# Presenter Disclosure

- **Faculty Member:**

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Adjunct Professor, Physics and Astronomy

- **Relationships with commercial interests:**
  - None to report

# Reference materials used for this presentation


- International Commission on Radiological Protection (ICRP) publications: **ICRP 60 (1991): Annals of the ICRP, Vol 2, No 1-3**. (ICRP 60, Pergamon Press, Oxford)
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# Radiation Safety

- Ingvar Fife

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# Radiation Safety

- Part I

  Radiation Protection Legislation and Principles of Justification, Optimization and Dose Limitation

- Part II

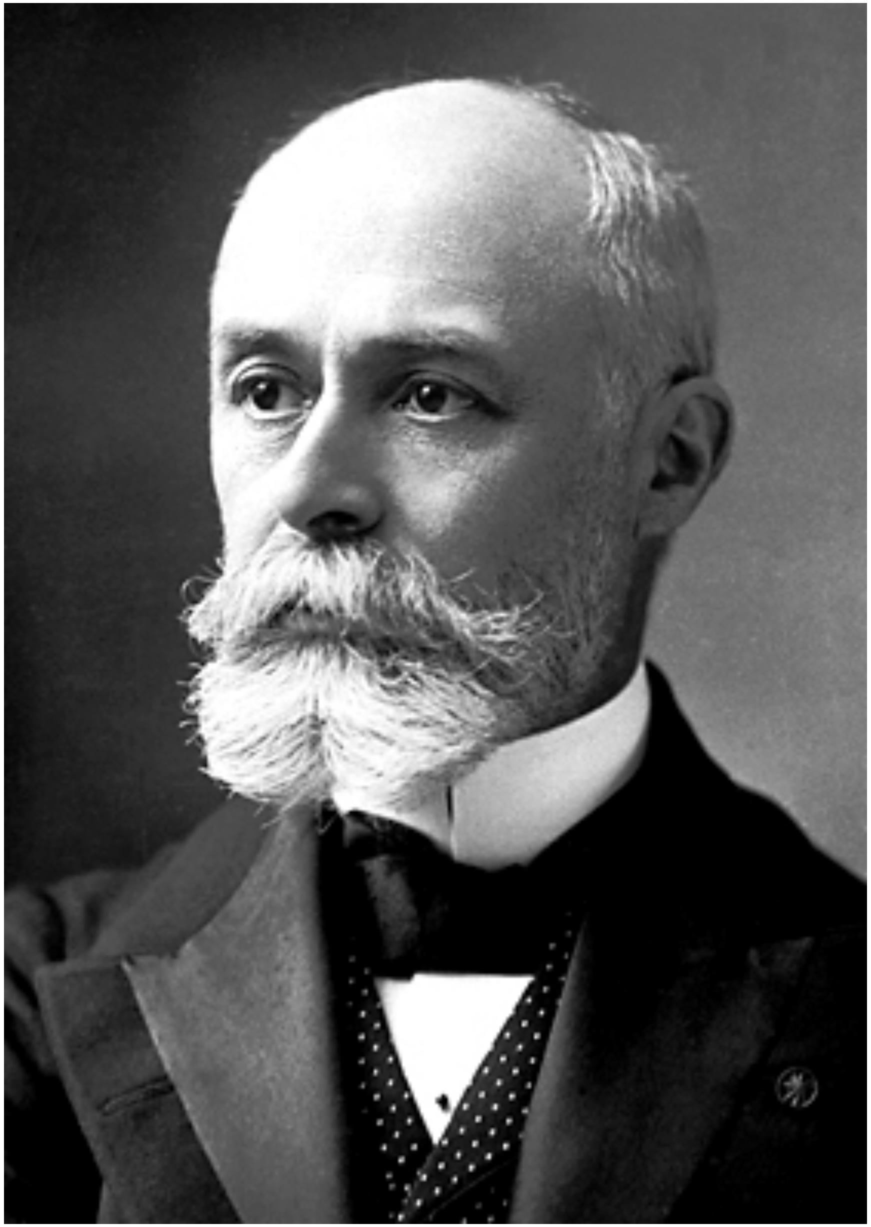
  Dose quantities and units

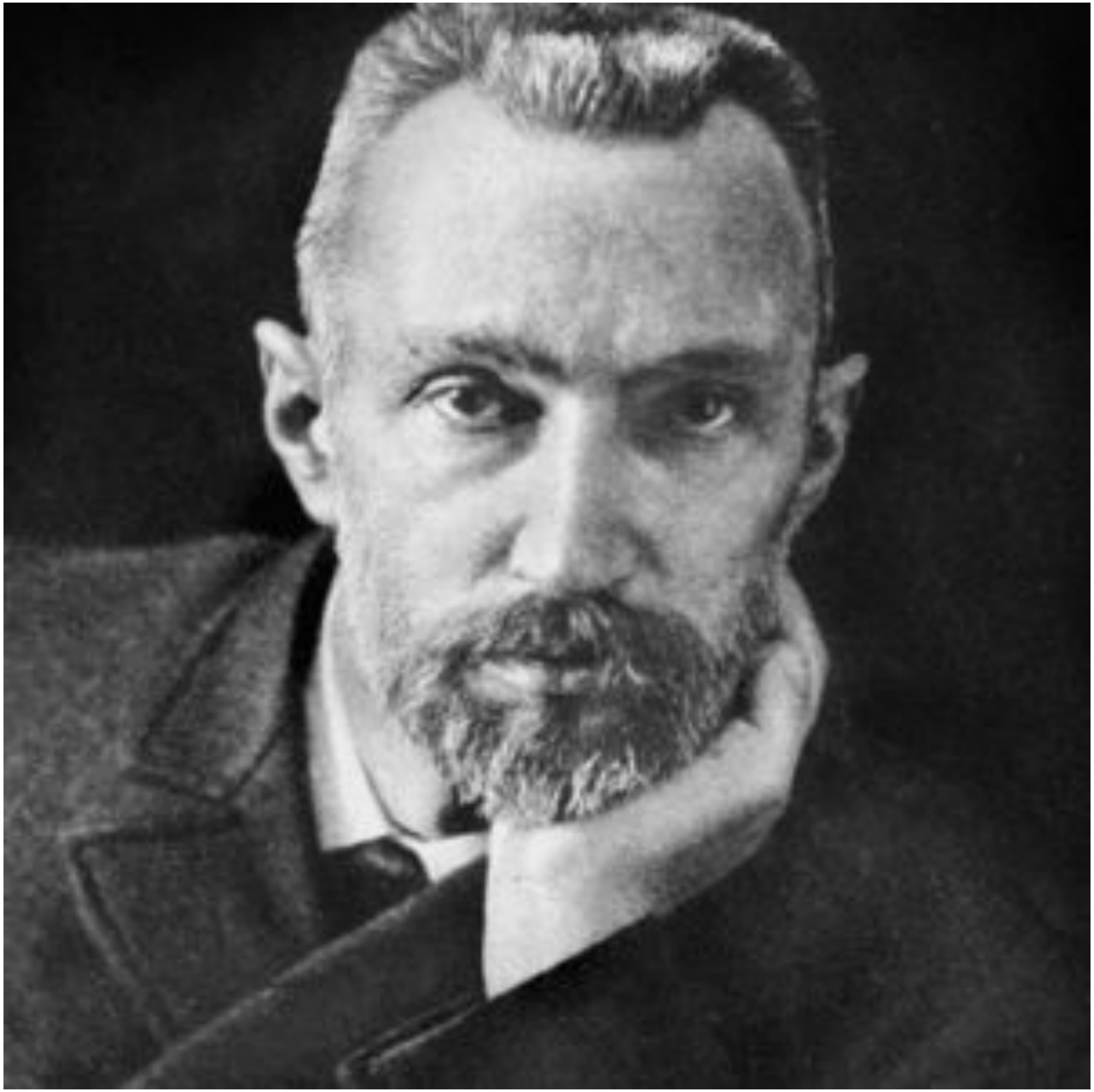
# Radiation Safety

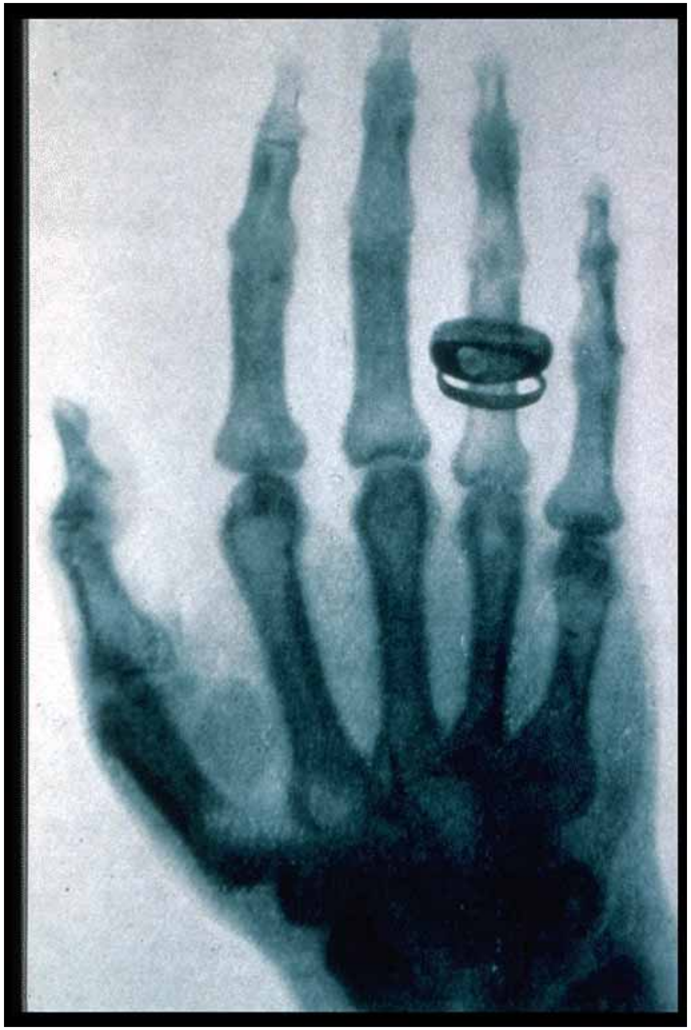
- Part I

  Radiation Protection Legislation and Principles of Justification, Optimization and Dose Limitation

