risks from both external and internal exposures.
- The total effective dose equivalent (TEDE) is the sum of the internal dose (CEDE) and the external dose (DDE).
- TEDE = CEDE + DDE

Dose Quantities

- Similarly, the total organ dose equivalent (TODE) is the sum of the committed dose equivalent (CDE) to an organ or tissue and the DDE to that organ or tissue.

- TODE = CDE + DDE

Dose Limits

Population	Dose Limit
Adult Worker	5 rem TEDE 50 rem TODE 15 rem eye dose equivalent
Minor Worker	500 mrem TEDE 5 rem TODE 1.5 rem eye dose equivalent
Member of the Public	100 mrem, with only 10 mrem from airborne emissions
Embryo/fetus of Declared Pregnant Worker	500 mrem during gestation period

External Dose

- An individual's external dose is inferred from:
  - dosimeter results.
  - radiation survey results.
  - both.

- The dosimeter provides a representative dose to the individual in most situations.

External Dose

The following variables affect external dose:

- radiation type and energy
- dose rate
- duration of exposure
- exposure geometry
- tissue composition and depth

Types of Dosimeters

The types of dosimeters used to measure individual dose are:

- Film Dosimeters
- Thermoluminescent Dosimeters (TLDs)
- Optically Stimulated Luminescence Dosimeters (OSLDs)
- Pocket Ionization Chambers
- Electronic Dosimeters

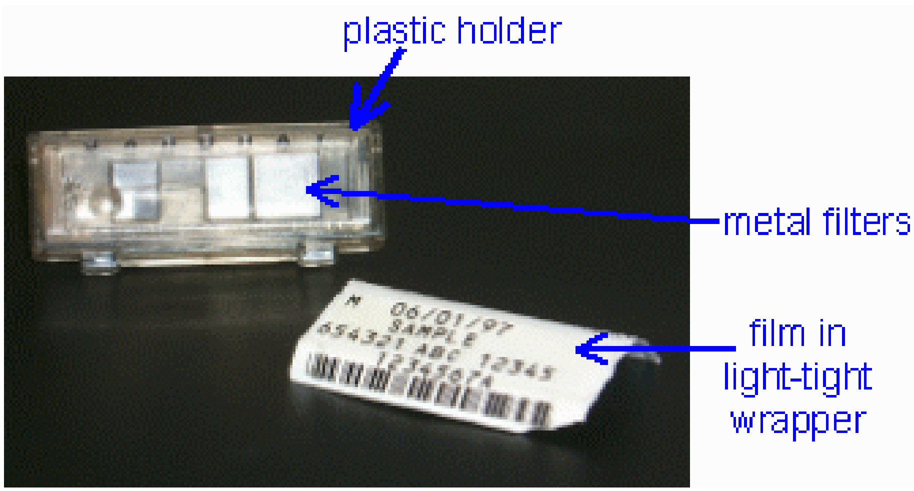
Film

- The film dosimeter, or film badge, consists of one or more dental radiographic film(s) wrapped in light-proof wrappers.

- The film wrapper is placed in a plastic holder which is clipped to the individual's clothing.

Film

Film



- Metal foils of Al, Cu, Cd, and/or Pb are placed in the badge holder to differentially absorb photons of different energies.
- The approximate energy of the photons exposing the individual can be determined by comparing the density of the film under the metal foils.

Film

- The sensitivity of the film is energy dependent below about 300 keV.

- This means that the film absorbs more radiation than tissue does.

Film

- The energy dependence of film results from the silver content of the film (silver has a higher atomic number than tissue).
- Above about 300 keV the film is nearly energy independent.

Film

- A window in the film holder allows beta dose to be determined for all but the weakest betas.
- After exposure the film is processed.
- Strict quality control during processing is required to ensure that the measured film density is produced by ionizing radiation and not poor processing.

Thermoluminescent Dosimeters (TLDs)

- Radiation exposure of thermoluminescent materials leaves some electrons in excited states.

- This stored energy is released in the form of light upon heating.

TLDs

- The light emitted is measured, and is proportional to the radiation absorbed by the TLD.

- Most TLDs are LiF crystals.

TLDs

LiF is nearly air/tissue equivalent, so it is energy independent from 10 keV to 10 MeV.

TLDs

Dose response is linear from 100 μGy (10 mrad) to approximately 10 Gy (1,000 rad).

