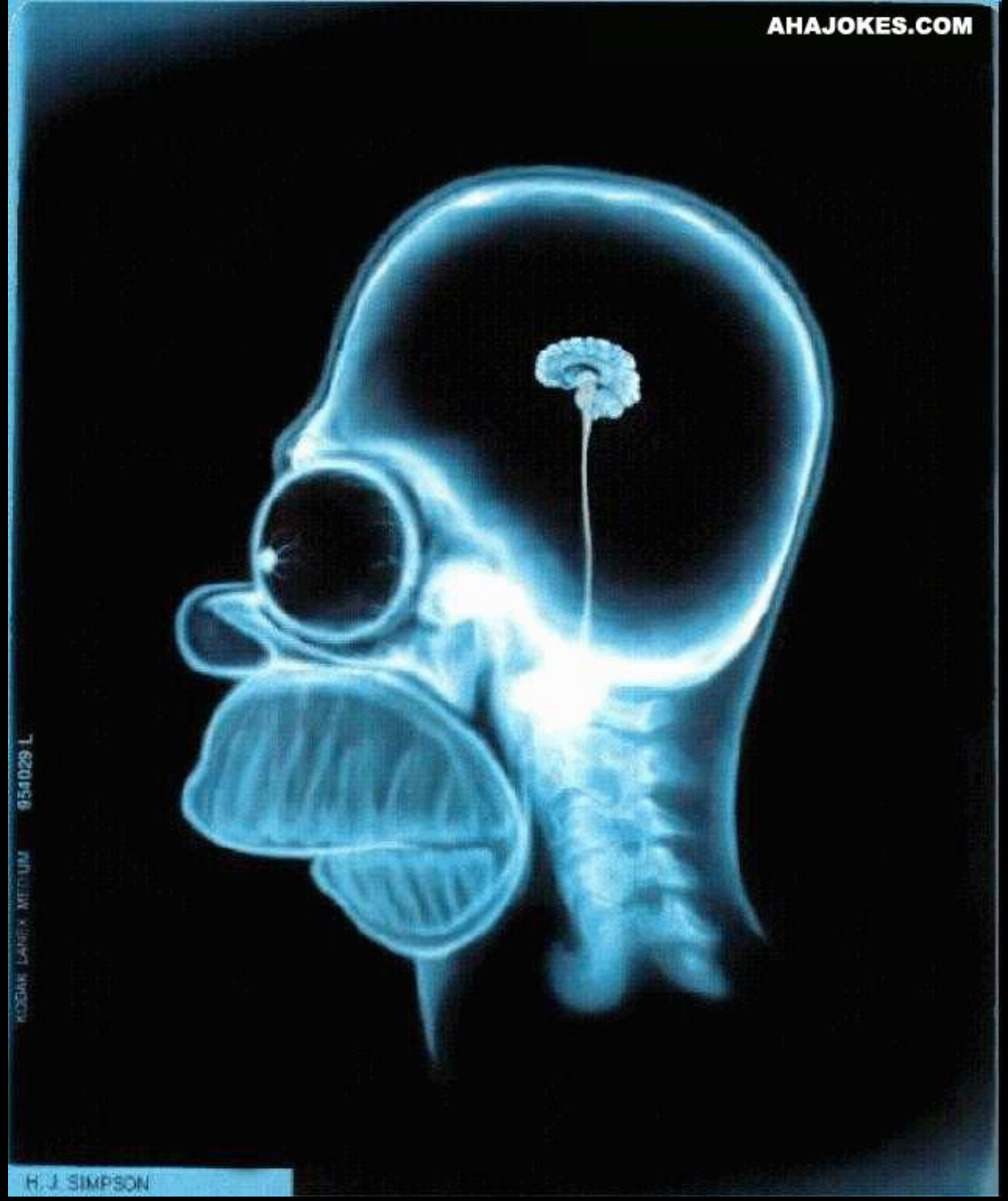

AHAJOKES.COM
KODAK LANEX MEDIUM
H. J. SIMPSON

First FRCR Examination in Clinical Radiology

Radiation Hazards and Dosimetry

(2h)

John Saunderson

Radiation Protection Adviser

1b. Radiation Hazards and Dosimetry

Biological effects of radiations

Risks of radiation

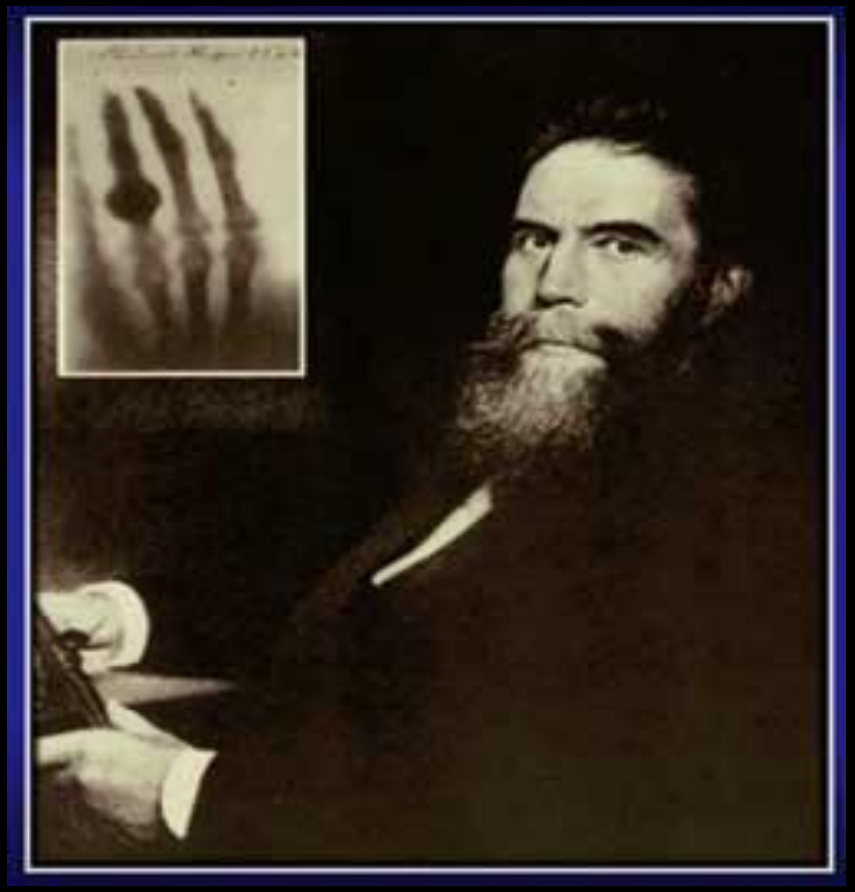
Principles of radiation protection

- Justification
- Optimisation
- Limitation

Kerma, absorbed dose, equivalent dose, effective dose and their units.

