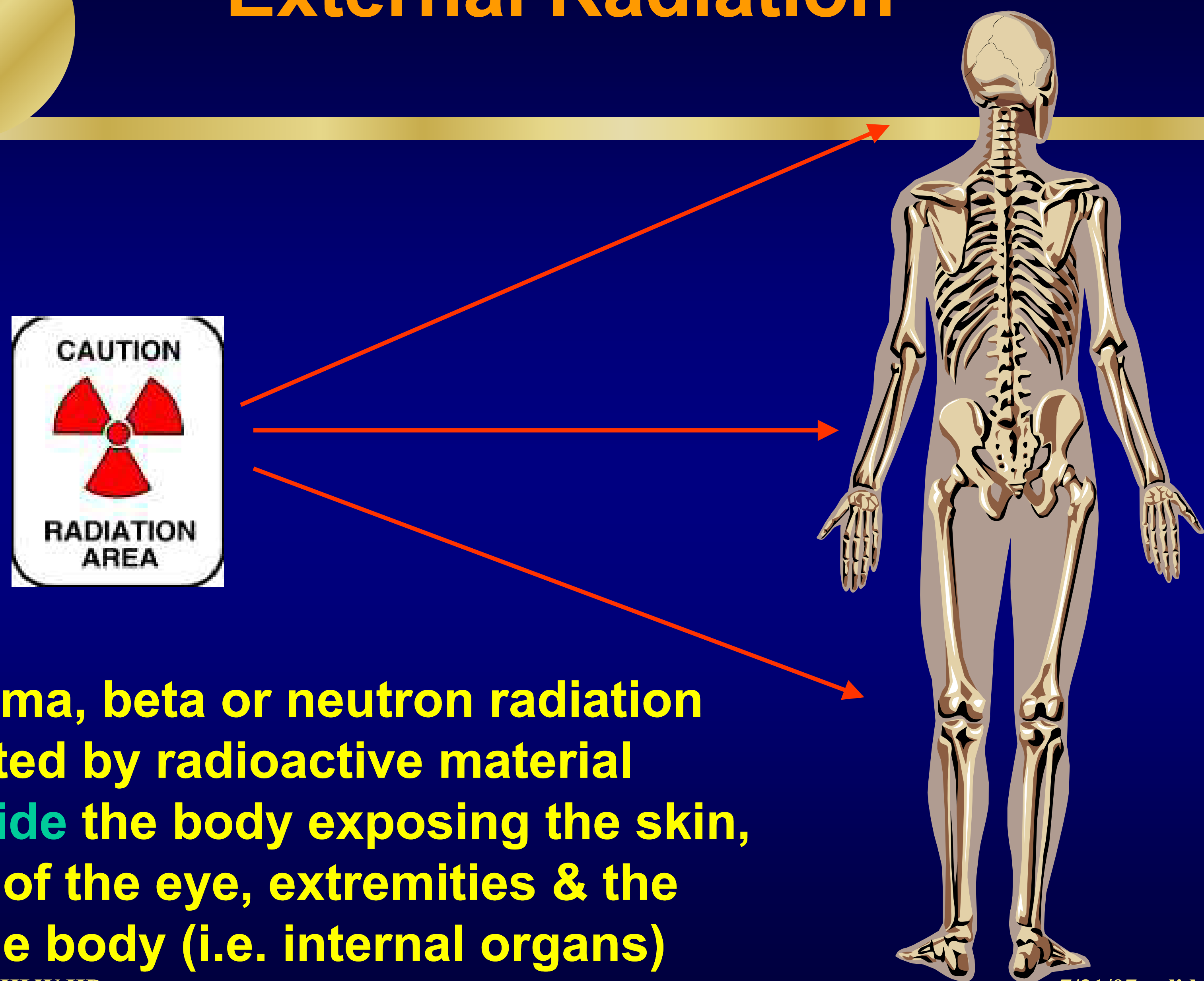
RADIATION QUANTITIES

Topics

- Dose
- Equivalent Dose and Dose Equivalent
- Effective Dose and Effective Dose Equivalent
- Committed Dose
- Regulatory Limits
- Risk Factors / Risk Comparisons

