Chapter 7

External and Internal Dosimetry

Objectives

- Discuss factors influencing external and internal doses
- Define terms used in external dosimetry
- Discuss external dosimeters such as TLDs, film badges, OSL dosimeters, pocket chambers, and electronic dosimetry

Objectives

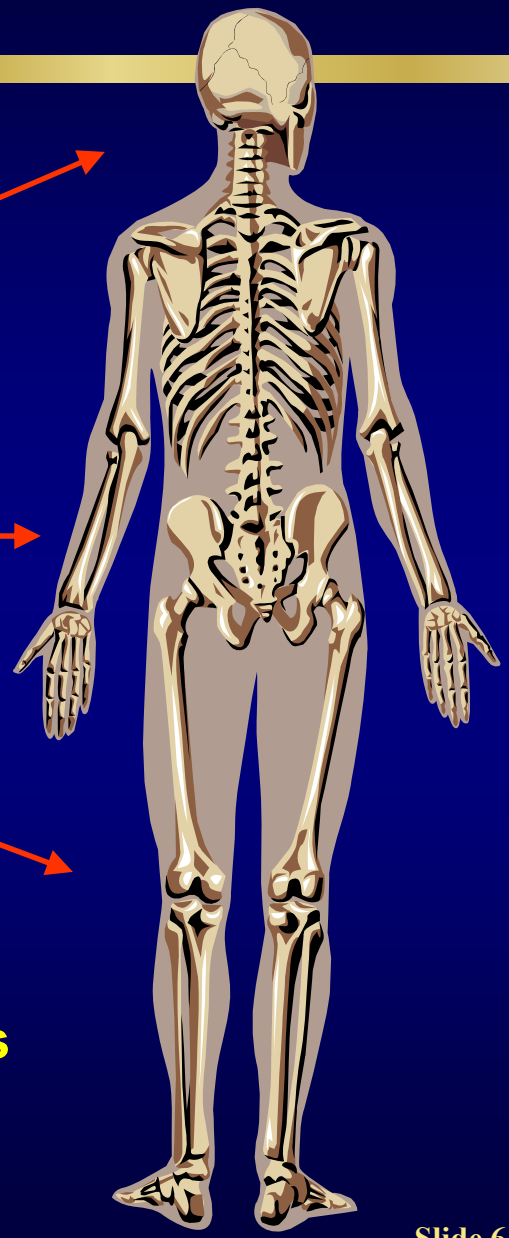
- Define terms used in internal dosimetry
- Discuss dose units and limits
- Define the ALI, DAC and DAC-hr
- Discuss radiation signs and postings

Objectives

- Discuss types of bioassays
- Describe internal dose measuring equipment and facilities
- Discuss principles of internal dose calculation and work sample problems

External Dosimetry

External Dosimetry



Gamma, beta or neutron radiation emitted by radioactive material outside the body irradiates the skin, lens of the eye, extremities & the whole body (i.e. internal organs)

External Dosimetry (cont.)

- Alpha particles cannot penetrate the dead layer of skin (0.007 cm)
- Beta particles are primarily a skin hazard. However, energetic betas can penetrate the lens of an eye (0.3 cm) and deeper tissue (1 cm)
- Beta sources can produce more penetrating radiation through bremsstrahlung
- Primary sources of external exposure are photons and neutrons
- External dose must be measured by means of appropriate dosimeters

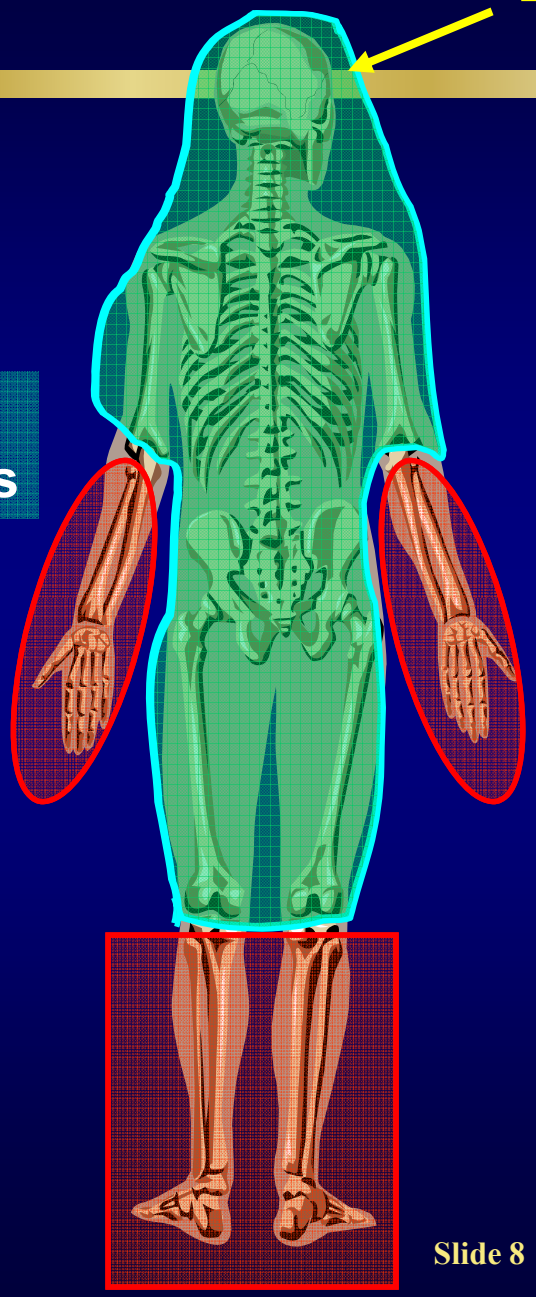
Dose Limit Application

Whole Body -
everything except extremities

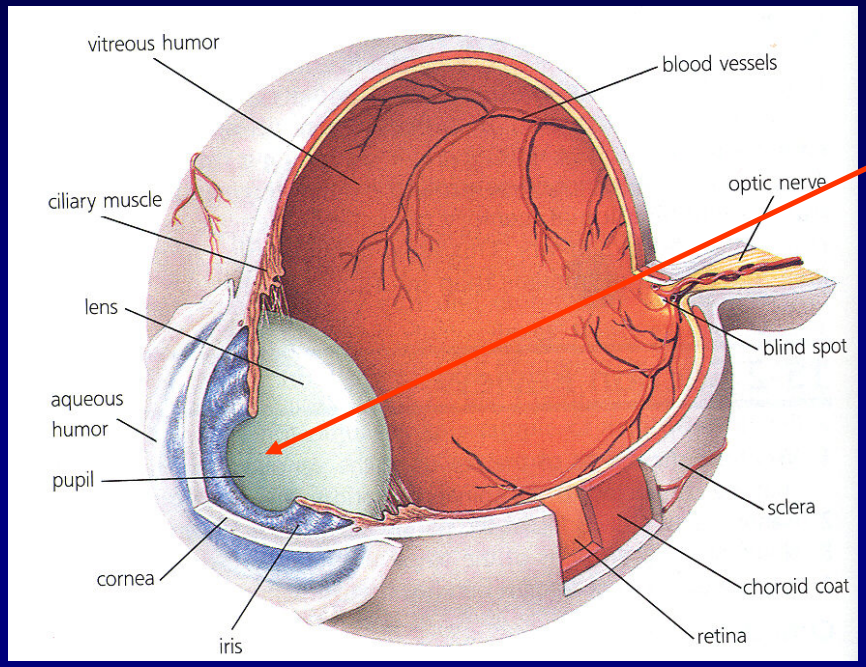
Skin of the Whole Body -
skin covering everything except extremities

Skin of the Extremities -
skin covering extremities

Extremities -
Elbows, and arms below elbows
knees, and legs below knees

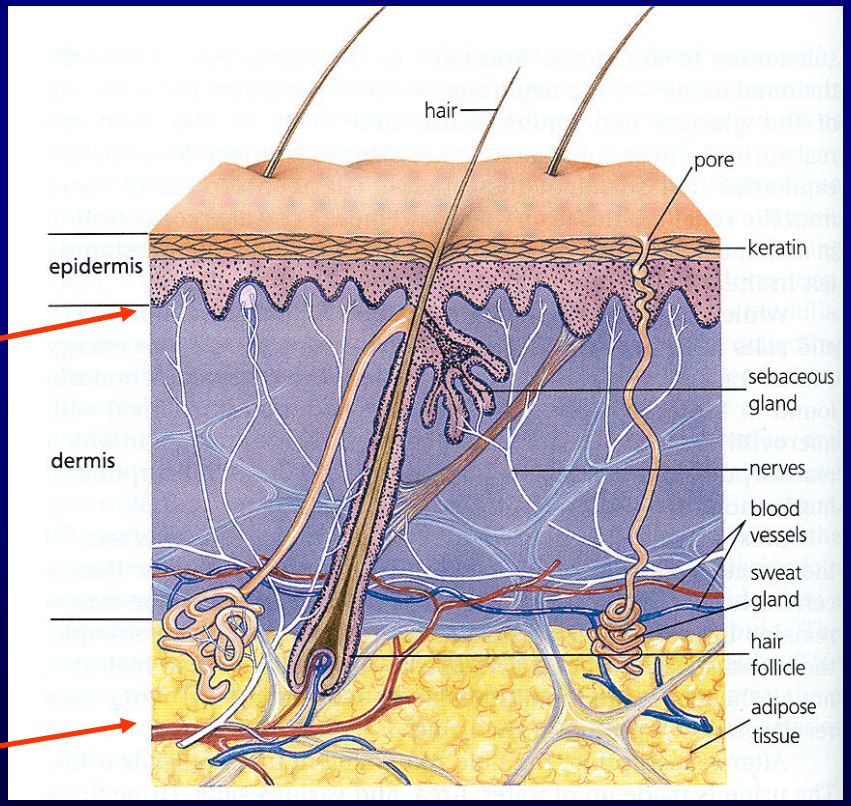


External Dose Measurements



The dose to the lens of the eye is measured at a depth of 0.3 cm

The shallow (skin) dose is measured at a depth of 0.007 cm



The deep (whole body) dose is measured at a depth of 1 cm

External Dose Terms

DDE	Deep Dose Equivalent, or
EDE	Effective Dose Equivalent (for external sources)
	"Whole Body Dose"
LDE	Lens Dose Equivalent
	"Eye Dose"
SDE_{ME}	Shallow Dose Equivalent to the Maximum Extremity
	"Extremity Skin Dose"
SDE_{WB}	Shallow Dose Equivalent to the Whole Body
	"Skin Dose"

Effective Dose Equivalent (EDE)

- The whole body is not always exposed to uniform external radiation fields.