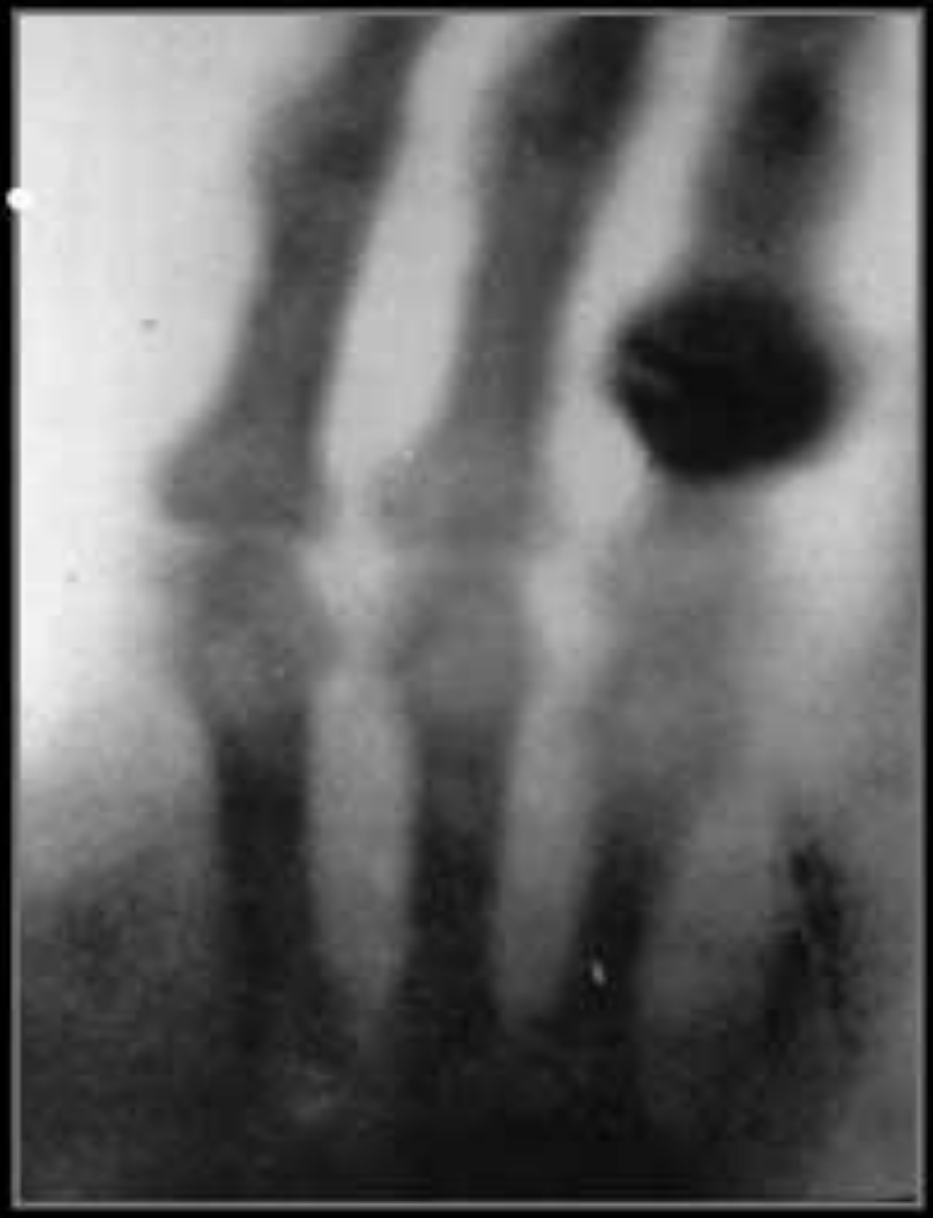
Wilhelm Roentgen

- Discovered X-rays on 8th November 1895

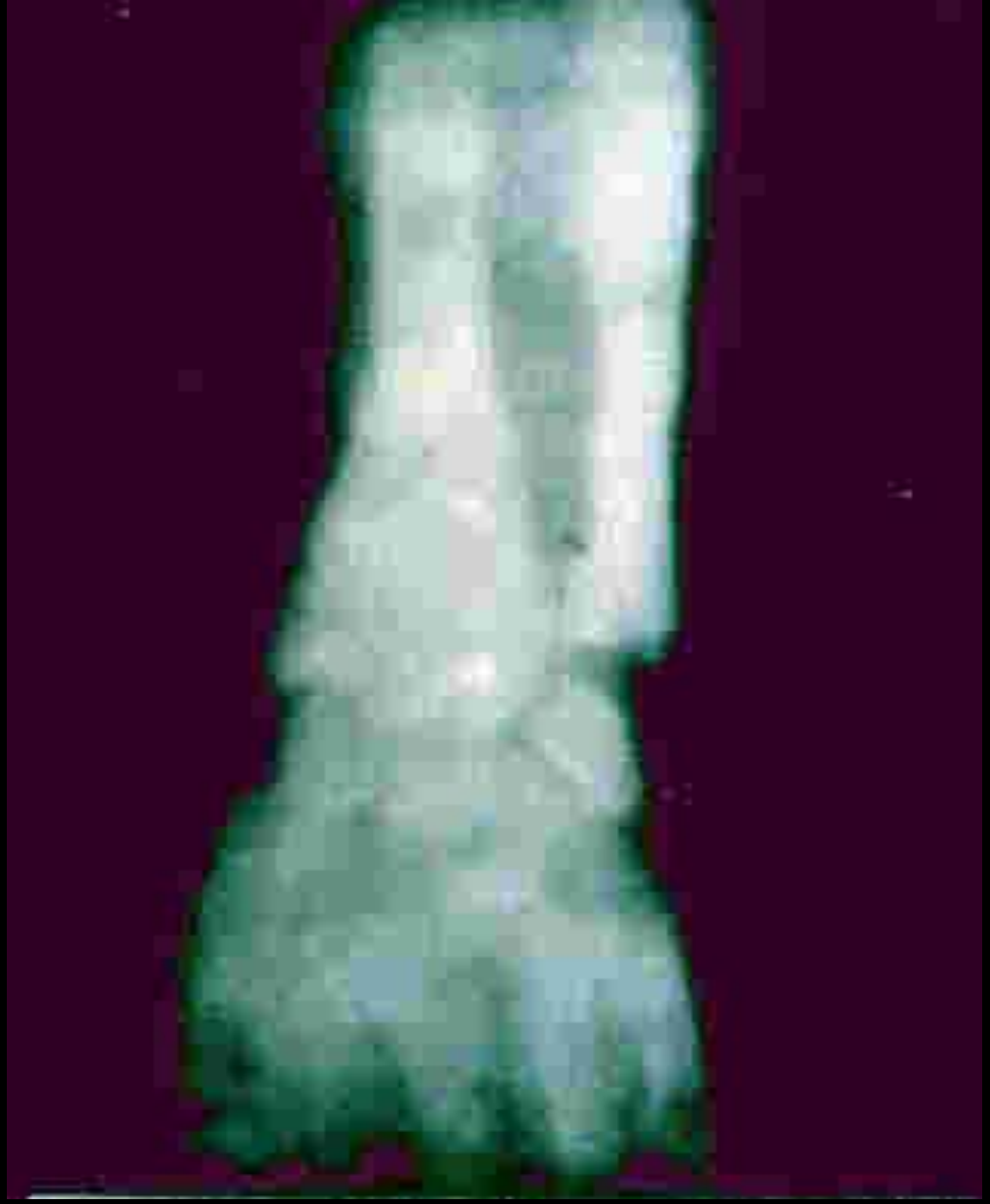


Henri Becquerel

- Discovered radioactivity on 26 February 1896



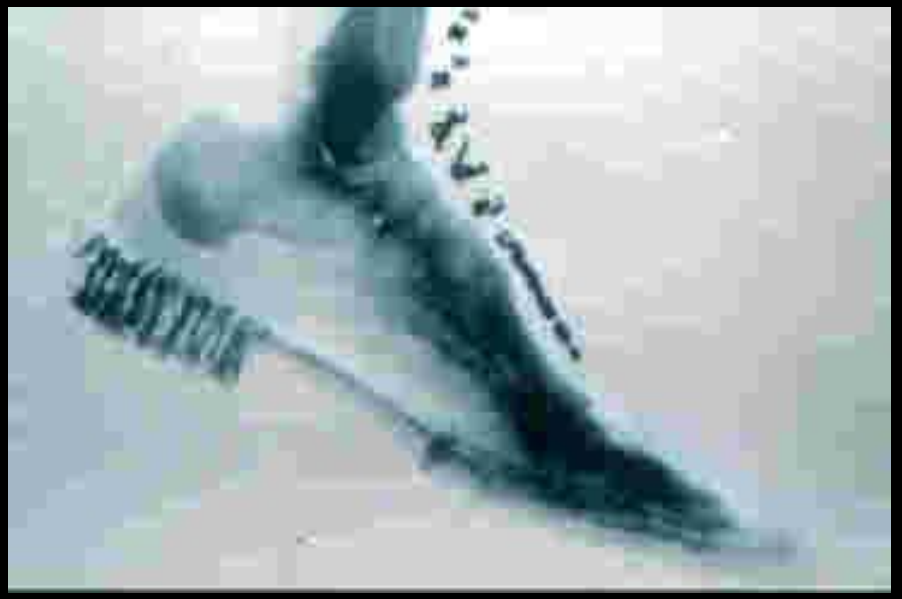
Frau Roentgen’s hand, 1895



Colles’ fracture 1896

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.

