What is radiation?

- Radiation is energy that travels through space or matter in the form of a particle or wave
- The effect radiation has on matter depends on the type of radiation and how much energy it has
  - Energy is measured in electron volts (eV)
    - 1 eV = 1.6×10^{-19} joules
  - More common to see kilo electron volts used (1 keV = 1,000 eV)

Types of radiation

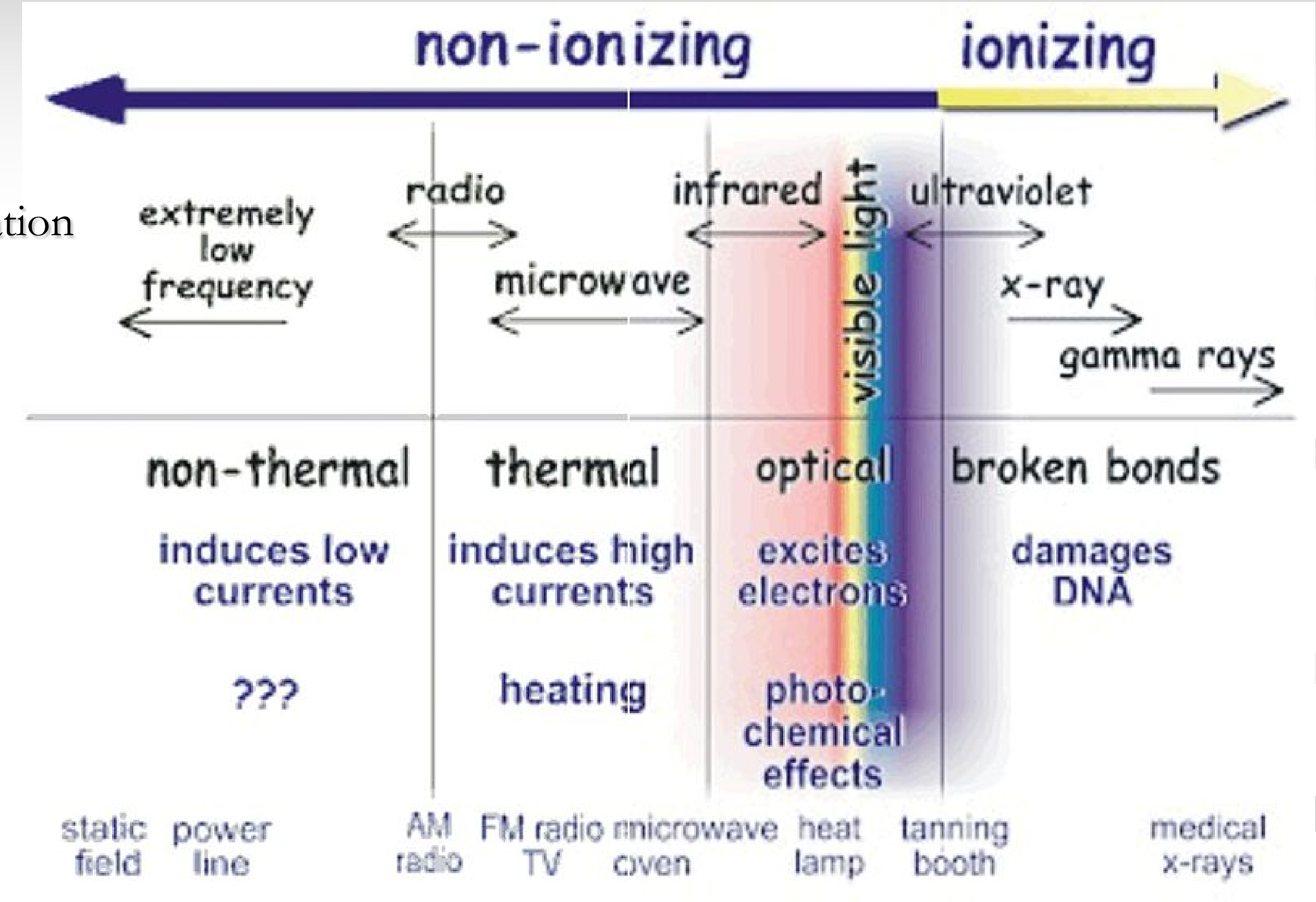
- 2 main categories
  - Particulate radiation: consists of particles that have mass and energy, and may or may not have an electric charge
    - Alpha particles and protons (positive charge)
    - Beta particles (positive or negative charge)
    - Neutrons (uncharged)
  - <u>Electromagnetic radiation: consists of photons that have energy, but no mass or charge (just like light, but higher frequency)</u>
    - <u>X rays</u>
    - <u>Gamma rays</u>