- A method to determine Effective Dose Equivalent (EDE) for external sources that are non-uniform is by wearing dosimeters on the front and back of the body (EPRI Method)

  Dosimeter results are weighted as follows:

  $$EDE = \frac{3}{4} Hi + \frac{1}{4} Lo$$

  Note: Details of other approved EDE methods are contained in Regulatory Guide 8.40, "Methods for Estimating Effective Dose Equivalent from External Exposure" published July 2010.

EDE (cont.)

- RG 8.40 also allows EDE to be used for medical personnel wearing protective aprons during radiology procedures
- Some NRC Agreement States have approved use of EDE in calculating external dose to hospital staff during medical x-ray fluoroscopy procedures
- In one approach, for example, the EDE = 0.04C + 1.5W, where C is the unshielded collar dosimeter reading and W is the shielded waist dosimeter reading (under the protective lead apron).

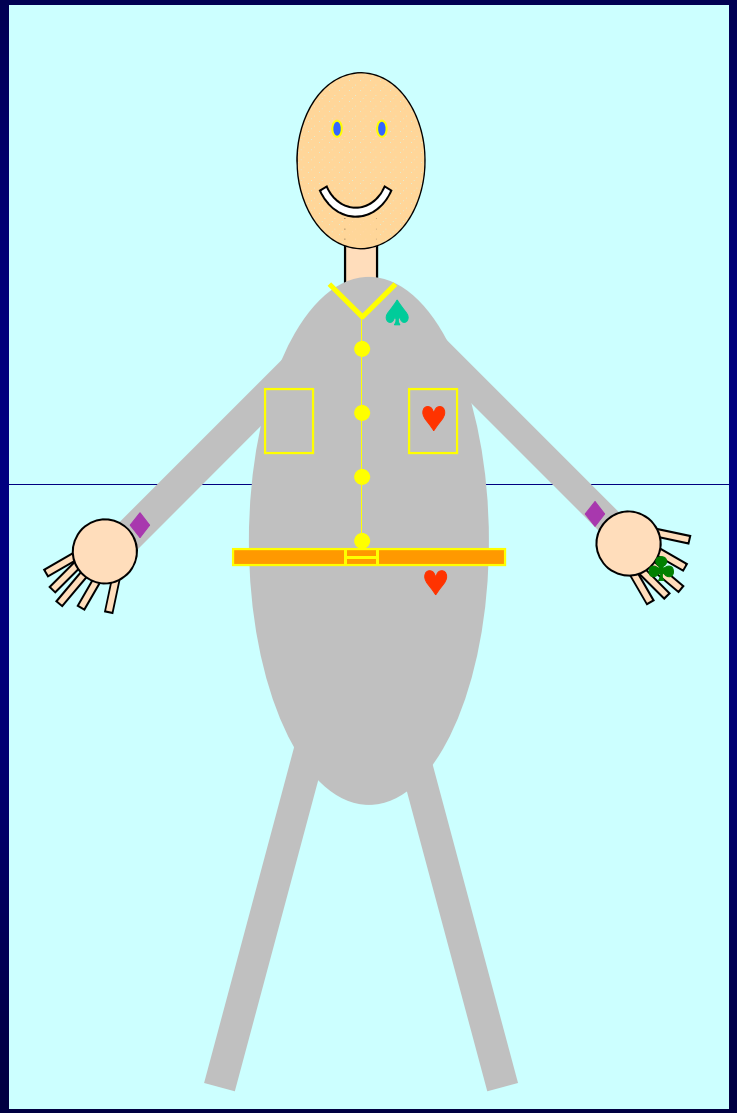
Dosimeter Locations

- ♥ Torso (belt or breast pocket) - measures whole body dose (DDE) (covers most important organs) and skin dose (DDE & SDE_{WB}) Note: Front and Back dosimeters can be worn to determine EDE for non-uniform rad. fields.

- ♠ Collar - measures lens of eye (LDE) also thyroid and head which are part of whole body (DDE & SDE_{WB}) - usually used when lead apron worn

- ♦ Wrist - measures extremity skin dose (SDE_{ME}) assuming fairly uniform dose pattern over hand and lower arm

- ♣ Finger - measures extremity (SDE_{ME}) assuming most dose to the hand and fingers - if dose originates in palm (e.g. from holding a source), the dosimeter should be worn on the inside of the finger (opposite to how a ring is normally worn)



Thermoluminescent Dosimeters (TLDs)

- Common TLD materials are LiF, CaF (near air/tissue equivalent – energy independent from 10 – 10k keV)
- Irradiated TLD material's electrons are raised and trapped at a higher energy state (band theory of solids)
- Emission of light (300-600 nm) when crystalline material is heated by reader
- Total light output (intensity) is proportional to the absorbed dose
- Glow curve provides permanent record
- TLD has wide, linear dose-response range (10 mrad to 1000 rad)
- TLD is accurate (some fading), small and rugged
- With Li-6 or B-10, they may provide neutron dose
- Can provide: SDE, LDE, and DDE

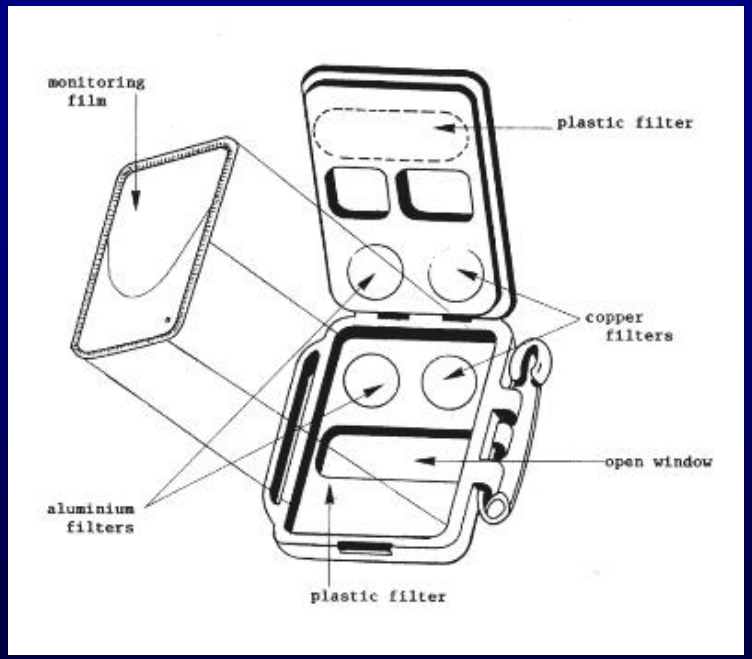
“Finger Ring” TLDs

- LiF chip
- Dose Range:

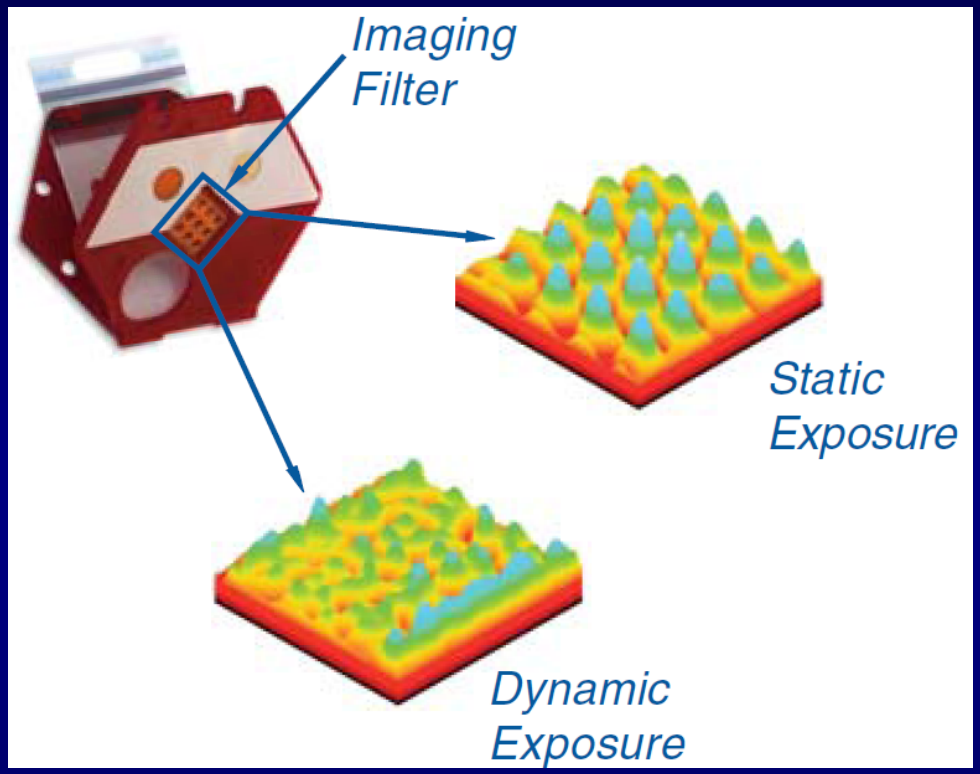
  Photon (> 15keV): 30 – 1000 mrem
  Beta (>200 keV): 40 – 1000 mrem