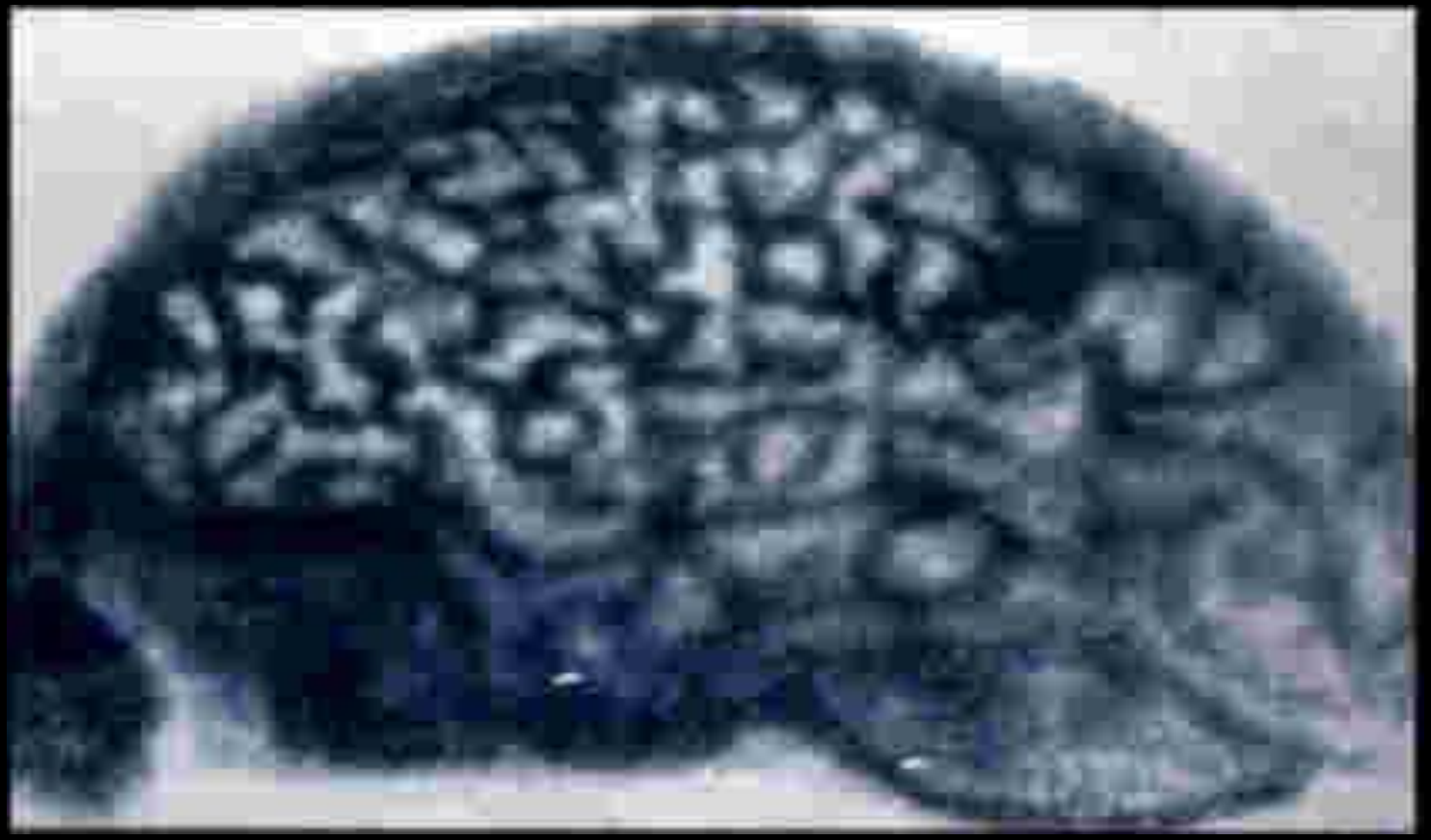


I'm full of daze,
Shock and amaze;
For nowadays
I hear they'll gaze
Thro' cloak and gown and even stays,
Those naughty, naughty Roentgen Rays.

(Wilhelma, Electrical Review, April 1896)

Dr Rome Wagner and

”First radiograph of the human brain” 1896



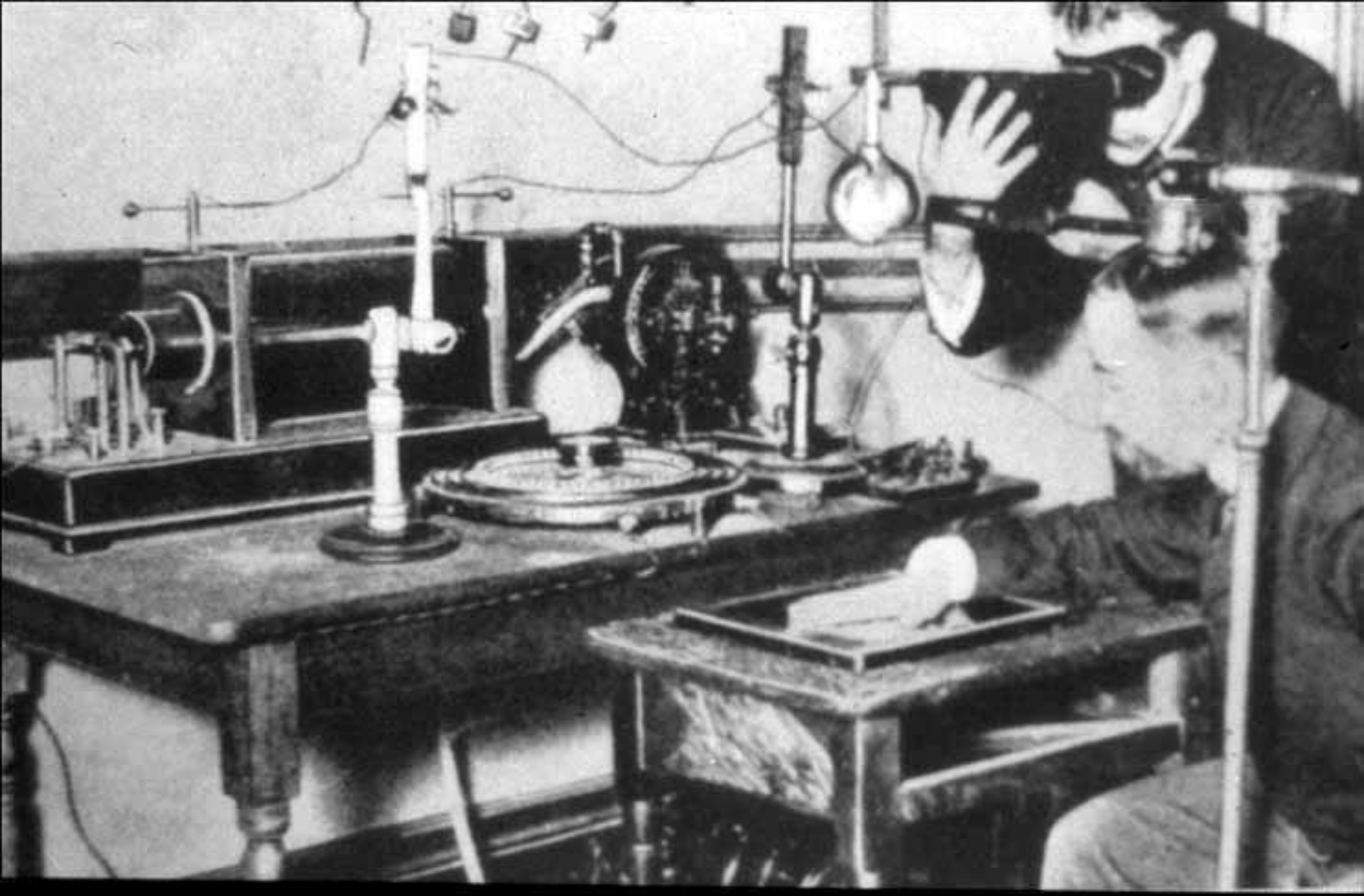
In reality a pan of cat intestines photographed by H.A. Falk (1896)

First Reports of Injury

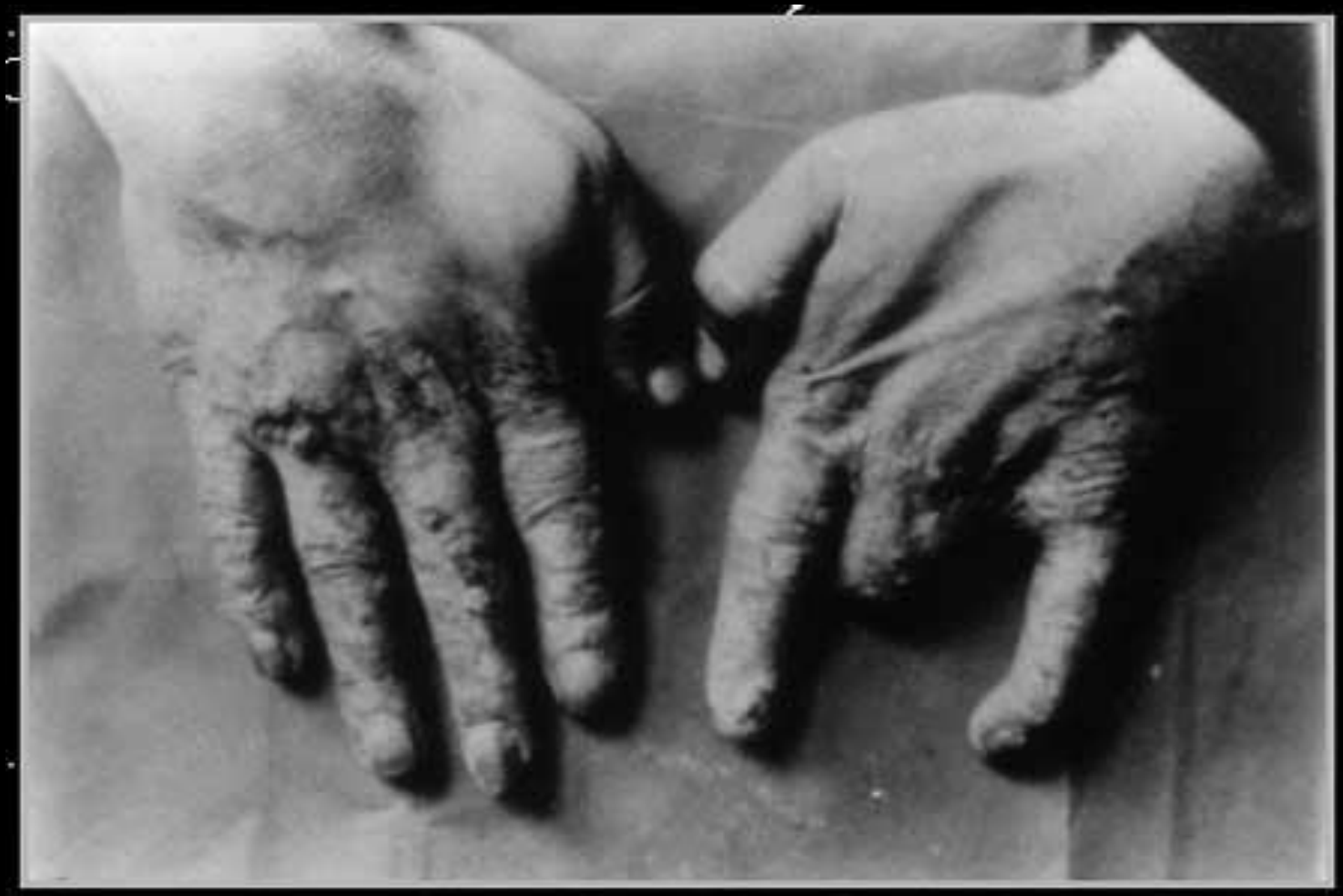
Late 1896

Elihu Thomson - burn from deliberate exposure of finger

Edison's assistant - hair fell out & scalp became inflamed & ulcerated



Mihran Kassabian (1870-1910)



Sister Blandina (1871 - 1916)

- 1898, started work as radiographer in Cologne
- held nervous patients & children with unprotected hands
- controlled the degree of hardness of the X-ray tube by placing her hand behind of the screen.

