Radiation Physics and Safety

Dr Dayea Oh
Oral and Maxillofacial Radiologist
UWA Dental School

Recommended Textbooks

Essentials of dental radiography and radiology 5th edition

by Whaites, Eric; Drage, Nicholas

Churchill Livingstone 2013

Pocket atlas of dental radiology

by Pasler, Friedrich A; Visser, Heiko

Flexibook, 2007

Oral radiology: principles and interpretation 7th edition

by White, Stuart C; Pharoah, M. J

Permalink 2014

- 8th edition available now

1. Radiation Physics

How is x-ray generated?

Contents

History of Dental X-ray

- Professor Wilhelm Conrad Roentgen discovered the X-ray in 1895
- Otto Walkhoff took first dental X-rays on himself *(took 25 minutes)*
  - *"It was a real torture but I felt tremendously happy when I saw the results. It was when I weighed up the importance of Roentgen's discovery for future dentistry."*

Indications for Dental X-rays

- Dental History
  - Previous treatment
- Clinical Signs and Symptoms
  - Dental Pain
  - Trauma
  - Caries
  - Periodontal Disease
  - Absence of teeth eg. delayed eruption
  - Impacted teeth
  - Implants, **etc**…

Nature of Radiation

- Radiation is the **transmission of energy** through space and matter.
- Occurs as particulate and electromagnetic radiation .

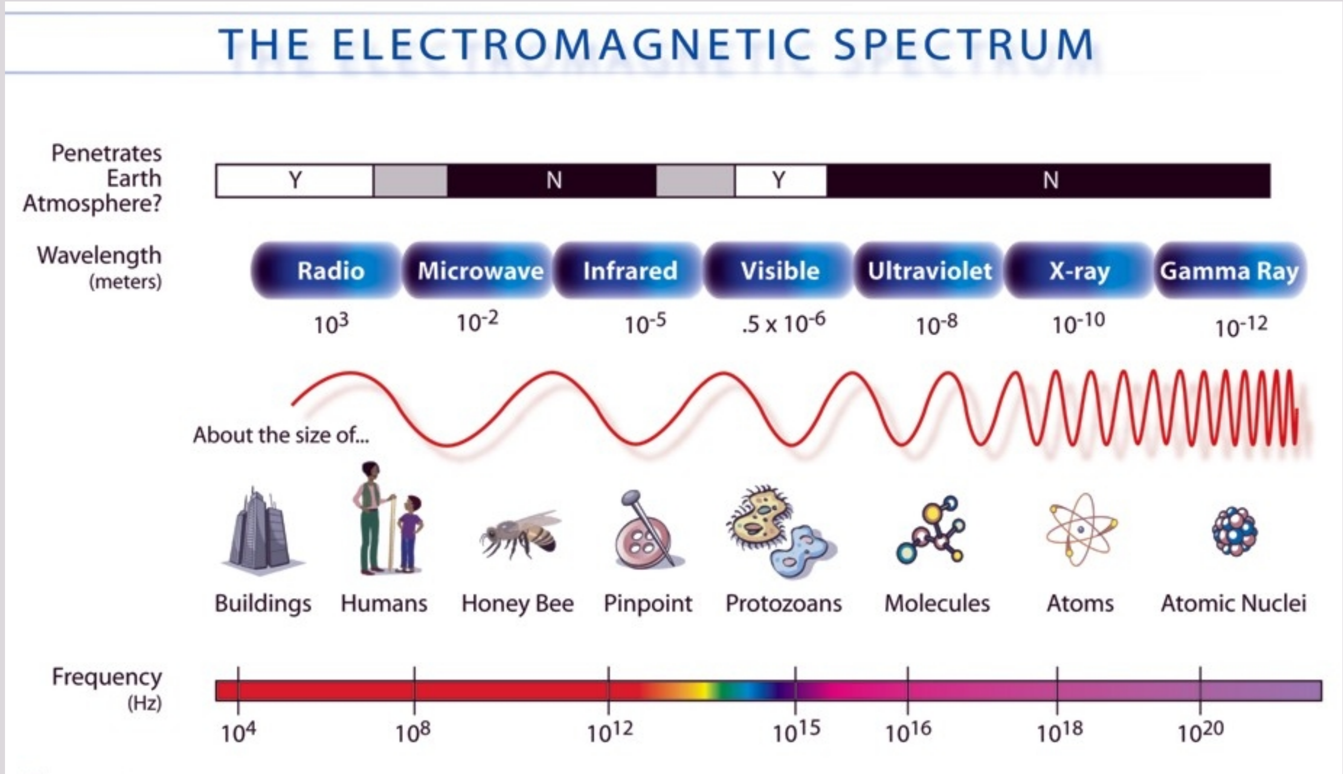
Two Basic Types of Radiation

Particulate Radiation

- Alpha particles
- Beta particles

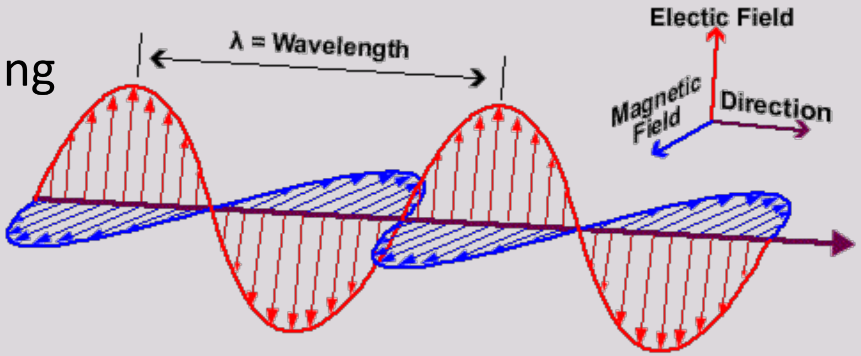
Electromagnetic Radiation

- Radio waves
- Microwaves
- Infrared waves
- Ultraviolet light
- Gamma radiation
- X-radiation



Electromagnetic Radiation (EMR)

1. **Quantum Theory:**
   - Considers electromagnetic radiation as small discrete particles of energy called **photons**.
   - Electron volt **(eV)** is the unit of energy
     - the amount of energy acquired by one electron accelerating through a potential difference of one volt.
2. **Wave Theory:**
   - Movement of photon energy through space as a combination of electric and magnetic fields.
   - Fields oriented in planes at right angles to one another that oscillate perpendicular to the direction of motion.



*γ rays, **x-rays**, UV rays, visible light, infrared radiation (heat), microwaves, and radio waves. All made up of photons.*

x-ray photons have high energy and short wavelengths

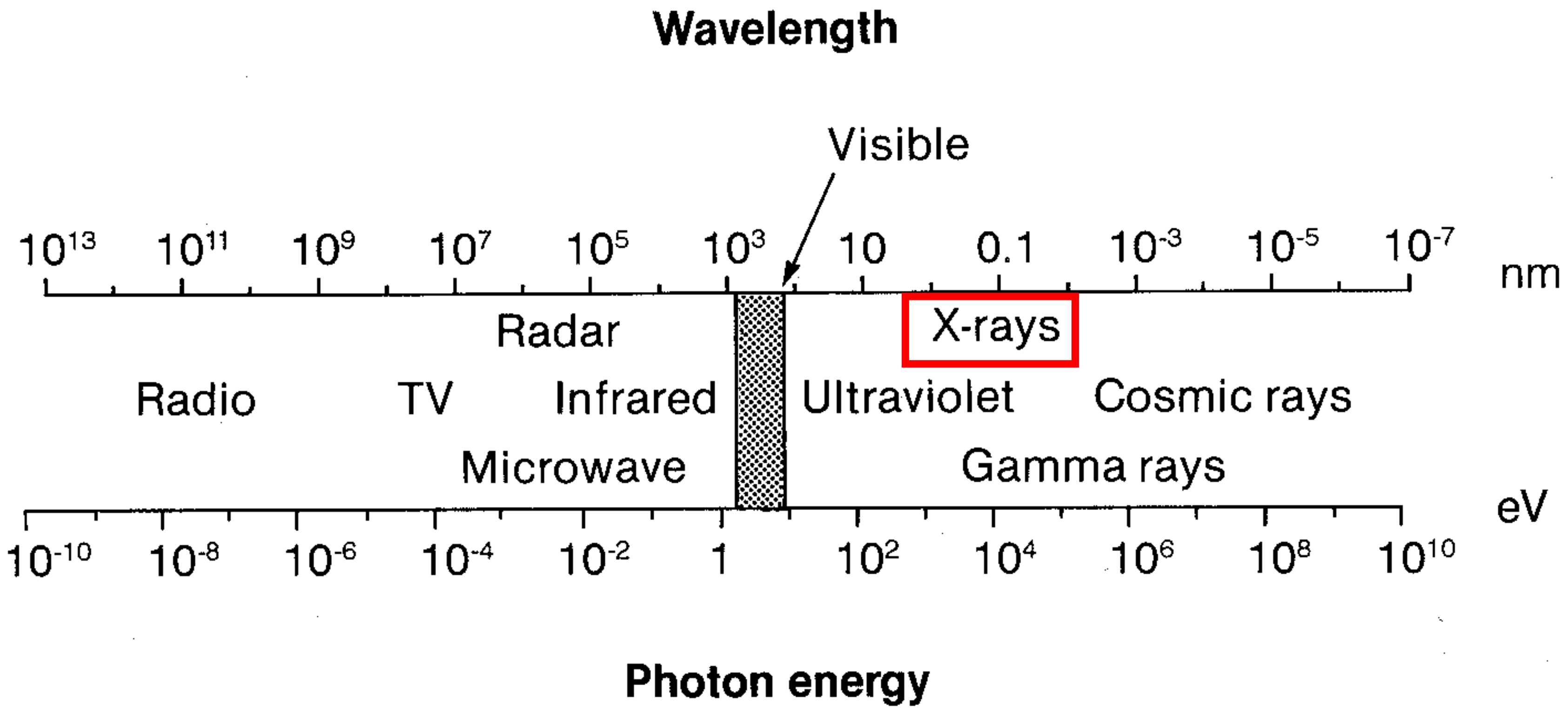
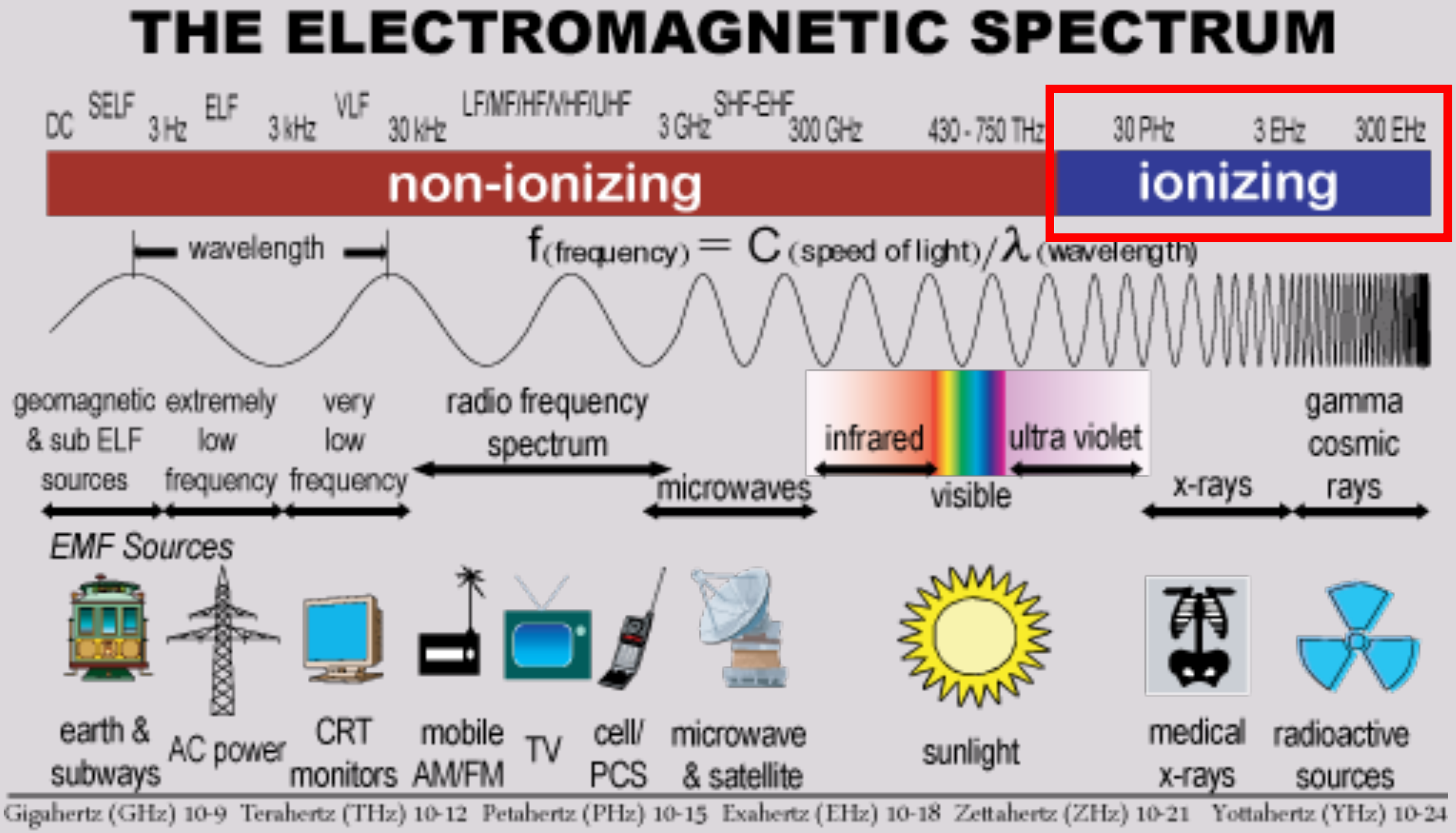


FIG. Electromagnetic spectrum showing the relationship between wavelength, photon energy, and physical properties of various portions of the spectrum. Note that the photons with shorter wavelengths have higher energy. Photons used in dental radiography have a wavelength of 0.1 to 0.001 nm.


THE ELECTROMAGNETIC SPECTRUM
DC
SELF
3 Hz
ELF
3 kHz
VLF
30 kHz
LF/MF/HF/VHF/UHF
3 GHz
SHF-EHF
300 GHz
430 - 750 THz
30 PHz
3 EHz
300 EHz
non-ionizing
ionizing
wavelength
f(frequency) = C (speed of light)/λ (wavelength)
geomagnetic & sub ELF sources
extremely low frequency
very low frequency
radio frequency spectrum
microwaves
infrared
visible
ultra violet
x-rays
gamma cosmic rays
EMF Sources
earth & subways
AC power
CRT monitors
mobile AM/FM
TV
cell/ PCS
microwave & satellite
sunlight
medical x-rays
radioactive sources
Gigahertz (GHz) 10-9 Terahertz (THz) 10-12 Petahertz (PHz) 10-15 Exahertz (EHz) 10-18 Zettahertz (ZHz) 10-21 Yottahertz (YHz) 10-24

Properties of X-ray

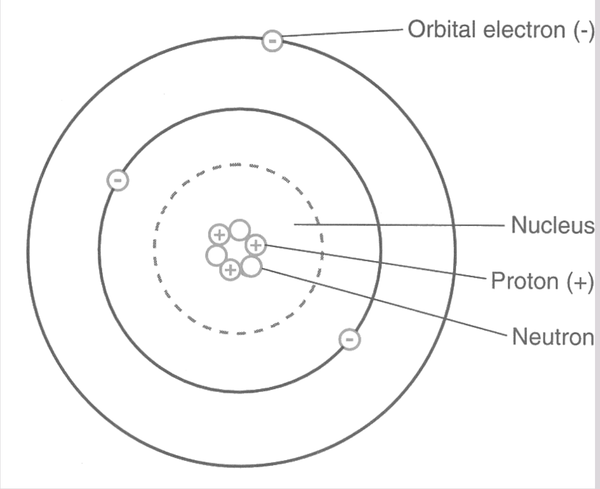
- Composed of photons (a quanta of energy)
- They are invisible
- They have high energy (short wavelengths & high frequencies)
- They have no mass or charge
- Travel at the speed of light
- **Each** x-ray photon travels in a straight line
- X-ray beam can be deflected and scattered
- Cannot be focused from their point of origin; they diverge
- Can penetrate or may be absorbed by matter (other factors also involved)
- Cause some substances to fluoresce
- Can affect photographic film
- They are **ionising radiation &** can cause biological damage

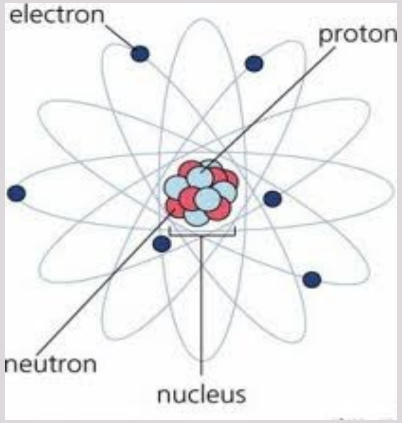
Matter - Atoms & Electrons

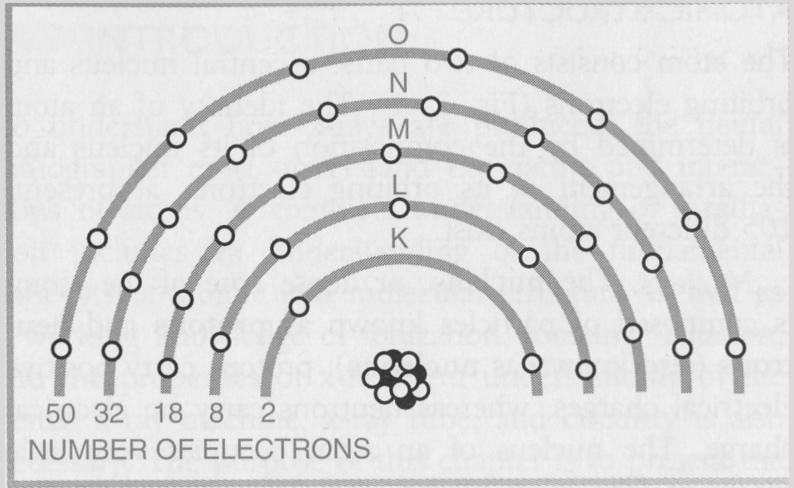
- **Atoms have electrons, protons and neutrons***

  **Hydrogen does not have a neutron*

  - **Atomic number = number of protons**
- Electrons orbit around the nucleus in circular or elliptical shells/orbits.
  - K, L, M, N, O (inner to outer shell)
  - Electrons in the inner shells are more tightly bound than the more distant outer shells
  - Each shell has a limit on the number of electrons
- Electrons can <u>move</u> from one shell to another if additional energy is added to overcome the **binding energy** of the electron to their shell.