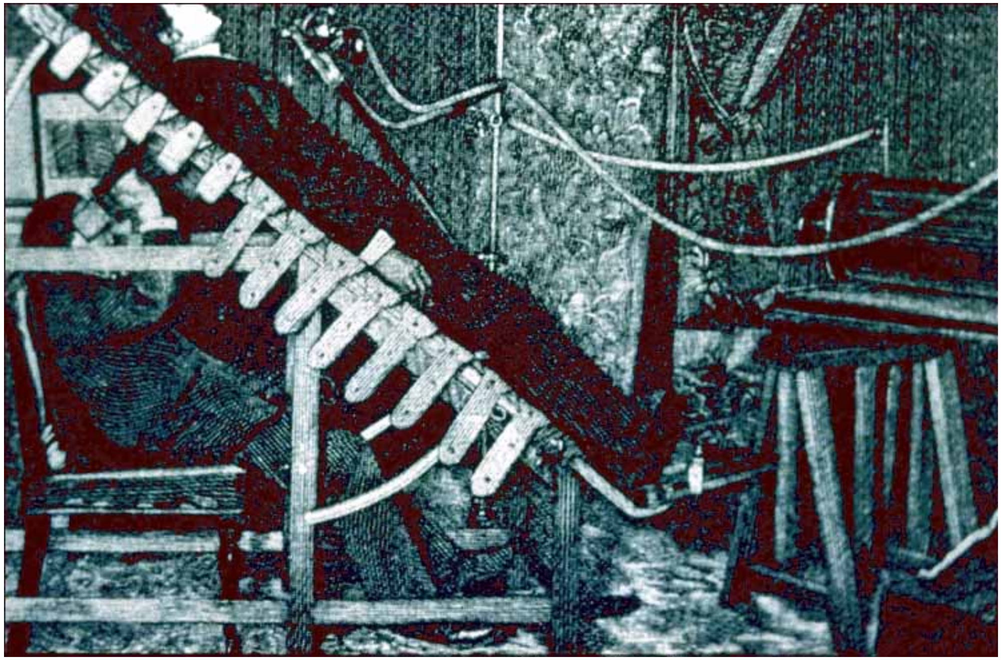
# Roentgen and an early radiograph



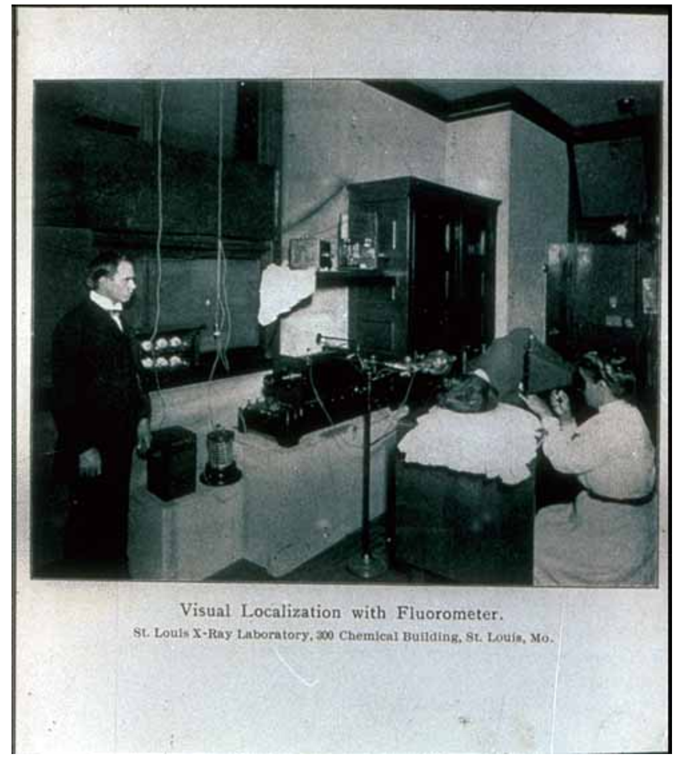


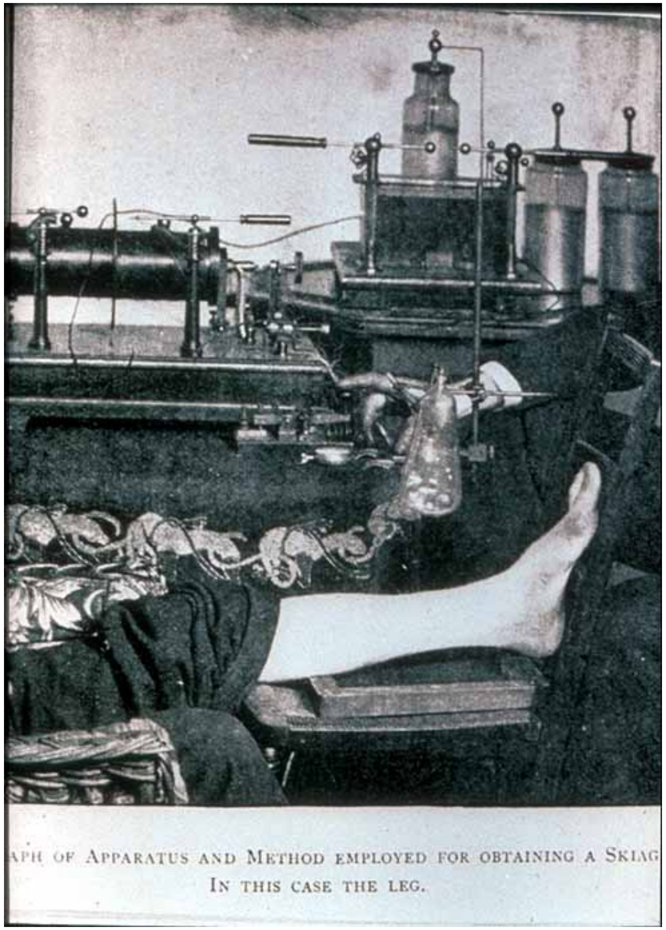
Radiograph of the hand of Albert von Kolliker, made at the conclusion of Roentgen's lecture and demonstration at the Wurzburg Physical-Medical Society on 23 January 1896.



Circa 1898



Visual Localization with Fluorometer.
St. Louis X-Ray Laboratory, 300 Chemical Building, St. Louis, Mo.





The X-ray found immediate military applications, here seen in the British River Wars on the Nile in 1896.

# Early years of radiation protection

| | |
|---|---|
| **1895** | |
| • Nov 8 | Discovery of X-rays – W Roentgen |
| **1896** | |
| • Jan 3 | X-ray discovery made public |
| • Feb | Discovery of radioactivity – H Becquerel |
| • Mar 3 | First reports of possible X-ray injury (eye damage) |
| • Apr 10 | Epilation noted from exposure |
| • Apr 18 | Skin effects noted |
| • Jul | First protective device (heavy glass plate to protect eyes) |
| • Nov 18 | Deliberately induced burn injuries |

# Early years of radiation protection

1898
- Apr Lead rubber gloves
- July Leaded X-ray tube housing
- Dec Radium discovered – P and M Curie (Radioactivity)

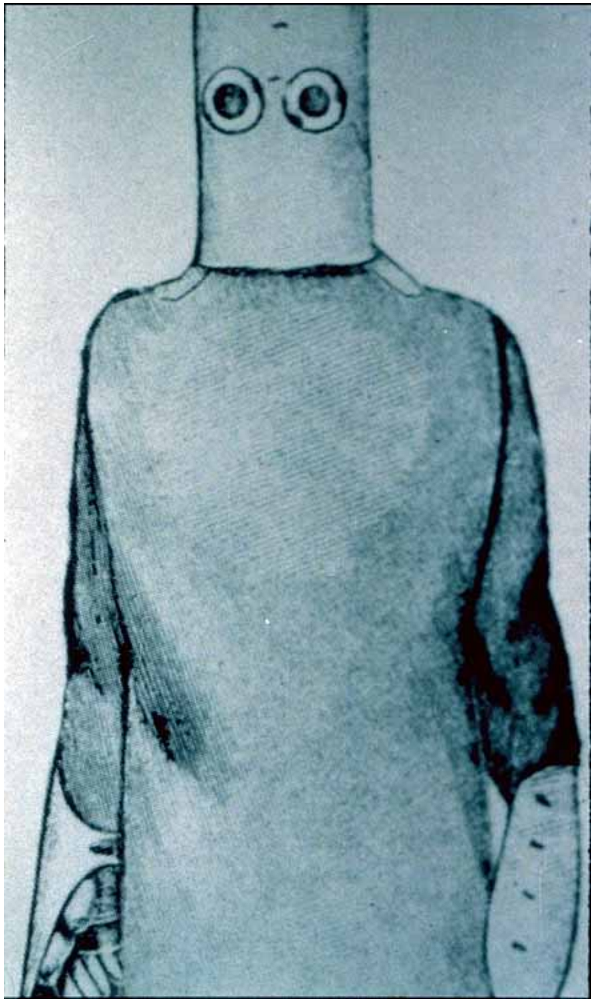
1901
- Skin burn caused by radium
- X-ray lethality to mammals demonstrated

1903
- Protection Committee proposed –Roentgen Ray Society

1904
- First death in X-ray worker attributed to overexposure

# Early radiation protection bodies

- 1915 British Roentgen Society adopts radiation protection recommendations
- 1920 First standing radiation protection committee
- 1921 British X-ray and Radium Protection Committee adopts recommendations
- 1922 American Roentgen Ray Society adopts radiation protection rules. Film badges used for dose monitoring
- 1928 International Committee formed (forerunner of ICRP) [Roentgen adopted]
- 1929 US advisory committee formed (forerunner of NCRP)



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Mihran Kassabian (1870 – 1910) Early Roentgen Ray Pioneer

## X-actly So!

The Roentgen Rays, the Roentgen Rays,
What is this craze?
The town's ablaze
With the new phase
Of X-ray's ways.

I'm full of daze,
Shock and amaze;
For nowadays
I hear they'll gaze
Thro' cloak and gown—and even stays,
These naughty, naughty Roentgen Rays.

(WILHELMA, in *Photograp*

***Roentgen craze*** – Electrical Review, April 1896


Roentgen
GERMANY
THE NEW ROENTGEN PHOTOGRAPHY.
"LOOK PLEASANT, PLEASE."