The Electromagnetic Spectrum

Type of Radiation

Effects

Source



wavelength

Ionizing Radiation

- Radiation is called ionizing if it is capable of forming ion pairs in matter
  - An ion pair is formed when an electron is removed from an atom, leaving a free electron and a positively charged atom
- The ability to ionize depends on factors including energy, mass, and charge
- Most non-ionizing radiation is not harmful

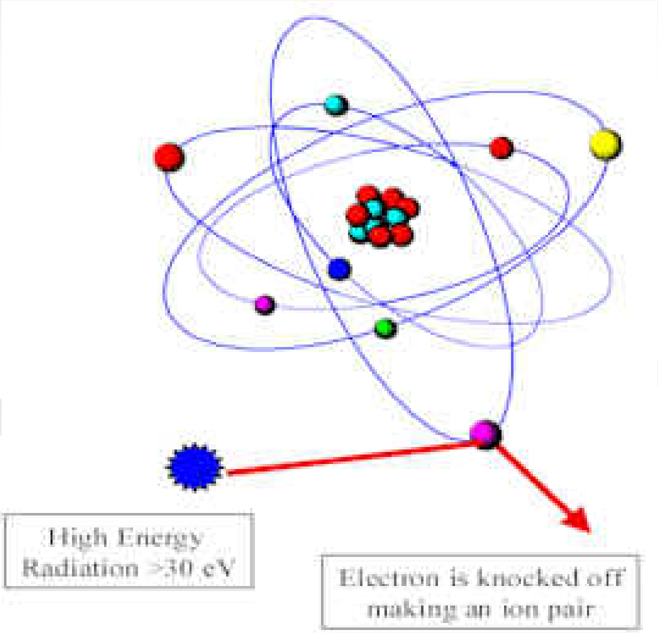


Figure taken from:
www.e-radiography.net/radsafety/rad_physics4.jpg

Radiation Quantities and Units

Radiation Measurement

- Count rate
- Exposure
- Absorbed dose
- Equivalent dose

  or dose equivalent
- Effective dose

  or effective dose equivalent

Measured directly

Difficult to measure directly, usually calculated

Always calculated

Exposure

- Exposure: the electric charge produced by photons (x rays or gamma rays) in a mass of air
- Traditional unit is the Roentgen (R)
- SI unit is Coulombs/kg air
- 1 R = 2.58 X 10^{-4} C/kg air
- Can be measured as a total exposure or an exposure rate

Absorbed Dose

- Absorbed dose: the energy deposited in a material by radiation per unit mass
- Traditional unit is the rad (radiation absorbed dose)
- 1 rad = 0.01 J/kg
- In SI units, rad has been replaced by Gray (Gy)
  - 1 Gy = 1 J/kg
  - 100 rad = 1 Gy
- You can convert exposure to dose *in air* using:

$$D_{air}\ (\text{rad}) = 0.876\,(\text{rad/R}) \times X\ (\text{R})$$

- *In tissue*, 1 rad is approximately equal to 1 R

Equivalent Dose /Dose Equivalent

- Takes into account that some kinds of radiation cause more biological harm than others
- The traditional unit for this is the <u>rem</u> (stands for Roentgen Equivalent Man)
- In SI units, the rem has been replaced by the sievert (Sv), where 1 Sv = 100 rem
- Equivalent dose: H (rem) = Σ (D (rad) * w_R)
  - w_R = radiation weighting factor
- Dose equivalent (pre-1990): H (rem) = Σ (D (rad) * Q)
  - Q = quality factor

Radiation Type	Quality Factor	Radiation Weighting Factor
x-rays, γ rays, or β particles	1	1
Neutrons (depends on energy)	2-11	5-20
Protons (high-energy)	10	2-5
Alpha particles	20	20

Effective Dose / Effective Dose Equivalent

- Takes into account that some tissues and organs in the human body are more sensitive to radiation than others
- Multiply the Equivalent Dose or Dose Equivalent to each organ/tissue by the tissue weighting factor (w_T) for that organ/tissue and add them all together
- Use equivalent dose and 1990 w_T values – get effective dose
- Use dose equivalent and 1977 w_T values – get effective dose equivalent
- The unit is still either rem or Sv

$$EDE = \sum H_T \times w_T$$

Tissue Weighting Factors

- <u>Tissue weighting factor</u>: the proportion of the risk of stochastic effects resulting from irradiation of an organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly
- <u>Stochastic effect</u>: A health effect that occurs randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold (example: getting cancer)