Ionising Radiation

- Ionisation is a process when an atom **loses an electron** and becomes a positive ion
- To ionise an atom, sufficient **energy** is required to overcome the electrostatic force (binding energy of the electrons to the nucleus)
- The binding energy of an electron is related to the atomic number of the atom and the orbital type.
  - Large atomic number = large no. of protons in the nucleus

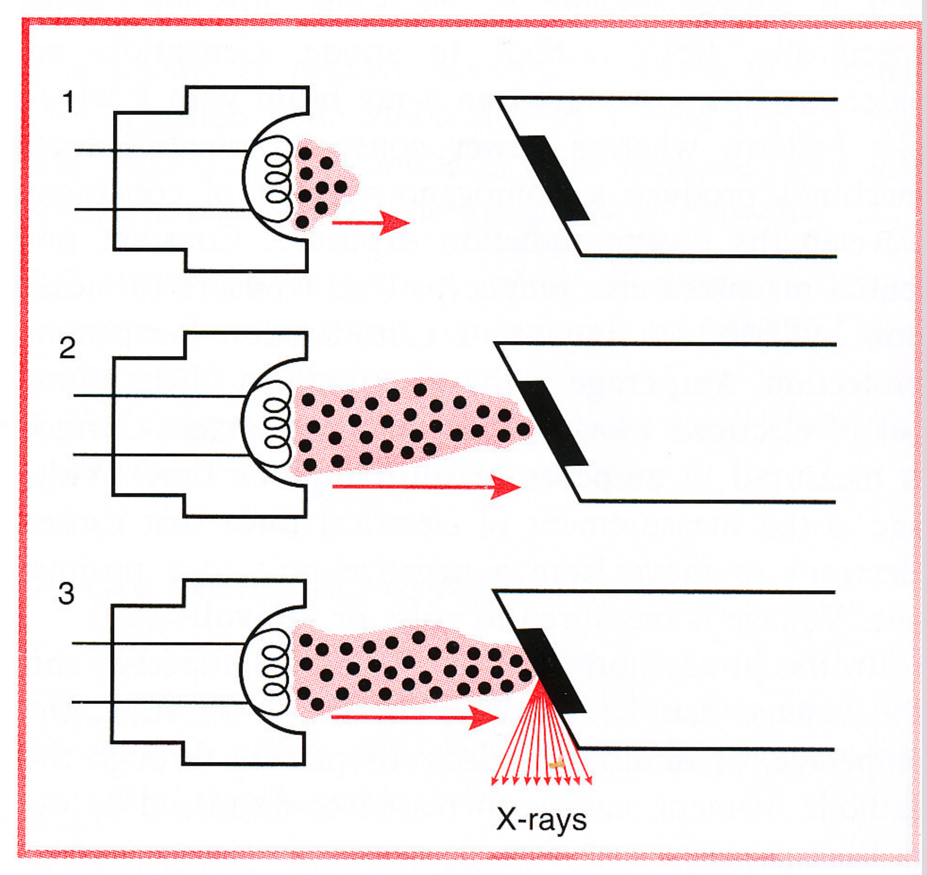
    → High bind energy of electrons electrons

    → High energy is required to IONIZE atoms
- For molecules, exposure to ionizing radiation may also break chemical bonds, fragmenting the molecule ➔ biological change!

X-ray Photon Production

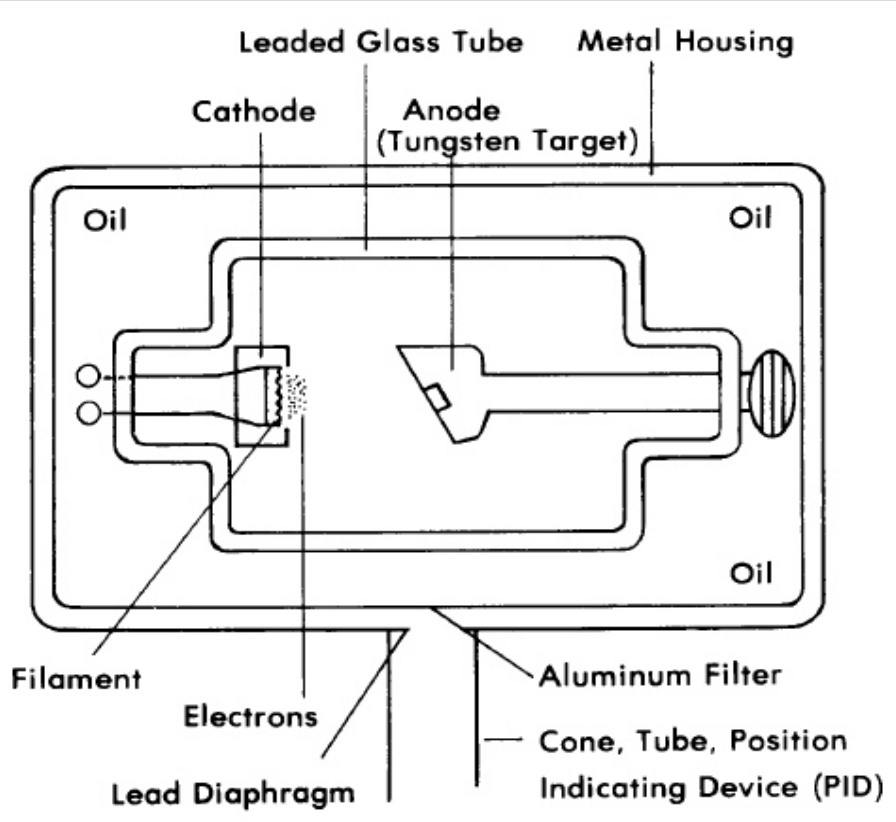
- The production of x-ray photons requires 3 important processes:

1. *Production* of electrons
2. *Acceleration* of these electrons such that they have high kinetic energy
3. *Impact* of these electrons into other atoms



Dental X-ray Tubehead

- Primary components of a tube head include:
  - ➢**X-ray tube and power supply**
- Other components:
  - An electrical insulating material, usually oil, surrounds the x-ray tube (conducts heat away from the x-ray tube).
  - **Lead Casing/Glass**: Removes scattered x-rays.
  - **Aluminium Filter**: removes soft (low energy) x-rays from the primary beam.
  - **PID** (position indicating device; 200mm in length) → provides optimum distance (least divergence & unclearness)
  - **Collimator** (opening) → restricts beam to usable size
  - Entire tube head is supported by **an arm** that is mounted on a wall.
  - **Control panel** available for adjusting: duration of exposure, and energy and exposure rate of the x-ray beam.

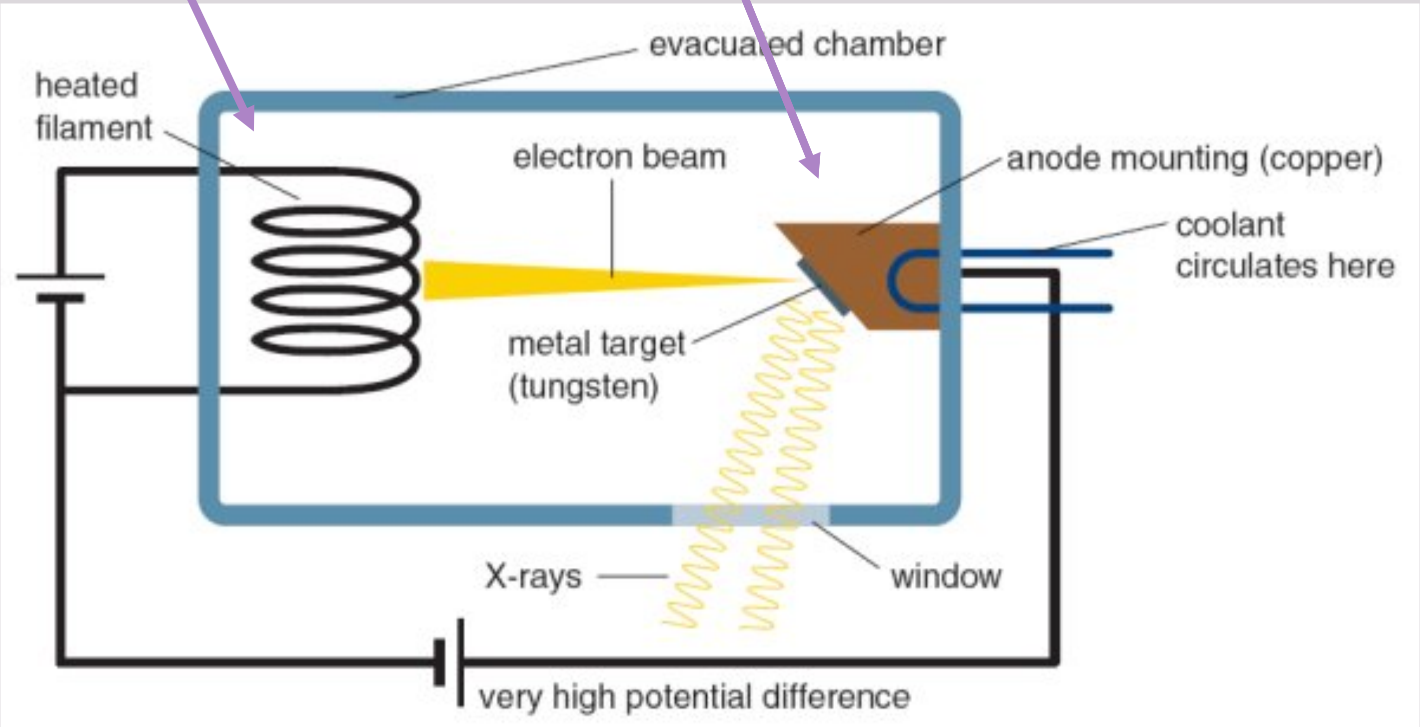


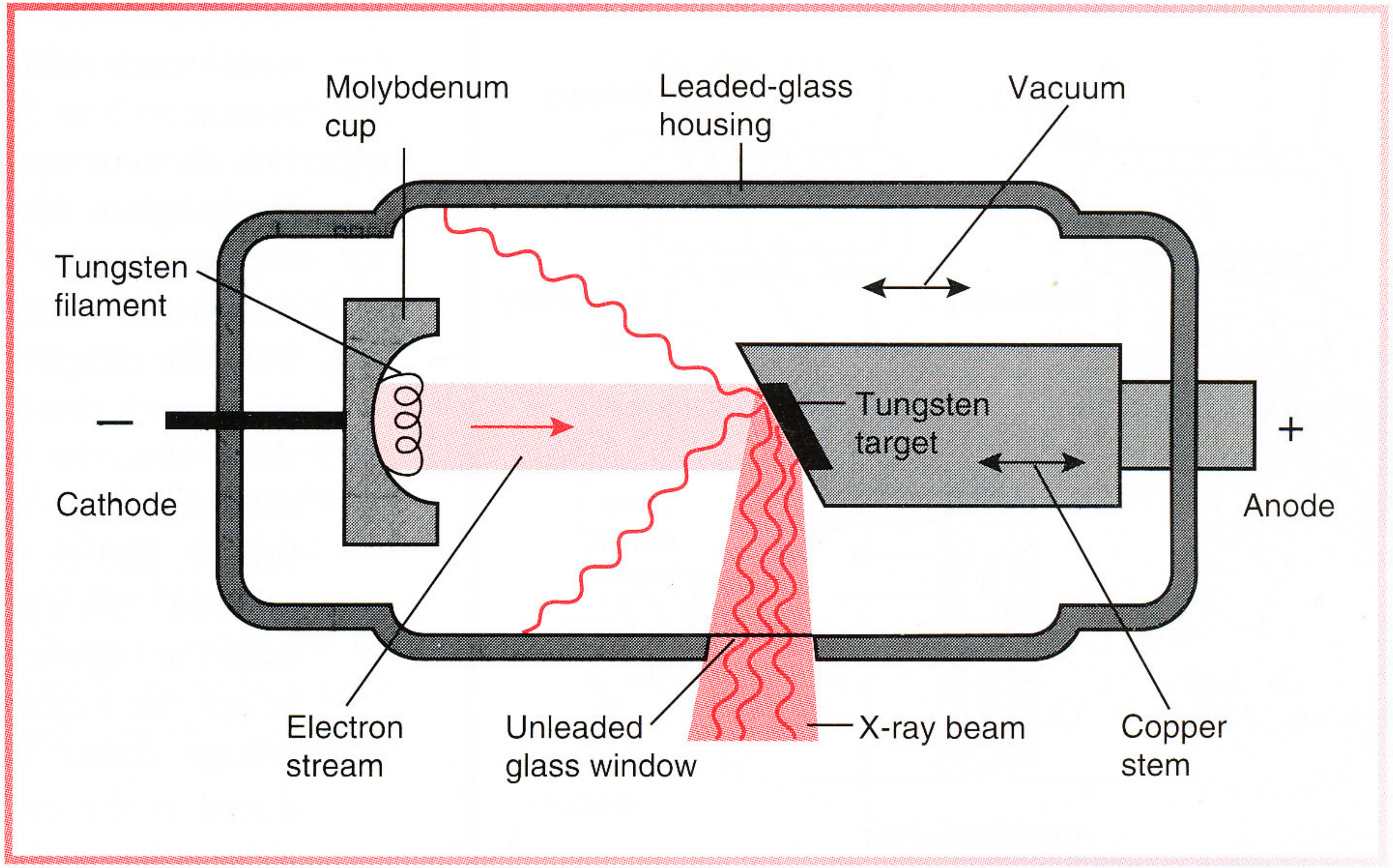
X-ray Tube

- Composed of a **cathode** (-ve) and an **anode** (+ve) within an **evacuated glass/tube**.

Power Supply
kVp & mA

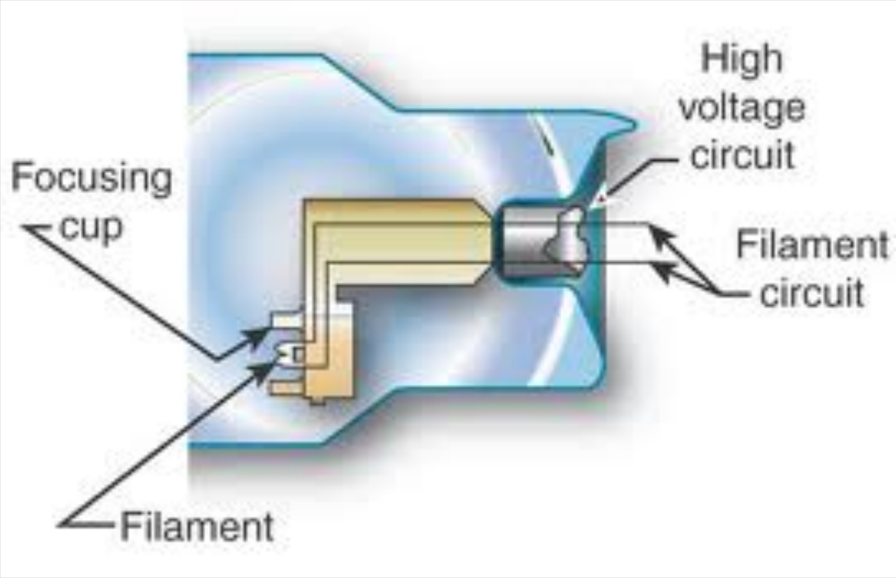
Typically, kvP of an intraoral x-ray machine is 70kvp




Molybdenum cup
Leaded-glass housing
Vacuum
Tungsten filament
–
Cathode
Tungsten target
+
Anode
Electron stream
Unleaded glass window
X-ray beam
Copper stem

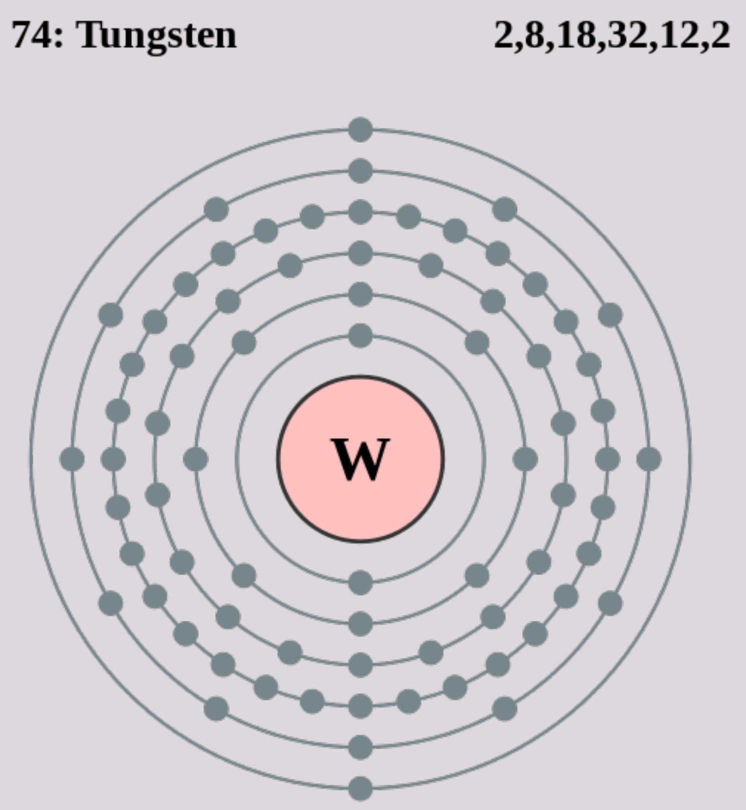
Cathode (-)

- The cathode (-ve) consists of **a tungsten filament** and a **molybdenum focusing cup**. The *filament* is the source of **electrons** within the x-ray tube.
- The filament is heated by the flow of current from the low-voltage source (~ 10 volts) and emits electrons at a rate proportional to the temperature of the filament.
- Focusing cup is also negatively charged.
  - Concave shape and charge serve to focus the electrons into a beam that is aimed at the **focal spot** on the anode. (electron clouds)
- Electrons are then accelerated (gaining kinetic energy) by the second high-voltage source (60-100 kilovolts) and move / are attracted to the positively charged anode (focal spot).



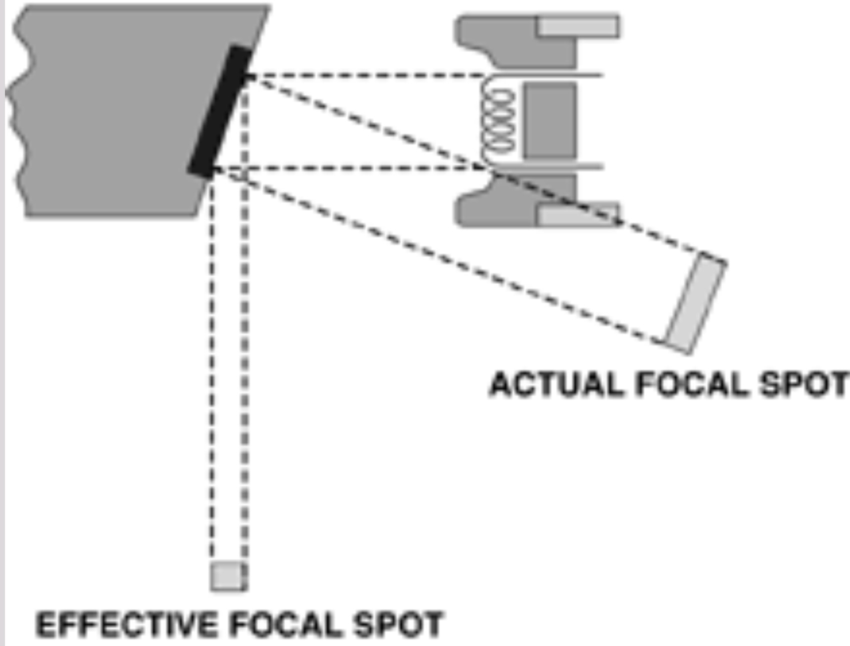
Tungsten Atom (Z = 74)

- Electron volt binding energy decreases as the shell to nucleus distance increases.
- Tungsten has an K shell electron binding energy is approximately 70keV.
- It has a high atomic number (74), a high melting point, *high thermal conductivity*, and low vapor pressure at the working temperatures of an x-ray tube.
  - *Tungsten has high thermal conductivity, thus readily dissipating its heat into the copper stem.*



Anode (+)

- Consists of a **tungsten target** in a **copper stem**.
- Typically, the target is placed at an angle (inclined about 20 degrees) to the electron beam
  - to generate a much smaller (outgoing) beam → the more 'focused' the beam, the sharper the radiographic image at the expense of generating more heat
- Target converts the kinetic energy of the colliding electrons into **x-ray photons**.
- Conversion of the kinetic energy of the electrons into x-ray photons is an inefficient process as 99% of the electron kinetic energy converted to heat.
- **A target made of a *high atomic number* material is most efficient in producing x rays.**
- Copper stem removes heat from the tungsten, reducing the risk of the target melting.
  - Additionally, the insulating oil carries heat away from the copper stem.