Circa 1896

# Measuring radiation / Dose Quantities

Early measurements

- Many units suggested based on range of radiation effects

e.g.

film blackening, chemical colour change, fluorescence, electrical resistance, temperature variation, biological effects, ionization

1933 Threshold erythema dose –"Quantity of radiation which, when delivered at a single sitting, will produce in 80%, of all cases tested, a faint reddening or bronzing of the skin, in 2-4 weeks after irradiation"

- 1937 ICRP

Adopt Roentgen (ionization in air) as unit for measurement for X and γ radiation

# The evolution of radiation protection

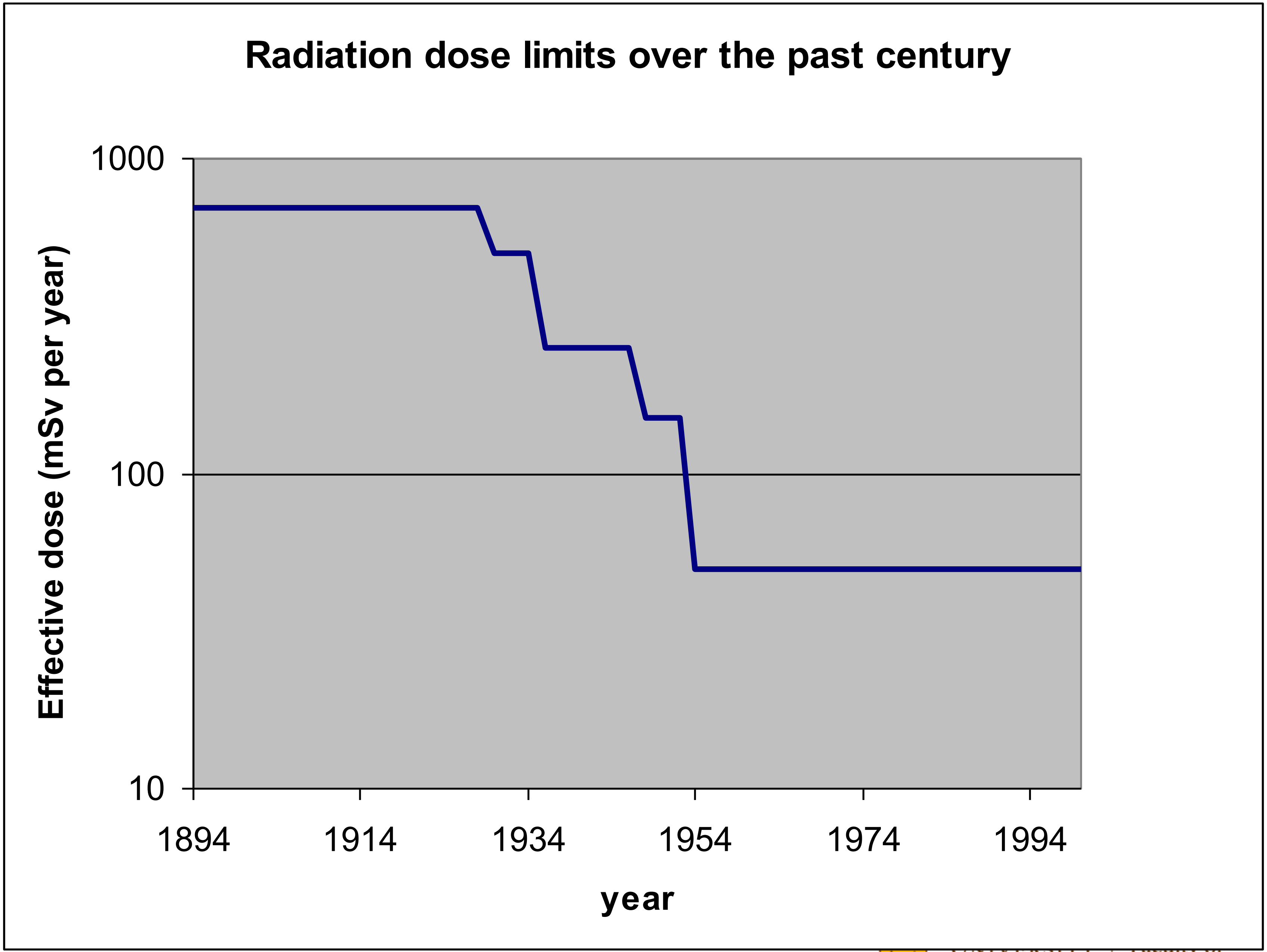
- Early years of radiation protection
- International advisory bodies
- ICRP 1 (1959), ICRP 26 (1977), ICRP 60 (1991)
  - Radiation protection dose quantities
  - Conceptual framework of radiation protection
  - System of radiation protection

# Radiation protection dose quantities

- 1959 ICRP Report 1
  - Exposure – Roentgen (R), absorbed dose (rad), roentgen equivalent man (rem)
- 1977 ICRP Report 26
  - Absorbed dose (Gy), dose equivalent (Sv), effective dose equivalent (Sv)
- 1991 ICRP 60, 2007 ICRP103 Update and additional guidance
  - Absorbed dose (Gy), equivalent dose (Sv), effective dose (Sv)

# Evolution of dose limits

- 1925First tolerance dose proposed: 0.01 of skin erythema dose per month (~700 mSv / year)
- 1931NCRP 0.2 R per day (500 mSv / year
- 1934NCRP 5 R per day for hands (1.25 Sv / year)
- 1936NCRP 0.1 R per day (250 mSv / year)
- 1944Maximum permissible dose concept
- 1949NCRP 0.3 R per week (150 mSv / year)
- 1955NCRP 5 rem per year (50 mSv)
- 1959ICRP 5 rem per year (50 mSv)
- 1985CNSC and IRR85 50 mSv per year
- 2000CNSC and IRR99 20 mSv per year

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# International advisory bodies

International Commission on Radiological Protection (ICRP)

- Formed 1928 – issued first report
- Published general recommendations on radiological protection in 1959, 1964, 1977, 1991
- Works and co-operated with
  - International Commission on Radiation Units and Measurements (ICRU)
  - World Health Organization (WHO)
  - International Atomic Energy Agency (IAEA)

# ICRP

"In preparing its recommendations, ICRP considers the fundamental principles and quantitative bases upon which appropriate radiation protection measures can be established, while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice, or regulations that are best suited to the needs of their individual countries"

The recommendations aim to provide an appropriate standard of protection without unduly limiting the beneficial practices giving rise to radiation exposure

# ICRP Publication 60

***1990 Recommendations of the ICRP***

- Dose quantities used in radiological protection
- Biological aspects of radiological protection
- Conceptual framework of radiological protection
- System of protection

# Detriment – radiation risk factors

Factors have been based on

- In vitro cell studies
- Animal experimentation
- Epidemiological studies in man
  - Medical exposures
  - Occupational exposures
  - Survivors of Hiroshima and Nagasaki
- Most data based on high dose studies with extrapolation to low doses


AP

# ICRP Data Sources

- ICRP in publication 60 looked at data from a variety of human exposures:
  - atomic bomb casualties
  - radiation exposure from medical procedures
  - “radium painters” data of 1920s (worker’s job was to paint the dials of aircraft instruments with radium-based paint. Their habit was to point the brush by putting it in their mouths)
- ICRP in publication 60 looked at data from animal radiation exposures

# ICRP- 60 Radiation Risk Summary

Table 3. Nominal probability coefficients for stochastic effects

| Exposed population | Detriment ($10^{-2}$ $Sv^{-1}$)[1] | | | |
|---|---|---|---|---|
| | Fatal cancer[2] | Non-fatal cancer | Severe hereditary effects | Total |
| Adult workers | 4.0 | 0.8 | 0.8 | 5.6 |
| Whole population | 5.0 | 1.0 | 1.3 | 7.3 |

[1] Rounded values.