External Radiation

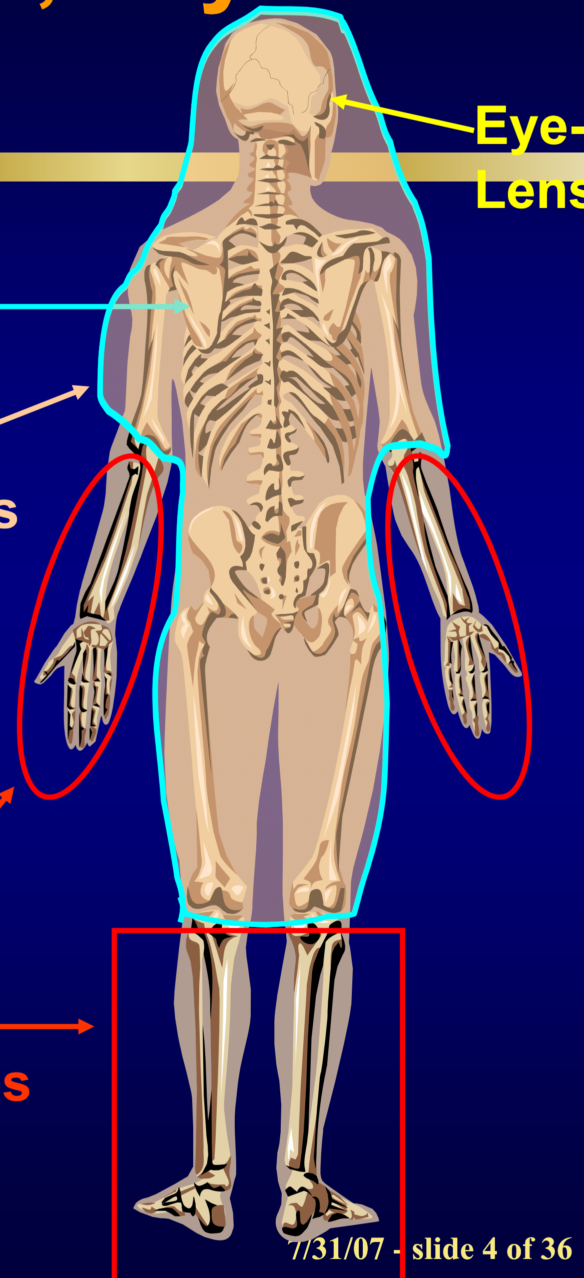


Gamma, beta or neutron radiation emitted by radioactive material outside the body exposing the skin, lens of the eye, extremities & the whole body (i.e. internal organs)

“Skin”, “Extremities”, “Eye” and “Whole Body”

Whole Body -
everything except extremities

Skin of the Whole Body -
skin covering everything except the extremities



Extremities -
arms below elbows and legs below knees

Doses From External Radiation Sources

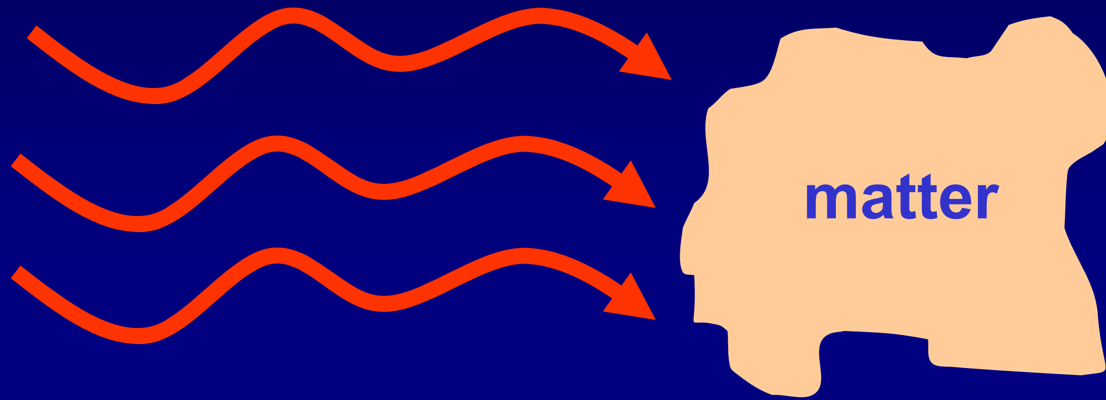
DDE - Deep Dose Equivalent
"Whole Body Dose"

LDE - Lens Dose Equivalent
"Eye Dose"

SDE_{ME} - Shallow Dose Equivalent to the Maximum Extremity
"Extremity Dose"

SDE_{WB} - Shallow Dose Equivalent to the Whole Body
"Skin Dose"

Dose



$$D = \frac{E}{\Delta m_{material}}$$

- Dose is the energy absorbed per unit mass

Dose

- Unit is the rad (English) or the Gray (SI)
  - 1 rad = 0.01 Gray
  - 1 Gray = 100 rad
- Defined for all types of ionizing radiation in any medium (we are concerned about living tissue)
- Defined at a point in the material
- Dose can be measured using instruments or dosimeters