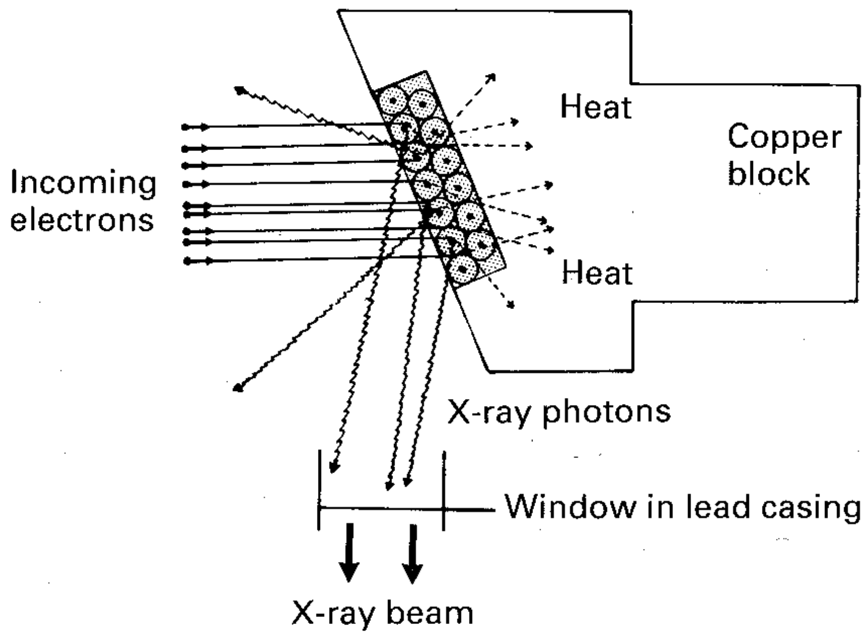


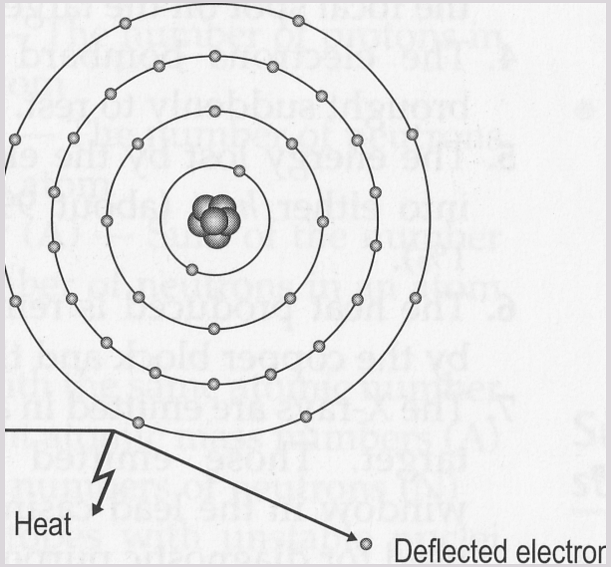
Fig. Diagram of the anode enlarged, showing the target and summarizing the interactions at the target.

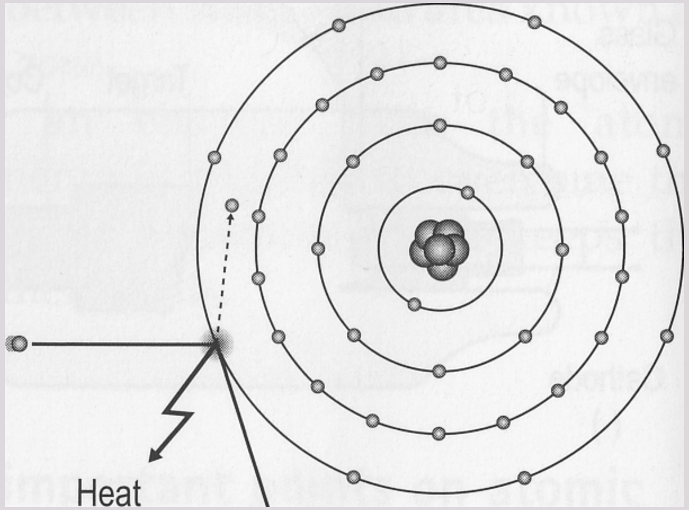
Heat Production in Tungsten Target (on Anode)

- Most high-speed electrons interacting with the tungsten target release their energy as heat (99%) ☹

- Heat is produced the following ways:

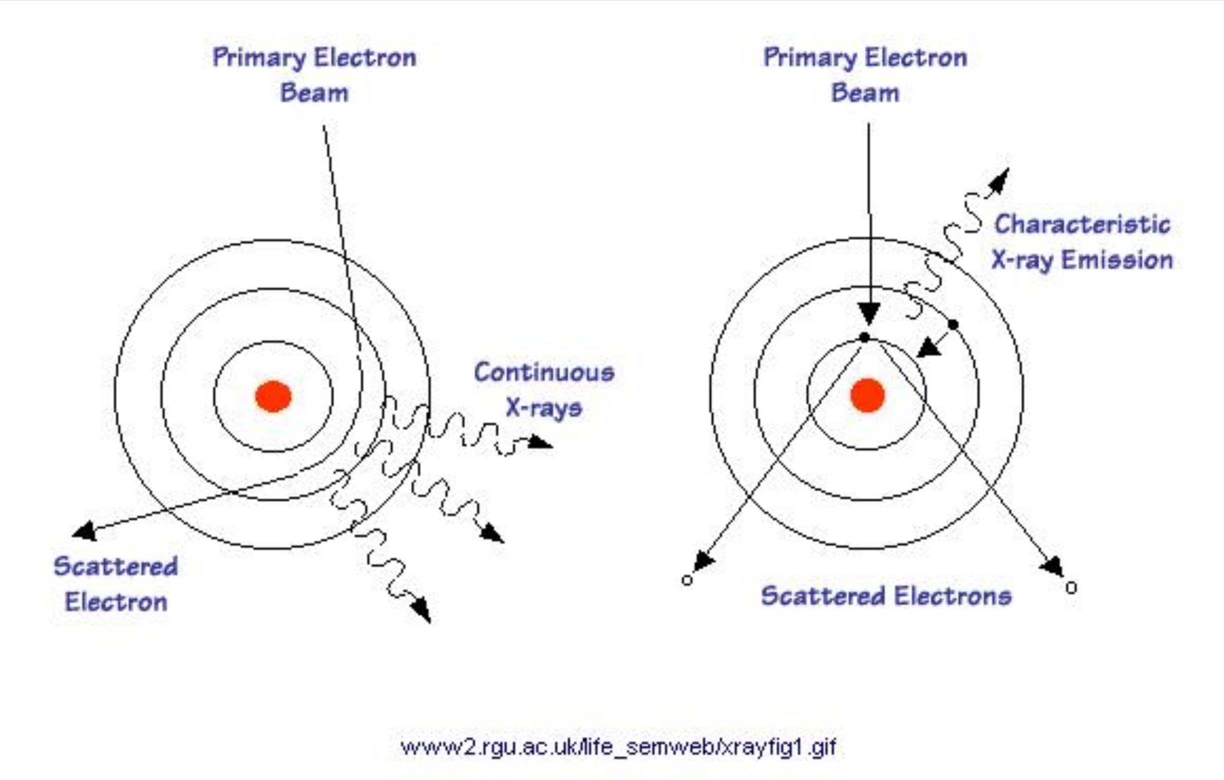
1. The incoming electron is **deflected** by the cloud of outer-shell target electrons with a small loss of energy in the form of heat
2. The incoming electron **collides with** an outer shell target electron displacing the target electron to a more peripheral shell (excitation) or displacing the target electron from the atom (ionisation) with a small loss of energy in the form of heat





X-ray Production in Tungsten Target (on Anode)

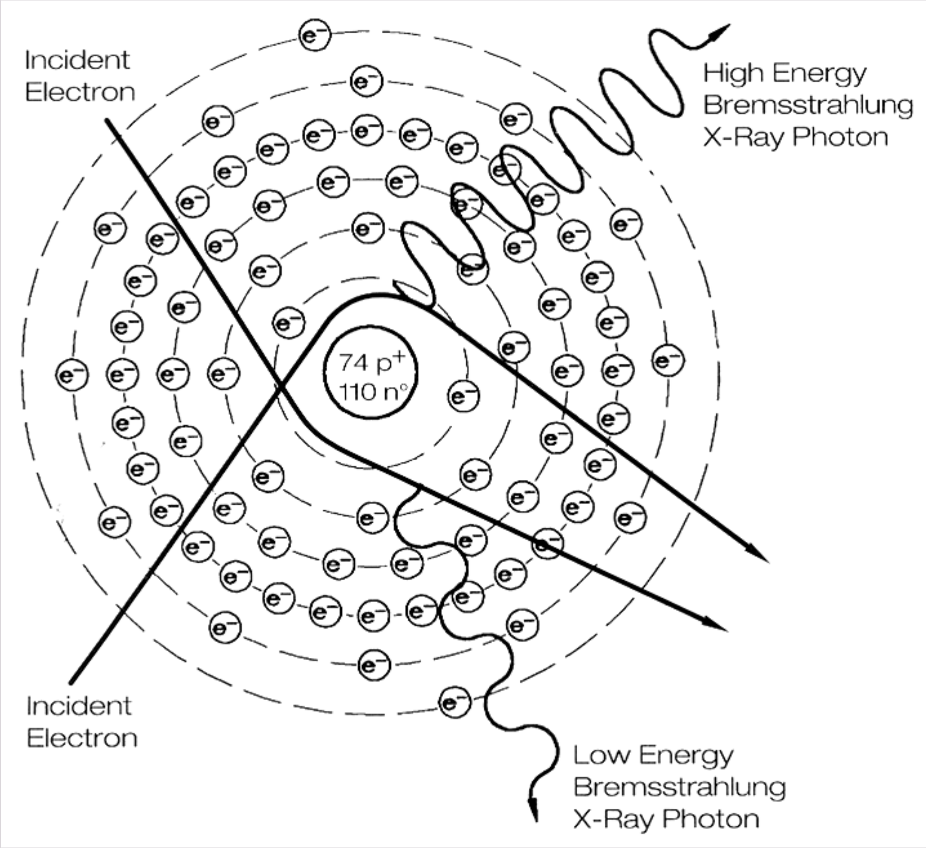
- The remaining 1% of the high-energy electrons convert their kinetic energy into x-ray photons by the formation of **Bremsstrahlung radiation** and **characteristic radiation**.



Bremsstrahlung Radiation

Bremsstrahlung = "Braking" in German

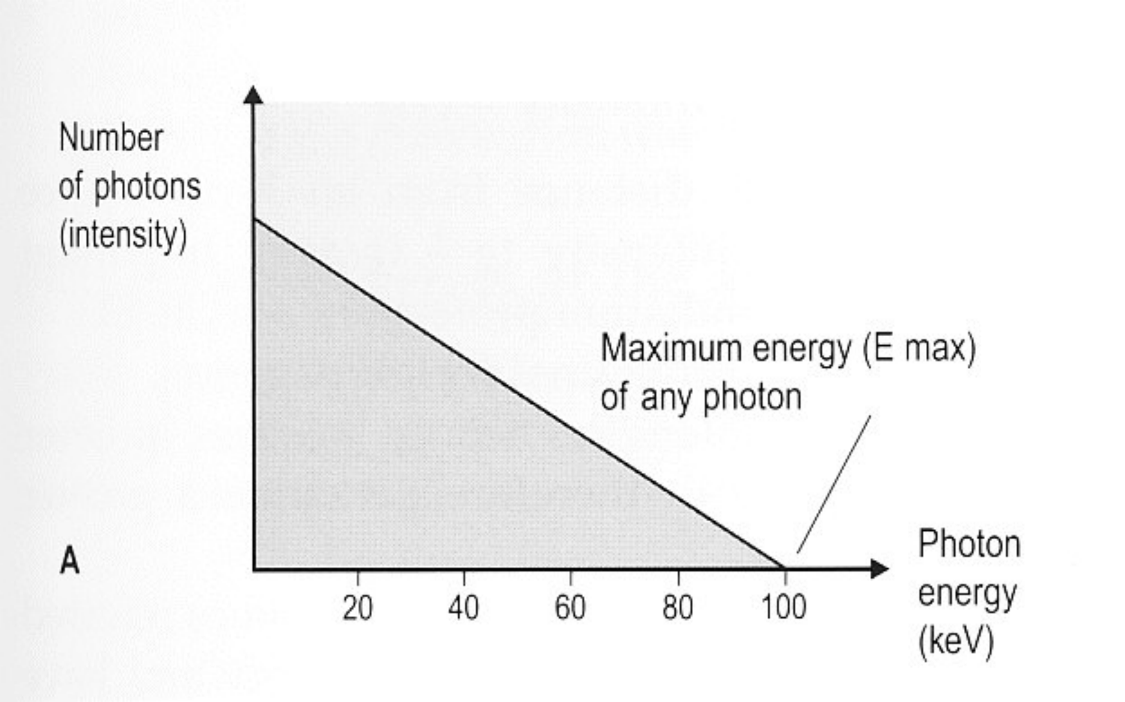
- More than **70%** of dental x-rays
- Electrons' sudden stopping or decrease in speed by tungsten nuclei causes the electrons to lose kinetic energy → producing bremsstrahlung photons
- The closer the electron approaches the nuclei, the greater the braking effect, and the greater the energy of the resulting bremsstrahlung photons.
    - High Z (atomic number) metals (more protons) are more effective in deflecting the path of the incident electrons.
    - Large deflections produce high-energy photons
    - Small deflections produce low-energy photons



Bremsstrahlung Radiation cont'd.

- Reality → more low energy
- Resultant spectrum shows a large number of small energy photons and a small number of high energy photons, with a continuous spectrum in between

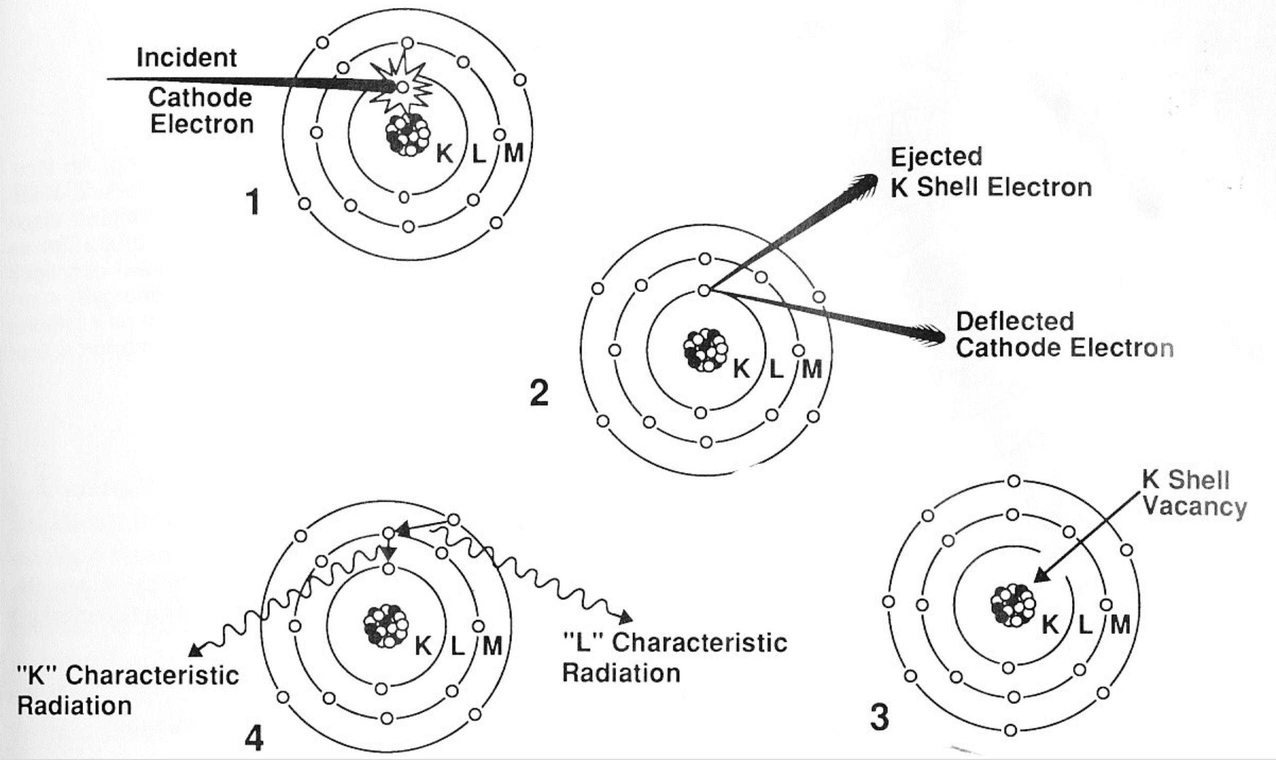
- **Note: Low energy photons have little penetrating power and do not contribute to a useful x-ray beam and a removed by filtration.**



Continuous Spectrum

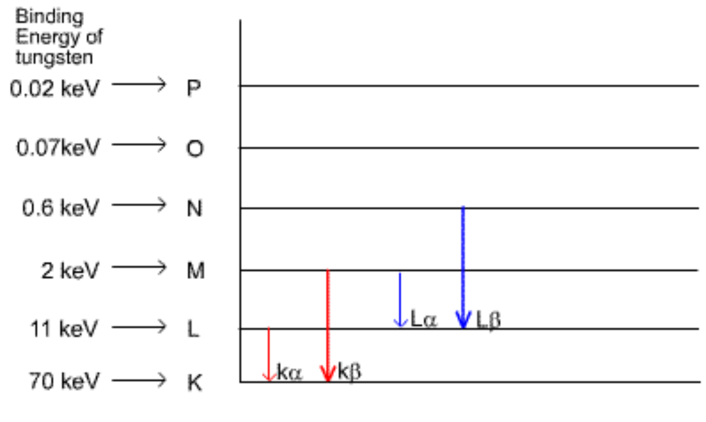
Characteristic Radiation

- Only a **small** fraction of dental x-rays
- Occurs when an incident electron (from the incoming beam) ejects an inner orbit electron from the tungsten target.
- The electron vacancy is filled by an electron from an outer orbit.
- A photon is emitted with energy equal to the difference in energy between the two orbits.
- The energies of characteristic photons are **discrete** because they represent the difference of the energy levels of electron orbital levels and hence are characteristic of the target atom.

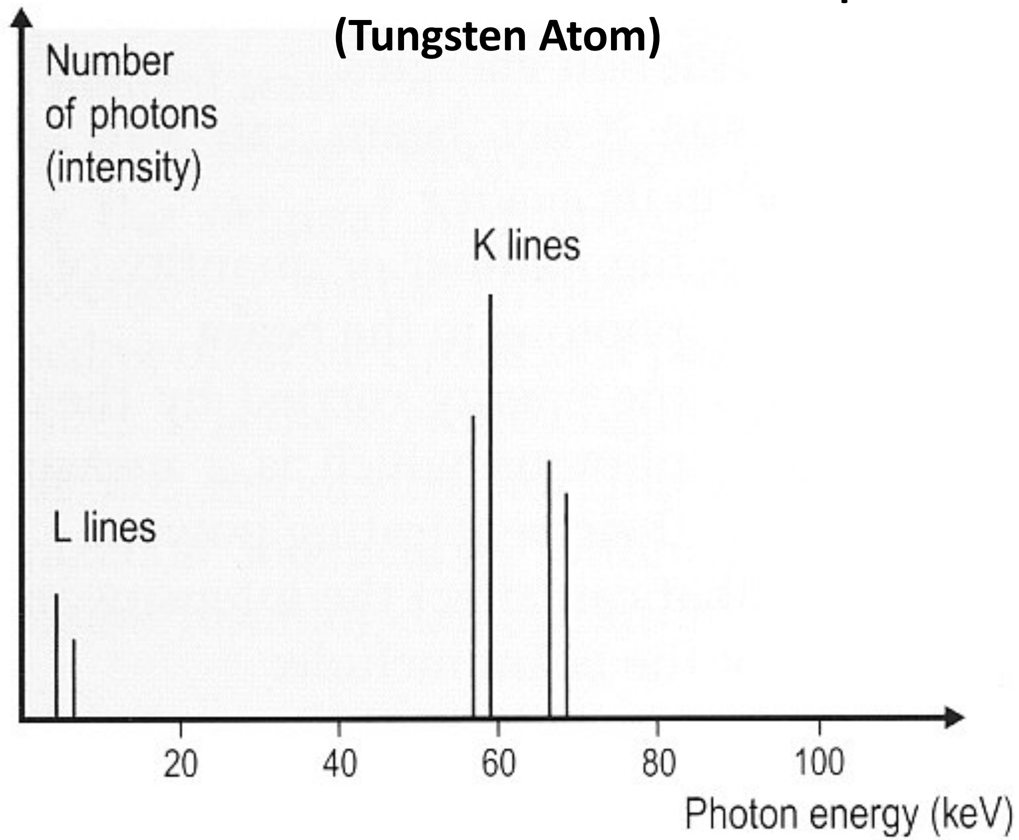


Characteristic Radiation cont'd.