Film Dosimeters

- Similar to x-ray film (silver bromide)
- Film is darkened by radiation (metallic silver)
- Dose is determined by measuring the optical density of the film
- Film response depends on type, energy and amount of incident radiation
- Permanent record
- Not useful for low-energy beta emitters such as H-3 or C-14



Optically Stimulated Luminescence Dosimeters (OSLs)



Optically Stimulated Luminescence Dosimeters (OSLs)

- OSLs (aluminum oxide) store energy much like TLDs, but use green light from a laser or LED to de-excite the electrons to determine the absorbed dose.
- The amount of blue light created is proportional to the dose received.
- OSLs can be read multiple times
- Dose measurement range:

  photon (5 keV – 40 MeV): 1 mrem – 1000 mrem

  beta (150 keV – 10 MeV): 10 mrem – 1000 mrem
- To measure neutron dose, an optional detector, CR-39 (solid-state track detector), must be used.

Pocket Dosimeters

- Small gas-filled cylinders used to measure X and gamma radiation
- Primary advantage is that they provide real-time radiation dose information to workers
- Typical dosimeters range from 0-200 mR, 0-500 mR, 0-5 R, and 0-50 R
- Should normally not be used as dose of record and should always be used with TLD or film badge

Direct Reading Dosimeters

For personnel working in radiation areas, Direct Reading Dosimeters provide an accurate and instantaneous indication of accumulated exposure.

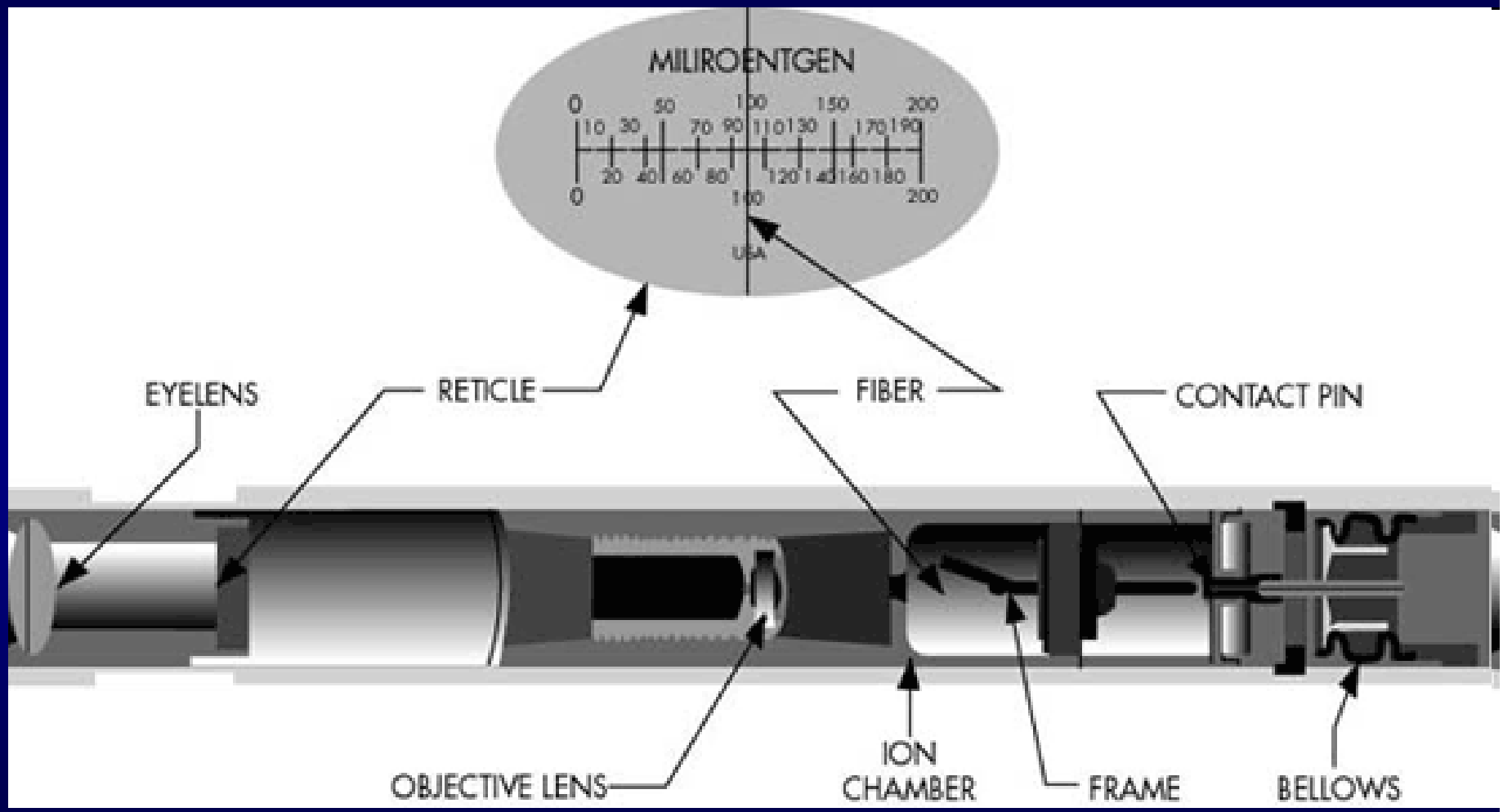
Accurate to 10% of True Dose. Less than 2% leakage/24 hours. Hermetically sealed.

Resembling fountain pens in size and appearance, they contain a quartz fiber electrometer and compound microscope.

The fiber is set at zero with a battery operated charger. As X- or gamma rays strike the charged Dosimeter, the fiber moves up scale in proportion to the radiation exposure.

019-200	200 mR Dosimeter	$135.00
019-500	500 mR Dosimeter	135.00
019-100	1 R Dosimeter	135.00
019-611	5 R Dosimeter	135.00
019-110	10 R Dosimeter	135.00
019-001	100 R Dosimeter	135.00
019-002	200 R Dosimeter	135.00
019-006	600 R Dosimeter	135.00

Figure 8-2. Direct Reading Pocket Dosimeter


MILIROENTGEN
0
50
100
150
200
10
30
70
90
110
130
170
190
20
40
60
80
120
140
160
180
0
100
200
USA
EYELENS
RETICLE
FIBER
CONTACT PIN
OBJECTIVE LENS
ION
CHAMBER
FRAME
BELLOWS

Electronic Dosimeters

- Electronic dosimeters have replaced pocket chambers at commercial nuclear facilities
- Based on solid state diode detector
- More rugged than pocket chambers and can be set to alarm
- Measure gamma dose from 0.1 mrem to 1000 rem
- Some models also measure neutron radiation

Internal Dosimetry

Internal Dosimetry Program

- An internal dosimetry program is part of an overall radiation protection program at a site
- Air sampling and bioassay programs are utilized to control internal dose to workers
- Effectiveness of engineering and administrative controls are evaluated by the program

Internal Dosimetry

- Internal dosimetry is an art based on science
- Dosimetrists must quantify the amount of radioactive material within the body
- Radionuclides distribute differently in the body (e.g. iodine seeks the thyroid, while strontium seeks the bone)

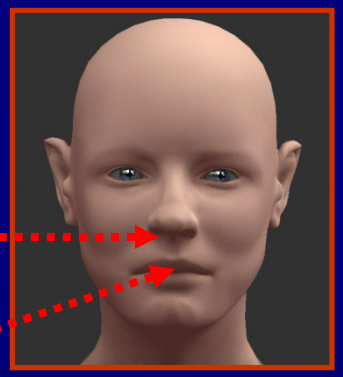
Internal Dosimetry

- Internal dose is defined as dose from radiation released by radioactive materials deposited inside the body

- Radioactive materials enter the body through:

Inhalation

Ingestion



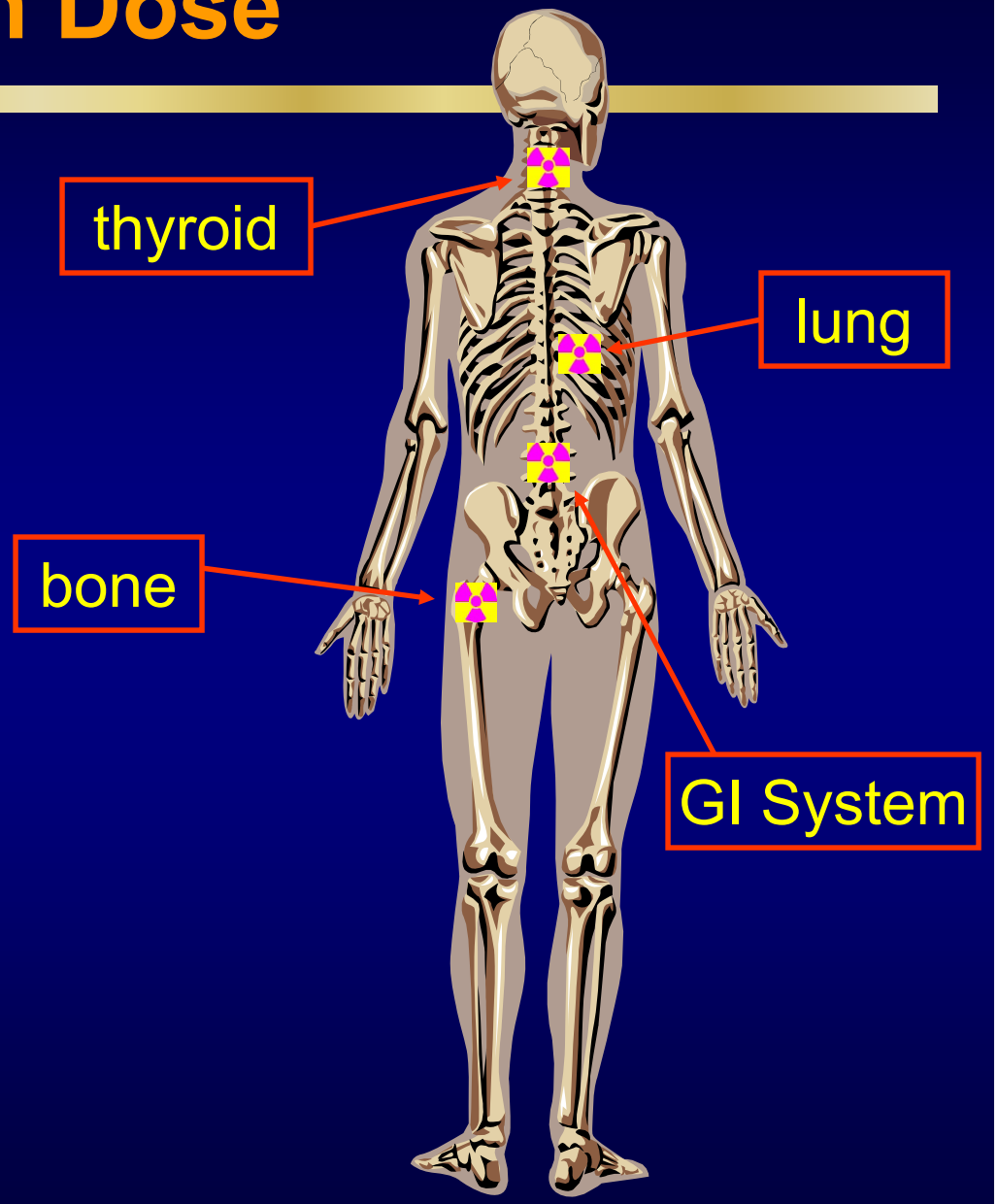
Absorption
(through skin or wounds)

Inhalation
ALI (Annual Limit on Intake)
DAC (Derived Air Concentration)

Ingestion
ALI (Annual Limit on Intake)

Internal Radiation Dose

Alpha, beta or gamma radiation emitted by radioactive material inside the body exposing any internal organ such as:



Tissue Weighting Factors

- In 1977, ICRP-26 recommended tissue weighting factors for the various tissues and organs of the human body based upon their susceptibility to radiation damage (stochastic, deterministic or hereditary effects).

- The tissue or organ dose from an intake is related to uniform whole body irradiation by use of the tissue weighting factors.

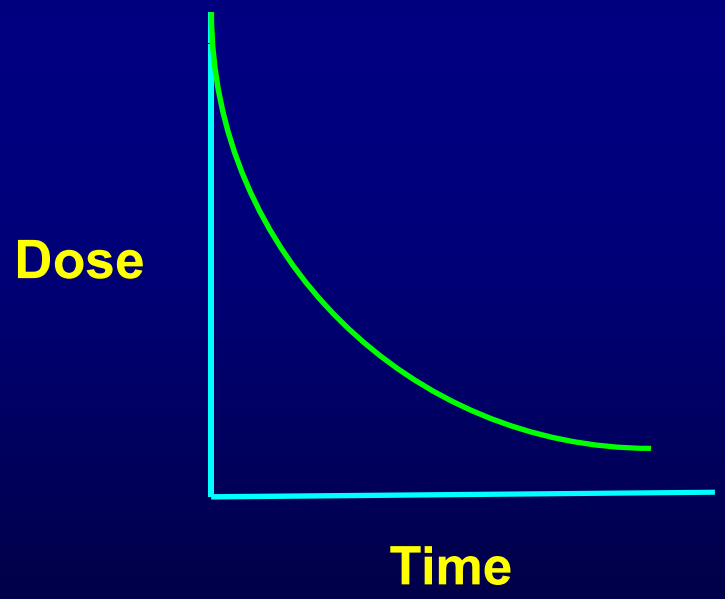
Internal Dose Terms

CDE Committed Dose Equivalent

CEDE Committed Effective Dose Equivalent

Committed Dose Equivalent (CDE)

The dose from internal sources can be accrued over many years. The dose delivered decreases as time passes due to the radioactive decay and biological elimination.



Committed Dose Equivalent (CDE)

- The radiation dose delivered to a worker's organ(s) over 50 years after the initial intake
- It is administratively convenient to assign the dose (CDE and CEDE) in the year of intake

Committed Effective Dose Equivalent

CEDE is related to CDE in the following way:

$$CEDE = \sum w_T * CDE_T$$

w_T is the tissue weighting factor that relates the risk to the organ (T) to an equivalent whole body risk.

To obtain the effective whole body dose (CEDE) we must sum the doses to all of the different organs.

Risk-Based Tissue Weighting Factors (ICRP-26 / 10CFR20 Values)

Tissue or Organ	Risk Weighting Factor
Gonads	0.25
Breast	0.15
Lung	0.12
Red Bone Marrow	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder	0.30
TOTAL	1.00

CEDE Calculation

Example:

After an accidental intake of radioactive material, the CDE to the worker's thyroid is determined to be 1000 mrem. Calculate the worker's CEDE.

$$CEDE = \sum w_T * CDE_T$$

CEDE = 0.03 x 1 rem = 0.03 rem or 30 mrem

(Dose of 1 rem to thyroid has same risk as a dose of 30 mrem to whole body)

Dose Limits

Occupational Dose - 10CFR20.1003

Occupational dose means the dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation or to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include doses received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive material and released under § 35.75, from voluntary participation in medical research programs, or as a member of the public.

Dose Term	Annual Limit	
OCCUPATIONAL		
LDE	15 rem	
SDE_{ME}	50 rem	
SDE_{WB}	50 rem	
DDE + CDE = TODE	50 rem	per organ
EDE + CEDE = TEDE	5 rem	
Minor	10% of adult limits	
Dose to E/F of DPW	0.5 rem	Pregnancy
Public TEDE	0.1 rem = 100 mrem	

Secondary and Derived Limits

ALI & DAC

Annual Limit on Intake, ALI

- The amount (e.g. μCi) of radioactive material taken into the body that would result in a CEDE of 5 rem or a CDE of 50 rem

Derived Air Concentration, DAC

- The concentration (e.g. μCi /mL) of a given radionuclide in air which, if breathed by reference man for a working year, results in an intake of one ALI

10 CFR Part 20
Appendix B

Annual Limit on Intake (ALI)

- Derived for each radionuclide and selected chemical forms
- Two types of ALIs - stochastic and non-stochastic (deterministic)
  - Stochastic ALI = CEDE of 5 rem/year (whole body)
  - Deterministic ALI = CDE of 50 rem/year (organ)

Derived Air Concentration (DAC)

DAC = (ALI μCi/y) / (2000 hr/y x 1.2×10^6 mL/hr)

Where:

DAC = μCi/mL

2000 hrs = occupational year (40 hrs/wk x 50 wk/y)

1.2×10^6 mL/hr = breathing rate for Reference Man

DAC-hours

- Breathing air at a concentration of 1 DAC for 1 hour results in an exposure of 1 DAC-hr

- For DACs derived from stochastic ALIs:

  2000 DAC-hrs = 5 rem CEDE
  1 DAC-hr = 2.5 mrem CEDE

- For DACs derived from deterministic ALIs:

  2000 DAC-hrs = 50 rem CDE
  1 DAC-hr = 25 mrem CDE

Dose Calculation Using 10CFR20 ALIs

CDE = (Intake / ALI) x 50 rem

CEDE = (Intake / ALI) x 5 rem

Where the intake is in units μCi

Problem

A worker inhales 25 μCi of Iodine-131.

Calculate CDE to the thyroid and the CEDE.