Absorbed Dose

- **Absorbed Dose (D) to a tissue or organ = the dose averaged over the volume of the tissue or organ**

$$D_T = \frac{\int_{m_T} D\,dm}{m_T}$$

- **Dose doesn't take into account the biological damage caused by the energy**

Dose Equivalent (H)

- Dose Equivalent (H) to a tissue or organ = the absorbed dose multiplied by a "quality factor" which considers the effectiveness of each type of radiation in producing biological harm - photons vs. beta vs. alpha vs. neutrons

$$H = D \times Q$$

(Q is the quality factor or more appropriately the radiation weighting factor written as w_R)

- Measured in "rem", it is defined at a point in the body
- Applies to individual organs and cannot be measured

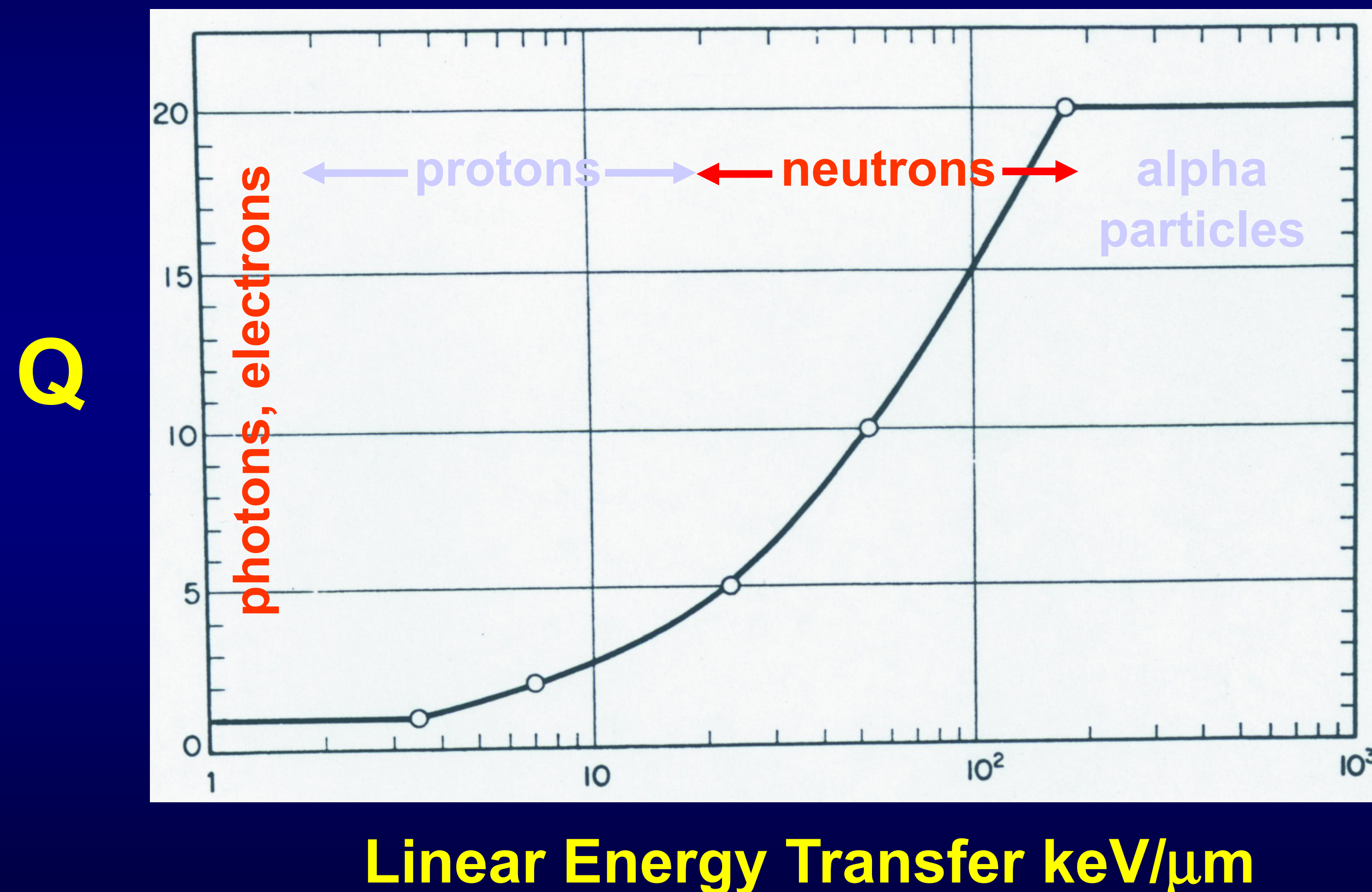
Equivalent Dose (H_T)