Tissue or Organ	w_T (2007 recomm.)	w_T (ICRP 60 - 1990)	w_T (ICRP 23 - 1977)
Gonads	0.08	0.20	0.25
Bone marrow	0.12	0.12	0.12
Colon	0.12	0.12	N/A
Lung	0.12	0.12	0.12
Stomach	0.12	0.12	N/A
Bladder	0.04	0.05	N/A
Breast	0.12	0.05	0.15
Liver	0.04	0.05	N/A
Esophagus	0.04	0.05	N/A
Thyroid	0.04	0.05	0.03
Skin	0.01	0.01	N/A
Brain	0.01	N/A	N/A
Salivary glands	0.01	N/A	N/A
Bone surface	0.01	0.01	0.03
Remainder	0.12	0.05	0.30

Table of Radiation Units

Quantity	Traditional Unit	S.I. Unit
Activity	Curie (Ci)	Becquerel (Bq)
Exposure	Roentgen (R)	Coulomb/Kilogram (C/kg)
Absorbed Dose	Rad	Gray (Gy)
Equivalent Dose	Rem	Sievert (Sv)

Radiation Protection Philosophy

ALARA

<u>A</u>s <u>L</u>ow <u>A</u>s <u>R</u>easonably <u>A</u>chievable

Radiation Protection Principles

- For <u>External Radiation</u>
  - Time
  - Distance
  - Shielding

Time

- Reduce time in a radiation area, exposure will be reduced.

$$Dose = Dose\ Rate \times Time$$

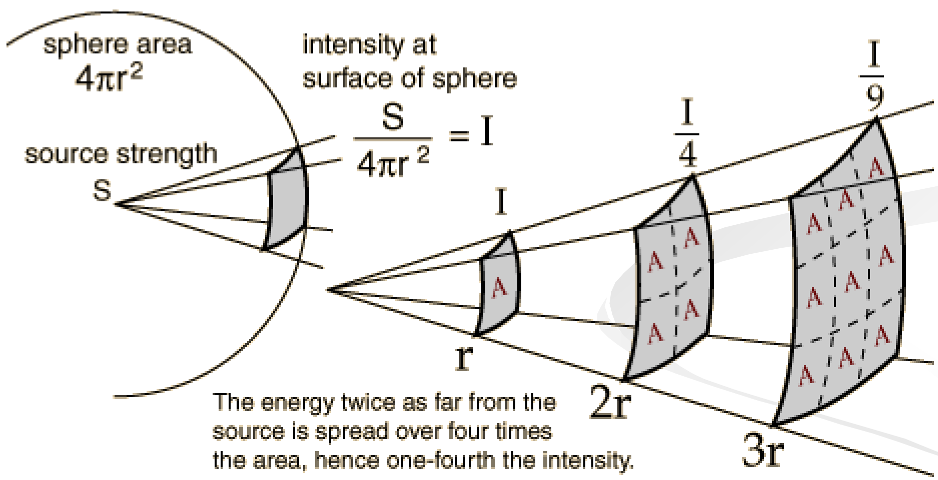
Distance

Inverse Square Law

- Applies to Gamma and X-ray radiation:
  - The intensity of the radiation (I) decreases in proportion to the square of the change in distance (d)
  - The effect of a change in distance can be calculated using:

$$I_1 d_1^2 = I_2 d_2^2$$

Inverse Square Law



Shielding

- Shielding material placed between the radiation source and personnel will reduce the radiation intensity by attenuation, and thus reduce the exposure received.
  - Attenuation: process by which a beam of radiation is reduced in intensity by absorption or scatter in the medium.

Shielding - Photons

- Shielding equation for gamma and x-ray radiation:

  I = intensity after passing through shield

  I_0= initial intensity of source

  μ = constant related to ability of material to block radiation

  x = thickness of shielding material

$$I = I_o e^{-\mu x}$$

Half-Value Layer

- Another way of determining shielding efficiency is by using the Half-Value Layer (HVL)
  - HVL: The thickness of a shielding material required to reduce the intensity of the radiation by one half.
  - This is commonly used for x-ray sources in which the photons have a range of energies
  - Is related to μ by: HVL = 0.693/μ
  - HVL equation:

$$I = \frac{I_0}{2^n}$$

where n = number of half-value layers

Dose Monitoring

- Exposure Monitoring
  - External radiation exposure is measured by personal monitoring devices. Personal monitoring is required when it is likely that an individual will receive in 1 year, a dose that is in excess of 10% of the allowed dose.
  - Not used for H-3, C-14, or S-35

Dose Monitoring

- At the University of Florida, whole body doses are determined using an optically stimulated luminescence dosimeter (Luxel).
  - This badge shall be worn on the front part of the body somewhere between the waist and the collar.