Given:

Iodine-131 deterministic ALI for thyroid = 50 μCi
Iodine-131 stochastic ALI = 200 μCi

Solution

CDE = (25 μCi / 50 μCi) x 50 rem = 25 rem to thyroid

CEDE = (25 μCi / 200 μCi) x 5 rem = 0.625 rem

Bioassay

Bioassay

The purpose of bioassay measurements are to:

- confirm the adequacy of radiological controls
- determine compliance with the occupational dose limits

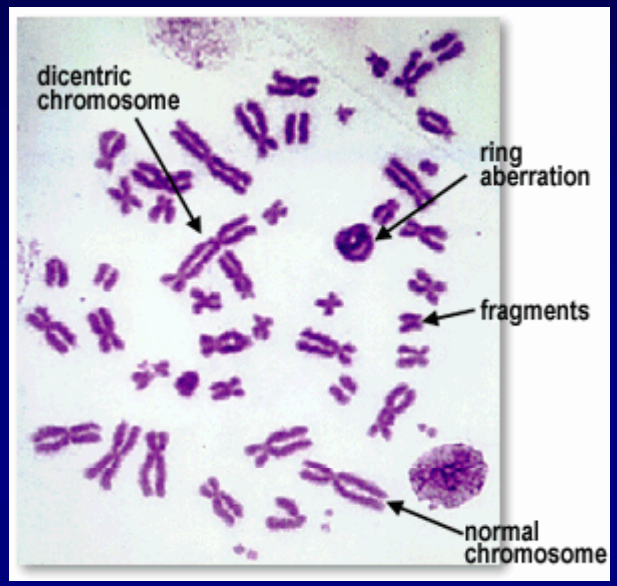
Bioassay

Two types of bioassay:

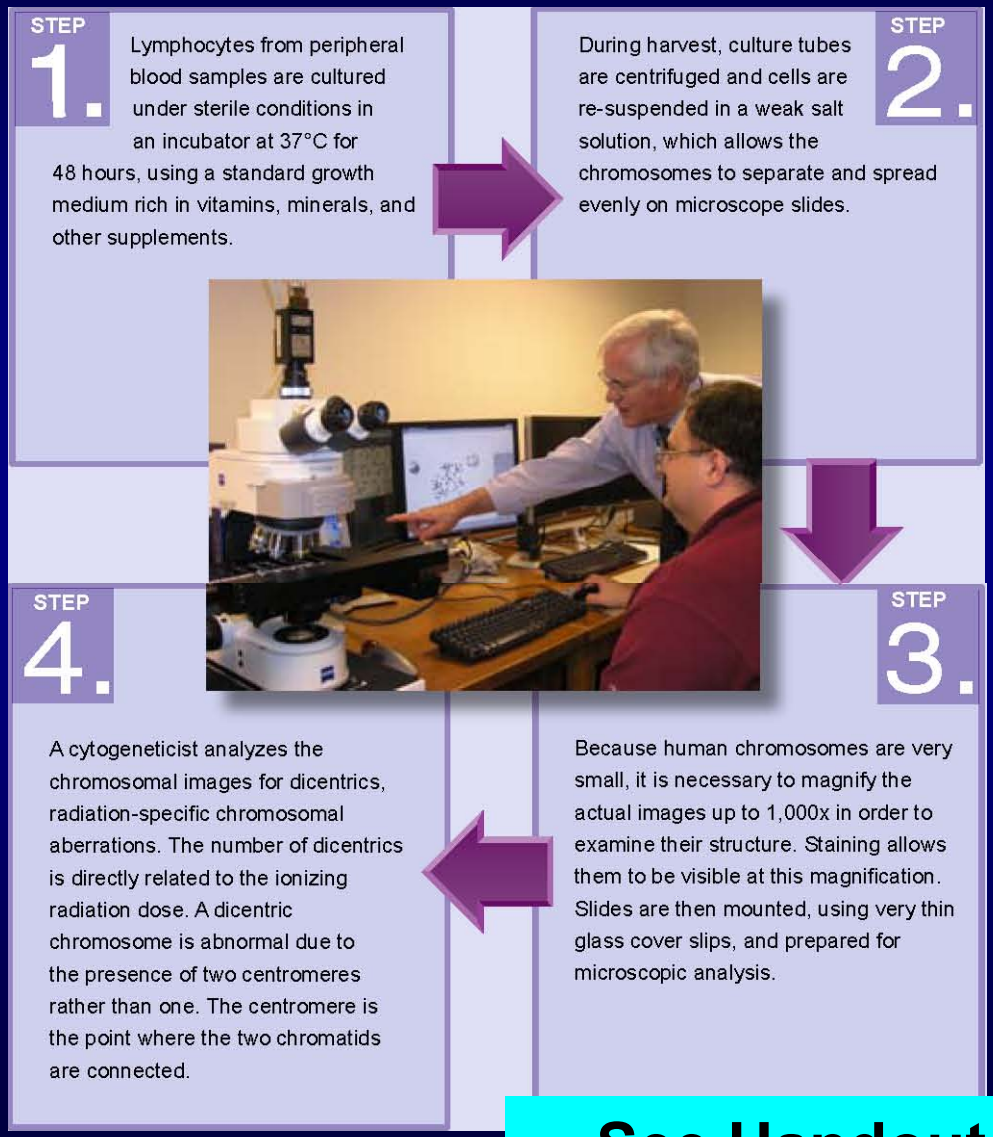
- **In-vitro bioassay (measures radioactivity in urine, feces, blood, tissue, etc.)**
- **In-vivo bioassay (measures radiation emitted from the body, using an external detector)**

In-vitro Bioassay

Cytogenetic Biodosimetry



http://www.orau.org/media-center/videos/programs/cyto-lab-orau.htm?keepThis=true&TB_iframe=true&height=450&width=645



See Handout

In-vivo Bioassay

Most common in-vivo bioassay methods are:

- **whole-body counting**
- **thyroid counting (specifically for iodine)**
- **lung counting**

Frequency of Bioassays

- Baseline, at initial hire
- When it is suspected that an intake occurred (e.g. presence of contamination in nasal swabs)
- At some established frequency or at discretion of health physics staff (e.g. random bioassays)
- At termination of employment

Whole-Body Counting

- Best method for detecting photon emitters if neither the radionuclide nor its location in the body is known
- Geometric configurations include chair, linear, fixed, and scanning whole-body counters
- Possible to detect pure beta emitters (e.g. P-32) by measuring bremsstrahlung

Individual Organ Counting

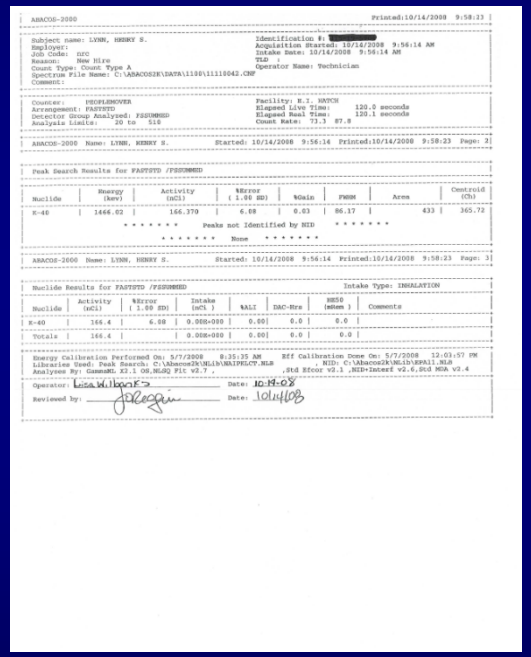
- Designed for those radionuclides that tend to concentrate in a particular body organ:
  - Iodine in thyroid gland
  - Insoluble radionuclides that concentrate in lungs or intestines, liver or kidney, brain or bone
- Geometry is optimized for a particular part of the body for a particular radionuclide

Wound Monitoring

- Direct bioassay method if the skin has been penetrated by contamination
- As with organ counters, wound counting generally results in optimum geometry
- Quantification of the radionuclide is difficult since the geometry of the wound may not be well known and the distribution of the contamination may not be readily determined

Measurement Equipment

Typical NaI whole-body counter



ABACOS-2000 Printed:10/14/2008 9:58:23

Subject name: LYNN, HENRY S.
Employer:
Job Code: nrc
Reason: New Hire
Count Type: Count Type A
Spectrum File Name: C:\ABACOS2K\DATA\1100\11110042.CNF
Comment:

Identification #: [redacted]
Acquisition Started: 10/14/2008 9:56:14 AM
Intake Date: 10/14/2008 9:56:14 AM
TLD :
Operator Name: Technician

Counter: PEOPLEMOVER
Arrangement: FASTSTD
Detector Group Analyzed: FSSUMMED
Analysis Limits: 20 to 510

Facility: E.I. HATCH
Elapsed Live Time: 120.0 seconds
Elapsed Real Time: 120.1 seconds
Count Rate: 73.3 87.8

ABACOS-2000 Name: LYNN, HENRY S. Started: 10/14/2008 9:56:14 Printed:10/14/2008 9:58:23 Page: 2

Peak Search Results for FASTSTD /FSSUMMED

Nuclide	Energy (kev)	Activity (nCi)	%Error (1.00 SD)	%Gain	FWHM	Area	Centroid (Ch)
K-40	1464.02	166.370	6.68	0.03	86.17	433	365.72

* * * * * * * Peaks not Identified by NID * * * * * * *
* * * * * * * None * * * * * * *

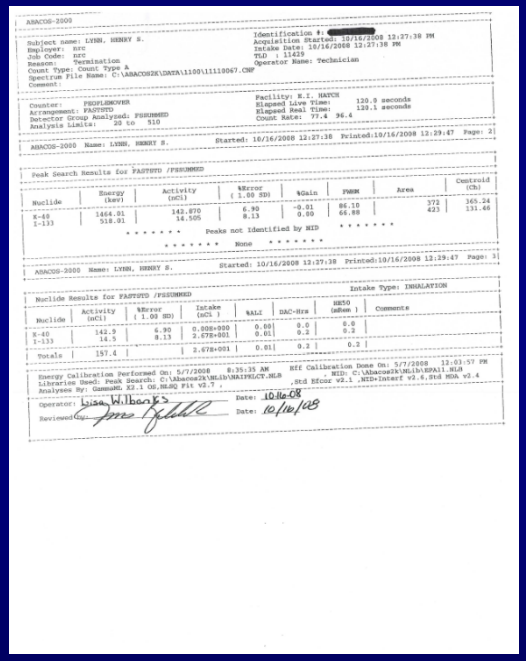
ABACOS-2000 Name: LYNN, HENRY S. Started: 10/14/2008 9:56:14 Printed:10/14/2008 9:58:23 Page: 3