TLDs

Other Li compounds and applications are:

- $Li_2B_4O_7$:Cu for measuring skin dose equivalent
- $Li_2B_4O_7$:Cu with plastic shield for measuring deep dose equivalent
- $CaSO_4$:Tm for measuring low doses, e.g. daily checks

TLDs

- Like film, TLDs are sent to a processor who reads the TLDs and reports the results.

- TLDs are usually exchanged on a quarterly basis instead of monthly like film badges.

Optically Stimulated Luminescence Dosimeters (OSLD)

- This dosimeter is a crystalline solid like the TLD.
- When exposed to radiation, it stores energy in the same manner as TLD material.

OSLD

- The stored energy in the TLD is released by heat.
- The stored energy in the OSLD is released by exposing it to laser light.

OSLD

- The principal advantage of the OSLD over film and TLD is the sensitivity.
- The OSLD can measure down to about 0.01 mSv (1 mrem).
- Film and TLD cannot measure less than about 0.1 mSv (10 mrem).

Dosimeter Processing

- Dosimeter processors must be accredited by the National Voluntary Laboratory Accreditation Program, or NVLAP, which is currently not voluntary.

- The accreditation program ensures that the processors meet specific standards and that dosimeter results are reliable.

Secondary Dosimeters

The film badges, TLDs , and OSLDs are accepted by the regulatory agencies as primary dosimeters, or the dosimeters that will be used to measure the worker's dose of record.

Secondary Dosimeters

- There are times when secondary or supplemental dosimeters are appropriate.

- Secondary dosimeters are not used to measure the dose of record, but can provide additional information.

Pocket Dosimeters

- Pocket ionization chambers (pocket dosimeters) are compact, easy-to-carry devices that indicate an individual's accumulated dose immediately, eliminating the delay of dosimeter processing.

- Pocket dosimeters should be worn on the upper front part of the body close to the primary dosimeter.

Pocket Dosimeters

For example, they are often issued to emergency workers during emergencies or emergency drills.

Electronic Dosimeters

- Electronic dosimeters (EDs) are used as secondary dosimeters at many facilities, particularly at nuclear power plants.
- EDs, like the pocket dosimeter, provide an immediate result of accumulated dose.

Electronic Dosimeters

- Audible alarms for accumulated dose and dose rate.
- Stable readout that is not affected by physical activity (drift).
- Wide range of accumulated doses and dose rates.

Electronic Dosimeters

- Real time dose monitoring using radiotelemetry.
- Electronic storage of daily dose in a data base.

Electronic Dosimeters

In spite of these advantages, electronic dosimeters are not currently accepted by regulatory agencies in the U.S. as primary dosimeters.

External Dosimetry Issues

- Where should a dosimeter be worn?
- Are there situations where a worker may need to wear more than one dosimeter?

Where to Wear?

- NRC regulations require that dosimeters be worn on the part of the body likely to receive the highest dose.

- Usually this will be on the front of the body, but will depend on the situation.

More Than One?

- When only one dosimeter is issued to a worker, it is usually a whole body dosimeter.
- Additional dosimeters may be necessary when parts of the body could receive more exposure than the whole body dosimeter indicates.

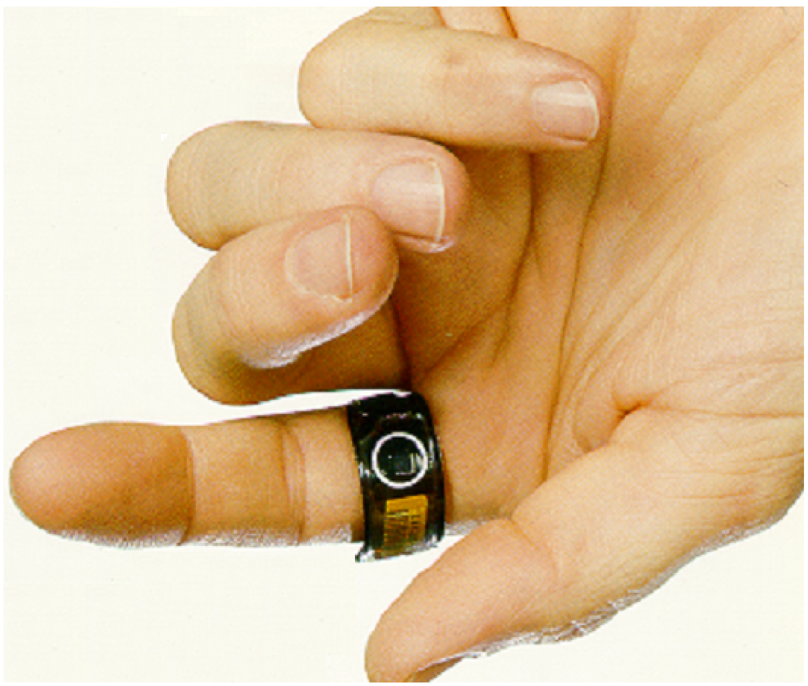
More Than One?