Dose Monitoring

Luxel Dosimeter:

Dose Limits

- Maximum Permissible Exposure for Occupational Workers

Whole Body:	5.0 REM /year
Eye:	15 REM /year
Skin or Extremity:	50 REM /year
50 REM committed dose equivalent to any individual organ or tissue /year	

Dose Limits

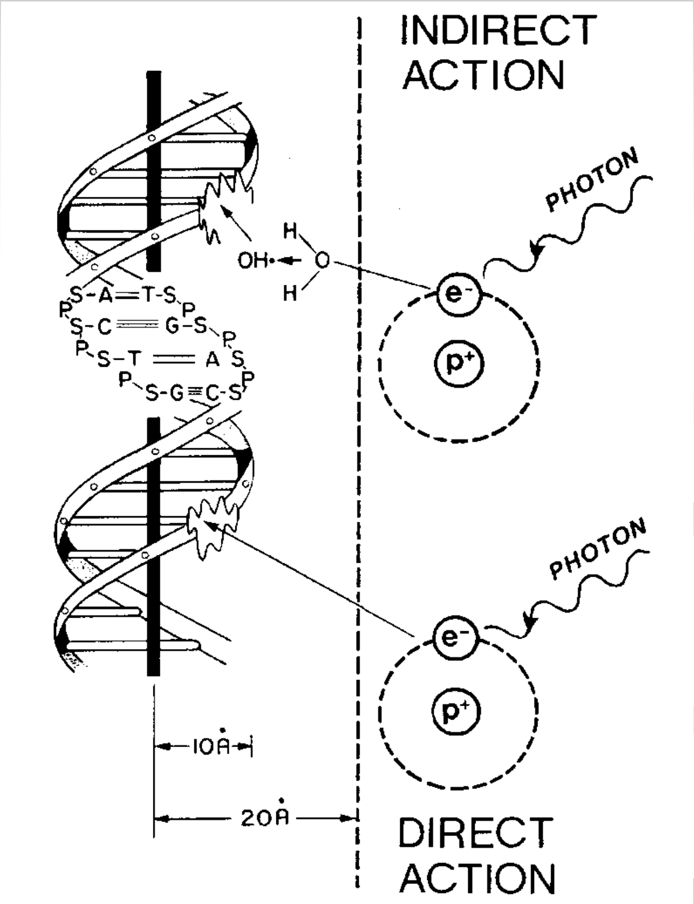
- Occupational Dose limit for individual members of the public:
  - Total effective dose equivalent to individual members of the public shall not exceed 0.1 rem in a year.

DNA is the primary target for biological damage

Radiation Damage Mechanisms

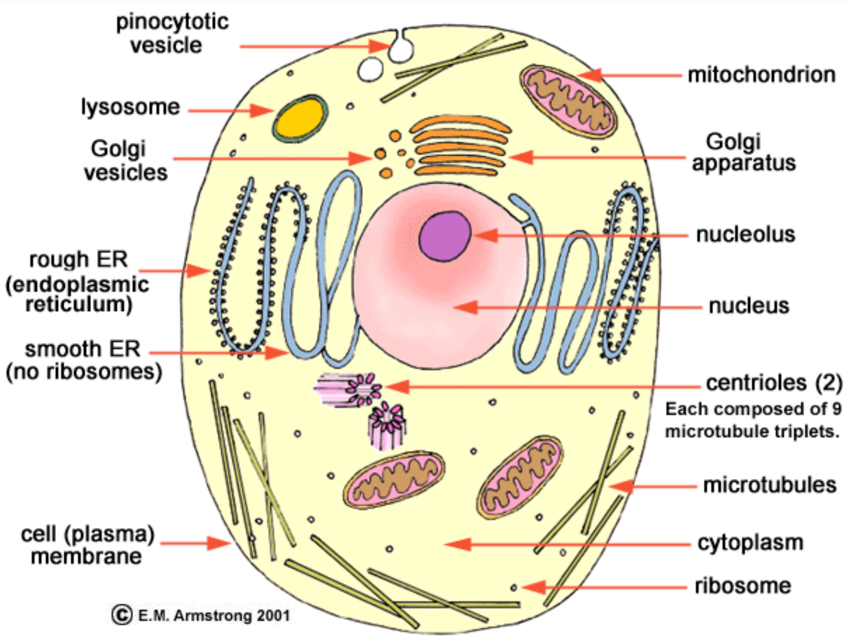
1. Direct Action: Direct ionization of the DNA molecule, which may result in genetic damage.