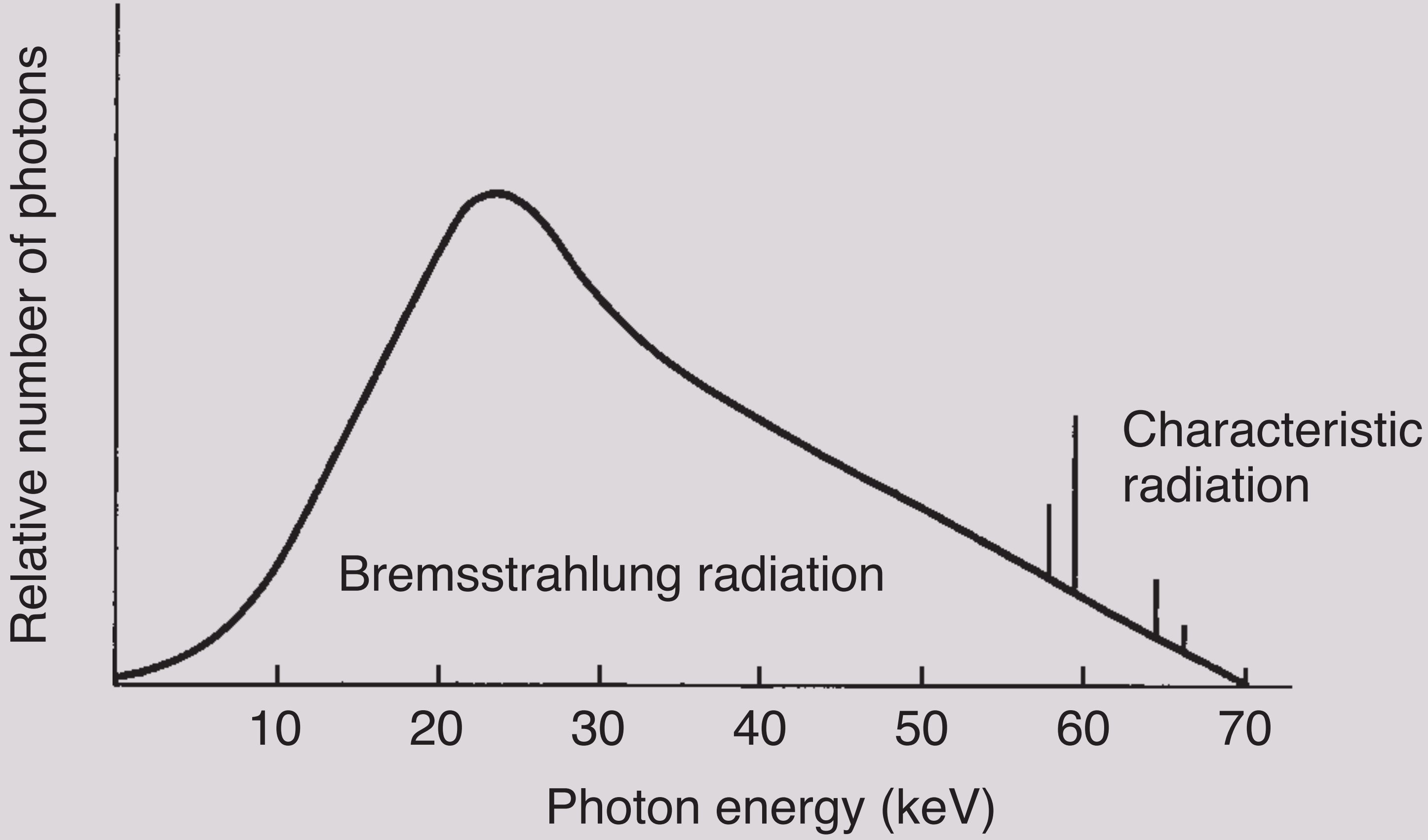
- Discrete, specific energies (**characteristic**) ie. no continuous spectrum

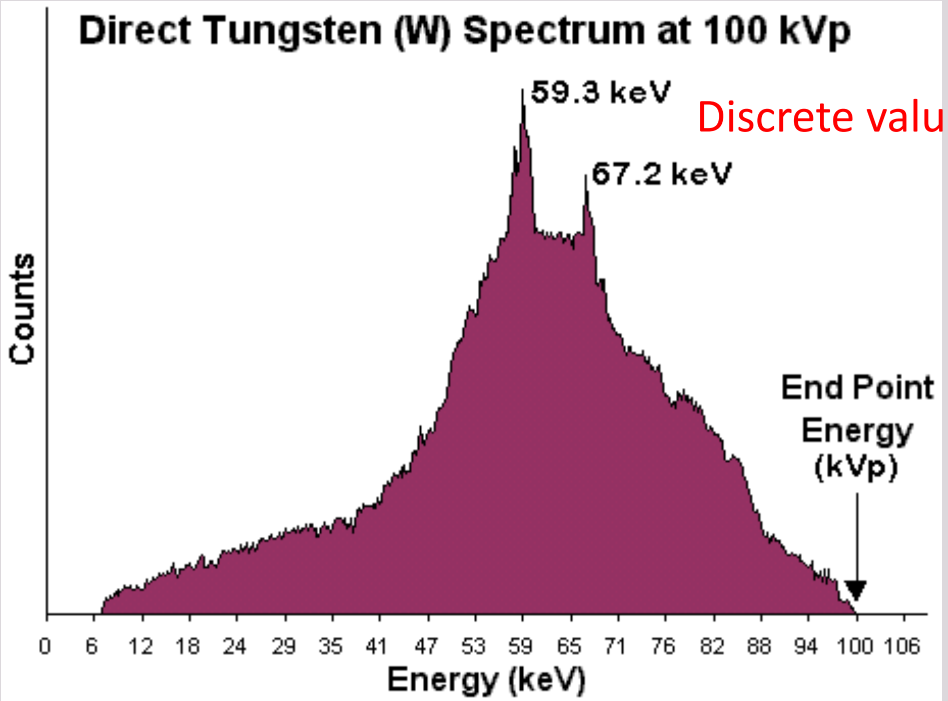


Characteristic Radiation Spectra (Tungsten Atom)



Spectrum of X-ray Photons
(at 70 kVp & 100 kVp, Tungsten Target)





Discrete values

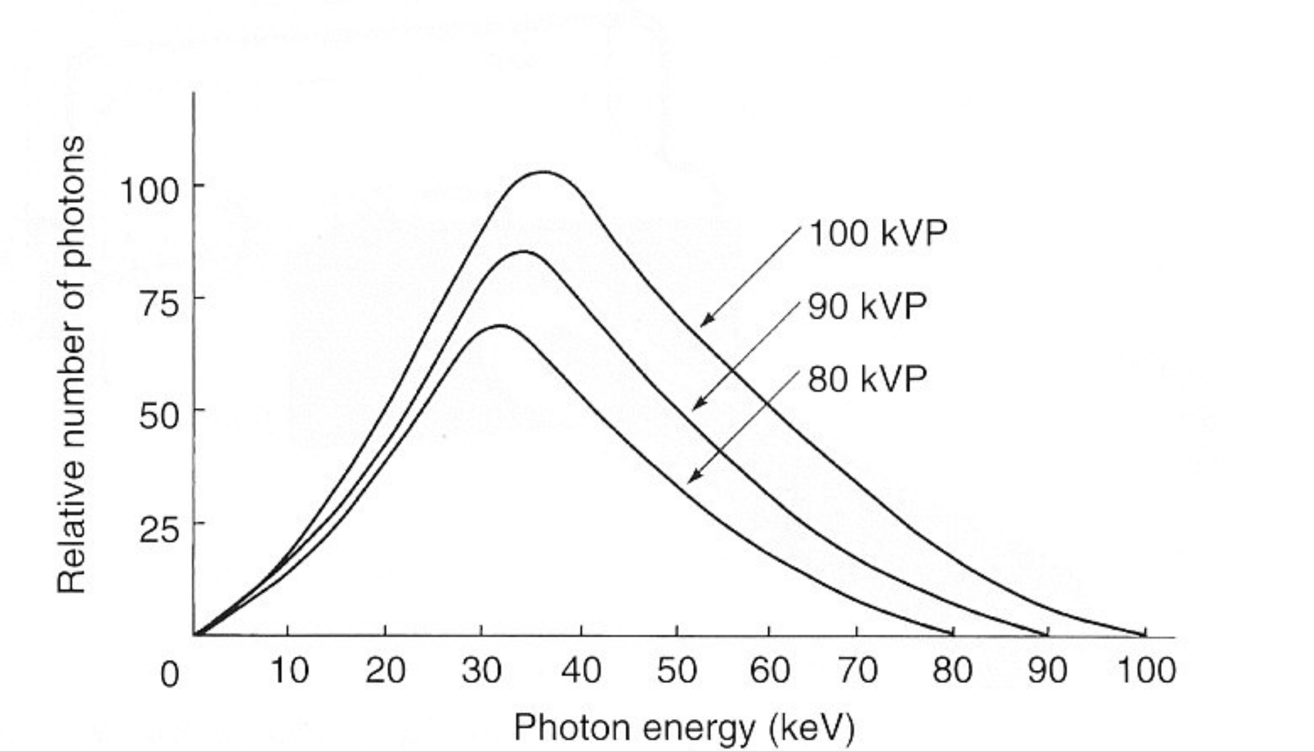
Factors Controlling the X-ray Beam

1. Tube Voltage (kVp)
2. Filtration
3. Tube Current (mA)
4. Duration (time in seconds)
5. Collimation
6. Target-Patient Distance
   - Inverse-square law

X-ray Altered by: Tube Voltage (kVp)

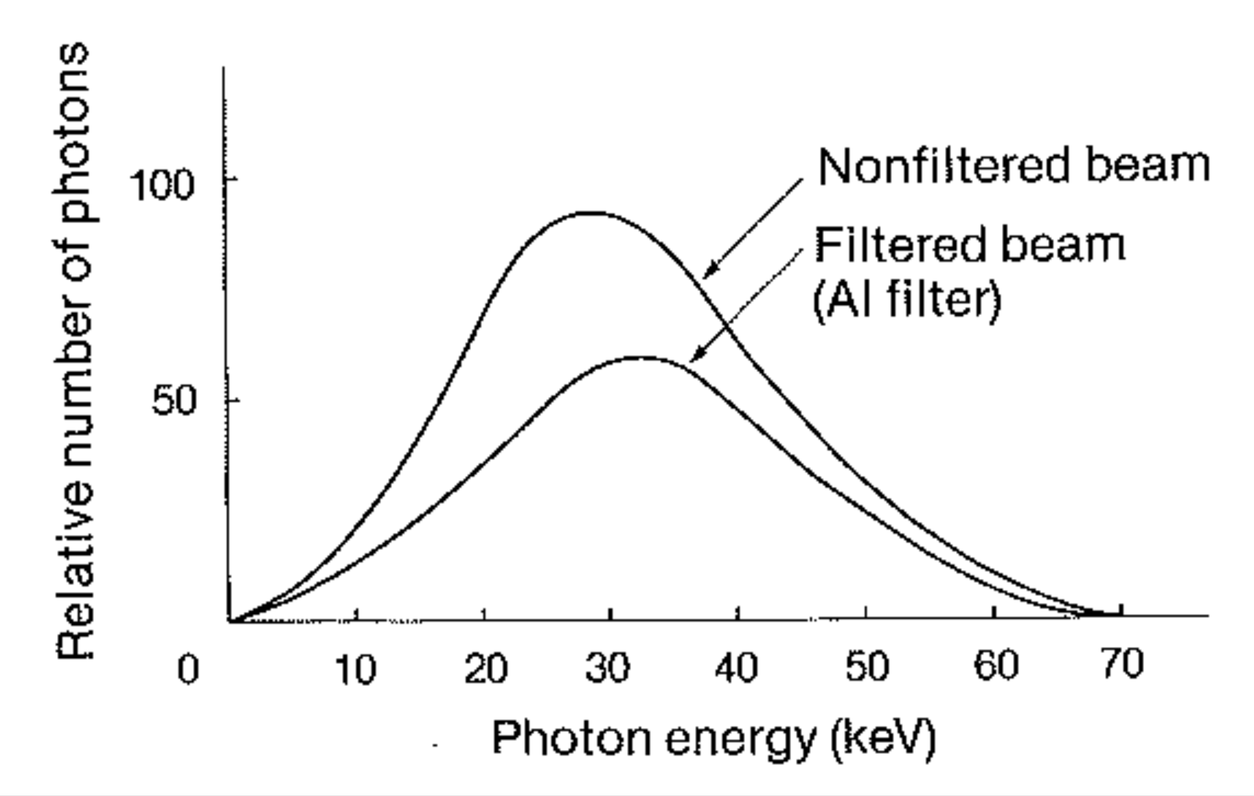
- Spectrum of photon energies showing that as the kVp increases (mA constant) there is a corresponding increase in:

1. the mean energy of the beam,
2. the total number of photons emitted, and
3. the maximum energy of the photons.



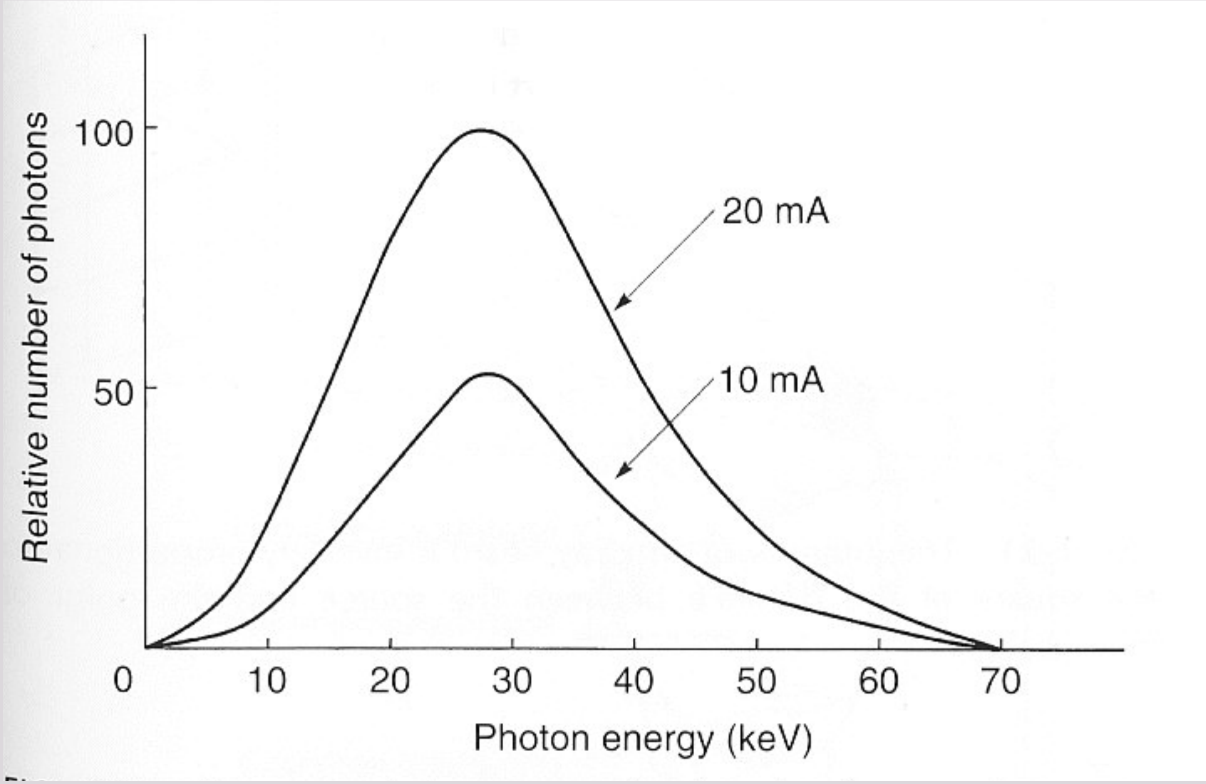
X-ray Altered by: Filtration of Beam

- Filtration of an x-ray beam with aluminium results in the preferential **removal of low-energy photons**, reducing the intensity of the beam but increasing its mean energy. (also decrease in no. of photons)



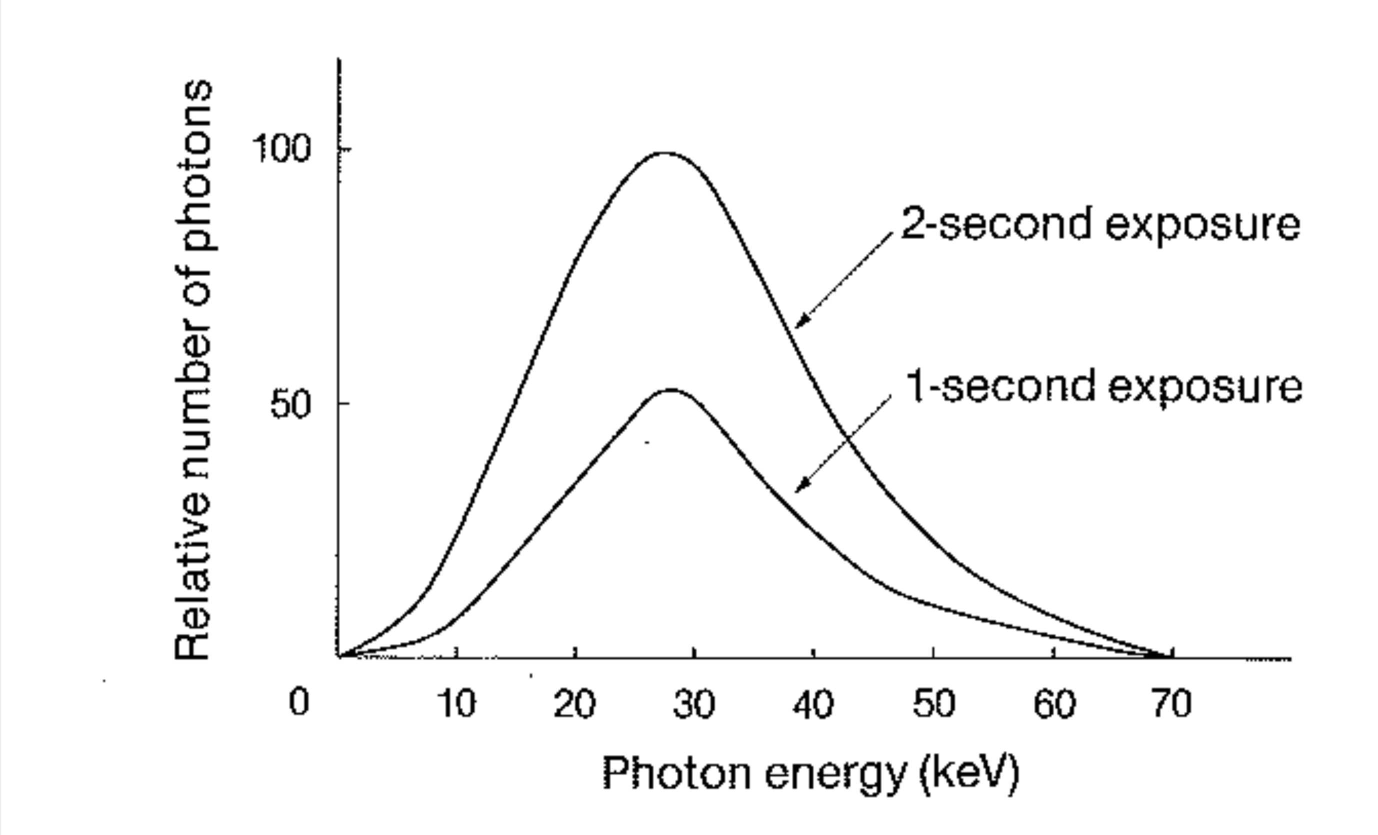
X-ray Altered by: Exposure Rate / Tube Current (mA)

- Spectrum of photon energies resulting from increasing the tube current (mA) while maintaining the tube voltage (kVp).