For example, extremity dosimeters are issued to radiopharmacists or radiochemists who frequently handle and prepare large amounts of radioactivity.

More Than One?

The most common extremity dosimeter is a TLD finger ring.

More Than One?



The flat portion of the ring (which contains the TLD) must be worn facing the palm or back of the dominant hand, whichever orientation will measure the greatest dose.

More Than One?

- High dose tasks could require a number of dosimeters located on various parts of the body, e.g. front and back, head, neck, feet and/or hands.

- Pregnant workers may be issued a second dosimeter for assessment of the dose to the embryo/fetus. (usually worn at the abdomen)

Lead Aprons and Dosimeters

- Usually, the dosimeter should not be shielded.
- However, some situations require knowledge of the dose for a shielded part of the body in addition to the dose outside of a shield (location of highest dose).

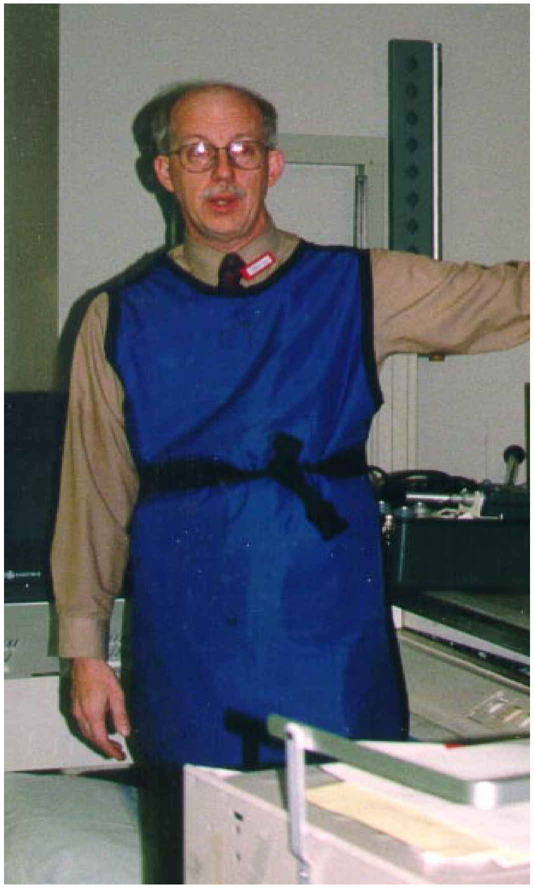
Lead Aprons and Dosimeters

- The classic example of this is occurs in diagnostic radiology departments.
- Many diagnostic radiology procedures require the worker to wear a lead apron.

Lead Aprons and Dosimeters

- The primary dosimeter should be worn at the collar outside the apron, the location of the highest whole body dose.

- On the other hand, the result of this dosimeter may not be representative of the dose to the rest of the whole body, shielded by the apron.



Lead Aprons and Dosimeters

- Two dosimeters may be worn by workers wearing lead aprons:
  - one at the collar outside the apron.
  - one on the trunk under the apron.

- The vendors can color-code the dosimeters so that workers can wear them consistently (e.g. red neck and yellow belly).

Weighting

- If two dosimeters are worn, which dosimeter result becomes the dose of record?

- The answer is: It depends on the state where you work !

Weighting

- Some facilities are weighting dosimeter results to reasonably estimate the effective whole body dose when a lead apron is worn.

- Several formulae are reported, but the Webster formula is very common:
  - **$EDE = 1.5\ H_W + 0.04\ H_C$.**
    - H_W is the result of the waist dosimeter (under the apron).
    - H_C is the result of the collar dosimeter (outside the apron).

Weighting

- NRC has issued several summaries that address this topic.
- Some states allow dose weighting for diagnostic and interventional radiology procedures.

Weighting

NCRP Report #122 Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low Let Radiation (1995) discusses the issue in more detail.

Summary

- Use film, TLD, and OSL dosimeters for primary dosimeters.
- Use pocket chambers, electronic dosimeters, and additional film, TLD, or OSL dosimeters for secondary dosimeters.