Sister Blandina

- After 6 months strong flushing & swellings of hands
- diagnosed with an X-ray cancer,
- some fingers amputated
- then whole hand amputated
- whole arm amputated.

Sister Blandina

- 1915 severed difficulties of breathing
- extensive shadow on the left side of her thorax
- large wound on her whole front- and back-side
- Died on 22nd October 1916 .

Do not adjust your set

William Rollins

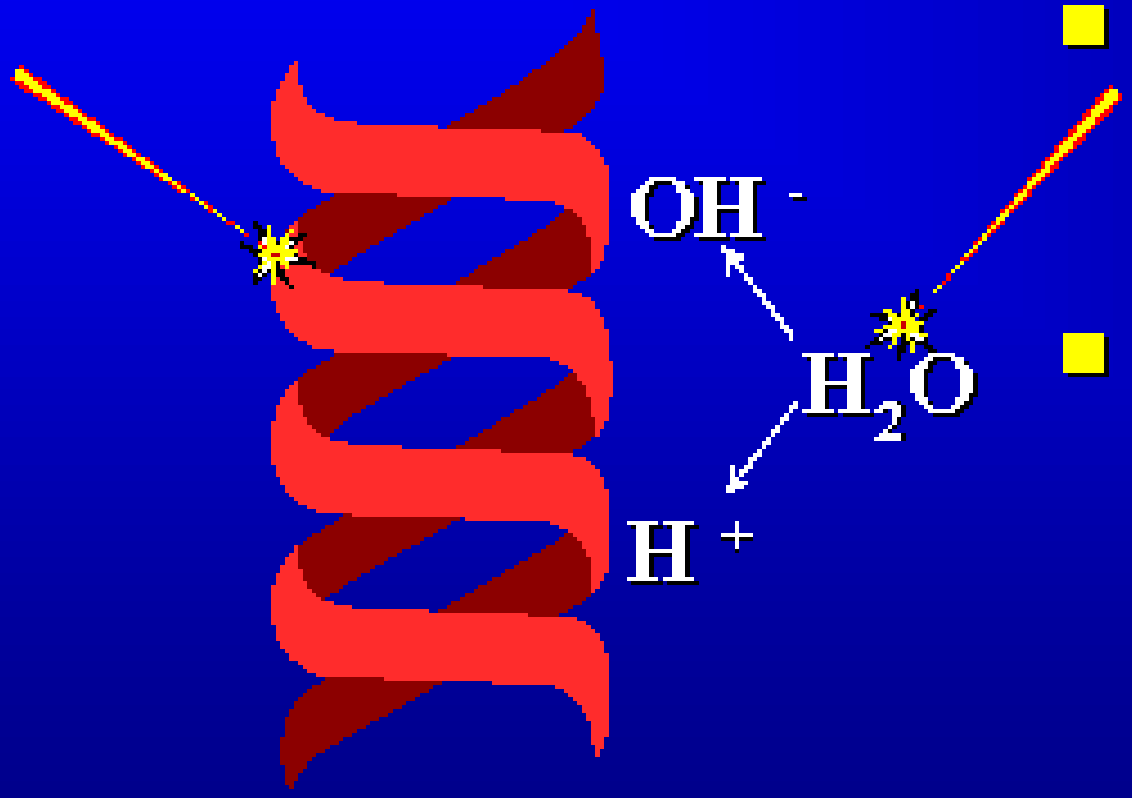
- Rollins W. **X-light kills**. *Boston Med Surg J 1901;144:173.*
- Codman EA. **No practical danger from the x-ray**. *Boston Med Surg J 1901;144:197*

Mechanisms of Radiation Injury

- LD(50/30) = 4 Gy
  - ≅ 280 J to 70 kg man
  - ≅ 1 milli-Celsius rise in body temp.
  - ≅ drinking 6 ml of warm tea

i.e. not caused by heating, but ionisation.

Physical and Chemical Damage to DNA from Radiation



- Physical damage occurs when DNA struck directly.
- Chemical attack can occur from ions and free radicals created when radiation impacts fluid surrounding DNA.

Methods of Potential Damage from Ionizing Radiation

- **Direct Action**

  assumes damage occurs as a result of a *direct hit* on the cell's essential molecules (DNA); such a hit would result in cellular damage or even cell death

Methods of Potential Damage from Ionizing Radiation

- **Indirect Action**

  assumes cellular damage occurs as a result of the action of radiation on *water* (roughly 85% of a cell's composition); damage results from the *indirect action* of toxic compounds on cellular DNA

Free Radicals

- $H_2O + \gamma \rightarrow H_2O^+ + e^-$
  - $H_2O^+ \rightarrow OH^\bullet + H^+$
    - $OH^\bullet + e^- \rightarrow OH^-$ *(hydroxyl radical)*
- $H^+ + H_2O \rightarrow H_3O^+$
- $OH^\bullet + OH^\bullet \rightarrow H_2O_2$ *(hydrogen peroxide)*
- $O_2 + e^- \rightarrow O_2^-$ *(produces peroxyl radicals)*

Effects on Cell

- Cell death after abnormal mitosis
- Cell death prior to mitosis
- Abnormal mitosis followed by repair
- Abnormal, sublethal mitosis with replication of damage in subsequent generations
- Delayed DNA synthesis or prolonged mitosis
- Changes in cellular protoplasm during mitosis (cytokinesis)

Law of Bergonié and Tribondeau (1906)

- *(more a "rule of thumb")*
- cells tend to be radiosensitive if they have three properties
    1. Cells have a high division rate.
    2. Cells have a long dividing future.
    3. Cells are of an unspecialized type

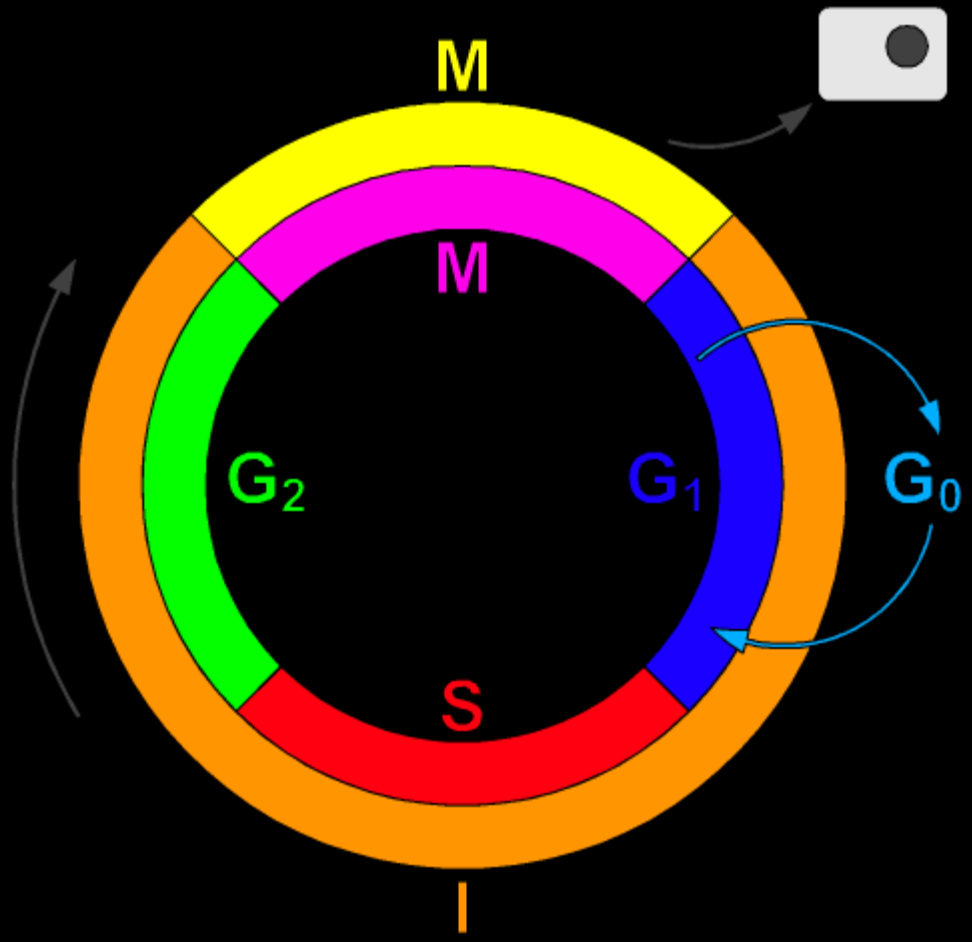
(Note, three important exceptions to 3. - small lymphocytes, primary oocytes and neuroblasts)

Relative Radiosensitivities of Common Cells

Low: mature blood cells, muscle cells, ganglion cells, mature connective tissues

High: gastric mucosa, mucous membranes, esophageal epithelium, urinary bladder epithelium

Very High: primitive blood cells, intestinal epithelium, spermatogonia, ovarian follicular cells, lymphocytes.