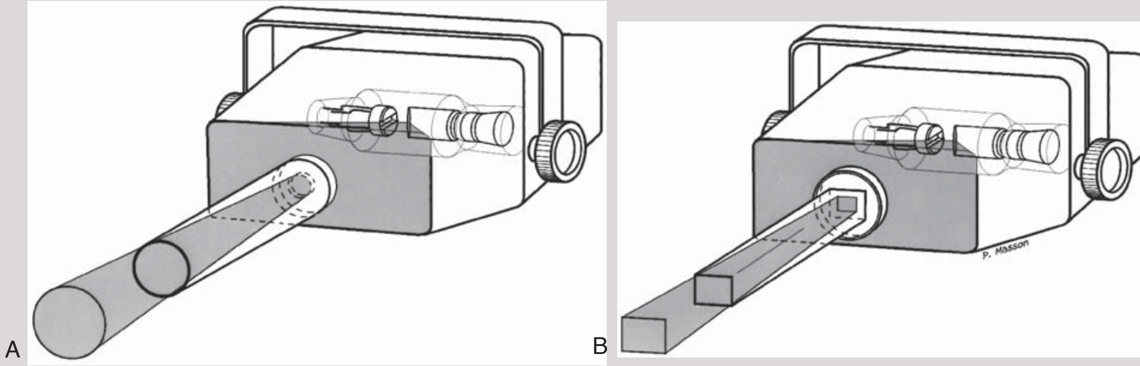
X-ray Altered by: Duration / Exposure Time

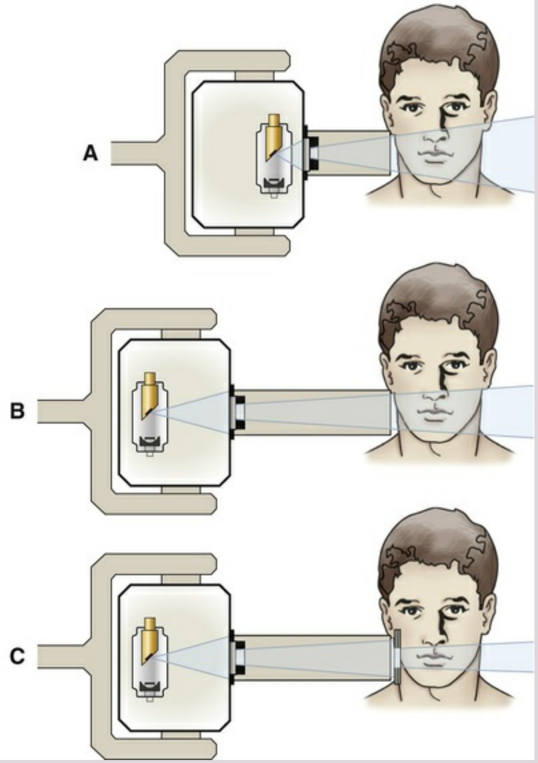
- As the exposure time increases the total number of photons increases, but the mean energy and maximum energy of the beams are unchanged.

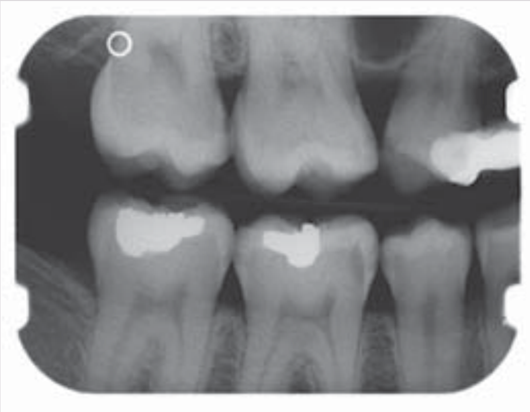


X-ray Altered by: Collimation (shape of the beam)

- A collimator is a metallic barrier with an aperture in the middle used to reduce the size of the x-ray beam
- Dental x-ray beams are usually collimated to a circle (7 cm in diameter)
  - Less frequently, there are rectangular collimators in dentistry
- Typically, round collimators are built into open-ended aiming cylinders.
- Rectangular collimators further limit the size of the beam to just larger than the x-ray film (intraoral x-ray films are rectangular), thereby further reducing patient exposure.



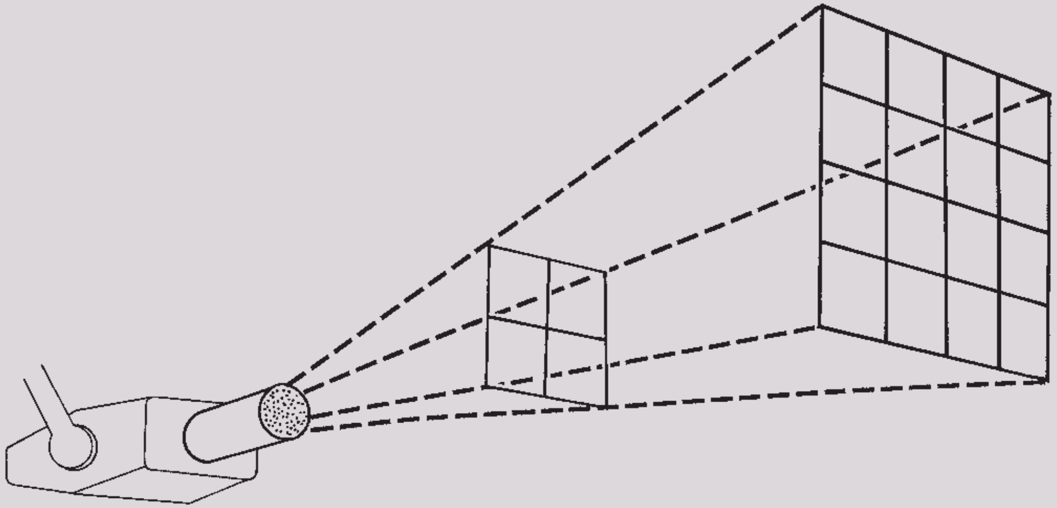


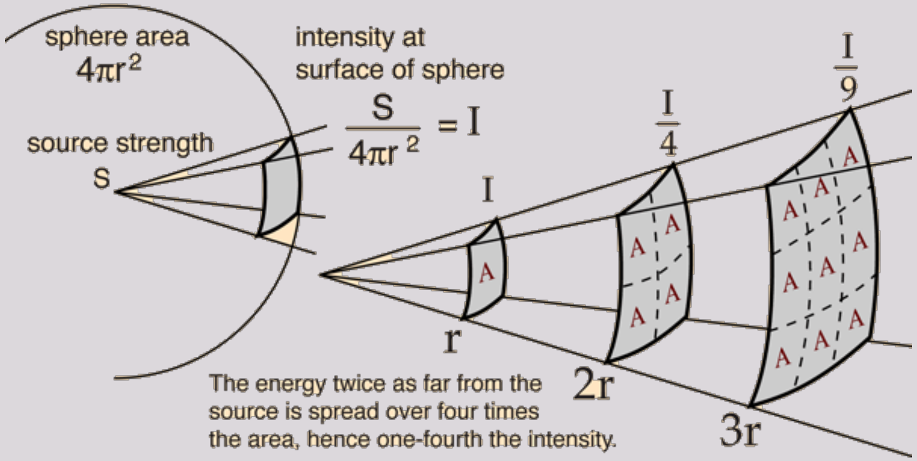


X-ray Altered by: Intensity / Distance

- **Inverse Square Law =** For a given beam, the intensity is inversely proportional to the square of the distance from the source
- The intensity of an x-ray beam (the number of photons per cross-sectional area per unit of exposure time) depends on the distance of the measuring device from the focal spot.

2x distance = ¼ x Radiation





2. Radiation Safety

How to minimise radiation for patient and staff?

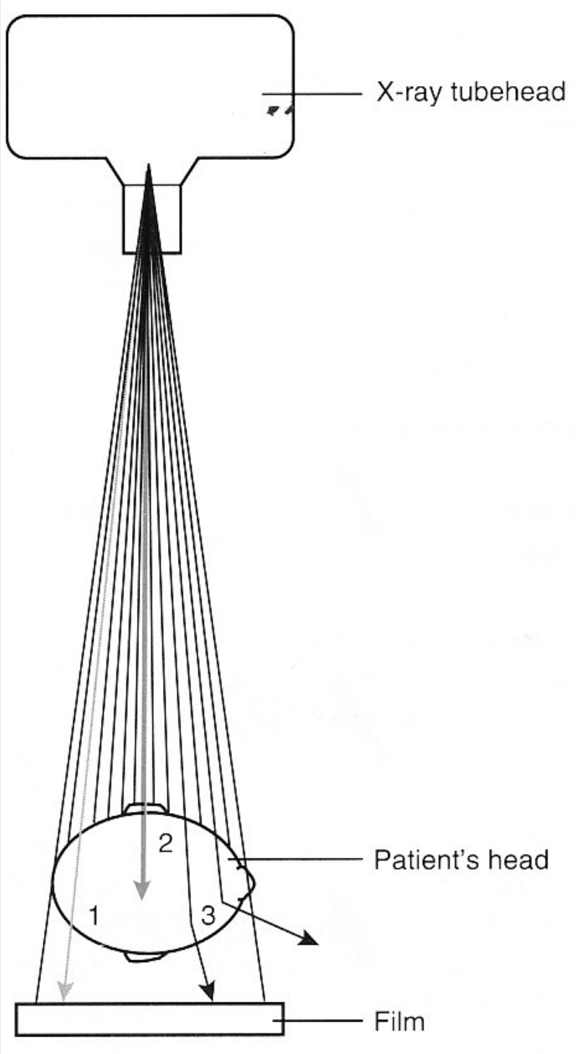
Contents

- X-ray & Tissue (eg. Patient) Interaction
- Direct and Indirect Damage
- Biological Effects of X-rays (& all other ionising radiation)
- Dosimetry
- Other Sources of Ionising Radiation (Patient Education)
- How to minimise radiation in clinic?

Patient Interactions with X-ray Photon

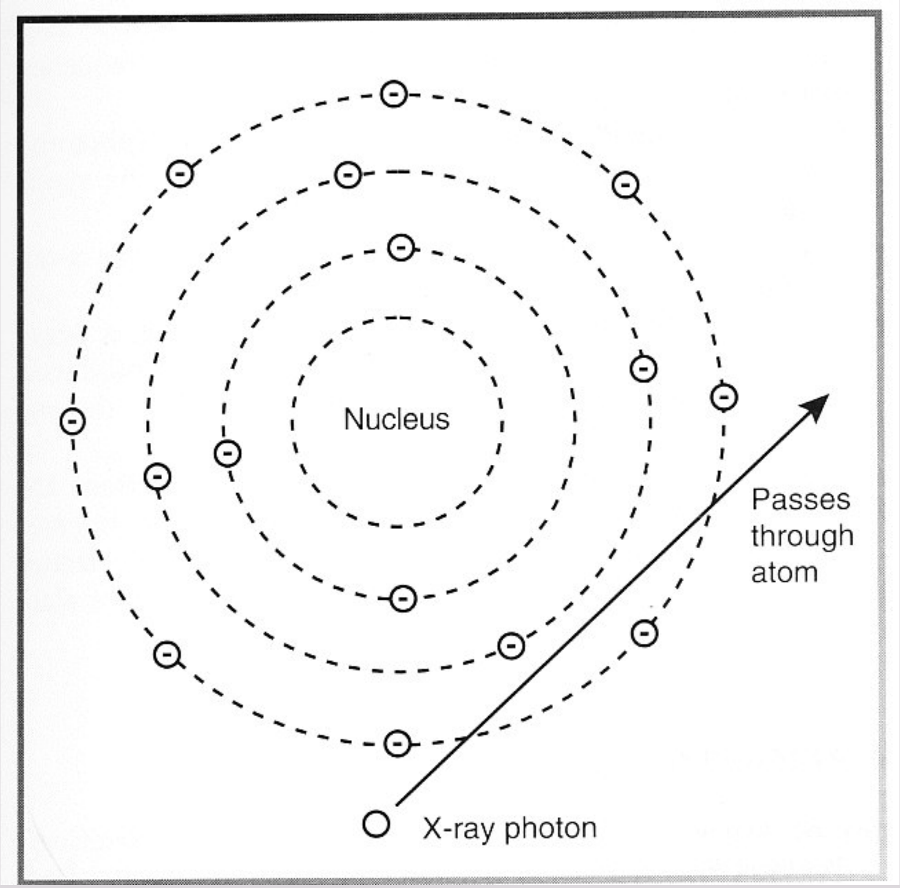
3 possible outcomes:

1. X-ray photons **pass through** patient without any interaction
2. X-ray photons are **completely absorbed** by patient
3. X-ray photons are **scattered** (coherent and incoherent)



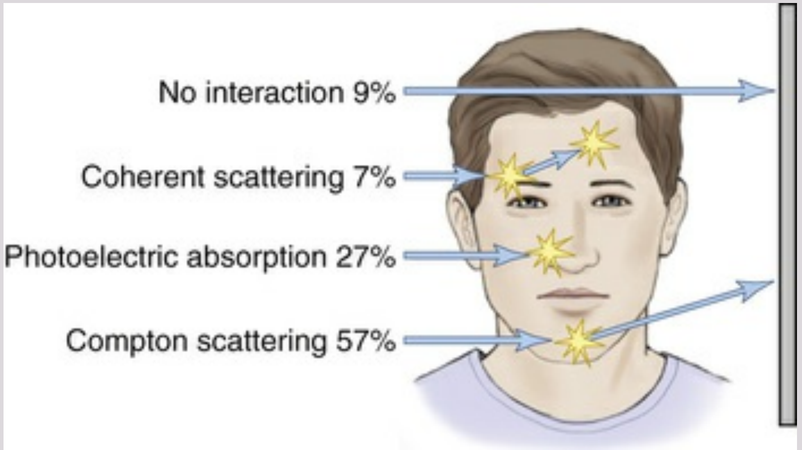
No Interaction with Tissues (Atoms)

- X-ray photon passes through atom unchanged
- These photons contact the film emulsion or receptor to produce an area of darker density
- ~9% of the primary photons



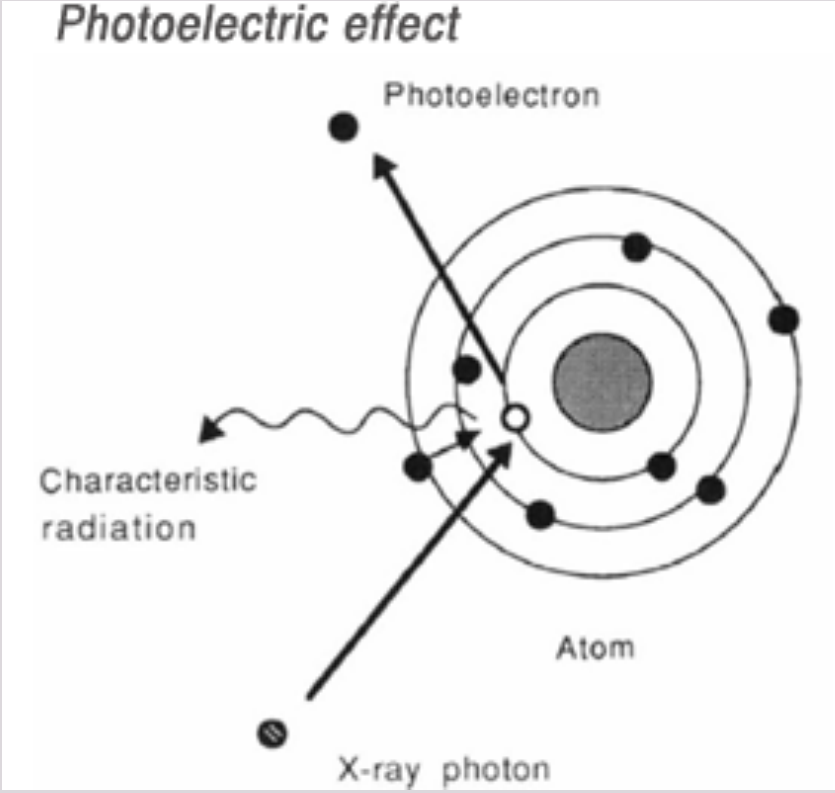
X-ray Absorption & Scattering

- As the x-ray beam passes through tissues, photons get absorbed or scattered by the tissues, resulting in decreased energy of the beam
- **Beam attenuation:** reduction of the x-ray beam intensity as it passes through tissues.
- In a dental x-ray beam, there are three means of beam attenuation:
  - **1) Photoelectric absorption (~27%)**
  - **2) Thompson/Coherent scattering (~7%)**
  - **3) Compton/Incoherent scattering (~57% of the primary beam)**



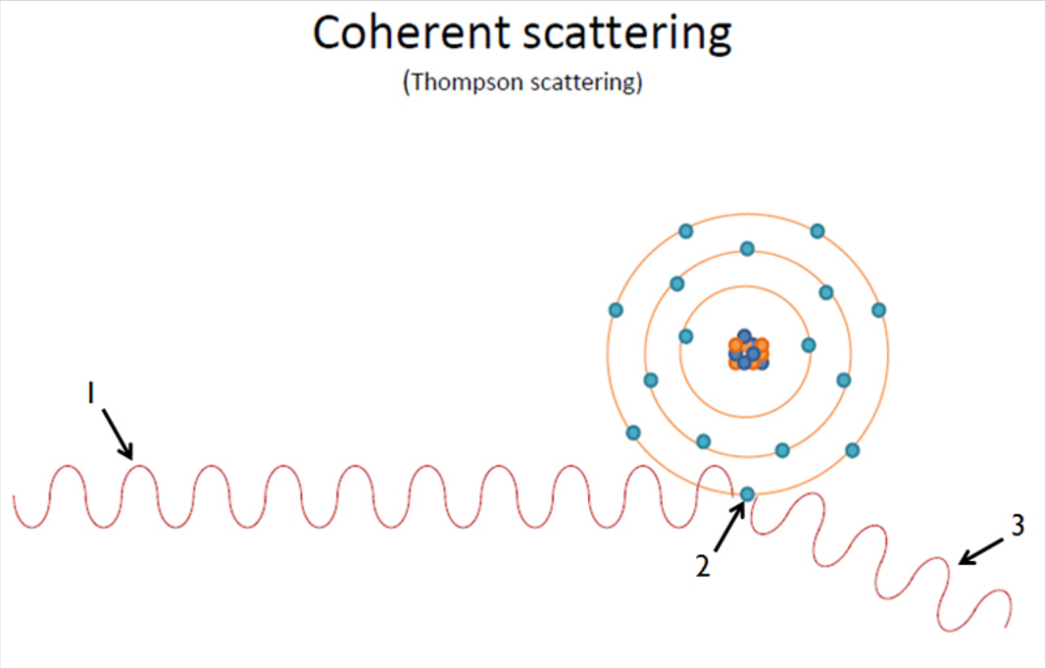
Photoelectric Absorption

- Incident photon interacts with an inner orbital electron of an atom in the patient.
  - Incident photon gives up all of its energy and ceases to exist.
  - Incident photon **ejects the electron** from its inner orbital, and it becomes a recoil electron (photoelectron).
- An atom that has participated in a photoelectric interaction is **ionized** as result of the loss of an electron.
- Electron deficiency is instantly filled, releasing characteristic radiation
- The characteristic photons generated are of such low energy that they are **absorbed within the patient** and do not fog the film.
- Primary contributor to diagnostic imaging.