- Averaged over tissue or organ
- Unit of measure is the Sv or rem

$$H_T = \sum_r w_r \bullet D_{T,r}$$

- The Equivalent Dose differs from the Dose Equivalent
- Dose equivalent presents the absorbed dose at a specific location in tissue weighted by a distribution of quality factors (Q)
- These are influenced by the LET (linear energy transfer) distribution of the radiation at that site

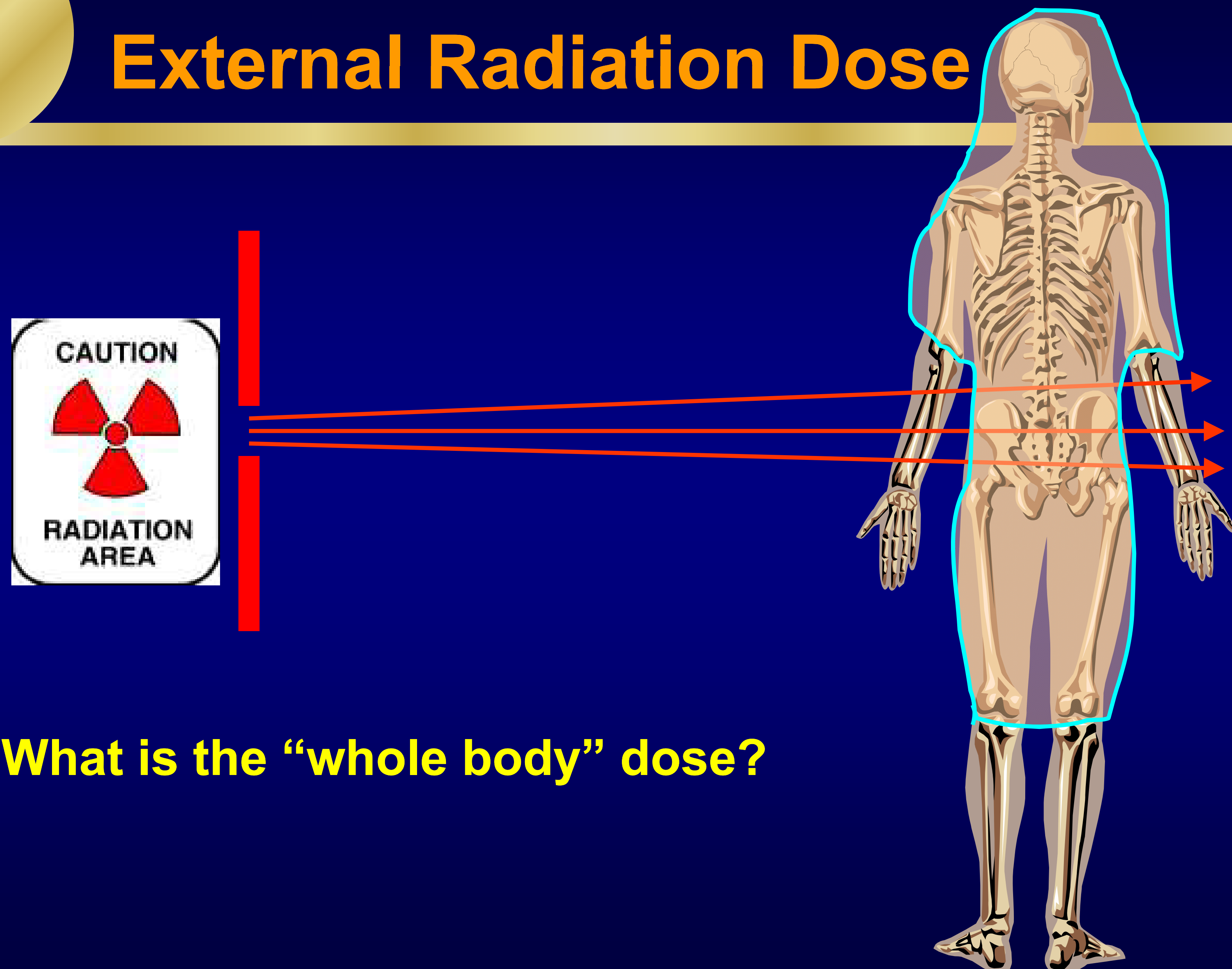
Quality Factor



Q/w_R Values

Radiation Type	Quality Factor (Q) Radiation Weighting Factor (w_R)
Alphas	20
Betas	1
Photons (Gamma/X-ray)	1
Neutrons	3-10

Non-Uniform External Radiation Dose



What is the "whole body" dose?