In general,

- cells are most radiosensitive in late M and G_2 phases
- and most resistant in late S

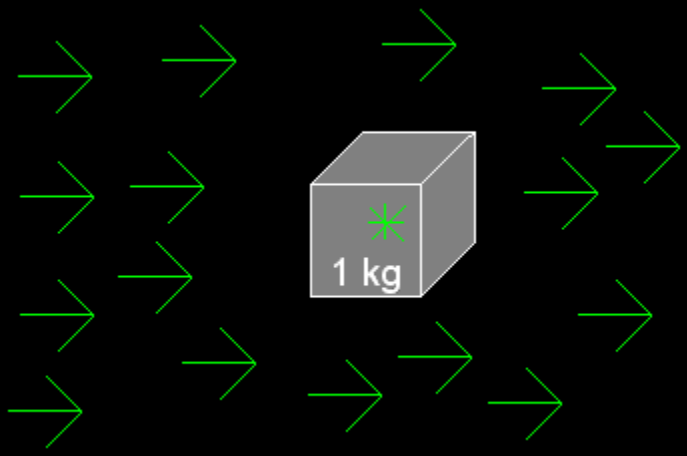
For cells with a longer cell cycle time and a significantly long G_1 phase, there is a second peak of resistance late in G_1

Radiation Quantities and Units

- Absorbed dose
- Equivalent dose
- Effective dose
- others .

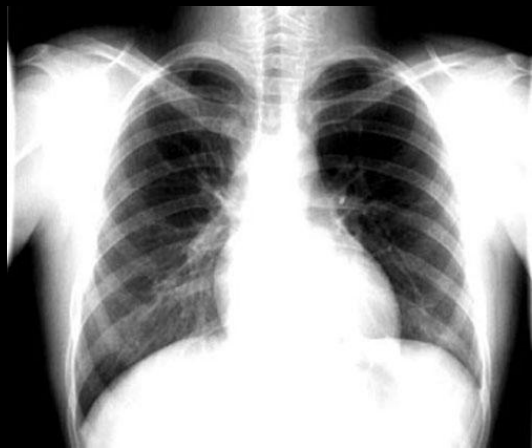
Absorbed Dose (D)

- Amount of energy absorbed per unit mass [$D=d\varepsilon/dm$]
- 1 Gray (Gy) = 1 J/kg
- Specific to the material, e.g.
  - absorbed dose to water
  - absorbed dose to air
  - absorbed dose to bone.



Typical Values of D

- Radiotherapy dose = 40 Gy to tumour *(over several weeks)*
- LD(50/30) = 4 Gy to whole body *(single dose)*
- Annual background dose = 2.5 mGy whole body
- Chest PA = 160 μGy entrance surface dose .



Equivalent Dose ($H_{T,R}$)

- Absorbed dose to tissue x radiation weighting factor [$H_{T,R} = w_R.D_{T,R}$]
- Units are Sieverts (Sv)
  - All photons, electrons and muons, $w_R = 1$
  - Neutrons, w_R = 5-20 *(depending on energy)*
  - Protons, $w_R = 5$
  - Alpha particles, $w_R = 20$
- For X-rays, 1 Gy = 1 Sv
- For alphas, 1 Gy = 20 Sv .

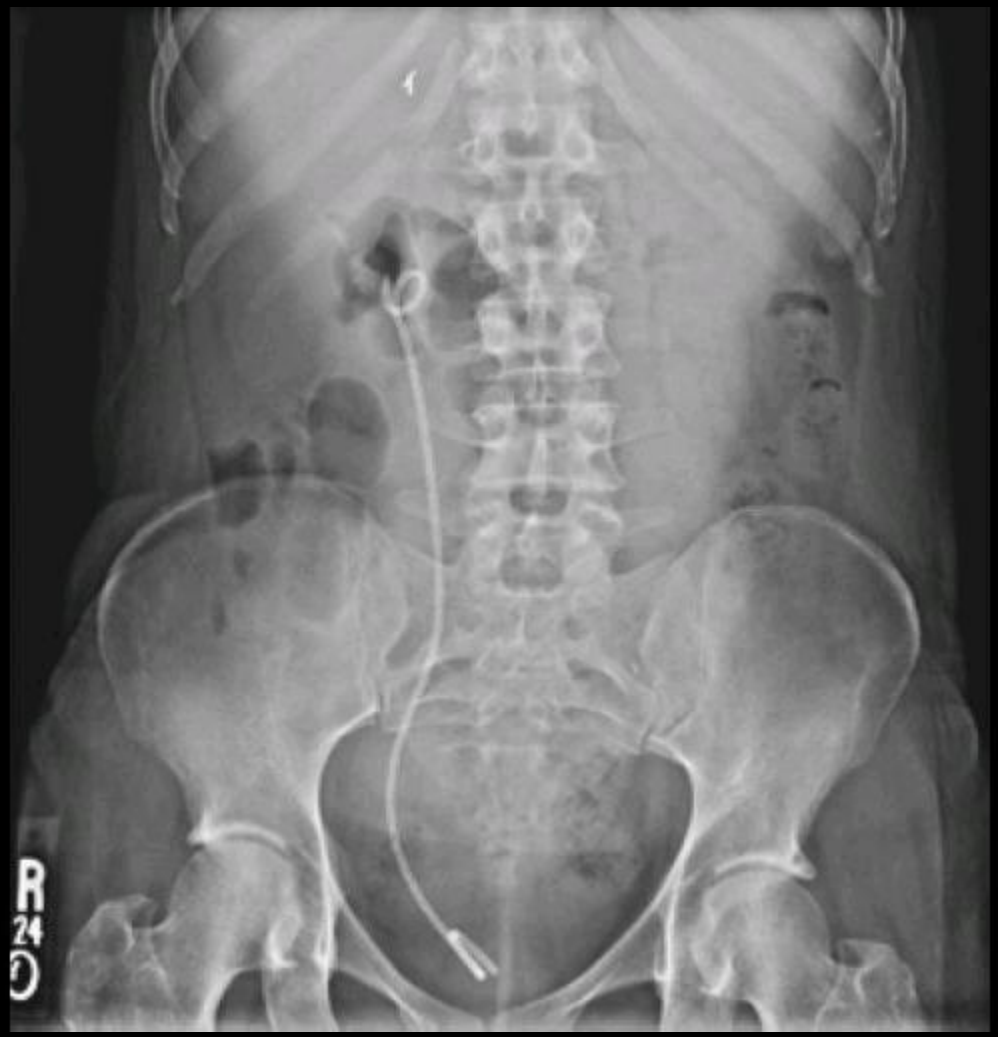
Effective Dose (E)

- Sum of equivalent doses to each tissue/organ x organ weighting factors
- $E = \Sigma_T w_T.H_T$
- Units are Sieverts (Sv)

Tissue or organ	w_T (2007)
Gonads	**0.08**
Red bone marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Bladder	**0.04**
Breast	**0.12**
Liver	**0.04**
Oesphagus	**0.04**
Thyroid	**0.04**
Skin	0.01
Bone surfaces	0.01
Brain	**0.01**
Salivary glands	**0.01**
Remainder	**0.12**

Example

- Abdomen PA
- 80 kVp
- 2.5 mm Al filtration
- 75 cm FSD
- 35 x 43 cm film
- 5.4 mGy entrance skin dose



Tissue or Organ			
Ovaries			
Testes			
Lungs			
Stomach			
Colon			
RBM			
Thyroid			
Breasts			
Oesophagus			
Liver			
Urinary bladder			
Skin			
Total bone			
Brain			
Salivary glands			
Average remainder			
		Effective dose = $\Sigma_T w_T.H_T$	

Tissue or Organ	Organ dose, H_T (mSv)		
Ovaries	0.805		
Testes	0.079		
Lungs	0.037		
Stomach	0.417		
Colon	0.718		
RBM	0.599		
Thyroid	0.000		
Breasts	0.007		
Oesophagus	0.042		
Liver	0.518		
Urinary bladder	0.450		
Skin	0.386		
Total bone	0.697		
Brain	0.000		
Salivary glands	0.000		
Average remainder	0.472		
			Effective dose = $\Sigma_T\ w_T.H_T$

Tissue or Organ	Organ dose, H_T (mSv)	Weighting Factor, w_T	
Ovaries	0.805	0.04	
Testes	0.079	0.04	
Lungs	0.037	0.12	
Stomach	0.417	0.12	
Colon	0.718	0.12	
RBM	0.599	0.12	
Thyroid	0.000	0.04	
Breasts	0.007	0.12	
Oesophagus	0.042	0.04	
Liver	0.518	0.04	
Urinary bladder	0.450	0.04	
Skin	0.386	0.01	
Total bone	0.697	0.01	
Brain	0.000	0.01	
Salivary glands	0.000	0.01	
Average remainder	0.472	0.12	
		Effective dose = $\Sigma_T\ w_T.H_T$	

Tissue or Organ	Organ dose, H_T (mSv)	Weighting Factor, w_T	H_T x w_T (mSv)
Ovaries	0.805	0.04	0.032
Testes	0.079	0.04	0.003
Lungs	0.037	0.12	0.004
Stomach	0.417	0.12	0.050
Colon	0.718	0.12	0.086
RBM	0.599	0.12	0.072
Thyroid	0.000	0.04	0.000
Breasts	0.007	0.12	0.001
Oesophagus	0.042	0.04	0.002
Liver	0.518	0.04	0.021
Urinary bladder	0.450	0.04	0.018
Skin	0.386	0.01	0.004
Total bone	0.697	0.01	0.007
Brain	0.000	0.01	0.000
Salivary glands	0.000	0.01	0.000
Average remainder	0.472	0.12	0.057
Effective dose = Σ_T w_T.H_T			