Coherent Scattering / Thompson Scattering

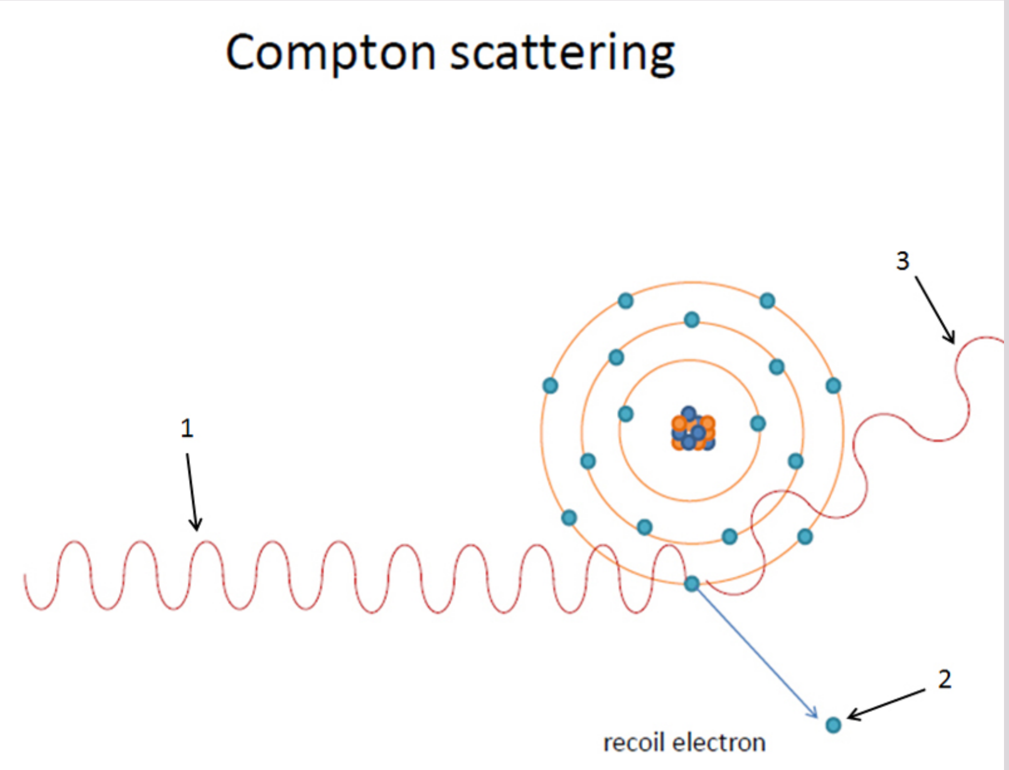
- Occurs minimally (7%)
- **Low-energy incident photon** (<10 keV) interacts with a whole atom *(patient's)*
- Atom becomes momentarily **excited** and incident photon ceases to exist.
- Excited atom returns to the ground state and generates another x-ray photon with the same frequency (energy) as the incident photon, **however** this secondary photon is emitted in a different direction than the path of the incident photon (scattered).



Coherent scattering contributes little to film fog (reduced image contrast)
** Too low energy*

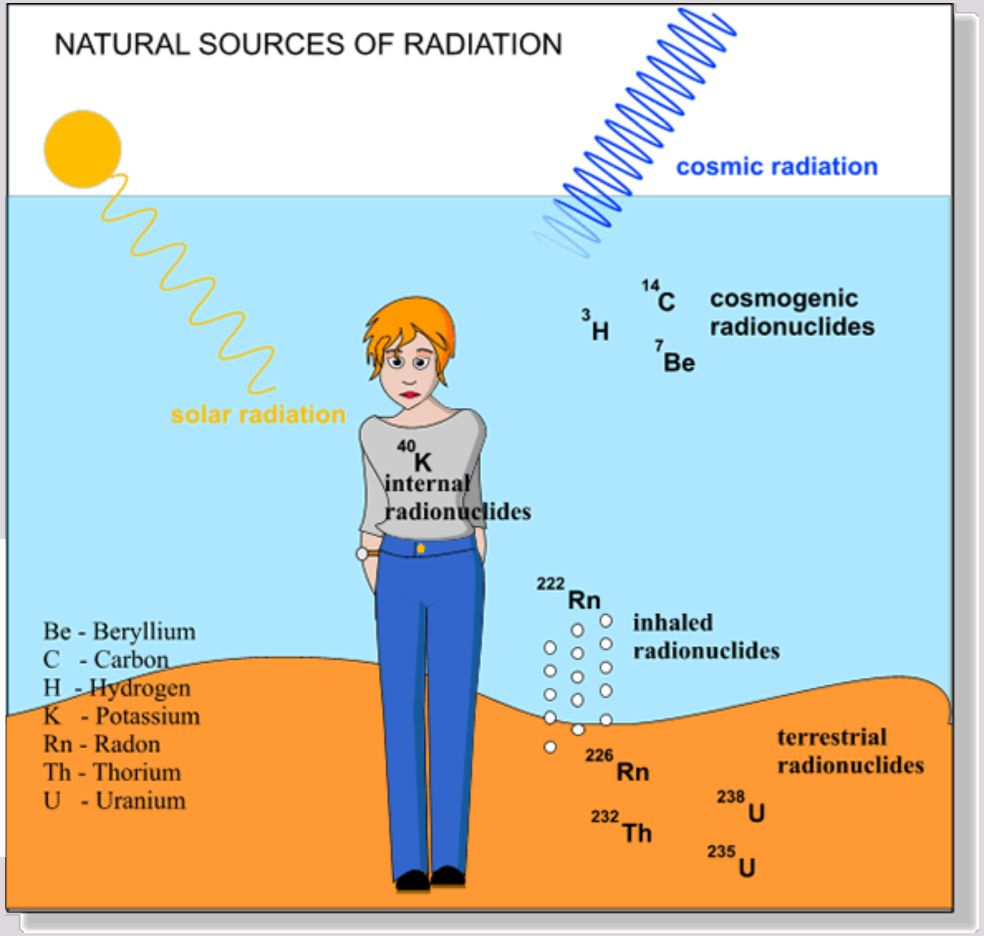
Compton Scattering

- About 57% of interactions in a dental x-ray beam exposure involve Compton scattering.
- Occurs when a photon interacts with an <u>outer orbital</u> electron.
- **Recoil electron**: collided electron receives kinetic energy and recoils from the point of impact.
- **Scattered photon**: the path of the incident photon is deflected by this interaction and is scattered in a new direction.
- As with photoelectric absorption, Compton scattering results in the **loss of an electron** and **ionization** of the absorbing atom.
- Scattered photons travel in all directions, carry no useful information and degrade the image by reducing contrast. (film fog) ☹



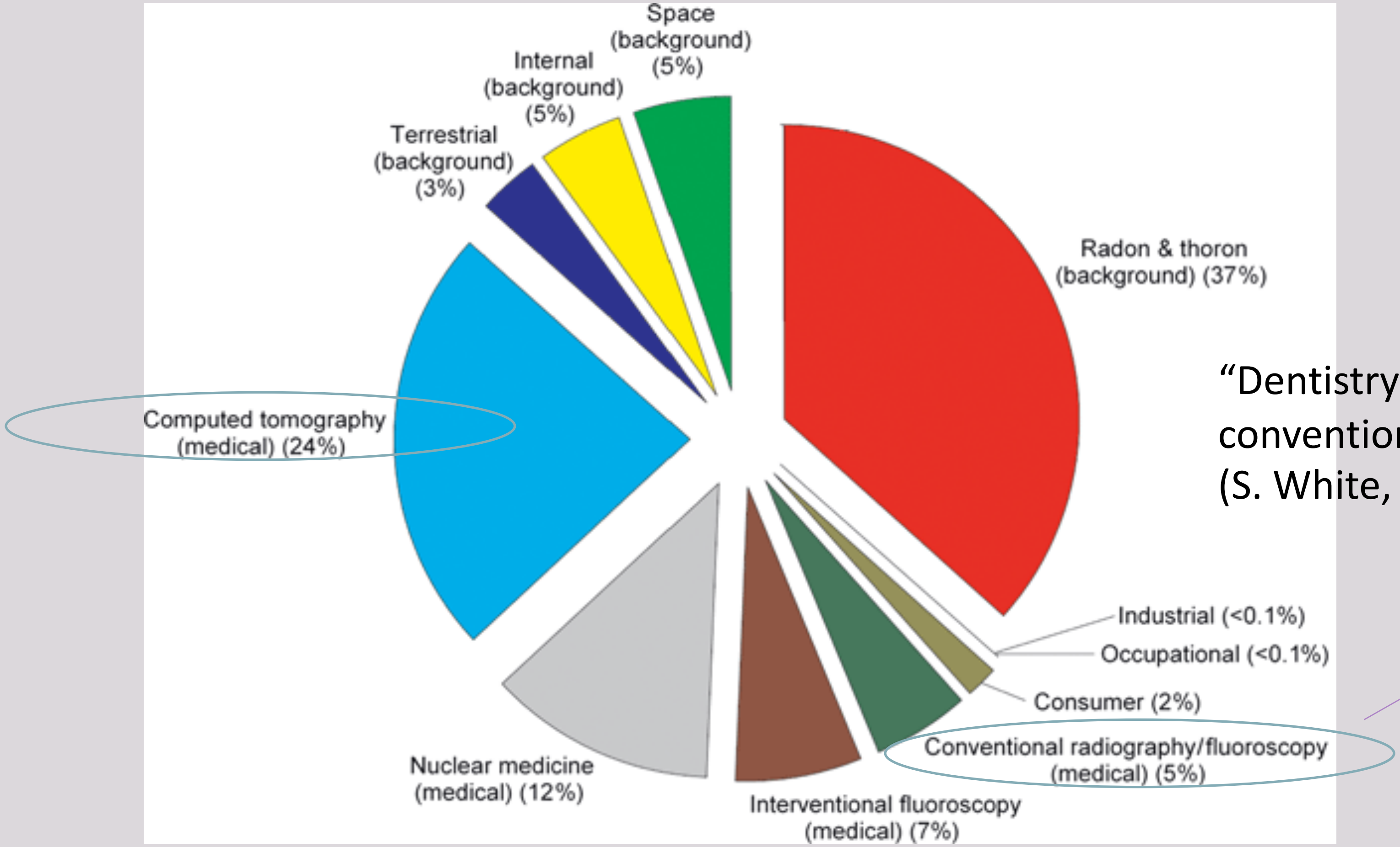
Sources of Ionizing Radiation

- Natural Source
  - Background radiation (cosmic, terrestrial, etc.)
  - **Approx. each person receives 2 mSv per year**
  - 1 day of background radiation = ~0.005mSv
- Artificial Source
  - **Medical & Dental**
  - Consumed products (potassium)
  - Occupational
  - Nuclear
- Natural >>> Artificial per year



http://4.bp.blogspot.com/-O_gmmpJVDfI/TaOT4rGGUYI/AAAAAAAAAC0/yCLtzvafE4k/s1600/ioniz.+radiation.gif

In the US study (2006)



"Dentistry contributes only **2.5% of this 5%** from conventional radiography/fluoroscopy category." (S. White, ADJ 2012)

Percent contributions of various sources of exposure to the total effective dose in the US population for 2006.

Radiation Dose Quantities and Units

Units for measuring quantities of radiation

QUANTITY	SI UNIT	TRADITIONAL UNIT	CONVERSION
Exposure	Coulomb/kilogram (C/kg)	Roentgen (R)	1 C/kg = 3876 R
Absorbed dose	Gray (Gy)	rad	1 Gy = 100 rad
Equivalent dose	Sievert (Sv)	rem	1 Sv = 100 rem
Effective dose	Sievert (Sv)	—	—
Radioactivity	Becquerel (Bq)	Curie (Ci)	1 Bq = 2.7×10^{-11} Ci

Account for biologic effects

1 Sv = 1000 mSv (milli)

1 mSv = 1000 *u*Sv (micro)

Radiation Dose Quantities and Units

- **Absorbed dose:** radiation (in Joules) received by **patient** (in kg)
- **Equivalent dose**: radiation absorbed by an organ
  - It is used to compare biologic effects of radiation on different types of tissue or organ
  - Unit is the **Sievert (Sv)**
- **Effective dose**: radiation absorbed by an organ, affecting the **entire body**.
  - Effective dose = equivalent dose x tissue weighting factors (W_T) according to ICRP 2007
    - Tissues are grouped into:
      - high risk ($W_T = 0.12$),
      - moderate risk ($W_T = 0.4\text{-}0.8$) &
      - low risk ($W_T = 0.01$)
  - Example) 100mSv to skin (=low risk tissue, $W_T = 0.01$) = 1mSv to body
  - It is used to estimate the risk in humans.
  - Unit is the **Sievert (Sv)**

Tissue Weighting Factors & Radiosensitivity

Organs/tissue	2007 W_T
Gonads	0.08
Bone marrow (red)	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	0.04
Breast	0.12
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Bone surface	0.01
Brain	0.01
Salivary glands	0.01
Remainder	0.12*

ICRP 2007 Tissue Weighting Factors

BLOOD CELLS REPRODUCTIVE CELLS YOUNG BONE	RADIOSENSITIVE
SKIN GLANDS	RADIORESPONSIVE
MUSCLE NERVE MATURE BONE	RADIORESISTANT

Figure List of types of cells in order of sensitivity to x rays.

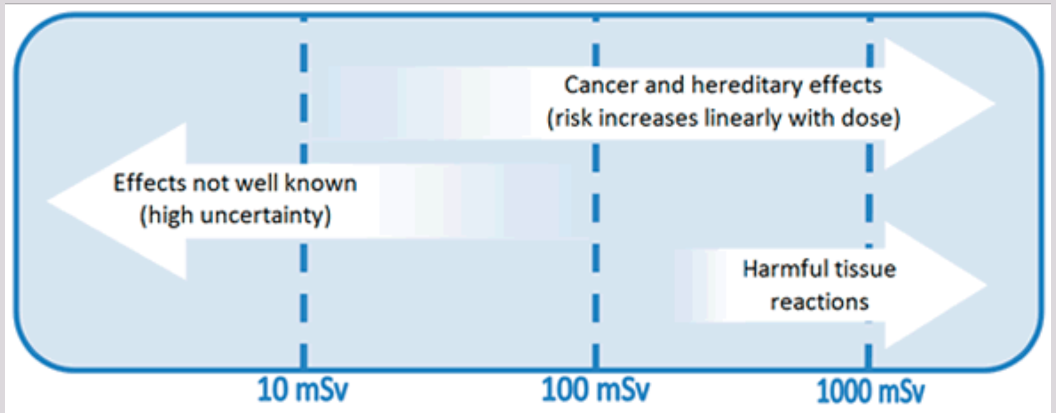
Sensitive cells are more susceptible to damage:

- Cells with a high mitotic activity
- Cells with a high metabolic activity
- Pluripotential (primitive) cells
- Eg. Children

TABLE Effective dose from diagnostic x-ray examinations (mSv)

Barium enema*	4.06
Upper gastrointestinal tract*	2.44
Computer tomography*	
Head and body	1.11
Abdomen*	0.56
Skull*	0.22
Chest*	0.08
Full-mouth survey†	
20 films, round collimation	0.084
Full-mouth survey†	
20 films, rectangular collimation	0.033
Interproximal survey†	
4 films, round collimation	0.017
Panoramic tomography†	0.007
Interproximal survey	
4 films, rectangular collimation	0.007

*From National Council on Radiation Protection and Measurements: *NCRP Reports* 100, Bethesda, MD, 1989.
†From White SC: *Dentomaxillofac Radiol* 21:118-126, 1992.



Intra-oral x-ray (bitewing / PA) = ~4μSv (0.004mSv)
→ Comparable to daily Australian background radiation **(4-5μSv at sea level)**

OPG ~ 10μSv
Ceph view ~5μSv
CBCT varies from 5 to 1073 μSv (depends on many factors)

Annual Dose Limits (ARPANSA, 2020)

- Allowable annual dose limits in Dentistry (effective dosage)
  - Public: 1mSv / year (averaged over 5 years)
    - Special clause: Can exceed in special circumstances (eg. Radiotherapy) as long as it is 1mSv averaged over 5 years
  - **Dental workers**: 20mSv / year (averaged over 5 years)
    - <u>No more than 50mSv in any one year</u>
    - *If under 18 but over 16, limit is 6 mSv per year*

Ionising Radiation & Cell Damage

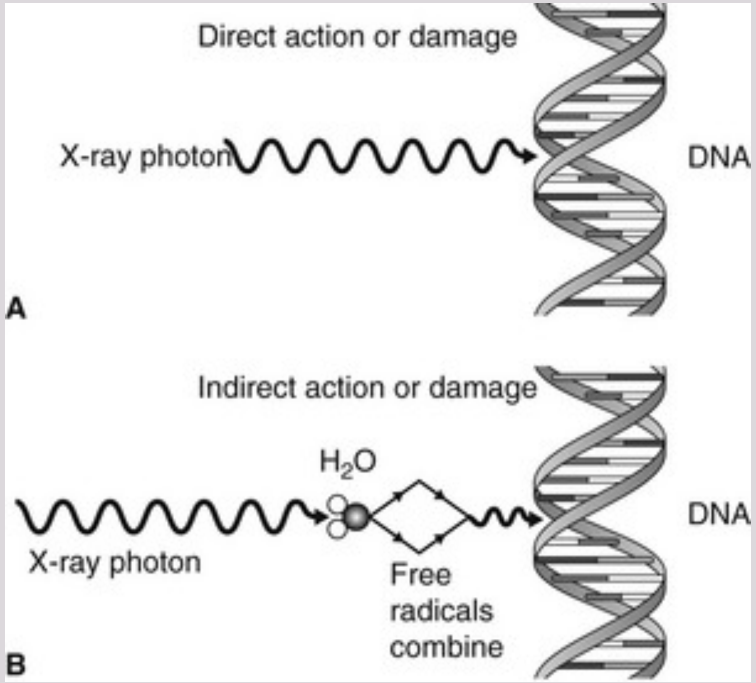
1. It may pass directly through the cell <u>without</u> causing any damage
2. It may interact with cells and cause **DAMAGE**

   Cells can either:

   a) Repair itself
   b) Mutate, or
   c) Die

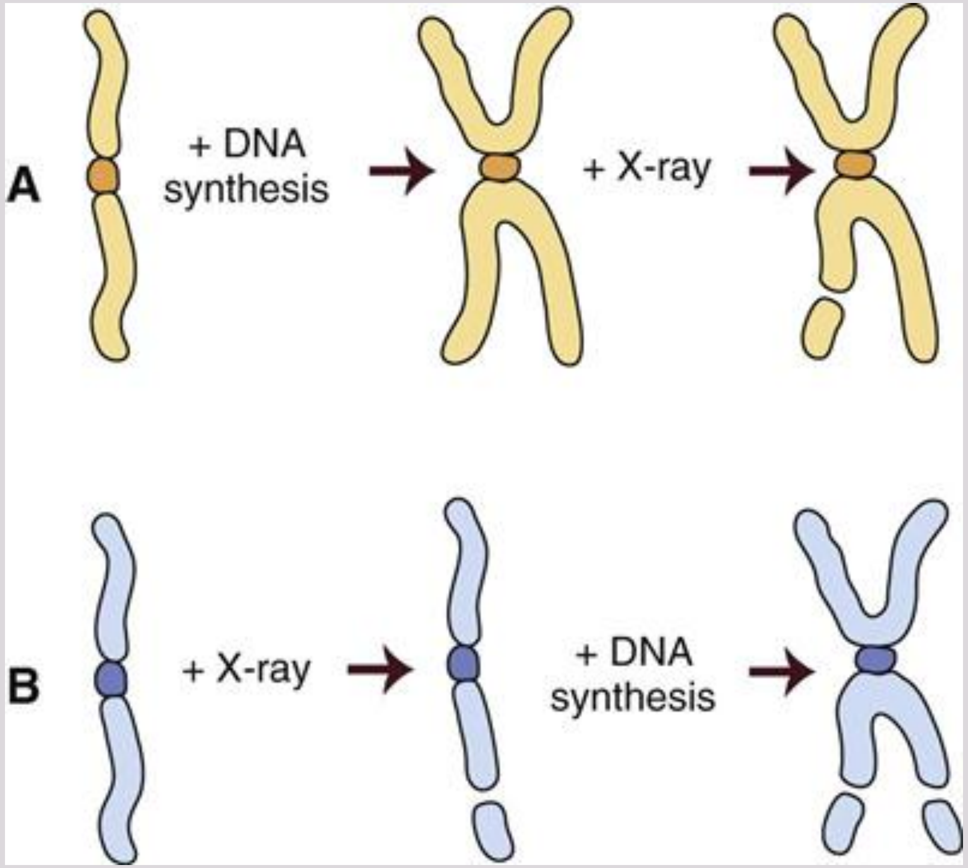
Ionising Radiation & Cell Damage

- Damage to cell walls, mitochondria, mRNA, nuclear membrane, **DNA**, etc.
- **DIRECT** damage:
  - 25%-30% of total damage
  - Direct damage to atoms / molecules eg. DNA
- **INDIRECT** damage:
  - 70%-75% of total damage
  - Radiolysis of water (in cells) → release of toxic **free radicals**
- **Changes to DNA result in:**
  - Changes in genetically sensitive information
  - Changes in structural protein synthesis
  - Changes in enzyme structure and function and enzyme substrate