[2] For fatal cancer, the detriment coefficient is equal to the probability coefficient.

# ICRP 60: Conceptual Framework of Radiological Protection

A system of radiological protection should aim to do more good than harm, should maximize the net benefit, and should aim to limit the inequity that may arise from a conflict of interest between individuals and society as a whole.

Framework intended to prevent occurrence of deterministic effects and to ensure all reasonable steps are taken to reduce the induction of stochastic effects

# Conceptual framework of radiological protection

- Practice

Human activities increasing overall exposure to radiation

  - Medical exposures
  - Nuclear power

- Intervention

Human activities decreasing overall exposure from existing sources

  - Reduction of doses from natural radiation
  - Restriction after radiation accidents

# Conceptual framework of radiological protection

Three types of exposure defined

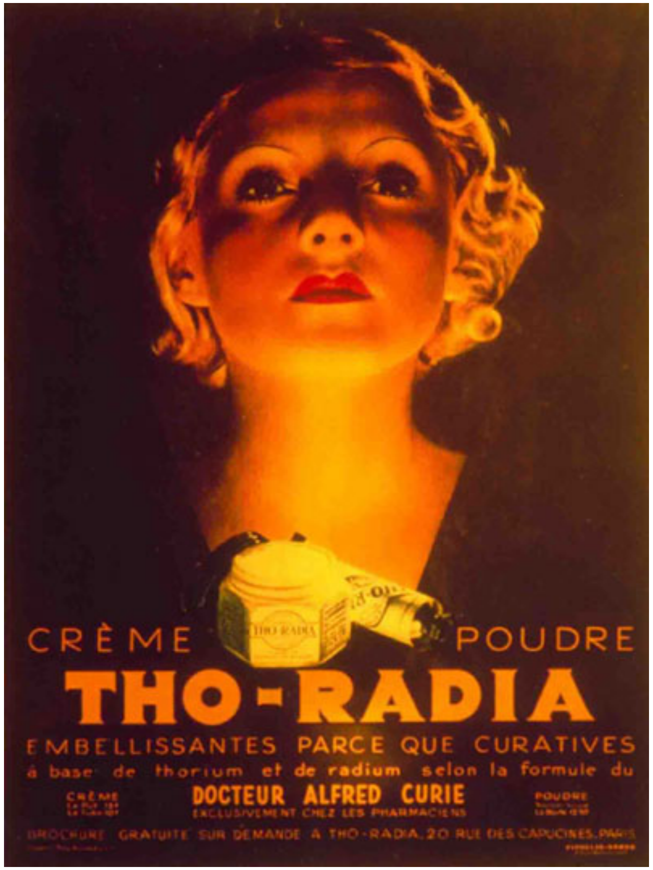
- Occupational exposure
  - Exposure incurred at work
- Medical Exposure
  - Exposure of patients, carers, volunteers in biomedical research
- Public exposure
  - All other exposures

# System of protection in practices

- JUSTIFICATION
- OPTIMIZATION
- DOSE LIMITS

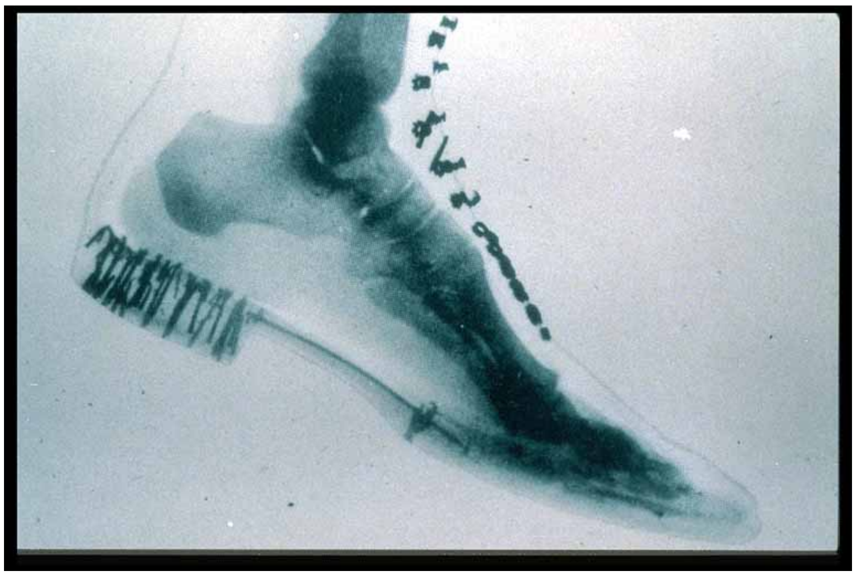
# ICRP 60: Justification

No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes




# Thorium / radium face cream 1933

# Radiograph of foot in shoe, March 1896 and shoe fitting X-ray unit, 1950s



Circa 1896

Similar unit found in operation in 1981
{Banned in 33 states in 1970}

# ICRP 60: Optimization

In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and potential exposures should be kept as low as reasonably achievable, economic and social factors being taken into account

***ALARA and ALARP***

# ICRP 60: Dose Limitation

The exposure of individual resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring no individual is exposed to radiation risks that are judged to be unacceptable in any normal circumstances

# Radiation protection regulation dose limits

**CNSC limit:**

- **20 mSv for occupational dose**
- **1 mSv for general public dose**

# Manitoba Radiation Protection Act

https://web2.gov.mb.ca/bills/40-4/b037e.php

# Scope of Act

- regulates the installation, operation and maintenance of equipment that emits or detects ionizing radiation

# Background

- Bill 37 was introduced (first reading) in the Manitoba Legislature on June 9, 2015 by the Minister of Health

- It replaces the existing X-Ray Safety Regulations
  - very old and out-of-date (30+ years)
  - have become frail and deficient
    - based on ICRP 26, 1977

# Roles of the radiation protection act

- Health protection for
  - workers
  - general public
- Health protection for patients
  - use appropriate, maintained equipment
- Occupational protection is well established in all sectors
- Patient protection is relatively new

# Limitations

- Some aspects of patient protection are the remit of the CPSM and other professional bodies e.g. CAR
- Act cannot interfere with clinical practice
  - consistent with professional bodies that oversee professional practice
- No radioactive sources
- Minimal impact on practice and costs

# Goals of Act

- provide contemporary and robust legislation
- follow recommendations of ICRP 60, 1990 and ICRP 103, 2007
- harmonize with federal and provincial legislation across Canada
  - fill gaps in the federal legislation (nuc med and multimodality equipment)
- include justification
  - reinforce principles of optimization and dose limitation