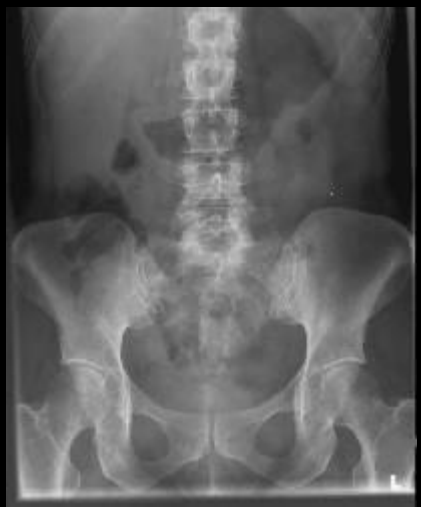
Tissue or Organ	Organ dose, H_T (mSv)	Weighting Factor, w_T	H_T x w_T (mSv)
Ovaries	0.805	0.04	0.032
Testes	0.079	0.04	0.003
Lungs	0.037	0.12	0.004
Stomach	0.417	0.12	0.050
Colon	0.718	0.12	0.086
RBM	0.599	0.12	0.072
Thyroid	0.000	0.04	0.000
Breasts	0.007	0.12	0.001
Oesophagus	0.042	0.04	0.002
Liver	0.518	0.04	0.021
Urinary bladder	0.450	0.04	0.018
Skin	0.386	0.01	0.004
Total bone	0.697	0.01	0.007
Brain	0.000	0.01	0.000
Salivary glands	0.000	0.01	0.000
Average remainder	0.472	0.12	0.057
		Effective dose = Σ_T w_T.H_T	0.36 mSv

What's effective dose for?

- Organ doses ranged
  - from 0.00 mSv (brain, thyroid)
  - to 2.97 mSv (kidneys)
- Effective dose was 0.36 mSv
- Risk of inducing cancer ≡ risk of 0.36 mSv to all organs/tissues.

Typical Values of E

- Barium enema = 7 mSv
- CT abdomen = 10 mSv
- Conventional abdomen = 1.0 mSv
- Chest PA = 20 μSv
- Annual dose limit for radiation workers = 20 mSv
- Annual background dose = 2.5 mSv .



Radiation Quantities and Units

- Absorbed dose, D
  - Gray (Gy)
  - e.g. organ dose
- Equivalent dose, H
  - accounts for type of radiation
  - Sieverts (for X-rays 1 Sv = 1 Gy)
- Effective dose, E
  - accounts for different organ sensitivity
  - “whole dose dose”
  - Sv

Kerma (K)

- **K**inetic **E**nergy **R**eleased per unit **MA**ss
- sum of the initial kinetic energies of all the charged particles liberated by uncharged ionizing radiation per unit mass [$K=dE_{tr}/dm$]
- 1 Gray (Gy) = 1 J/kg
- Specific to the material, e.g.
  - Air kerma – (most electronic radiation meters are calibrated in this)
- At high photon energies K > D [at 1000keV e.g. $D_{air} = 0.997.K_{air}$]
- At low photon energies K ≈ D [at 100keV e.g. $D_{air} = 0.9998.K_{air}$]

Typical Value of K

- Typical X-ray set output at 80 kVp
  - 14 mGy per 100 mAs at 75 cm .

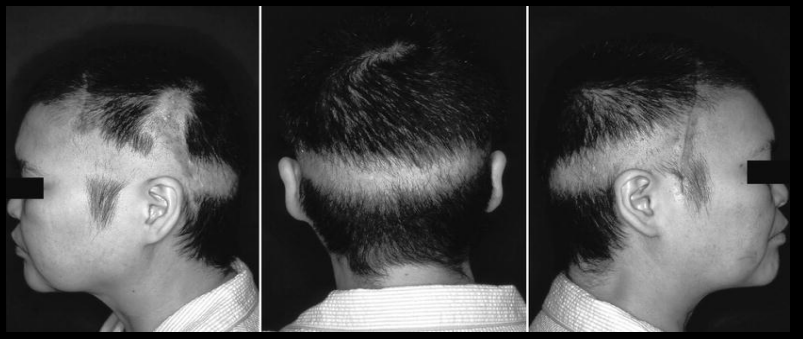
Others

- Dose equivalent (Sv) - superseded by equivalent dose
- Effective dose equivalent (Sv) - superseded by effective dose
- Ambient dose equivalent (Sv) - dose a particular depth *(often used for personal dosimeter results)*
- Dose area product ($Gy.cm^2$) - dose x field size
- Exposure (R or C/kg) – electrical charge produced in 1 kg of air
- Collective dose (manSv) - effective dose x number of people exposed .

Old Units

- 100 rad = 1 Gy = 100cGy
- 100 rem = 1 Sv
- 100 R ≈ 0.9 Gy

Two Types of Effect



- Tissue reactions
  - *deterministic effects/ non-stochastic effects*
- Stochastic effect (“chance effects”)
  - somatic

  - hereditary

Deterministic Effects

- Caused by significant cell necrosis
- Not seen below a threshold dose
- Above the threshold, the bigger the dose, the worse the effect .

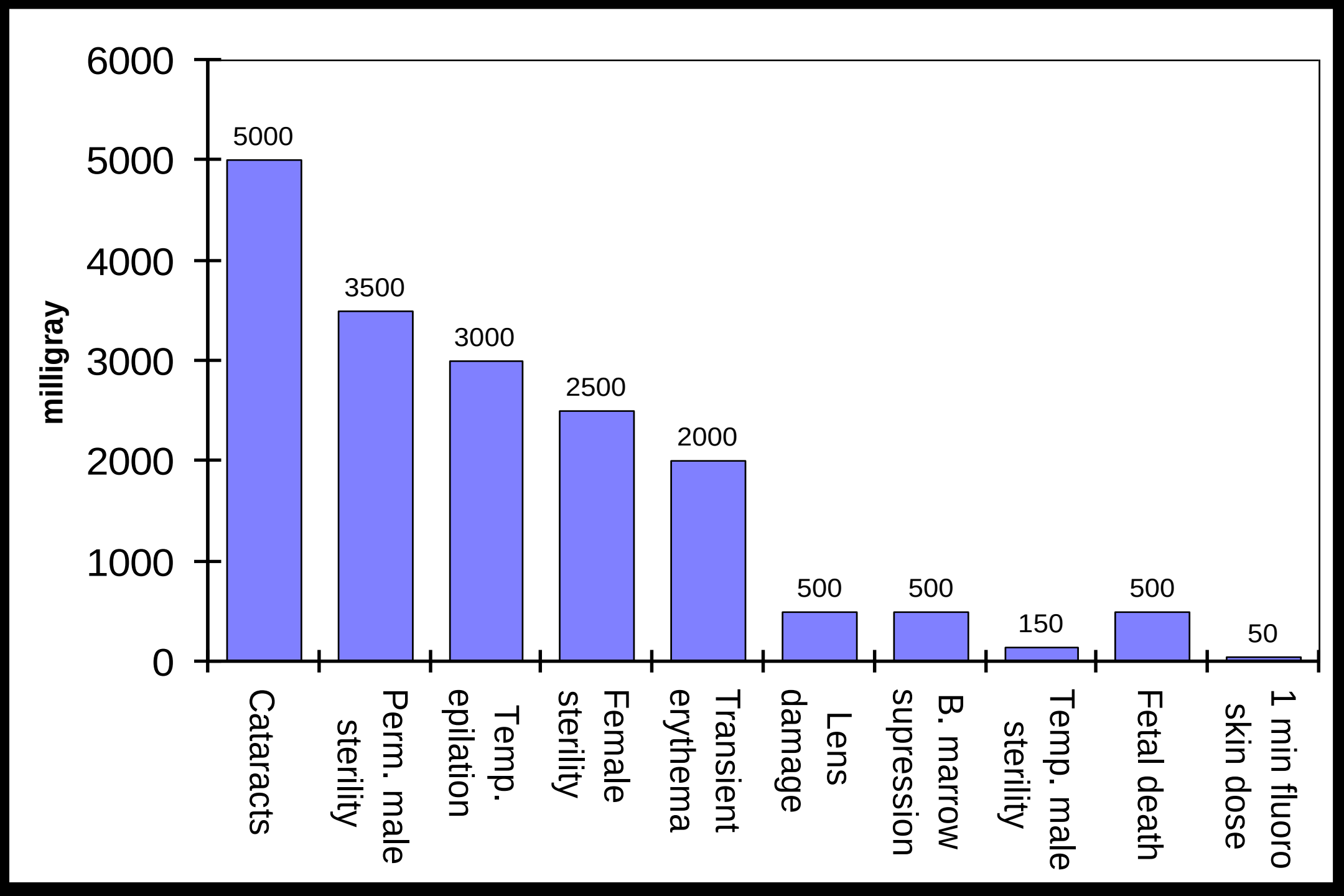

milligray
6000
5000
4000
3000
2000
1000
0
5000
3500
3000
2500
2000
500
500
150
500
50
Cataracts
Perm. male sterility
Temp. epilation
Female sterility
Transient erythema
Lens damage
B. marrow supression
Temp. male sterility
Fetal death
1 min fluoro skin dose

Table A.3.4. Projected threshold estimates of the acute absorbed doses for 1% incidences of morbidity and mortality involving adult human organs and tissues after whole body gamma ray exposures.