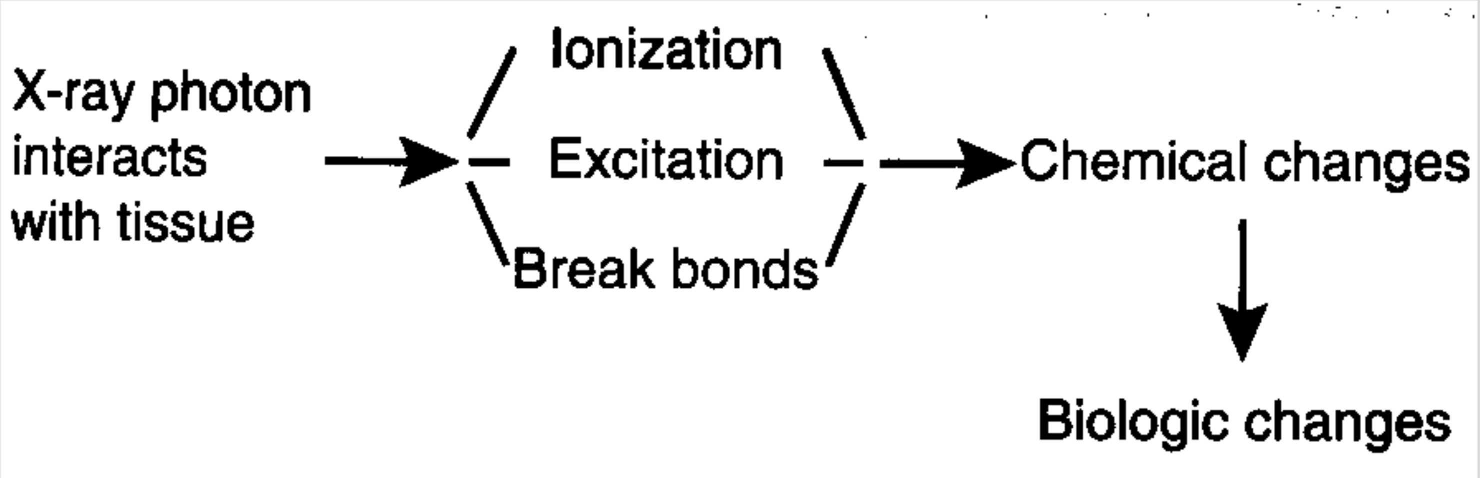


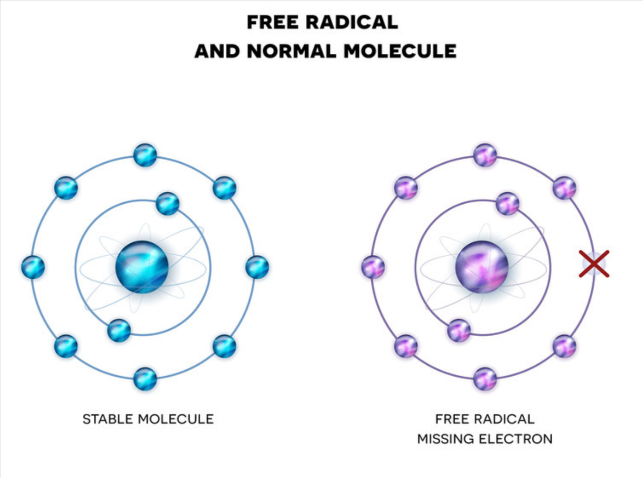
DNA Damage

- When only one strand is damaged **(single strand defects/breaks)**, the other strand can be used as a template to guide the correction of the damaged strand. → *repair*
- **Double strand breaks** are hard to repair and often result in cell death. ☹



Direct Damage





- When an atom becomes ionized, it become unstable = free radicals, which are highly reactive and short-lived
- Free radicals then quickly stabilize by dissociation (breaking apart) or cross-linking → Structurally and functionally different molecules and a consequent biologic change.

Dissociation & Cross-linking

Molecule (RH) becomes Free Radical R*

Free radical production:

$$RH + \text{x-radiation} \rightarrow R^{\bullet} + H^{+} + e^{-}$$

Free radical fates:

Dissociation:

Breaking apart

$$R^{\bullet} \rightarrow X + Y^{\bullet}$$

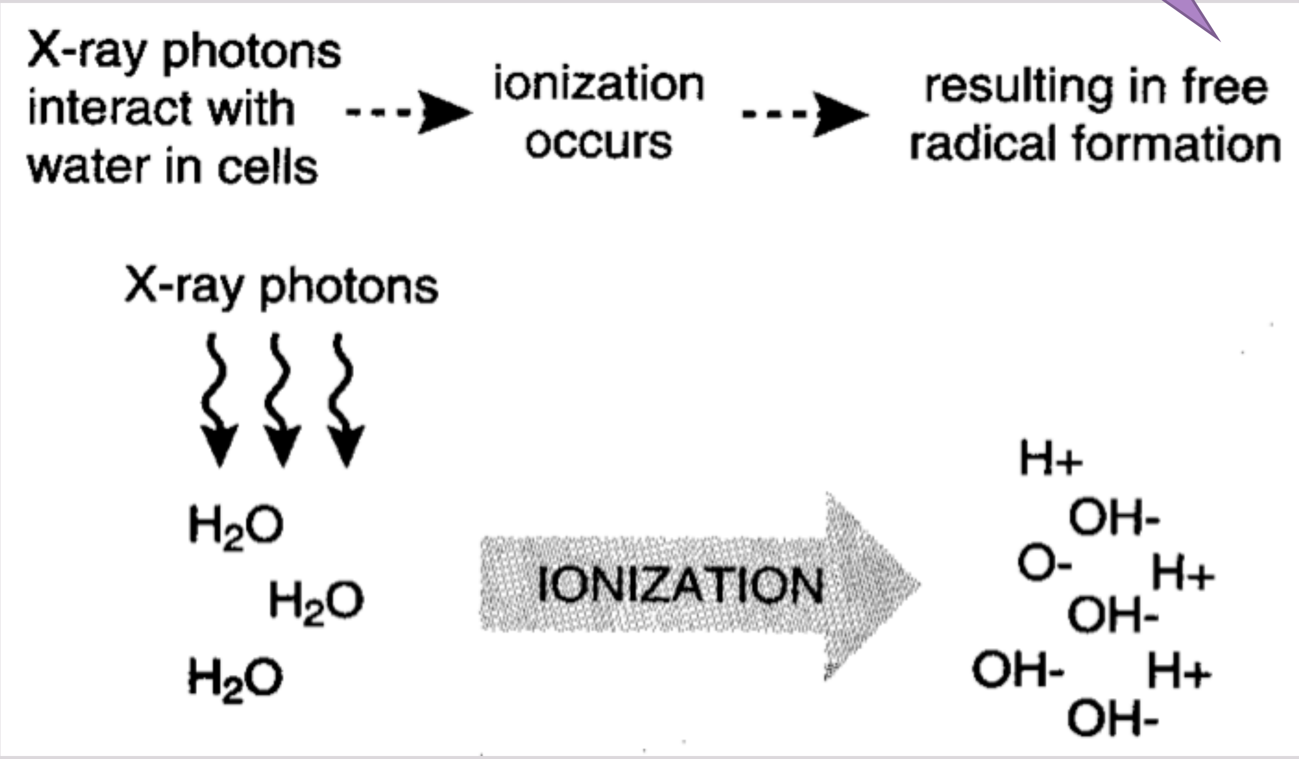
Cross-linking:

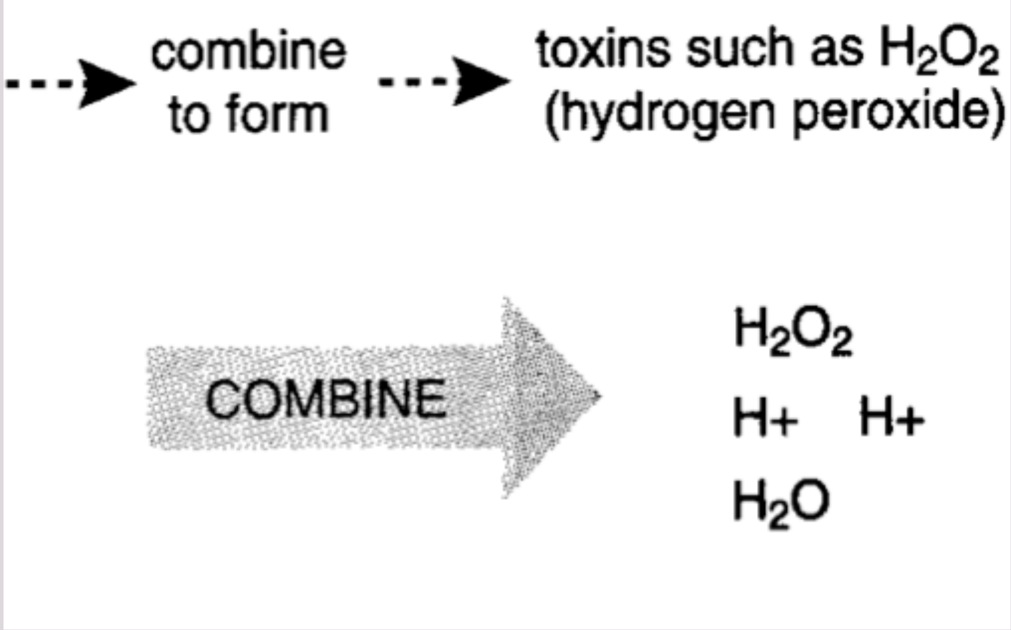
$$R^{\bullet} + S^{\bullet} \rightarrow RS$$

Joining of two molecules

Formation of structurally and functionally different molecules

Indirect Damage





~75% of cell is water

Oxidative damage to cells

Further toxic damage to cells

Biological Effects of Ionizing Radiation

Stochastic and Non-stochastic Effects

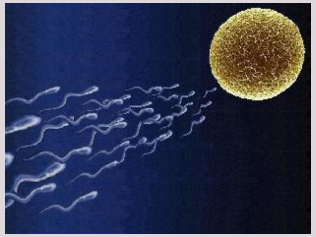
1. Stochastic effects on somatic tissues
2. Stochastic effects on genetic tissues
3. Non-stochastic effects / Deterministic effects (always on somatic tissues)

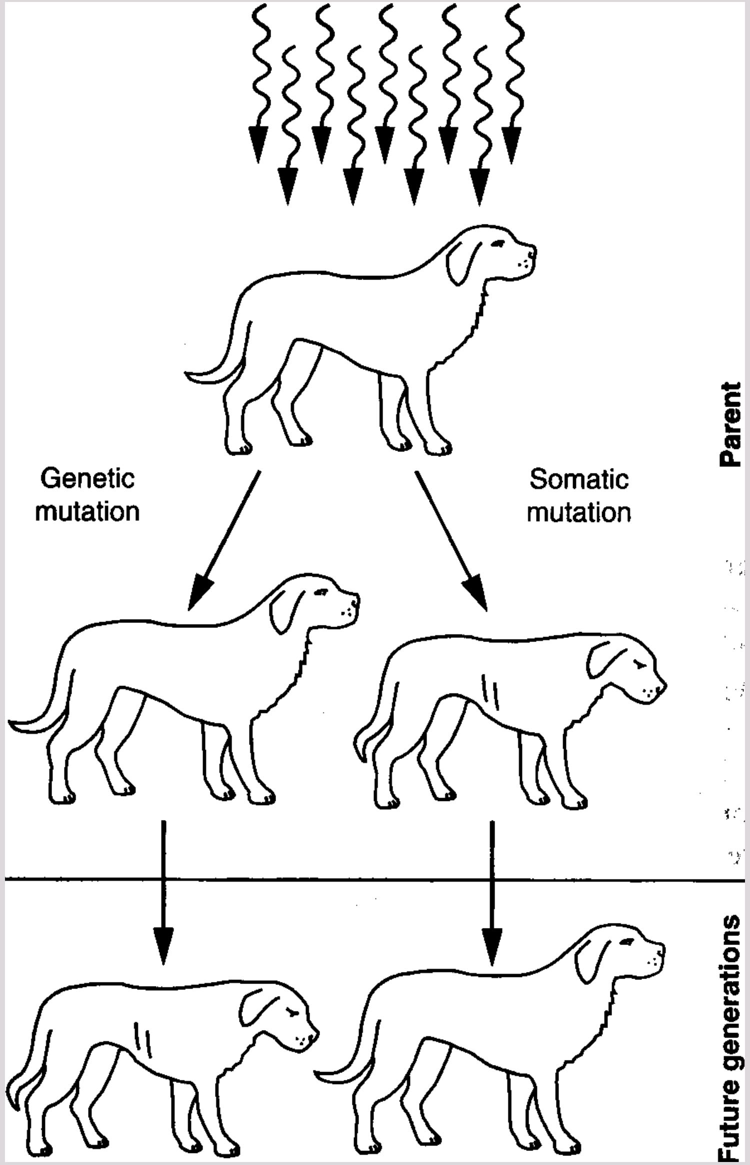
1. Somatic Stochastic Effect

- *'Somatic' = body cells*
- Probability of the change occurring *(not severity)* of which, is greater for a higher radiation dose
- **No safe dose (= no threshold)**
- Therefore, every exposure has the <u>possibility</u> of producing a stochastic effect
- **Cancer**

2. Genetic Stochastic Effect

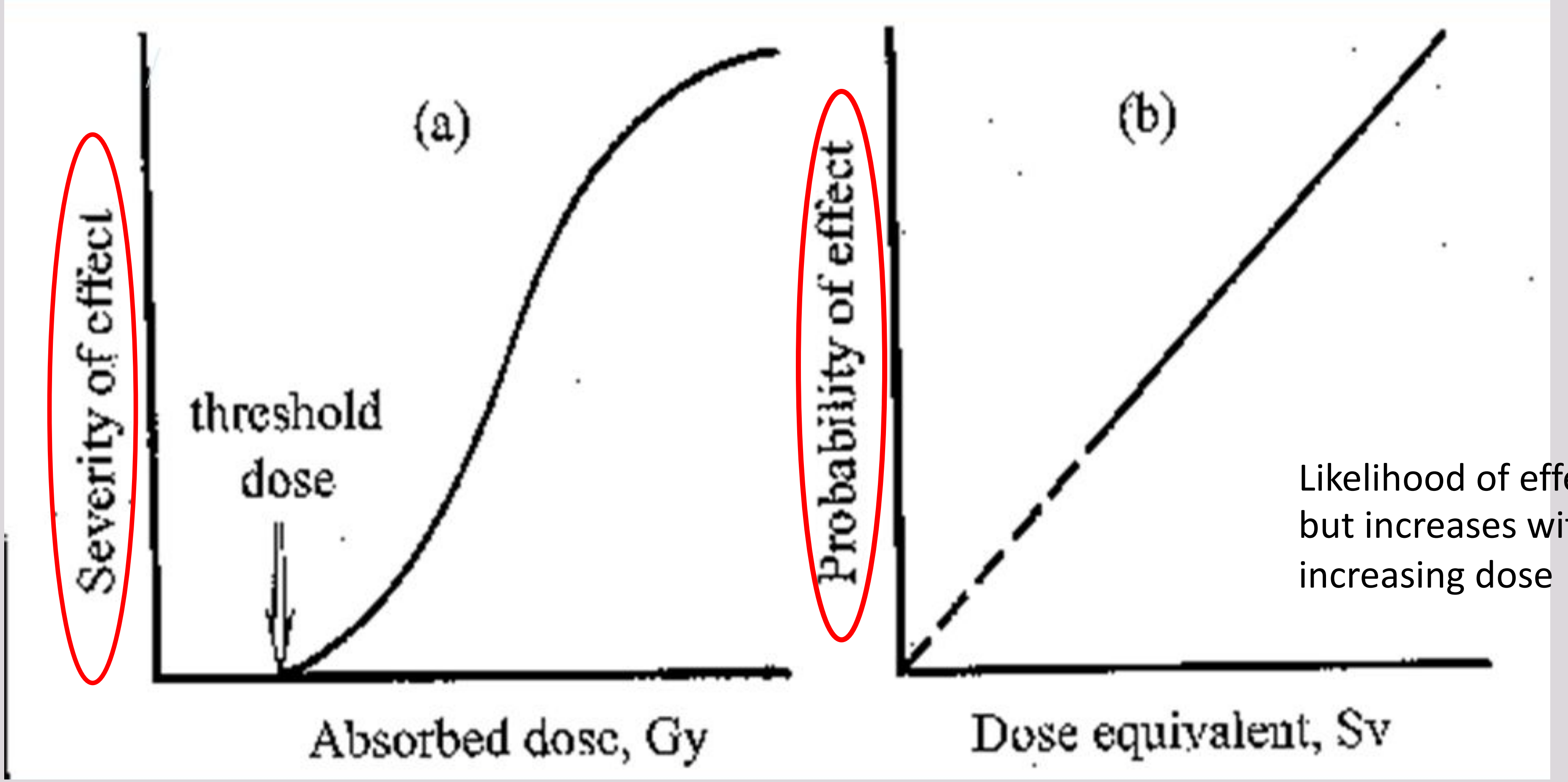
- **Reproductive organs**
- Damage to gonad / reproductive cells can result in congenital abnormality of the offspring
- **No safe threshold**
- Risk of inducing a heritable mutation is estimated to be about 2 in 100,000 per mSv





3. Non-stochastic / Deterministic Effect

- **Somatic tissues**
- **Severity** of the change is **proportional to dose**
- There is a **threshold dose** below which no effect is seen
- Biological Changes: loss of somatic function (> 1Gy ➔ not seen in dental)
  - Xerostomia, loss of taste, skin reddening, hair loss, cataract formation
  - Severe = death



Likelihood of effect is random, but increases with with increasing dose

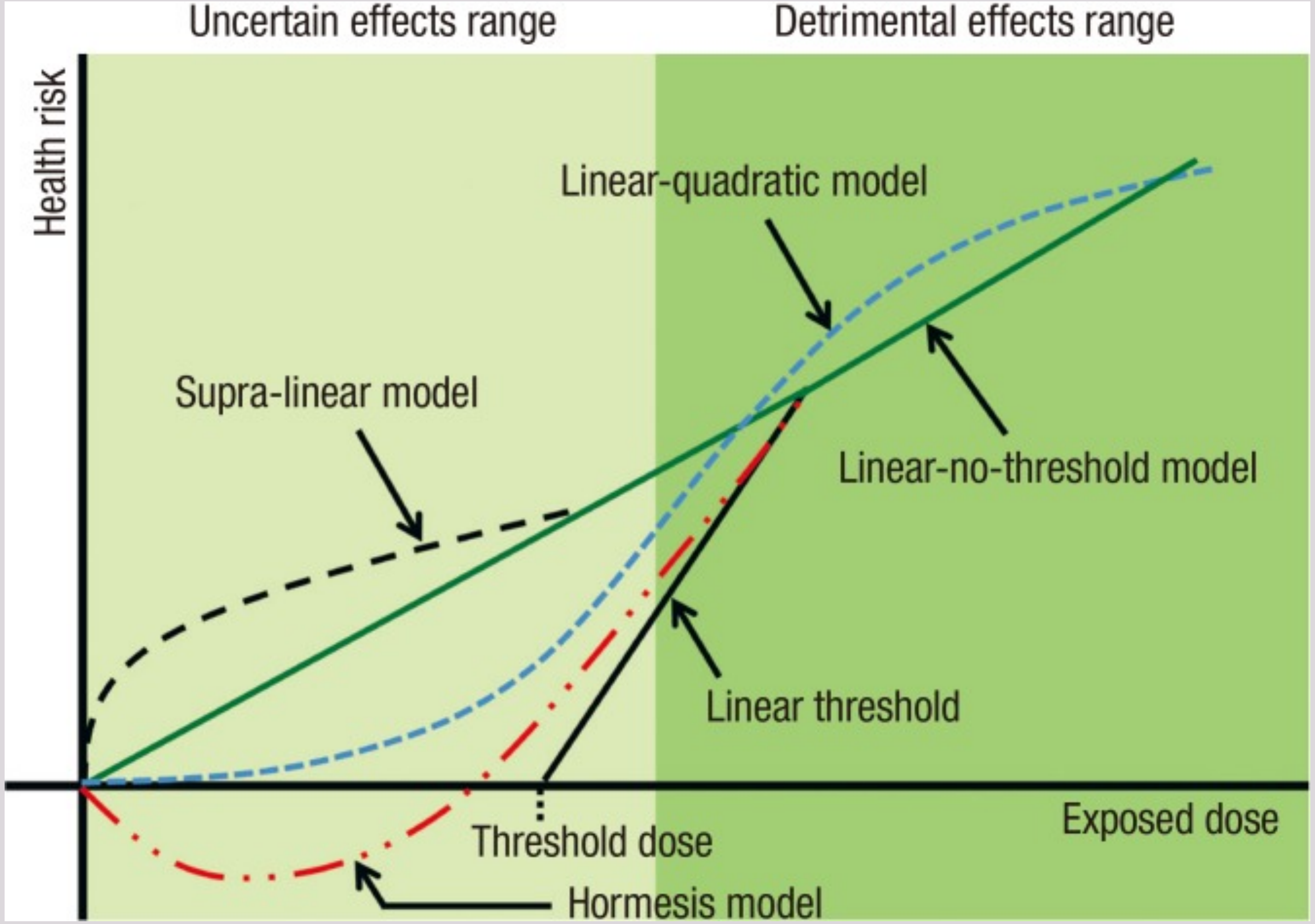
Non-stochastic

Stochastic (linear type)