Effective Dose Equivalent (EDE)

- The EDE (H_E) attempts to relate separate, non-uniform radiation dose equivalents which may expose only certain portions of the whole body to an effective dose from a single "whole-body" dose equivalent
- Although we are talking about dose to organs inside the body, this is still an "external" dose situation since the radiation originates outside the body

$$H_E = \sum_t w_t \bullet H$$

- Unit of measure is the rem or Sv

$$H_E = \sum_r \sum_t w_R \bullet w_t \bullet D$$

- The w_t values represent radiation risk for each "tissue (t)" exposed which will be discussed in a future slide

EDE Tissue Weighting Factors

Organs	w_T
Gonads	0.25
Breast	0.15
Red Bone Marrow	0.12
Lung	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder	0.30*

*A value of $w_T = 0.06$ applies to each of the remaining five organs receiving the highest dose, excluding the skin, eye and extremities

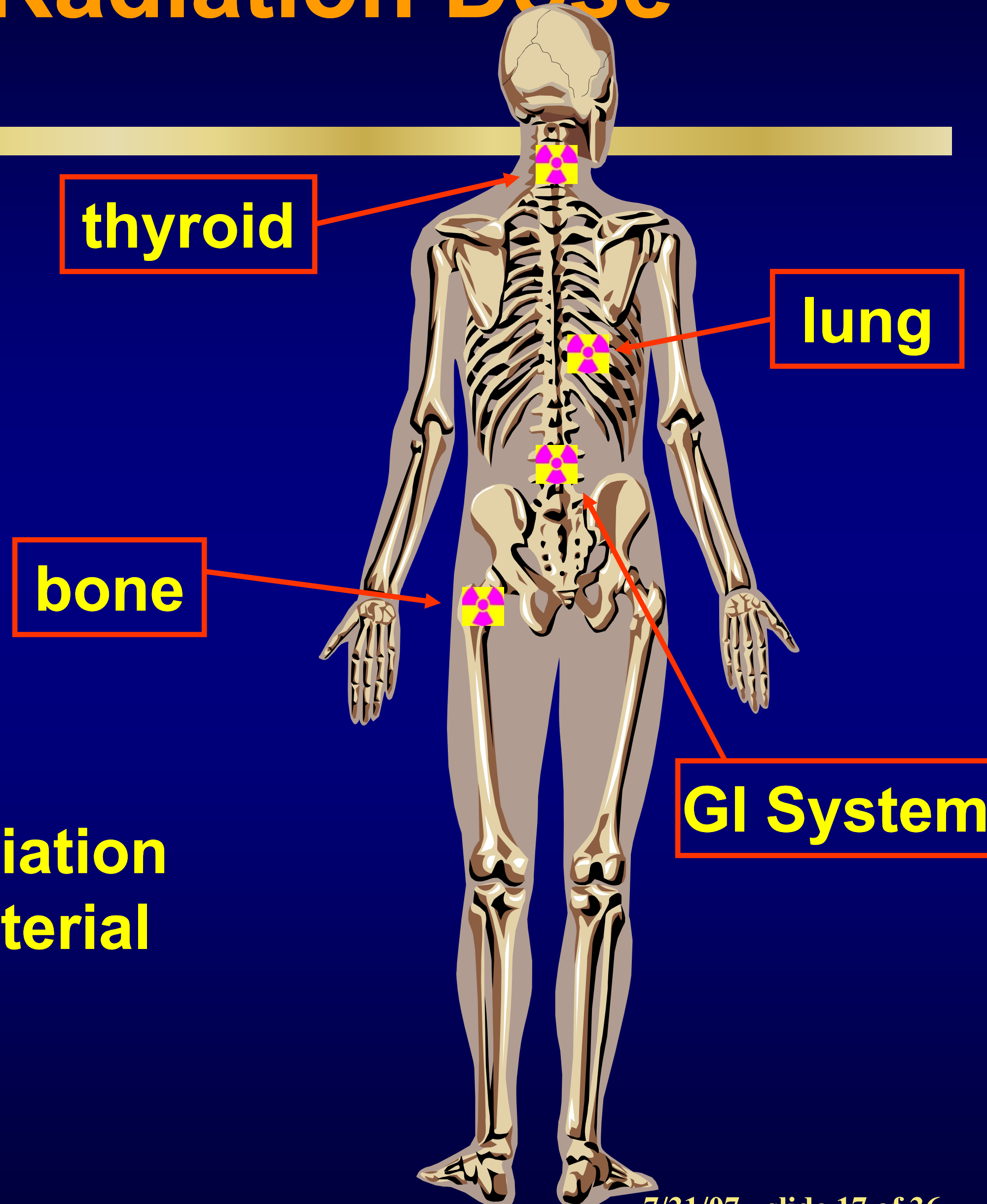
Dose Units

Quantity	Special Unit	SI Unit
Absorbed Dose	rad	Gray (Gy)
Dose Equivalent	rem	Sievert (Sv)
Activity	Curie (Ci)	Becquerel (Bq)

Conversions

1 rad	=	0.01 Gy		1 Gy	=	100 rad
1 rem	=	0.01 Sv		1 Sv	=	100 rem
1 Ci	=	3.7×10^{10} Bq		1 Bq	=	2.7×10^{-11} Ci
		37 GigaBq				27 picoCi