# What are main changes

- Modern language and approach
  - easier to update
- Relevant quantities, units and limits
- Consistent with Federal and Provincial regulations and professional bodies
- Patient-centered
- Clearly defined roles and responsibilities
- Act follows current work approach

# Occupational exposure

- Use of dose constraints in planning and optimization
  - Dose constraint < dose limit
- Dose limits for workers
- Occupational exposure of women of reproductive capacity

# Medical Exposure

- Generic justification of medical radiation procedures
- Individual justification of medical exposure
- Dose reduction by optimization of technique in diagnostic radiology
  - Reference dose levels
- Dose limits do not apply
- Procedures for irradiation of women who are or may be pregnant

# Public exposure

- Control of public exposure exercised by application controls at the source, rather than the environment
- Dose constraint
- Public dose limits apply

# System of protection in practices

- JUSTIFICATION
- OPTIMIZATION
- DOSE LIMITS

# Part II

# Radiation Safety

- Part II

  Dose quantities and units

# Radiation Protection Dose Quantities (ICRP 60 and 103)

- **Absorbed dose (D)**
  Energy imparted by ionizing radiation per unit mass of matter
  Units: Gray (Gy) (=J $kg^{-1}$)
- **Equivalent dose (H)**
  Average absorbed dose to tissue or organ weighted for radiation type
  Units: Sievert (Sv)
- **Effective dose (E)**
  Sum of equivalent doses to tissues and organs weighted according to risk factors associated with the tissues
  Units: Sievert (Sv)

# Absorbed Dose (D)

- Fundamental dosimetric quantity
- Energy absorbed from a beam of radiation per mass of material
- Units: Joules per kilogram, $Jkg^{-1}$

  defined as grays, Gy
- $1\ Gy = 1\ Jkg^{-1}$
- Is the most appropriate unit for the deterministic effects of radiation on that tissue or organ (e.g. skin burns or cataracts)

# Equivalent Dose ($H_T$) to organ or tissue

- Same absorbed dose to different organs will not produce same biological effect if radiation *type* is different
- Mean absorbed dose is multiplied by radiation weighting factor, $w_R$

X-rays, g-rays and electrons: $w_R = 1$

Protons: $w_R = 5$

a particles: $w_R = 20$

Neutrons: $w_R$ ranges from 5 - 20, depending on neutron energy

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# Equivalent Dose ($H_T$)

- For X-rays:

  Equivalent dose = mean absorbed dose to organ

- Units: Joules per kilogram, $Jkg^{-1}$

  given special name of sievert, (Sv)

# Effective dose

- **Equivalent doses** may be combined to account for their relative contribution to the harm to the body as a whole
- The various tissues and organs have differing radio sensitivities
- Accounted for by ***tissue weighting factors, $w_T$***
- $w_T$ based on tissue sensitivity to radiation but includes other factors

# Tissue Weighting Factors

| Tissue | $w_T$ | Tissue | $w_T$ |
|---|---|---|---|
| Gonads | 0.20 | Breast | 0.05 |
| Bone marrow | 0.12 | Liver | 0.05 |
| Colon | 0.12 | Oesophagus | 0.05 |
| Lung | 0.12 | Thyroid | 0.05 |
| Stomach | 0.12 | Skin | 0.01 |
| Bladder | 0.05 | Bone surfaces | 0.01 |
| Remainder | 0.05 | | |

# Effective Dose, E

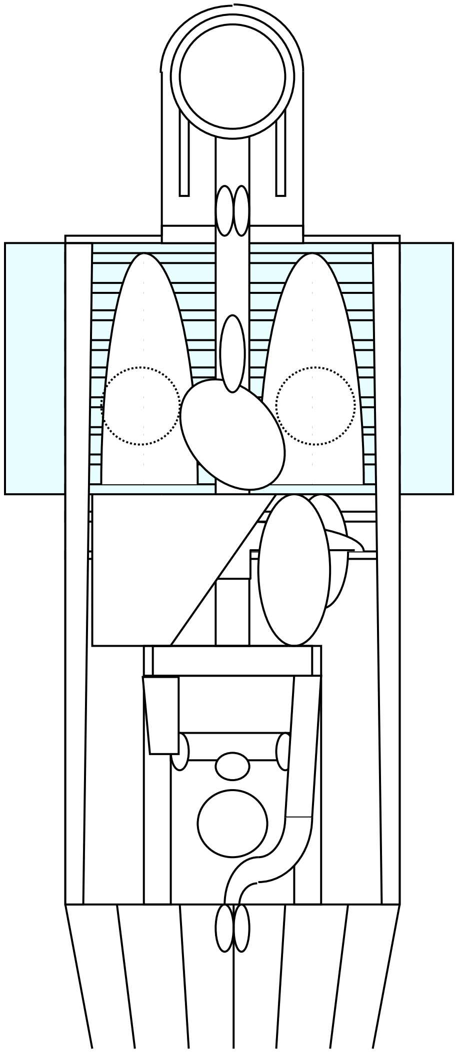
- Sum of the equivalent doses to all organs and tissues in the body multiplied by their $w_T$

$$E = \Sigma_T \; w_T H_T$$

Unit: Sievert (Sv) (=$Jkg^{-1}$)

- E gives information on overall risk of **stochastic effects** and can be used to compare risk from different types of exposure

# Effective dose calculation



Effective dose =

$H_{lung}$ * 0.12 + $H_{breast}$ * 0.05

+ $H_{thyroid}$ * 0.05 + $H_{liver}$ * 0.05

+ $H_{gonads}$ * 0.2 + ……..etc for all named organs with $w_t$

Organs without $w_t$ counted in 'remainder'