Summary

- In most cases, a single whole body dosimeter is adequate for inferring a representative dose to the whole body.
- Some situations may require additional dosimeters to obtain realistic dose estimates.

NRC Monitoring Requirements

	DDE	SDE	LDE
Adults	> 5 mSv/yr (500 mrem/yr)	> 15 mSv/yr (1500 mrem/yr)	> 50 mSv/yr (5000 mrem/yr)
Minors	> 1 mSv/yr (100 mrem/yr)	> 1.5 mSv/yr (150 mrem/yr)	> 5 mSv/yr (500 mrem/yr)
Declared pregnant women: DDE > 1 mSv/gestation (100 mrem/gestation).			
Individuals entering a high radiation area.			
Individuals entering a very high radiation area.			
Individuals who may have received radiation doses during the year while employed elsewhere.			

Who Should Be Monitored?

- The workers who should be monitored are a more difficult group to identify, because of the phrase "likely to receive" in the regulations.
- In the past, facilities monitored just about everyone under the rationale that it was the only way to know if monitoring was actually required, and because monitoring provided a degree of reassurance to workers.

Who Should Be Monitored?

- Today, as a result of ALARA requirements (including cost factors), most facilities avoid unnecessary issuance of dosimeters, relying on other means of determining the likelihood of exposure and providing reassurance.

- In a survey of research or academic institutions, the percentage of radiation workers assigned whole body dosimeters varied widely, from 6%-100%.[1]

Exchange Procedures

- The exchange procedures should be part of the dosimetry program procedures.

- The vendor will supply a shipping list with a new batch of dosimeters, which should be checked for accuracy.

Exchange Procedures

- The exposed dosimeters are exchanged with the new ones as soon as possible.

- Problems can arise from:
  - Lost or forgotten dosimeters.
  - Damaged dosimeters (laundered by mistake, etc.).

Exchange Procedures

- Unusual situations should be documented.
- The shipment to the vendor should be made as soon as most of the dosimeters are collected.
- A shipment should not be detained very long waiting for individual dosimeters to be returned.

The Control Dosimeter

- Each new shipment of dosimeters contains a control dosimeter.
- The purpose of the control dosimeter is to measure background (dose during transit and storage).

Control Dosimeter

- The control dosimeter should be sent back with the same batch of dosimeters in which it arrived.

- Any accumulated dose on the control dosimeter is subtracted from individual dosimeter results in that batch.

Control Dosimeter

- The control dosimeter must not receive any dose other than background during the deployment period, or individual dosimeter results may be significantly underestimated.
- The purpose of the control dosimeter is frequently misunderstood.

Control Dosimeter

- For example, the control dosimeter should NOT be mounted in a central location frequently occupied by the monitored workers.

- The control dosimeter should be carefully stored in a shielded location until it is due to be shipped back with the batch of dosimeters in which it arrived.

Training

A badged workers responsibilities include:

- Wearing the dosimeter at the assigned place.
- Wearing the dosimeter at all work times.
- Handling it properly when it is not being worn (no laundry, no trunk of the car, etc.).
- Not let others wear his/her dosimeter.
- Exchanging the dosimeter promptly.
- Notifying the RSO if there is an occupational exposure outside of work (part-time jobs, etc.) or previous exposure during the year with another employer.
- Not deliberately exposing, destroying, contaminating, falsifying or tampering with his/her own or another's dosimeter.

Reports

- Prior to January 3, 2008, NRC regulations (10 CFR 19) require that workers be notified of dosimeter results on at least an annual basis in writing.

- Currently, licensees must provide an annual report to each individual monitored, of the dose received in that monitoring year if:
  - the individual's occupational dose exceeds 1 millisievert (mSv) (100 millirem (mrem)) TEDE, or
  - 1 mSv (100mrem) to any individual organ or tissue, or
  - the individual requests his or her annual dose report.

- Workers have a right to review their dosimeter results at any time (in addition to the annual report).

References

- O’Brien, S.L. et al., Howard Hughes Medical Institute Dose Assessment Survey. Health Physics 71(6):966-969;1996.
- NCRP Report #122 Use of Personal Monitors to Estimate Effective Dose Equivalent and Effective Dose to Workers for External Exposure to Low Let Radiation (1995).
- Webster, E.W. EDE for exposure with protective aprons. Health Physics 56: 568-569, 1989.