Internal Radiation Dose



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

Committed

The dose from internal sources is accrued gradually over many years

$$D_{50} = \int_0^{50} D \, dt$$

The dose decreases as time passes due to radioactive decay and elimination of the material from the body

The dose received each year for 50 years is summed and assigned to the individual in the year that he/she is exposed (50 years chosen based on "working" lifetime)

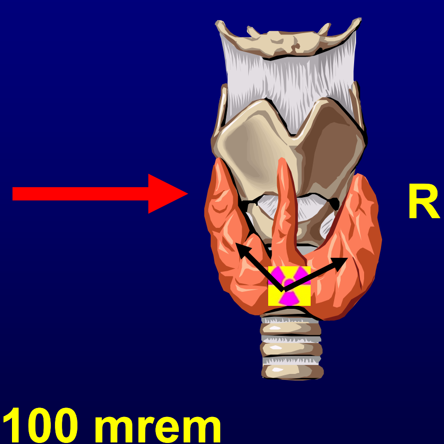
This 50 year dose is assumed to be "committed", i.e., the individual is destined to receive the dose it is administratively convenient to account for it now

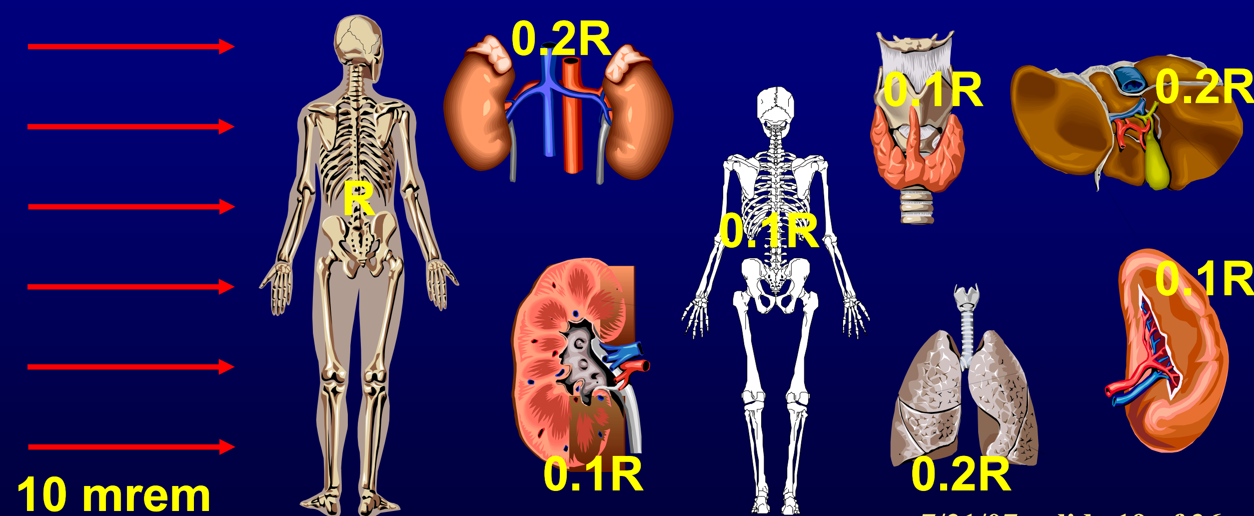
Effective

Internal sources deliver dose to organs in the body over many years

Each organ exposed by the internal sources incurs a risk

If the “whole body” (which includes all the organs inside) was “hypothetically” exposed to a uniform external source of radiation, then there would be a risk to each organ from this single “whole body” exposure





Effective

On the previous slide the thyroid incurred a risk “R” from a real dose of 100 mrem

The “effective” whole body dose of 10 mrem produced risks of “0.1R” to the thyroid, “0.2R” to the lungs etc.