Nuclide Results for FASTSTD /FSSUMMED — Intake Type: INHALATION

Nuclide	Activity (nCi)	%Error (1.00 SD)	Intake (nCi)	%ALI	DAC-Hrs	MES0 (mRem)	Comments
K-40	166.4	6.68	0.00E+000	0.00	0.0	0.0	
Totals	166.4		0.00E+000	0.00	0.0	0.0	

Energy Calibration Performed On: 5/7/2008 8:35:35 AM Eff Calibration Done On: 5/7/2008 12:03:57 PM
Libraries Used: Peak Search: C:\Abacos2k\ML1b\NAIPELCT.NLB NID: C:\Abacos2k\ML1b\EPA11.NLB
Analyses By: GammaHD X2.1 OS.NLHQ Fit V2.7 , ,Std Efcor v2.1 ,NID+Interf v2.6,Std MDA v2.4

Operator: Lisa Wilbanks Date: 10-14-08
Reviewed by: [signature] Date: 10/14/08



ABACOS-2000

Subject name: LYNN, HENRY S.
Employer: nrc
Job Code: nrc
Reason: Termination
Count Type: Count Type A
Spectrum File Name: C:\ABACOS2K\DATA\1100\11110067.CNF
Comment:

Identification #: [redacted]
Acquisition Started: 10/16/2008 12:27:38 PM
Intake Date: 10/16/2008 12:27:38 PM
TLD : 11429
Operator Name: Technician

Counter: PEOPLEMOVER
Arrangement: FASTSTD
Detector Group Analyzed: FSSUMMED
Analysis Limits: 20 to 510

Facility: E.I. HATCH
Elapsed Live Time: 120.0 seconds
Elapsed Real Time: 120.1 seconds
Count Rate: 77.4 96.4

ABACOS-2000 Name: LYNN, HENRY S. Started: 10/16/2008 12:27:38 Printed:10/16/2008 12:29:47 Page: 2

Peak Search Results for FASTSTD /FSSUMMED

Nuclide	Energy (kev)	Activity (nCi)	%Error (1.00 SD)	%Gain	FWHM	Area	Centroid (Ch)
K-40	1464.01	142.870	6.90	-0.01	86.10	372	365.24
I-133	518.01	14.505	8.13	0.00	66.88	423	131.46

* * * * * * * Peaks not Identified by NID * * * * * * *
* * * * * * * None * * * * * * *

ABACOS-2000 Name: LYNN, HENRY S. Started: 10/16/2008 12:27:38 Printed:10/16/2008 12:29:47 Page: 3

Nuclide Results for FASTSTD /FSSUMMED — Intake Type: INHALATION

Nuclide	Activity (nCi)	%Error (1.00 SD)	Intake (nCi)	%ALI	DAC-Hrs	MES0 (mRem)	Comments
K-40	142.9	6.90	0.00E+000	0.00	0.0	0.0	
I-133	14.5	8.13	2.67E+001	0.01	0.2	0.2	
Totals	157.4		2.67E+001	0.01	0.2	0.2	

Energy Calibration Performed On: 5/7/2008 8:35:35 AM Eff Calibration Done On: 5/7/2008 12:03:57 PM
Libraries Used: Peak Search: C:\Abacos2k\ML1b\NAIPELCT.NLB NID: C:\Abacos2k\ML1b\EPA11.NLB
Analyses By: GammaHD X2.1 OS.NLHQ Fit V2.7 , ,Std Efcor v2.1 ,NID+Interf v2.6,Std MDA v2.4

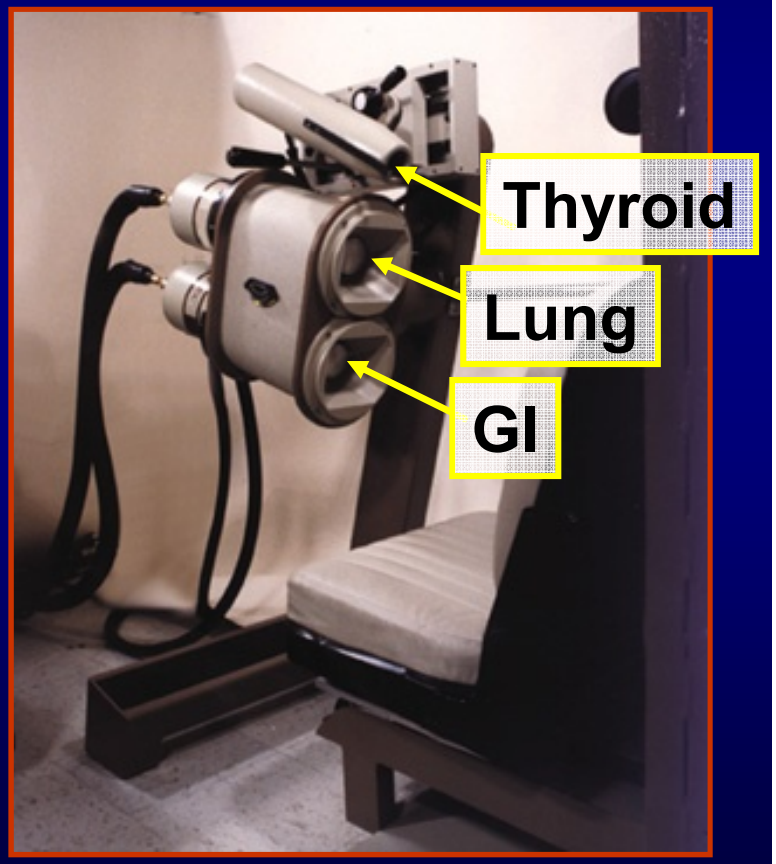
Operator: Lisa Wilbanks Date: 10-16-08
Reviewed by: [signature] Date: 10/16/08

Lung Counting

- Specialized form of organ counting
- Heavy metals such as Am, Cm, U and Pu are often alpha and beta emitters that also emit low yield gammas or X-rays
- Photon attenuation in chest wall must be accounted for

Measurement Equipment

- Chair counters usually have a thyroid detector and one or more detectors to view either the GI tract, or the torso
- Chair counters are designed to exclude from view parts of the body with high potential for contamination, e.g., hands, hair, and knees
- Designed to maximize detection efficiency for certain parts of the body



Ultimate Goal is to Determine Dose

1) Collect bioassay samples

2) From bioassay results, estimate intake

3) Then calculate dose (CDE and CEDE) using either:

- 10 CFR Part 20 Appendix B
- EPA Federal Guidance Report #11
- ICRP 30

Airborne Monitoring

Airborne Monitoring

Surveys for airborne radioactive material are conducted to

- evaluate the adequacy of engineering controls
- assign appropriate protective measures for personnel
- assess the dose to personnel

Airborne Monitoring

Airborne surveys may be for particulate material or for radioactive gases.

- Particulate material is assessed by sampling air through a filter media, such as filter paper
- Airborne radioactive iodine is sampled using charcoal or silver zeolite filters
- Volumetric gas samples are collected for radioactive gases such as Ar-41, Xe-133, Kr-85

Air Samplers

Dose Determination from Air Sampling

- Air sample determines air concentration (e.g. Bq/m^3)
- Multiply the air concentration times the volume of air inhaled to determine the activity inhaled (e.g. Bq)
- Then apply a dose conversion factor for the radionuclide(s) involved (Sv/Bq).
- Dose = (Concentration) (Time) (Breathing rate) (Dose Conversion Factor) (Conversion Factors)

Signs and Postings

Signs and Posting

- **Radiation Area**
  > 5 mrem/hr @ 30 cm

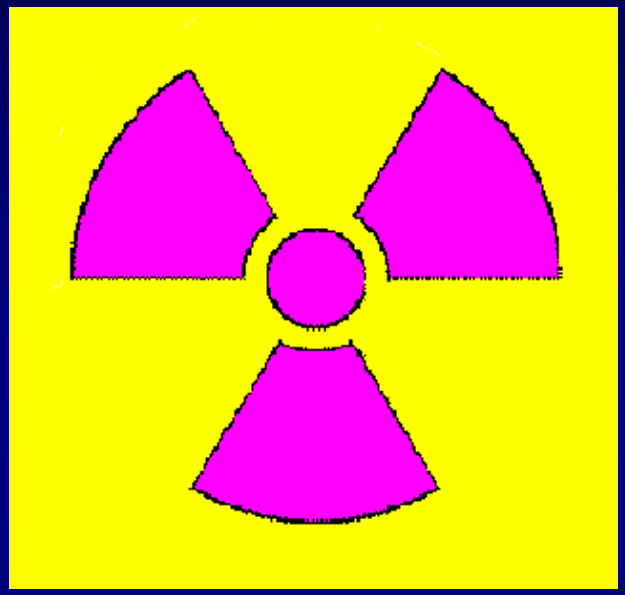
- **High Radiation Area**
  > 100 mrem/hr @ 30 cm