TABLE 2.1

Comparison of Stochastic and Deterministic Effects of Radiation

	Stochastic Effects	Deterministic Effects
Caused by	Sublethal DNA damage	Cell killing
Threshold dose	No	Yes
	There is no minimum threshold dose. Effect can be caused by any dose of radiation	Effect occurs only when the threshold dose is exceeded
Severity of clinical effects and dose	Severity of clinical effects is independent of dose; all-or-none response—an individual either manifests effect or does not	Severity of clinical effects is proportional to dose; the higher the dose, the more severe the effect
Relationship between dose and effect	Frequency of effect proportional to dose; the higher the dose, the higher the risk of manifesting the effect	Probability of effect independent of dose; most individuals manifest effect when threshold dose is exceeded
Caused by doses used in diagnostic radiology	Yes	No
Examples	Radiation-induced cancer	Osteoradionecrosis
	Heritable effects	Radiation-induced cataract formation
	Radiation-induced skin cancer	Radiation-induced skin burns


Uncertain effects range
Detrimental effects range
Health risk
Linear-quadratic model
Supra-linear model
Linear-no-threshold model
Linear threshold
Exposed dose
Threshold dose
Hormesis model

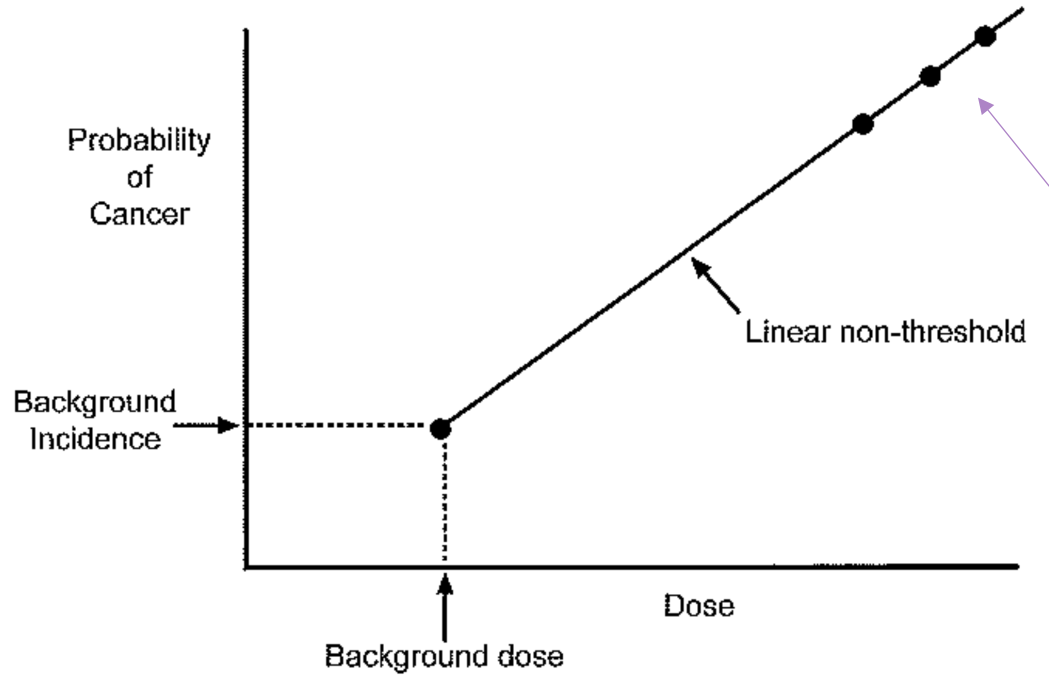


Fig 2. The linear non-threshold hypothesis posits that the risk of exposure to radiation, cancer, is linearly related to exposure dose, even to the smallest exposures above background levels. The solid dots on the upper right side of the schematic graph indicate that at higher doses, above those used in diagnostic imaging, there is a known linear relationship between excess cancer rates and dose.

3 accidents (>100mSv)

1. Fukushima Daiichi nuclear accident
2. Chernobyl
   ➔ *On-site workers received ~6 Sv (= 6000mSv), died in a month*
3. Three Mile Island (TMI) nuclear power plant accident

Cumulative Effect of X-ray

There is evidence that dose accumulated over a long period carries less risk than the same dose received over a short period.

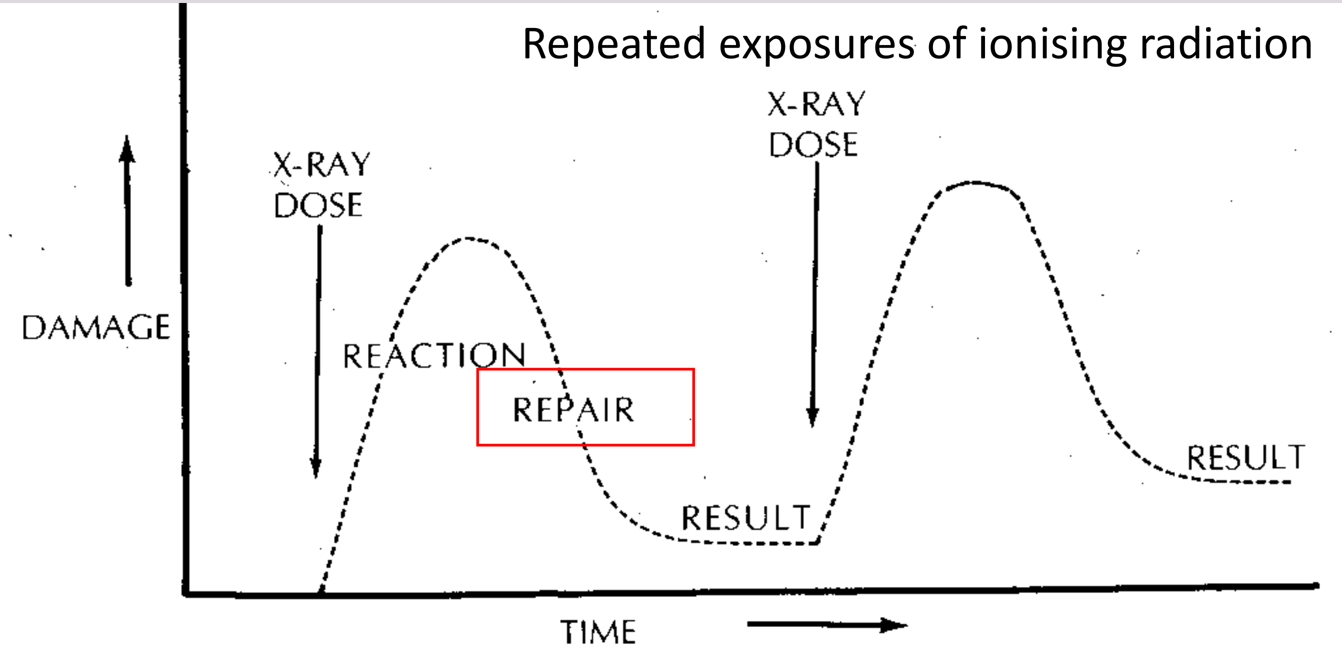


Figure Diagrammatic representation of cumulative effect of x-radiation.

This applies to **radiotherapy**. Typically, 2 Gy is delivered daily for a weekly exposure of 10 Gy. The radiotherapy course continues for 6 to 7 weeks until a total of 60 to 70 Gy is administered.

ALARA / ALARP / ALADA

- **A**s
- **L**ow
- **A**s
- **R**easonably
- **A**chievable

ALWAYS!

Principle of radioprotection stating that whenever ionizing radiation has to be applied to humans, animals or materials exposure should be as **low as reasonably or diagnostically achievable / practicable / acceptable** . It is fundamental to the **principles** of radiation protection.

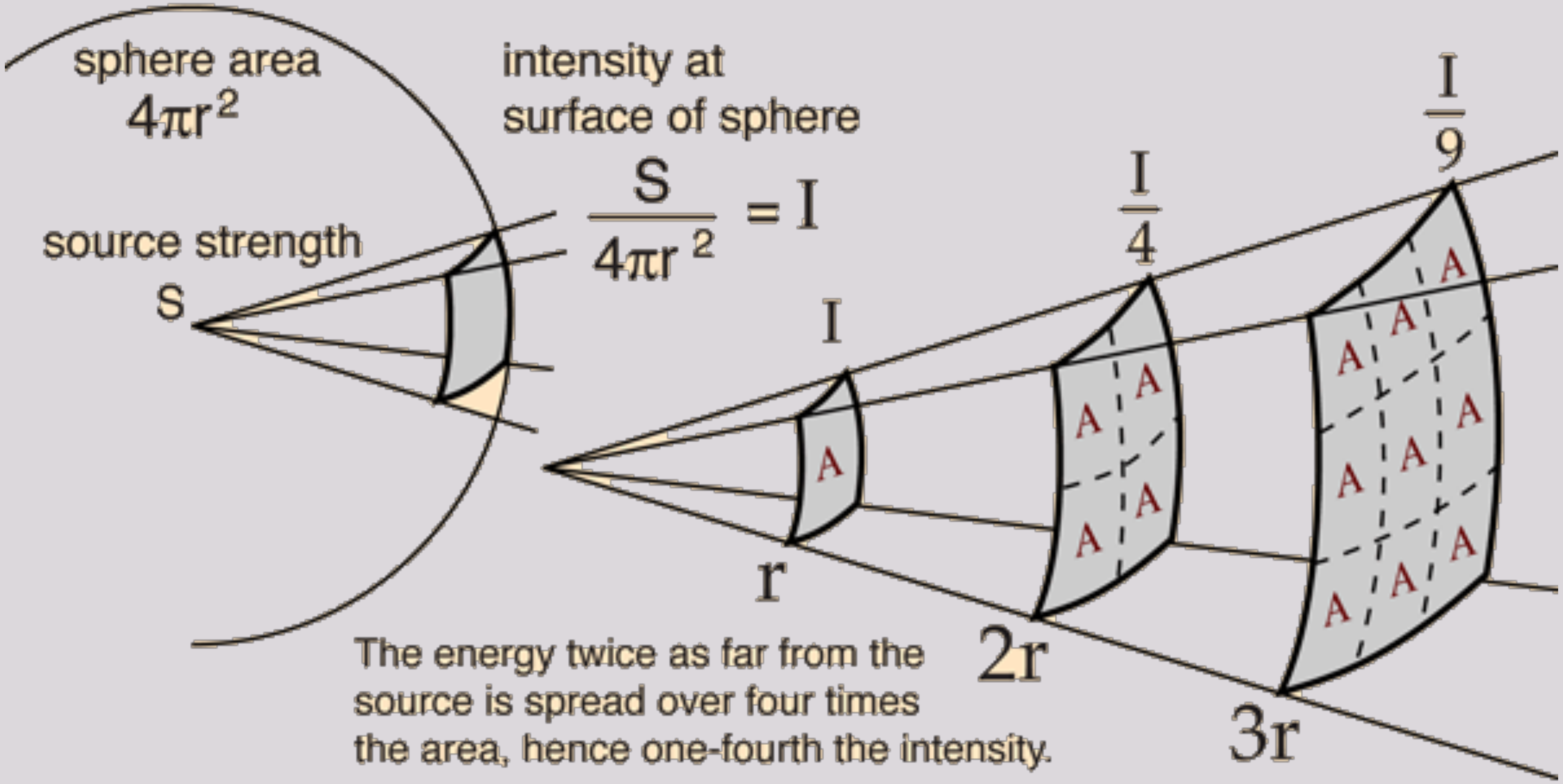
Minimising Exposure for Patient

- Only take radiographs when necessary
- Adequate filtration
- Adequate collimation
- Constant potential rectification
- Lead apron and thyroid shield *
- Fastest film or intensifying screens (in Analogue system)
- Use digital imaging
- Minimize technical errors
- Well-maintained equipment

Minimising Exposure for Dental Staff

- Avoid the primary beam
  - **Increase Distance (inverse square law), at least 2m**
- Shielding
- Position
- Most of the measures already mentioned to protect the patient

Inverse square law



the intensity of an *X-ray* beam at a given point is inversely proportional to the square of the distance from the source of *radiation*.

Dentist's Responsibilities

- **Patient Care**
- **Determination of the clinical NEED to take X-ray**
- **Radiography and dose determination**
- Processing technique (analogue films)
- Maintenance of radiographic records
- Maintenance of radiographic equipment
- <u>**Interpretation & Diagnosis** ***(get help from DMF Radiologist)***</u>
  - ***All 3D imaging legally requires radiologist's report in WA***

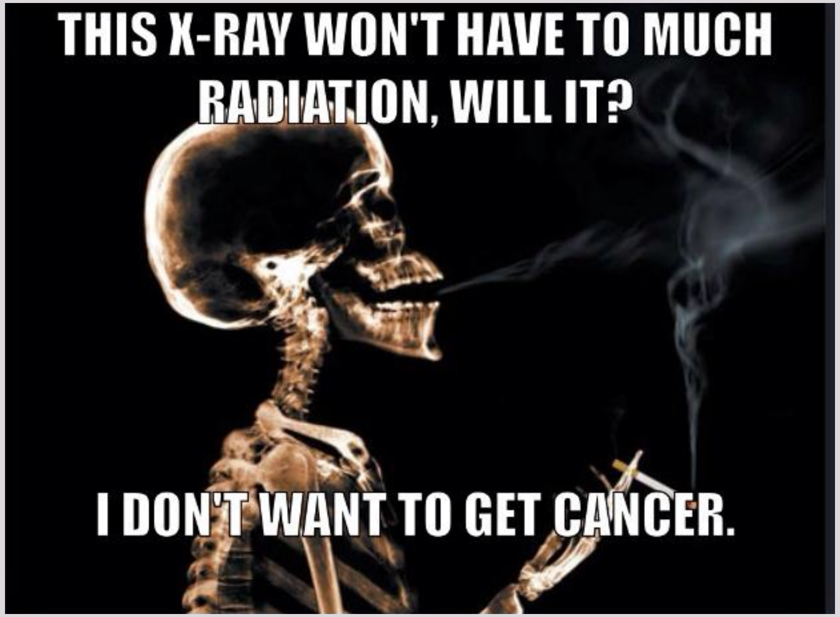
Irradiating Pregnant Women

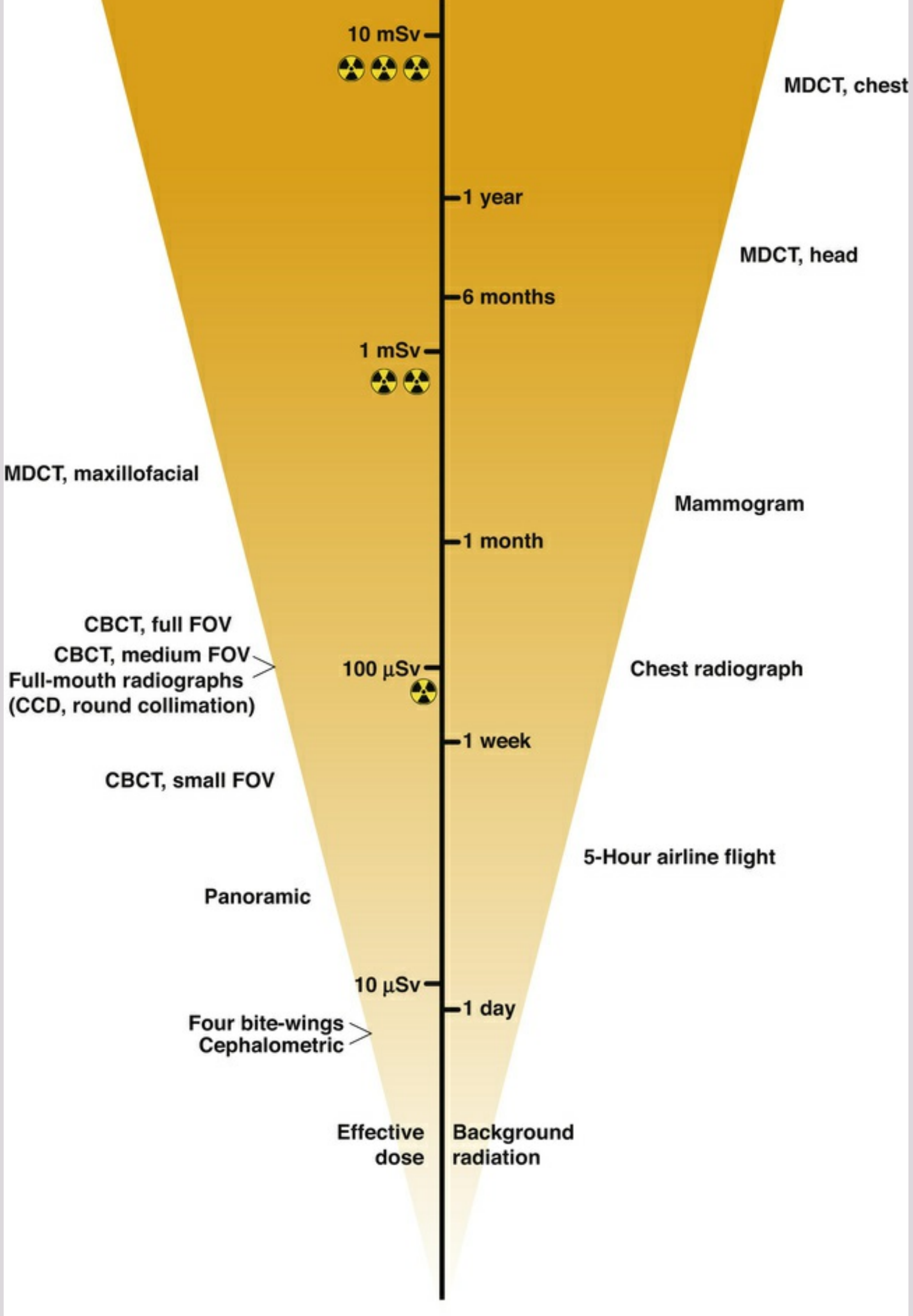
Probability of Child’s Death from Diagnostic X-ray (dental or medical) VS. Probability of Child’s Death from Maternal Smoking

→ 10 x annual patient radiation dose <<<<< 1 cig/day maternal smoking

Comparative risks during pregnancy*

Irradiation during gestation		
10 mSv	Death from childhood leukemia	1 in 3333
10 mSv	Death from other childhood cancer	1 in 3571
Maternal smoking		
1 pack or more/day	Infant death	1 in 3
Maternal alcohol consumption		
2 to 4 drinks/day	Signs of fetal alcohol syndrome	1 in 10
Major malformation at delivery		2.75%


THIS X-RAY WON'T HAVE TO MUCH RADIATION, WILL IT?
I DON'T WANT TO GET CANCER.


10 mSv
MDCT, chest
1 year
MDCT, head
6 months
1 mSv
MDCT, maxillofacial
Mammogram
1 month
CBCT, full FOV
CBCT, medium FOV
Full-mouth radiographs
(CCD, round collimation)
100 µSv
Chest radiograph
1 week
CBCT, small FOV
5-Hour airline flight
Panoramic
10 µSv
1 day
Four bite-wings
Cephalometric
Effective dose
Background radiation