When all these organ risks are added together they produce a total risk “R”

The “effective” dose to the whole body (which did not really occur) produced the same risk as the real dose which just exposed the thyroid so we can replace the real thyroid dose with the “effective” whole body dose

Example

- A radiation worker receives two different exposures
  - Whole body - gamma rays
  - Ingestion - alpha emitter which goes to the liver
- What is the worker's dose?
  - Gamma - 12 mrad measured with survey meter
  - Alpha - 10 mrad committed dose to the liver calculated from urine excretion sample
- The external and internal doses cannot be added - one is a whole body dose and the other is a dose to the liver only

Total Whole Body Dose

Why do we need an "effective" whole body dose?

The doses from External and Internal sources of radiation are like apples and oranges.

An external source is assumed to expose the whole body uniformly (including all of the internal organs) whereas internal sources expose only specific organs.

As a result, they cannot be added together without something to make them comparable.

The tissue weighting factor (w_T) is used to make apples look like oranges.

Doses From
Internal Radiation Sources

CDE_T - Committed Dose Equivalent

"Actual Internal Organ Dose"

CEDE - Committed Effective Dose Equivalent

"Effective Whole Body "*dose*" from Internal Sources"

$CEDE_T = w_T * CDE_T$ where w_T is the weighting factor which relates the risk to the organ (T) to a whole body risk. To obtain the effective whole body dose (CEDE) we must sum the doses to all of the different organs (CDE_T) adjusted for their weighted risk $CEDE = \sum w_T * CDE_T$

Liver

$CDE_{liver} \times w_{liver} = CEDE_{liver}$

Lung

$CDE_{lung} \times w_{lung} = CEDE_{lung}$

$CEDE_{liver} + CEDE_{lung} + \ldots = CEDE_{whole\ body}$

Old vs New
Tissue Weighting Factors (w_T)

Tissue	Old w_T	New w_T
Gonads	0.25	0.20
Red Bone Marrow	0.12	0.12
Colon		0.12
Lung	0.12	0.12
Stomach		0.12
Bladder		0.05
Breast	0.15	0.05
Liver		0.05
Oesopgagus		0.05
Thyroid	0.03	0.05
Skin		0.01
Bone Surfaces	0.03	0.01
Remainder	0.30	0.05

TEDE & TODE

- TEDE (Total Effective Dose Equivalent) is a fictitious dose composed of two separate doses:
  - an actual external dose (DDE) or calculated EDE and
  - a hypothetical “external” dose (CEDE) which produced the same risk as the actual organ dose(s) from internal RAM

$$\text{TEDE} = \text{DDE or EDE} + \text{CEDE}$$

- TODE (Total Organ Dose Equivalent) is a REAL dose consisting of an actual external whole body dose (DDE) plus an actual organ dose (CDE) from radioactive material inside the body - since there are many different organs, the TODE is specified for the organ receiving the highest dose

$$\text{TODE} = \text{DDE} + \text{CDE}_{max}$$

Example

- Given the following exposures:
  - Gamma (whole body) - 9 mrem
  - Beta (skin) - 1 rem
  - Alpha (liver) - 200 mrem

- What is the worker's effective dose equivalent?
  - Gamma (whole body - w_{wb} = 1) 9 mrem x 1 = 9 mrem
  - Beta (skin) - EDE is not defined
  - Alpha (liver - w_{liver} = 0.06) 200 mrem x 0.06 = 12 mrem
  - TEDE = 9+12 = 21 mrem

- What is the worker's effective dose?
  - Gamma (whole body - w_{wb} = 1) 9 mrem x 1 = 9 mrem
  - Beta (skin - w_{skin} = 0.01) 1 rem x 0.01 = 10 mrem
  - Alpha (liver - w_{liver} = 0.05) 200 mrem x 0.05 = 10 mrem
  - TED = 9+10+10 = 29 mrem

OCCUPATIONAL

10 CFR Part 20 Dose Term	Limit (annual)
DDE	N/A
LDE	15 rem
SDE_{ME}	50 rem
SDE_{WB}	50 rem
CDE	N/A
CEDE	N/A
DDE + CEDE = TEDE	5 rem
DDE + CDE = TODE	50 rem
Minor	0.5 rem
E/F of DPW	0.5 rem (9 mos)
Public TEDE	0.1 rem = 100 mrem
10 CFR Part 63 Public TEDE	0.015 rem = 15 mrem*
*Draft Revised Part 63 > 10K yrs	0.35 rem = 350 mrem