- **Very High Radiation Area**
  > 500 rad/hr @ 1 meter

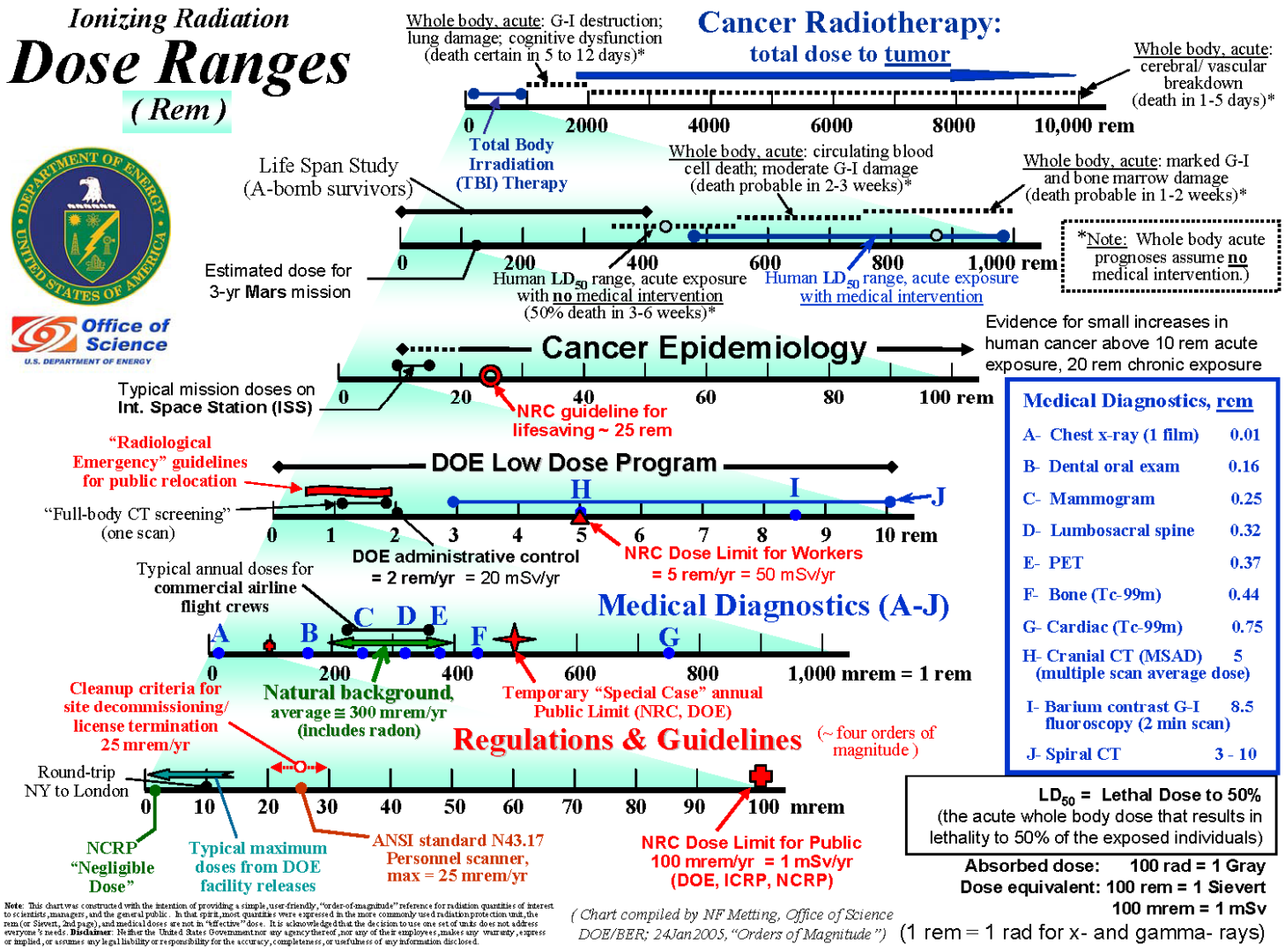
  500,000 mrad/hr

- **Airborne Radioactivity Area**
  > 1 DAC or 0.6% ALI =
  12 DAC-hours in a week

  0.006 x 2000 DAC-hrs = 12 DAC-hrs



DOE's Chart of Dose Ranges



QUESTIONS?

END OF PERSONNEL DOSIMETRY AND DOSE ASSESSMENT

Dose Units

Quantity	Traditional Unit	SI Unit
absorbed dose	rad	gray (Gy)
dose equivalent	rem	sievert (Sv)
activity	curie (Ci)	becquerel (Bq)

Conversions

100 rad = 1 Gy
100 rem = 1 Sv
1 Ci = 3.7×10^{10} Bq

Internal Dose Calculation Principles

- Stochastic weighting factors from ICRP 26 & 30 (1977) are used to calculate committed effective dose equivalent

- The Table on the next slide lists the ICRP weighting factors for various tissues/organs of concern

Tissue	Effect	Stochastic Risk Coefficient (rem^{-1})	ICRP 26 Weighting Factor
Gonads	Hereditary	4.0×10^{-5}	0.25
Breast	Cancer	2.5×10^{-5}	0.15
Red Bone Marrow	Leukemia	2.0×10^{-5}	0.12
Lung	Cancer	2.0×10^{-5}	0.12
Thyroid	Cancer	5.0×10^{-6}	0.03
Bone Surface	Cancer	5.0×10^{-6}	0.03
Remainder	Cancer	5.0×10^{-5}	0.3
Total	N/A	1.65×10^{-4} *	1.0

*** The new value is 4×10^{-4}**

CEDE

$$CEDE = \sum CDE_T * w_T$$

- **where CDE = 50 year integrated committed dose equivalent to each organ or tissue, T**
- **w_T = weighting factor for the corresponding organ or tissue**

Inhalation CDE

Nuclide	Class/f_1	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
		Committed Dose Equivalent per Unit Intake (Sv/Bq)							CEDE
Iodine									
I-120	D 1.0	$1.07\ 10^{-11}$	$1.28\ 10^{-11}$	$4.33\ 10^{-10}$	$1.28\ 10^{-11}$	$1.17\ 10^{-11}$	$\mathbf{1.55\ 10^{-9}}$	$5.02\ 10^{-11}$	$1.20\ 10^{-10}$
I-120m	D 1.0	$9.01\ 10^{-12}$	$1.23\ 10^{-11}$	$2.87\ 10^{-10}$	$1.22\ 10^{-11}$	$1.07\ 10^{-11}$	$5.84\ 10^{-10}$	$4.55\ 10^{-11}$	$\mathbf{7.15\ 10^{-11}}$
I-121	D 1.0	$1.96\ 10^{-12}$	$3.53\ 10^{-12}$	$4.69\ 10^{-11}$	$3.44\ 10^{-12}$	$3.02\ 10^{-12}$	$\mathbf{7.54\ 10^{-10}}$	$7.65\ 10^{-12}$	$3.21\ 10^{-11}$
I-123	D 1.0	$2.89\ 10^{-12}$	$4.87\ 10^{-12}$	$6.57\ 10^{-11}$	$5.97\ 10^{-12}$	$5.18\ 10^{-12}$	$\mathbf{2.25\ 10^{-9}}$	$7.89\ 10^{-12}$	$8.01\ 10^{-11}$
I-124	D 1.0	$3.49\ 10^{-11}$	$1.15\ 10^{-10}$	$7.45\ 10^{-10}$	$8.63\ 10^{-11}$	$7.78\ 10^{-11}$	$\mathbf{1.69\ 10^{-7}}$	$1.22\ 10^{-10}$	$5.23\ 10^{-9}$
I-125	D 1.0	$1.84\ 10^{-11}$	$9.25\ 10^{-11}$	$1.19\ 10^{-10}$	$4.41\ 10^{-11}$	$4.27\ 10^{-11}$	$\mathbf{2.16\ 10^{-7}}$	$3.33\ 10^{-11}$	$6.53\ 10^{-9}$
I-126	D 1.0	$3.48\ 10^{-11}$	$1.37\ 10^{-10}$	$6.34\ 10^{-10}$	$9.84\ 10^{-11}$	$9.02\ 10^{-11}$	$\mathbf{3.94\ 10^{-7}}$	$1.21\ 10^{-10}$	$1.20\ 10^{-8}$
I-128	D 1.0	$6.80\ 10^{-13}$	$7.15\ 10^{-13}$	$7.22\ 10^{-11}$	$7.17\ 10^{-13}$	$7.03\ 10^{-13}$	$5.34\ 10^{-11}$	$7.02\ 10^{-12}$	$\mathbf{1.28\ 10^{-11}}$
I-129	D 1.0	$8.69\ 10^{-11}$	$2.09\ 10^{-10}$	$3.14\ 10^{-10}$	$1.40\ 10^{-10}$	$1.38\ 10^{-10}$	$\mathbf{1.56\ 10^{-6}}$	$1.18\ 10^{-10}$	$4.69\ 10^{-8}$
I-130	D 1.0	$2.81\ 10^{-11}$	$4.87\ 10^{-11}$	$6.03\ 10^{-10}$	$4.55\ 10^{-11}$	$4.03\ 10^{-11}$	$\mathbf{1.99\ 10^{-8}}$	$8.02\ 10^{-11}$	$7.14\ 10^{-10}$
I-131	D 1.0	$2.53\ 10^{-11}$	$7.88\ 10^{-11}$	$6.57\ 10^{-10}$	$6.26\ 10^{-11}$	$5.73\ 10^{-11}$	$\mathbf{2.92\ 10^{-7}}$	$8.03\ 10^{-11}$	$8.89\ 10^{-9}$
I-132	D 1.0	$9.95\ 10^{-12}$	$1.41\ 10^{-11}$	$2.71\ 10^{-10}$	$1.40\ 10^{-11}$	$1.24\ 10^{-11}$	$\mathbf{1.74\ 10^{-9}}$	$3.78\ 10^{-11}$	$1.03\ 10^{-10}$
I-132m	D 1.0	$6.48\ 10^{-12}$	$8.88\ 10^{-12}$	$1.77\ 10^{-10}$	$8.86\ 10^{-12}$	$7.95\ 10^{-12}$	$\mathbf{1.65\ 10^{-9}}$	$2.01\ 10^{-11}$	$8.10\ 10^{-11}$
I-133	D 1.0	$1.95\ 10^{-11}$	$2.94\ 10^{-11}$	$8.20\ 10^{-10}$	$2.72\ 10^{-11}$	$2.52\ 10^{-11}$	$\mathbf{4.86\ 10^{-8}}$	$5.00\ 10^{-11}$	$1.58\ 10^{-9}$
I-134	D 1.0	$4.25\ 10^{-12}$	$6.17\ 10^{-12}$	$1.43\ 10^{-10}$	$6.08\ 10^{-12}$	$5.31\ 10^{-12}$	$2.88\ 10^{-10}$	$2.27\ 10^{-11}$	$\mathbf{3.55\ 10^{-11}}$
I-135	D 1.0	$1.70\ 10^{-11}$	$2.34\ 10^{-11}$	$4.41\ 10^{-10}$	$2.24\ 10^{-11}$	$2.01\ 10^{-11}$	$\mathbf{8.46\ 10^{-9}}$	$4.70\ 10^{-11}$	$3.32\ 10^{-10}$
w_T		0.25	0.15	0.12	0.12	0.03	0.03	0.3	1.0

$$CEDE = \Sigma(CDE_T * w_T) = (2.53E\text{-}11 * 0.25) + (7.88E\text{-}11 * 0.15) + (6.57E\text{-}10 * 0.12) + (6.26E\text{-}11 * 0.12) + (5.73E\text{-}11 * 0.03) + (2.92E\text{-}7 * 0.03) + (8.03E\text{-}11 * 0.06) * 5 =$$