2. Indirect Action: Radiation ionizes water, which causes free radicals to form. Free radicals attack targets such as DNA. Much more common.



Possible Effects to Cells

1. Radiation may pass through cell without doing any damage.
2. Damage may occur but be repaired.
3. The damaged cell may reproduce in its damaged form.
4. The cell may die.



LONG TERM EFFECTS

Delayed effects due to previous acute high dose exposures or from chronic low dose exposure over many years.

- Cancer
- Embryological Effects
- Cataracts
- Life span shortening

Genetic Effects

- Genetic effects = heritable mutations to DNA
- Seen in mammals but no convincing evidence in humans
- Very difficult to measure due to subtle effects, long lifespans, uncertainties in background rate, and confounding factors
- Japanese bomb survivors
  - 77,000 births with no substantial evidence of genetic effects

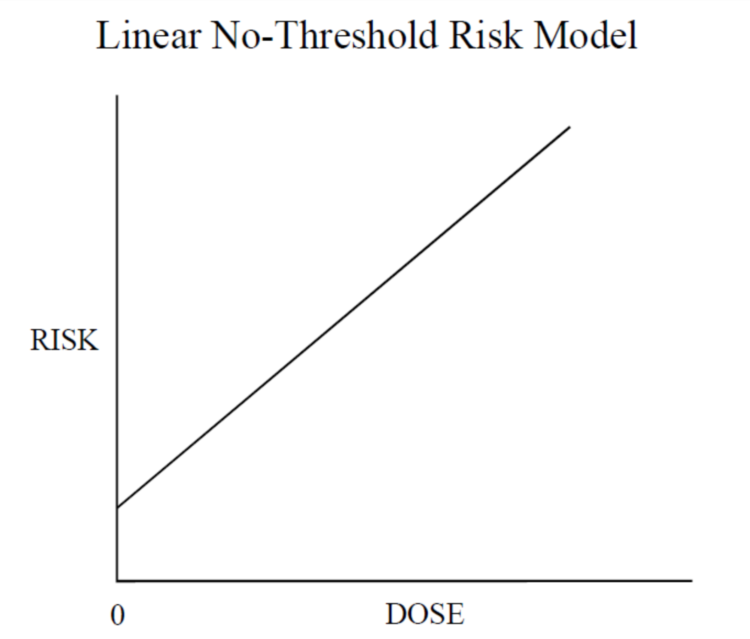
Human Evidence of Radiation Carcinogenesis

- Radium dial painters
- Radiologists and dentists
- Uranium miners
- Atomic bomb survivors
- Patients receiving medical procedures