More Miscellaneous Dose Terms

Peak Dose

The highest annual dose projected to be received by the reasonably maximally exposed individual (RMEI)

"Mean" Dose

Reality dictates that there is no unique answer when projecting future doses based on a variety of assumptions and scenarios. As a result many different projected doses will be calculated. However compliance must be based on some objective standard. 10 CFR 63.303 states that "…. compliance is based upon the mean* of the distribution of projected doses of DOE's performance assessment…"

More Miscellaneous Dose Terms

The following terms are specific to Radon exposures:

Working Level (WL)

Any combination of short-lived radon decay products in 1 liter of air that has a potential alpha energy release of 1.3×10^5 MeV. The concentration of ^{222}Rn, in 100% equilibrium with its decay products, that corresponds to 1 WL is 100 pCi/L.
(1 pCi/L = 37 Bq/m^3)

Working Level Month (WLM)

Exposure to 1 WL for 170 hours. Thus, 1 WLM = 170 WL-hrs

Airborne Activity Limits
ALI & DAC

ALI: The amount of activity that would give you over a period of 50 years a dose limit (5 rem to the whole body or 50 rem to an organ) is called the "Annual Limit on Intake" or ALI. It is in units of activity (e.g., μCi or Bq).

DAC: Dividing the ALI by the amount of air you breathe doing light work during a working year (40 hours per week times 50 weeks per year = 2,000 hours) is the "Derived Air Concentration" or DAC.

1 hour @ 1 DAC = 1 DAC-hr
1 DAC-hr = 2.5 mrem CEDE
2,000 DAC-hrs = 1 ALI = 5 rem CEDE

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

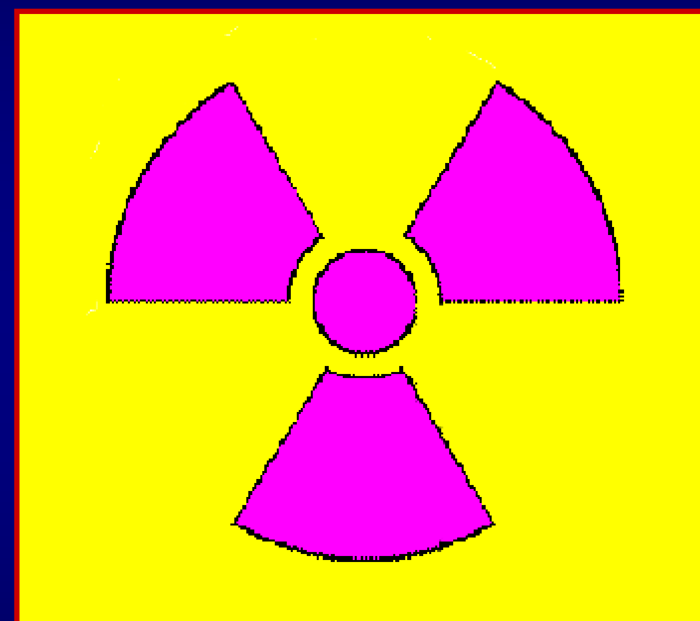
500,000 mrad/hr

Airborne Radioactivity Area

> 1 DAC or 0.6% ALI or

12 DAC-hours in a week

0.006 x 2000 DAC-hrs
= 12 DAC-hrs



Airborne Radioactivity Area Sign at Yucca Mountain

Collective EDE

- Many people may receive an effective dose
- The Collective EDE is defined as the sum of all EDE's in a population

$$H_{EC} = \sum_i H_{E,i}$$

- We can determine risk to an exposed population
- Unit is the person-rem

	Individual	Dose (rem)
Population	A	1.35
	B	0.62
	C	2.76
	D	1.11
	E	0.28
	F	0.94
	G	3.20
	Total	10.26

Collective Dose 10.26 person-rem

Average (individual) Dose 1.47 rem/person

(2 exceeded the average and 5 were below the average)
(median = 1.11 rem)

Individual	Dose (rem)
A	1.35
B	0.00
C	2.76
D	1.73
E	0.00
F	0.94
G	3.48
Total	10.26

Collective Dose	10.26 person-rem
Average Dose	1.47 rem/person

(median = 1.35 rem)

Avg Dose to Exposed Pop	2.05 rem/person

(median = 1.73 rem)

THE END