$CEDE = \Sigma CDE_T * w_T =$

(2.53E-11 * 0.25) + (7.88E-11 * 0.15) + (6.57E-10 * 0.12) + (6.26E-11 * 0.12) + (5.73E-11 * 0.03) + (2.92E-7 * 0.03) + (8.03E-11 * 0.06)* 5 =

6.325E-12 + 1.182E-11 + 7.884E-11 + 7.512E-12 + 1.719E-12 + 8.76E-9 + 4.818E-12 *5 =

lung

6.325E-12 + 1.182E-11 + 7.884E-11 + 7.512E-12 + 1.719E-12 + 8.76E-9 + 2.409E-11 = 8.89E-9 Sv/Bq

thyroid

8.89E-9 Sv/Bq * 100 rem/Sv * 1000 mrem/rem * 3.7E4 Bq/µCi = 32.893 mrem/µCi

Review Questions

- List three factors influencing external radiation dose
- List three types of radiation that can be an external source of dose
- What type of radiation is usually associated with dose to the skin and lens of eye?

Review Questions

- What type of ionizing radiation cannot penetrate the dead skin layer and thus is not an external hazard?

- Define the terms “Skin”, “Extremities”, and “Whole Body”

- Define the terms DDE, LDE, SDE_{ME}, and SDE_{WB}

Review Questions

- At what depth in human tissue is the DDE measured? The LDE? The SDE?
- State two common TLD materials
- Is film dosimetry useful for low energy beta emitters such as H-3 or C-14?

Review Questions

- Explain how dose is determined with OSL dosimeters.
- What is one primary advantage of pocket dosimeters?
- Should pocket dosimeters be used as the dose of record?
- State two advantages of electronic dosimeters over pocket chambers

Review Questions

- List three pathways by which radioactive materials can enter the body
- List three types of ionizing radiation that can produce an internal dose
- What is the weighting factor for the lung?

Review Questions

- What is the weighting factor for the thyroid?
- Define the terms CDE, CEDE, TEDE, and TODE
- What is the special unit for absorbed dose? The SI unit?
- What is the special unit for dose equivalent? The SI unit?

Review Questions

- What is the special unit for activity? The SI unit?

- One Gy equals _____ rad

- One Sv equals _____ rem

- One Ci equals _____ Bq

Review Questions

- What is the occupational dose limit for DDE?
- What is the occupational dose limit for CDE?
- What is the occupational dose limit for TEDE?
- What is the occupational dose limit for TODE?

Review Questions

- What is the occupational dose limit for a minor?
- What is the dose limit for an embryo/fetus of a DPW?
- What is the TEDE limit to a MOP?
- What is the SDE_{ME} dose limit?

Review Questions

- What is the SDE_{WB} dose limit?
- Are weighting factors used to calculate CDE?
- What is the mathematical relationship between CDE and CEDE?
- Define the terms ALI and DAC. What is their relationship?

Review Questions

- One ALI equals _____ DAC-hrs
- For DACs derived from stochastic ALIs, one DAC-hr equals _____ mrem CEDE
- For DACs derived from deterministic (i.e. non-stochastic) ALIs, one DAC-hr equals _____ mrem CDE

Review Questions

- 1 sALI equals _____ rem CEDE
- 1 nALI equals _____ rem CDE to the maximum exposed organ
- What posting is required in an area where the dose rate is 65 mrem/hr at 30 cm from the source?
- What posting is required in an area where the dose rate is 120 mrem/hr at 30 cm from the source?

Review Questions

- Define Very High Radiation Area
- What posting is required in an area where a worker would receive 20 DAC-hrs per week?
- What two primary programs should be in place to control internal dose to workers?
- Radioiodine primarily seeks this organ?

Review Questions

- Sr-90 primarily seeks this organ?

- Determination of internal dose is dependent on what three concepts?

- _____ and _____ were derived to limit intakes of radioactive material to ensure that workers do not exceed NRC dose limits

Review Questions

- The most common way for workers to intake radioactive materials is through _____?
- List three NRC-endorsed methods that licensees can use to calculate internal dose
- State the ICRP 60 cancer mortality risk coefficients for workers and the public, respectively

Review Questions

- State the two principal types of bioassays
- Whole body counting is what type of bioassay method?
- Can external contamination on the body affect a whole body counting result?
- Why is it a good idea for a licensee to conduct baseline whole body counting on a new employee?

Review Questions

- How can a pure beta emitter (e.g. P-32) be detected in the body using whole body counting?
- One useful direct bioassay method if the skin has been penetrated by contamination is _____
- List two principal types of detectors for whole body counting
- When is individual organ counting beneficial?

Review Questions

- List three factors influencing external radiation dose
- List three types of radiation that can be an external source of dose
- What type of radiation is usually associated with dose to the skin and lens of eye?

Review Questions

- What type of ionizing radiation cannot penetrate the dead skin layer and thus is not an external hazard?

- Define the terms "Skin", "Extremities", and "Whole Body"

- Define the terms DDE, LDE, SDE_{ME}, and SDE_{WB}

Review Questions

- At what depth in human tissue is the DDE measured? The LDE? The SDE?
- State two common TLD materials
- Is film dosimetry useful for low energy beta emitters such as H-3 or C-14?

Review Questions

- Explain the principle of OSL
- What is one primary advantage of pocket dosimeters?
- Should pocket dosimeters be used as the dose of record?
- State two advantages of electronic dosimeters over pocket chambers

Review Questions

- List three pathways by which radioactive materials can enter the body
- List three types of ionizing radiation that can produce an internal dose
- What is the weighting factor for the lung?

Review Questions

- What is the weighting factor for the thyroid?
- Define the terms CDE, CEDE, TEDE, and TODE
- What is the special unit for absorbed dose? The SI unit?
- What is the special unit for dose equivalent? The SI unit?

Review Questions

- What is the special unit for activity? The SI unit?

- One Gy equals _____ rad

- One Sv equals _____ rem

- One Ci equals _____ Bq

Review Questions

- What is the occupational dose limit for DDE?
- What is the occupational dose limit for CDE?
- What is the occupational dose limit for TEDE?
- What is the occupational dose limit for TODE?

Review Questions

- What is the occupational dose limit for a minor?
- What is the dose limit for an embryo/fetus of a DPW?
- What is the TEDE limit to a MOP?
- What is the SDE_{ME} dose limit?

Review Questions

- What is the SDE_{WB} dose limit?
- Are weighting factors used to calculate CDE?
- What is the mathematical relationship between CDE and CEDE?
- Define the terms ALI and DAC. What is their relationship?

Review Questions

- One ALI equals _____ DAC-hrs
- For DACs derived from stochastic ALIs, one DAC-hr equals _____ mrem CEDE
- For DACs derived from deterministic (i.e. non-stochastic) ALIs, one DAC-hr equals _____ mrem CDE

Review Questions

- 1 sALI equals _____ rem CEDE
- 1 nALI equals _____ rem CDE to the maximum exposed organ
- What posting is required in an area where the dose rate is 65 mrem/hr at 30 cm from the source?
- What posting is required in an area where the dose rate is 120 mrem/hr at 30 cm from the source?

Review Questions

- Define Very High Radiation Area
- What posting is required in an area where a worker would receive 20 DAC-hrs per week?
- What two primary programs should be in place to control internal dose to workers?
- Radioiodine primarily seeks this organ?

Review Questions

- Sr-90 primarily seeks this organ?
- Determination of internal dose is dependent on what three concepts?
- _____ and _____ were derived to limit intakes of radioactive material to ensure that workers do not exceed NRC dose limits

Review Questions

- The most common way for workers to intake radioactive materials is through _____?
- List three NRC-endorsed methods that licensees can use to calculate internal dose
- State the ICRP 60 cancer mortality risk coefficients for workers and the public, respectively

Review Questions

- State the two principal types of bioassays
- Whole body counting is what type of bioassay method?
- Can external contamination on the body affect a whole body counting result?
- Why is it a good idea for a licensee to conduct baseline whole body counting on a new employee?

Review Questions

- How can a pure beta emitter (e.g. P-32) be detected in the body using whole body counting?
- One useful direct bioassay method if the skin has been penetrated by contamination is _____.
- List two principal types of detectors for whole body counting.
- When is individual organ counting beneficial?