Allows risks of different exposures to be compared

# Hierarchy of Dose Quantities

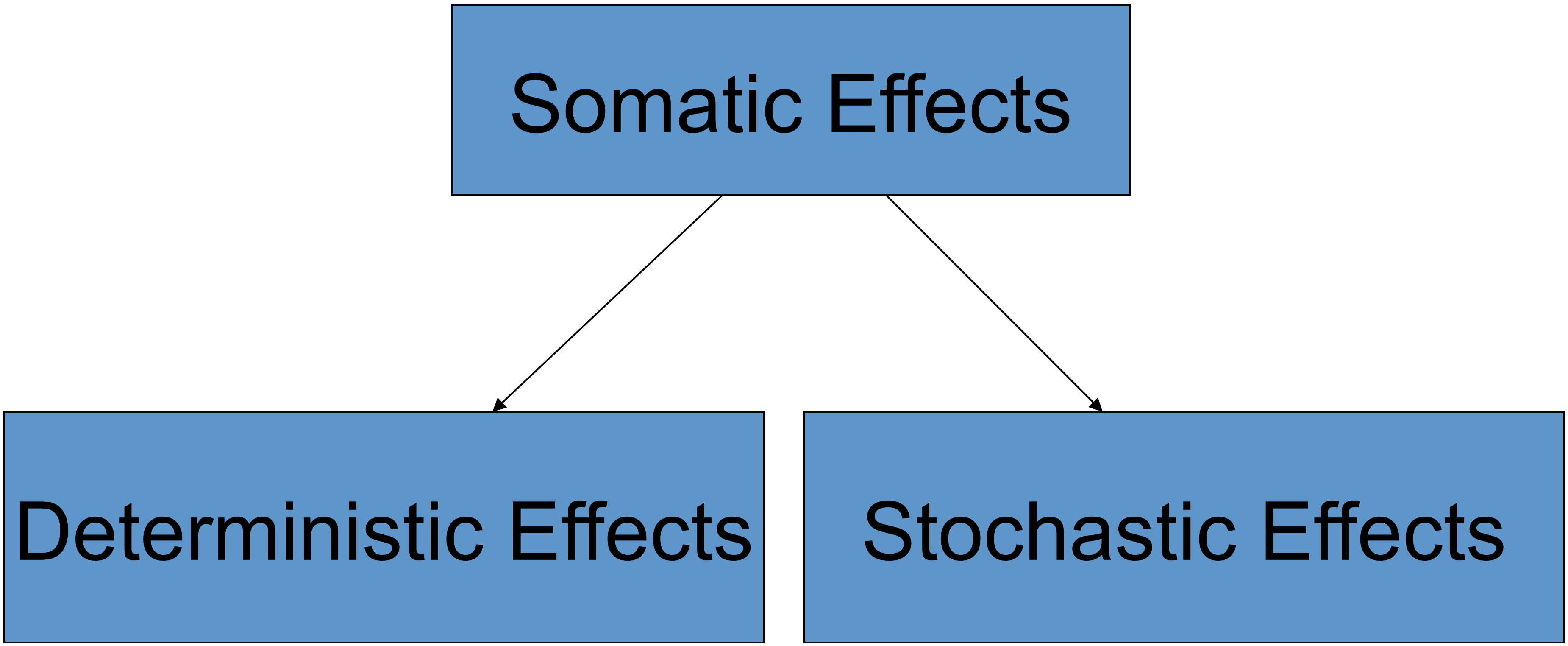
**Absorbed Dose**
energy imparted by radiation to a unit mass of tissue

**Equivalent Dose**
absorbed dose weighted for harmfulness of different radiations

**Effective Dose**
equivalent dose weighted for susceptibility to harm of different tissues

**Collective Effective Dose**
effective dose to a group from a source of radiation

# Biological Effects of Ionizing Radiation

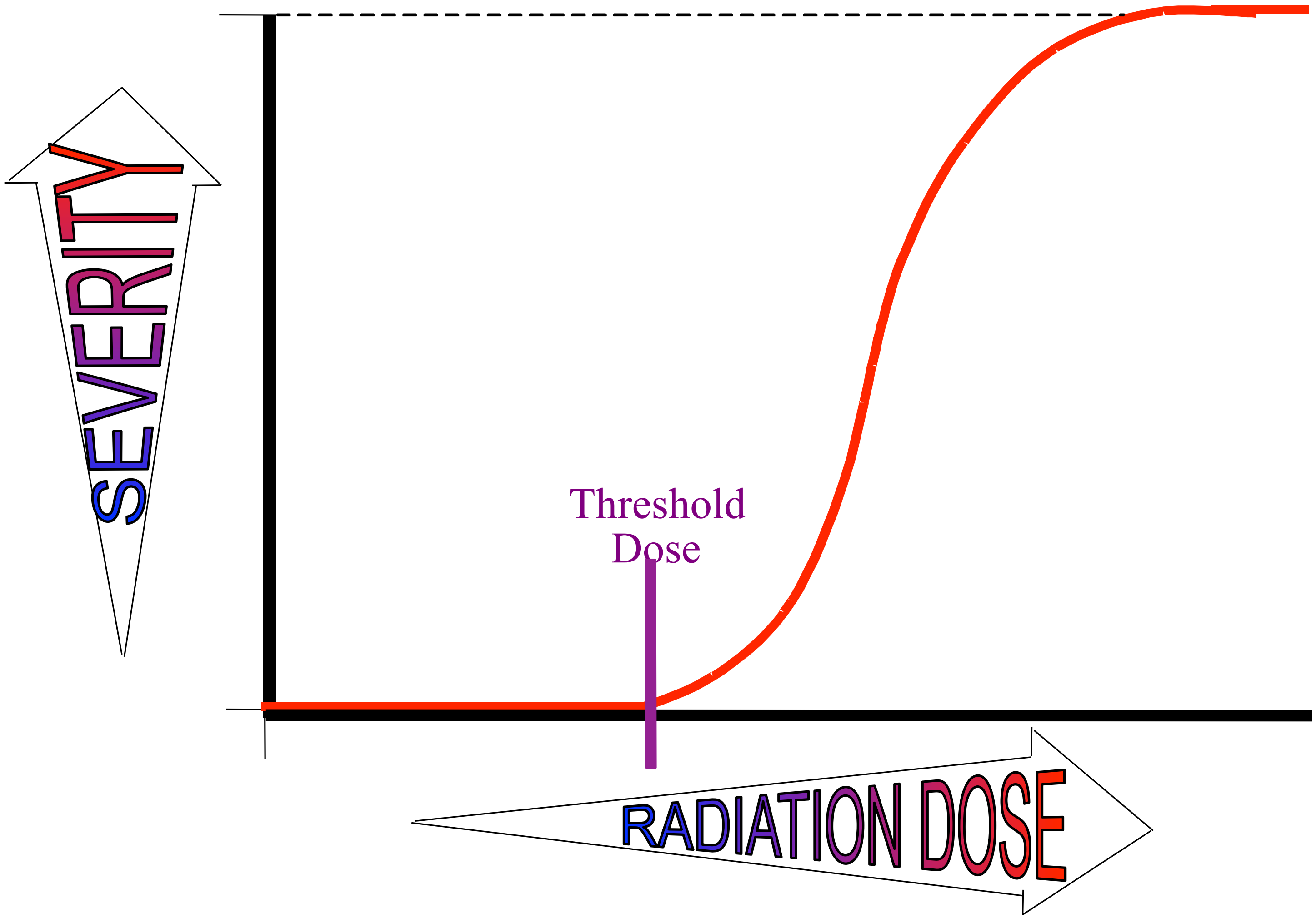


# Deterministic Effects

Non-Stochastic Effects: A health effect where the severity of the effect increases as dose increases.