Cancer Risk from Chronic Exposure

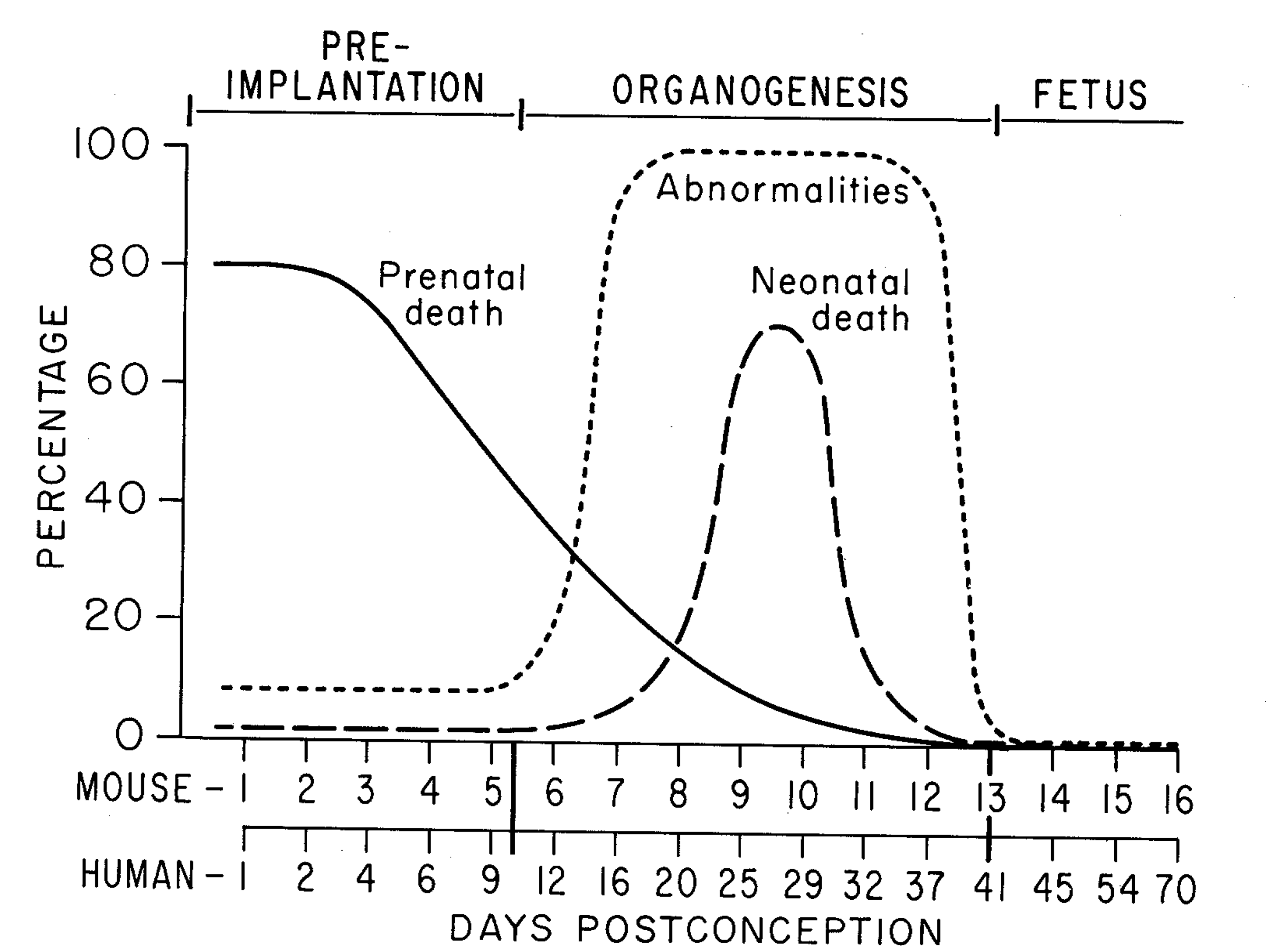
From the NRC:

- LINEAR - An increase in dose results in a proportional increase in risk
- NO-THRESHOLD - Any dose, no matter how small, produces some risk
- The risk does not start at 0 because there is some risk of cancer, even with no occupational exposure.
- Exposure to radiation is not a guarantee of harm. However, because of the linear, no-threshold model, more exposure means more risk, and **<u>there is no dose of radiation so small that it will not have some effect.</u>**



EFFECTS ON EMBRYO AND FETUS

- Embryonic/fetal cells are rapidly dividing!
  - High sensitivity
  - Higher probability that damage will be reproduced over a large number of cells
- Effects depend on stage of gestation



PRE-
IMPLANTATION
ORGANOGENESIS
FETUS
100
80
60
40
20
0
PERCENTAGE
Abnormalities
Prenatal
death
Neonatal
death
MOUSE - 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
HUMAN - 1 2 4 6 9 12 16 20 25 29 32 37 41 45 54 70
DAYS POSTCONCEPTION

REGULATIONS FOR PREGNANT WORKERS

1. Limit embryo/fetus dose equivalent to 500 mrem (0.5 rem) total.
2. Once a pregnancy becomes known limit embryo fetus dose equivalent to 50 mrem per month, excluding medical exposure
3. Wear two personnel monitors. Fetal monitor under apron at waist. Maternal, outside apron at collar.

FEDERAL GUIDELINES FEDERAL REGISTER 1/27/87

"The health protection objectives…for the unborn should be achieved in accordance with the provisions of Title VII of the Civil Rights Act of 1964…with respect to discrimination in employment practices."

-VOLUNTARY declaration of pregnancy to employer as soon as soon as possible.

FEDERAL GUIDELINES
FEDERAL REGISTER 1/27/87

Protection of the unborn is a joint responsibility of the employer and the worker.

Protection through:

Use of protective equipment, worker self selection, and temporary job rotation.