Effect	Organ/tissue	Time to develop effect	Absorbed dose (Gy)[e]
Morbidity:			*1% Incidence*
Temporary sterility	Testes	3–9 weeks	~0.1[a,b]
Permanent sterility	Testes	3 weeks	~6[a,b]
Permanent sterility	Ovaries	< 1week	~3[a,b]
Depression of blood-forming process	Bone marrow	3–7 days	~0.5[a,b]
Main phase of skin reddening	Skin (large areas)	1–4 weeks	<3–6[b]
Skin burns	Skin (large areas)	2–3 weeks	5–10[b]
Temporary hair loss	Skin	2–3 weeks	~4[b]
Cataract (visual impairment)	Eye	Several years	~1.5[a,c]
Mortality:			
Bone marrow syndrome:			
– without medical care	Bone marrow	30–60 days	~1[b]
– with good medical care	Bone marrow	30–60 days	2–3[b,d]
Gastro-intestinal syndrome:			
– without medical care	Small intestine	6–9 days	~6[d]
– with good medical care	Small intestine	6–9 days	>6[b,c,d]
Pneumonitis	Lung	1–7 months	6[b,c,d]

[a] ICRP (1984).
[b] UNSCEAR (1988).
[c] Edwards and Lloyd (1996).
[d] Scott and Hahn (1989), Scott (1993).
[e] Most values rounded to the nearest Gy; ranges indicate area dependence for skin and differing medical support for bone marrow.

Radiation-Induced Skin Injuries, from FDA, Sept 1994, "Avoidance of serious x-ray induced skin injuries to patients during fluoroscopically-guided procedures"

Effect	Threshold Dose	Fluoroscopy time to reach threshold		Time to onset of effect
		Typical fluoro. dose rate of 20 mGy/min	High-level dose rate of 200 Gy/min	
Early transient erythema	2 Gy	1 hr 42 min	10 min	hours
Temporary epilation	3 Gy	2½ hr	15 min	3 weeks
Main erythema	6 Gy	5 hr	30 min	10 days
Permanent epilation	7 Gy	6 hr	35 min	3 weeks
Dry desquamation	10 Gy	8 hr	50 min	4 weeks
Invasive fibrosis	10 Gy	8 hr	50 min	
Dermal atrophy	11 Gy	9 hr	55 min	> 14 wks
Telangiectasis	12 Gy	10 hr	1 hr	> 52 wks
Moist desquamation	15 Gy	12½ hr	1 hr 15 min	4 weeks
Late erythema	15 Gy	12½ hr	1 hr 15 min	6-10 wks
Dermal necrosis	18 Gy	15 hr	1 hr 30 min	> 10 wks
Secondary ulseration	20 Gy	17 hr	1 hr 40 min	> 6 wks

Example of Radiation Injury in Fluoroscopy

- 40 year old male
- coronary angiography
- coronary angioplasty
- second angiography procedure due to complications
- coronary artery by-pass graft
- all on a single day.