- Cataracts
- Sterility
- Loss of Hair (Epilation)
- Skin Reddening (Erythema)
- Acute Radiation Syndrome
- Death

# Deterministic Effects

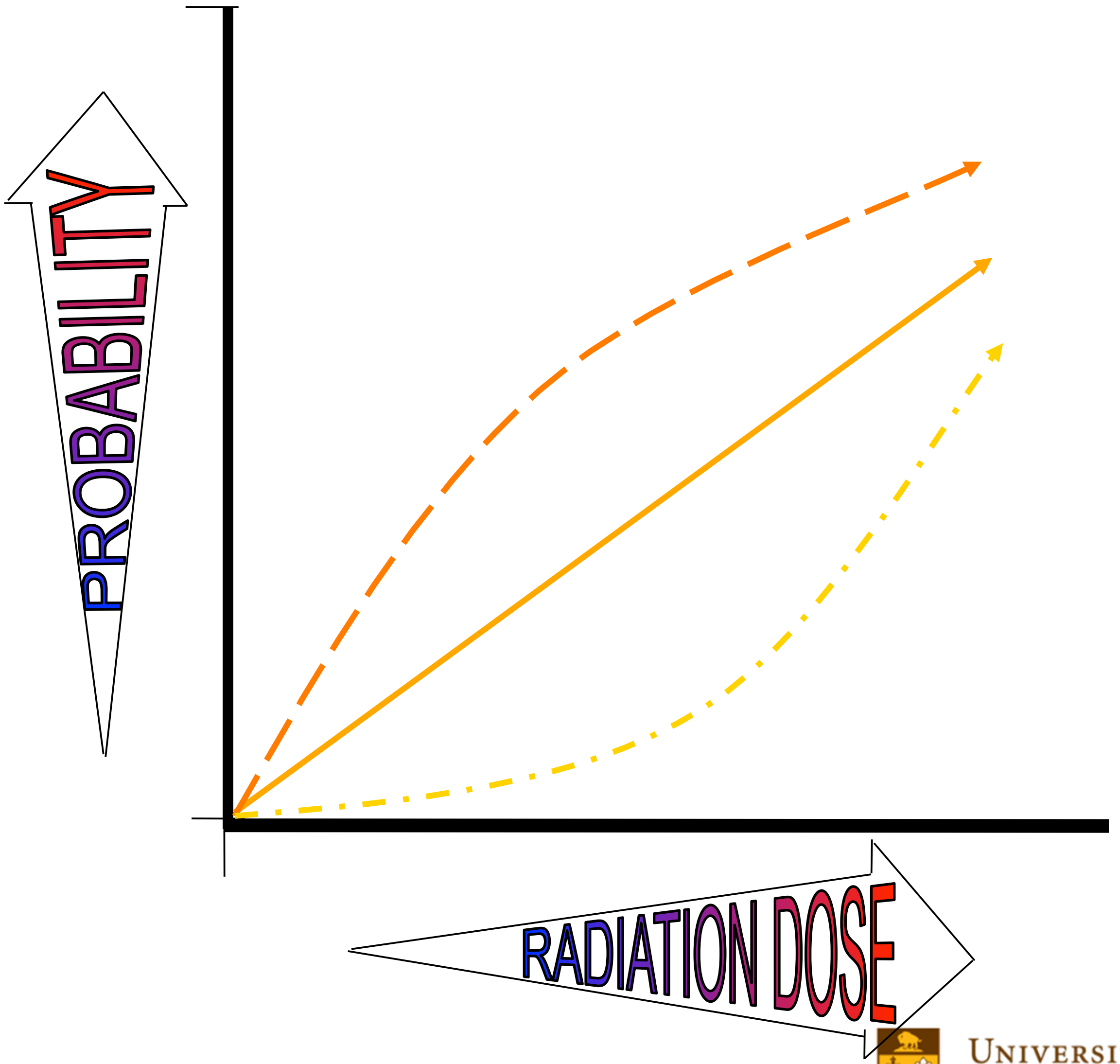


# Stochastic Effects

Stochastic Effects: A health effect where the "risk" of occurrence increases as dose increases.

- Fatal Cancer
- Non-fatal cancer (thyroid cancer)
- Tumor
- Genetic effects

# Stochastic Effects



# Range of effective dose and the median values from CBCT in μSv

| Dental CBCT unit type | Effective Dose (μSv) |
|---|---|
| Dento-alveolar | 11-674 (61) |
| Craniofacial | 30-1073 (87) |

Taken from EU Radiation Protection No. 172 Cone beam CT for dental and maxillofacial radiology (Evidence-based guidelines)

# Effective dose from conventional dental imaging techniques in μSv

| Exam | Effective dose (μSv) |
| --- | --- |
| Intraoral radiograph | < 1.5* |
| Panoramic radiograph | 2.7 – 24.3 |
| Cephalometric radiograph | < 6 |
| MSCT maxillo-mandibular | 280 – 1410 |

* For single intraoral radiograph calculated from 4 bitewing examination both using a photostimulable phosphor plate or F speed film with rectangular collimation. Substitution of round collimation increased this figure by almost five times.

Taken from EU Radiation Protection No. 172 Cone beam CT for dental and maxillofacial radiology (Evidence-based guidelines)

# Radiation Exposure from Medical Diagnostic Imaging Procedures

| Diagnostic procedure | Typical effective dose (mSv) | Equivalent period of natural background radiation[1] |
|---|---|---|
| Abdomen | 1.2 | 5 months |
| Cardiac Angiography | 4.6 – 15.8 | 1.75 – 5.85 years |
| Chest (single PA film) | 0.02 | 2.7 days |
| Pelvis | 0.7 | 3 months |
| Cervical spine (neck) | 0.08 | 1.4 weeks |
| Lumbar spine | 0.7 | 3 months |
| Teeth (panoramic) | 0.09 | 12 days |
| Skull | 0.03 | 4 days |
| Barium enema | 7 | 2.6 years |
| IVU (kidneys and bladder) | 2.5 | 11 months |
| CT angiography of coronary arteries | 10 | 3.7 years |
| CT head | 2 | 9 months |
| CT abdomen/pelvis | 10 | 3.7 years |
| CT urographic study | 44.1 | 16.3 years |
| Mammography, screening (four views) | 0.7 | 3 months |
| PET, whole body | 14 | 5.2 years |
| PET/CT, whole body | 25 | 9.2 years |
| Thyroid scan (Tc-99m) | 1 | 4.4 months |
| Bone scan (Tc-99m) | 4 | 1.5 years |
| Myocardial imaging (Tc-99m) | 4 | 1.5 years |
| Background Radiation, annual dose in Canada | 2.7 | 1 year |

1. National average = 2.7 mSv per year (source: Health Canada)
2. Approximate lifetime risk for patients 16 - 69 years old: for pediatric patients multiply risks by about 2; for geriatric patients divide risks by about 5
3. Health Physics Society. Radiation Exposure from Medical Diagnostic Imaging Procedures. Health Physics Society Fact Sheet. Downloaded 7 Sep. 2007 from https://hps.org/documents/meddiagimaging.pdf

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**Cone Beam Radiology Technique and Interpretation Certification**

December 2-4, 2016

27. Stochastic effects include:

A. Osteoradionecrosis
B. Cataracts
C. Acute radiation syndrome
D. Cancer
E. Mucositis

- To estimate risk of stochastic effects, one needs to calculate:

a) Computed tomography dose index
b) Dose length product
c) Conversion factors for air dose
d) Effective dose

- Equivalent dose accounts for

a) Different radiation susceptibility of tissues
b) Relative biological effectiveness of radiation types
c) Differences in dose between plain radiography and CT
d) Deterministic risk from radiation accidents

- The principles of radiation protection include all of the following principles except:

a) Avoid exposure if the patient expresses fear of radiation
b) Ensure exposure is optimized
c) The exposure is justified based on sound clinical judgement
d) Precautions are taken to limit the exposure


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