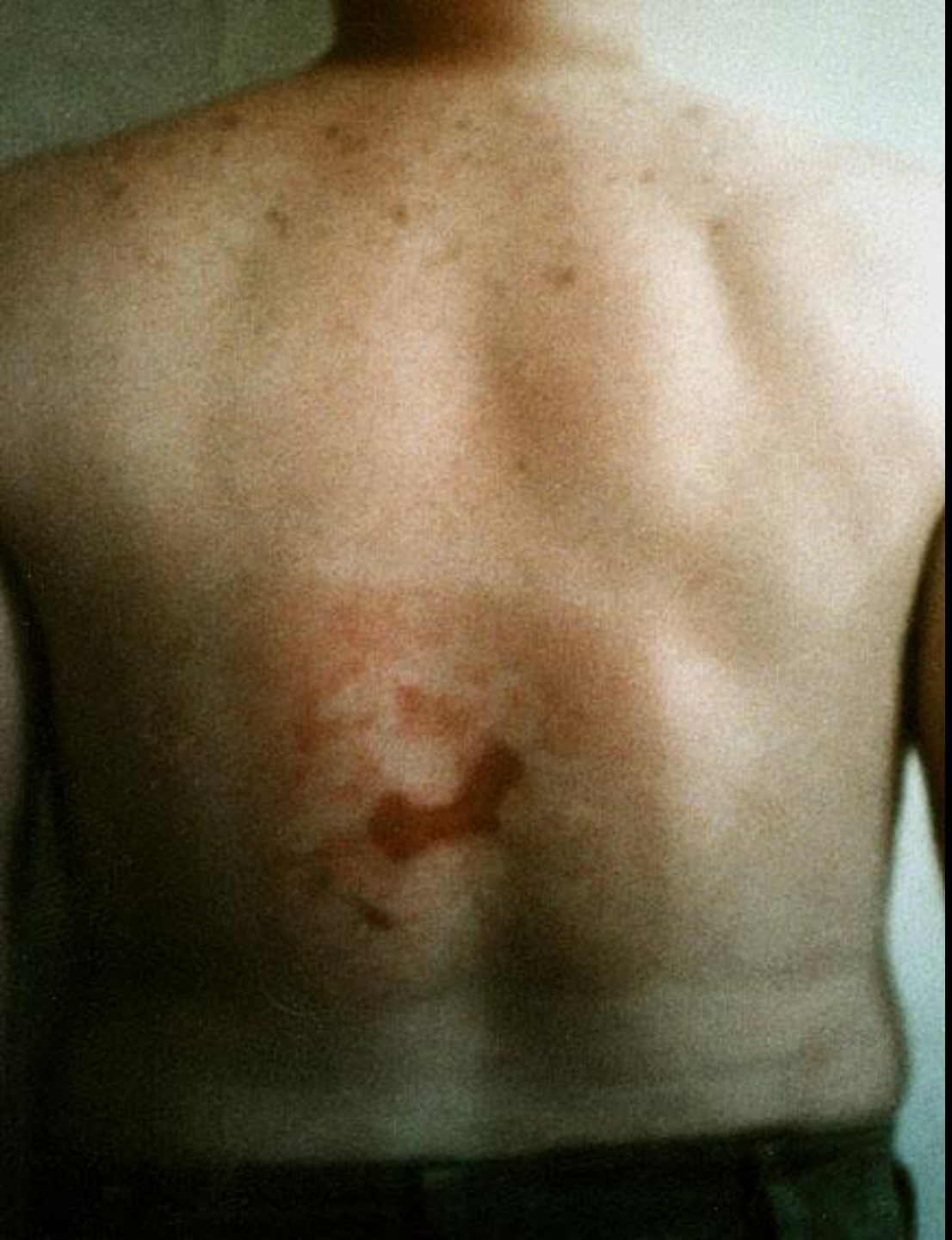


Fig. A

6-8 weeks after multiple coronary angiography and angioplasty procedures

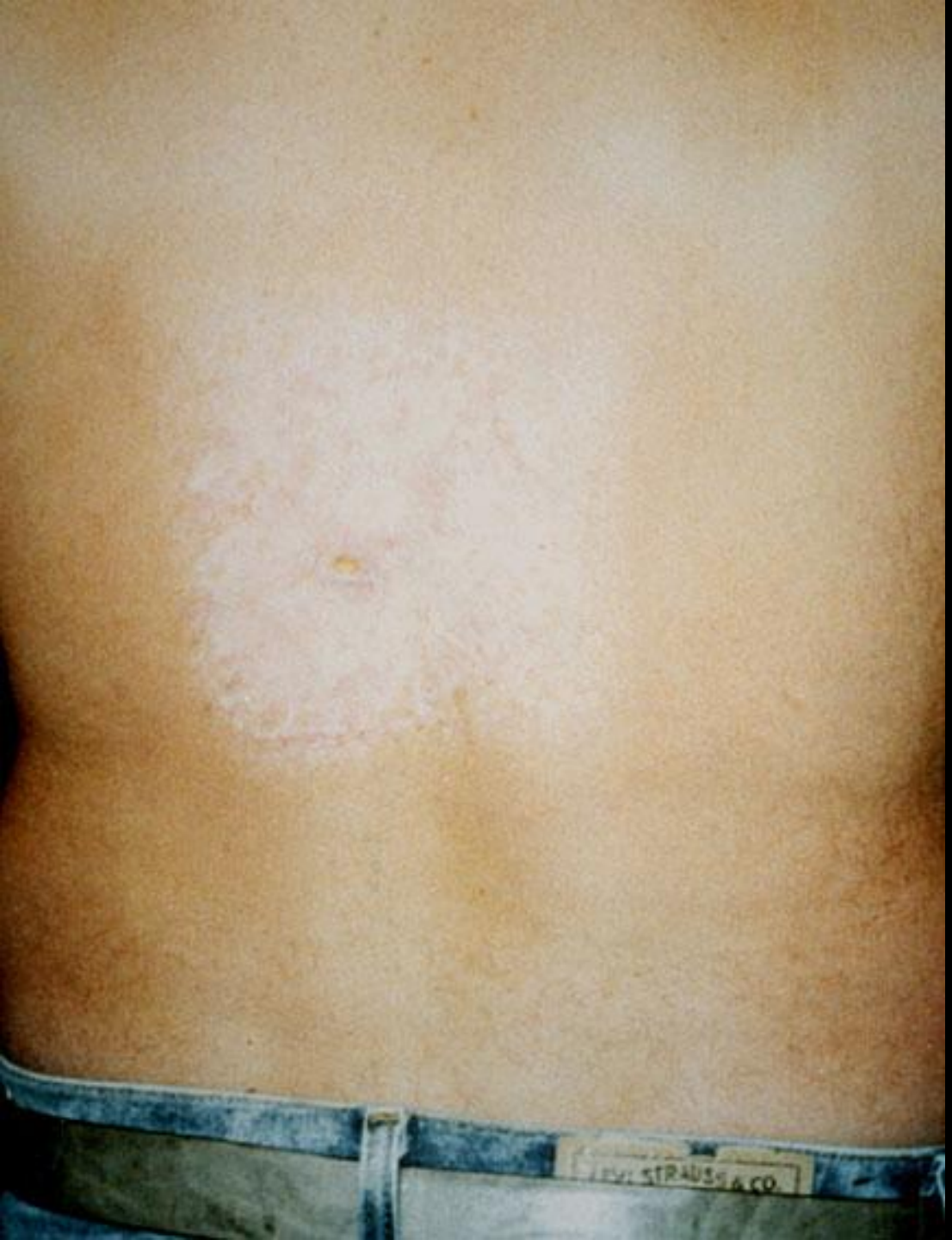


Fig. B

16 to 21 weeks after procedure, with small ulcerated area present

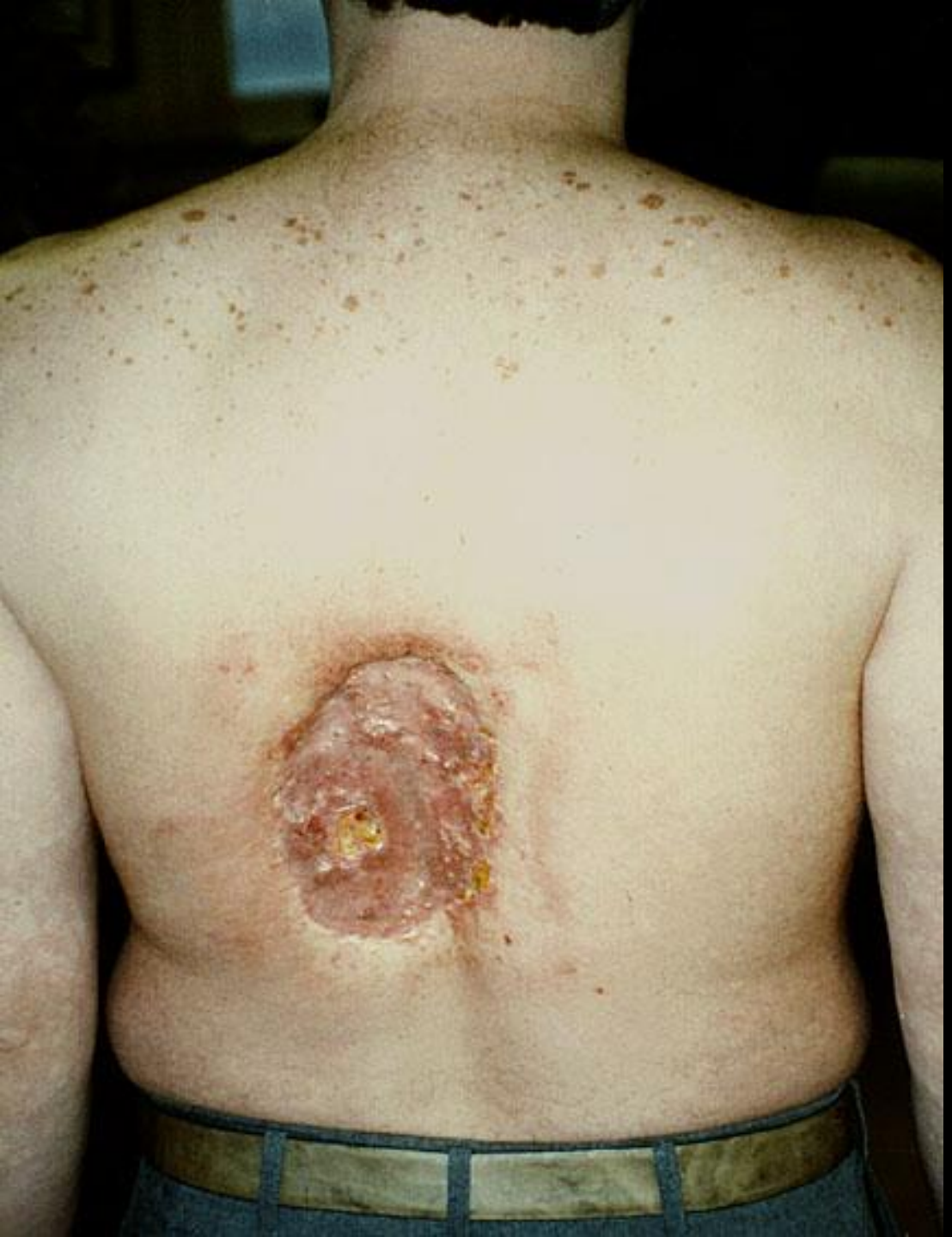


Fig. C

18-21 months after procedure, evidencing tissue necrosis

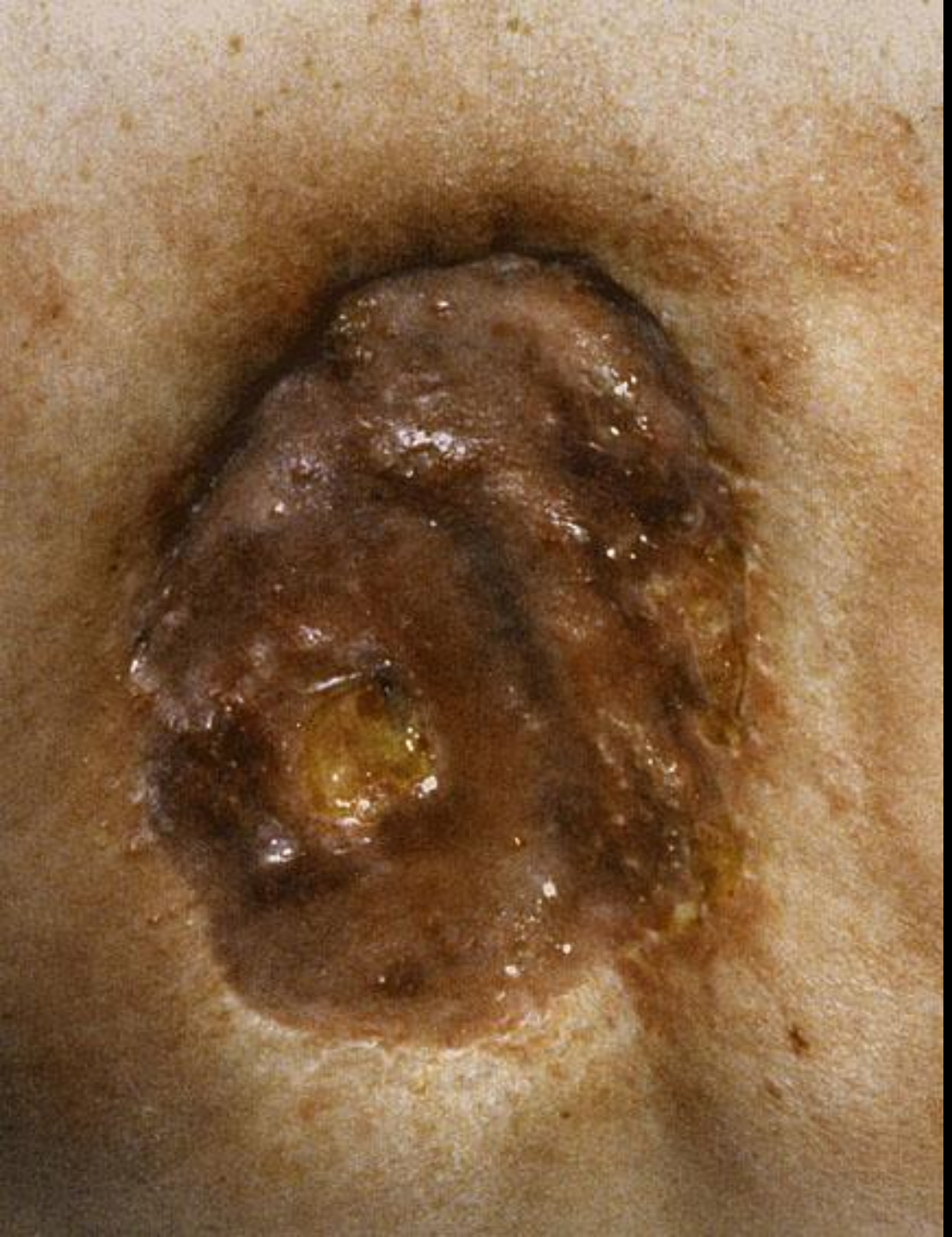


Fig. D

Close up of lession in Fig. C

From injury, dose probably in excess of 20 Gy .

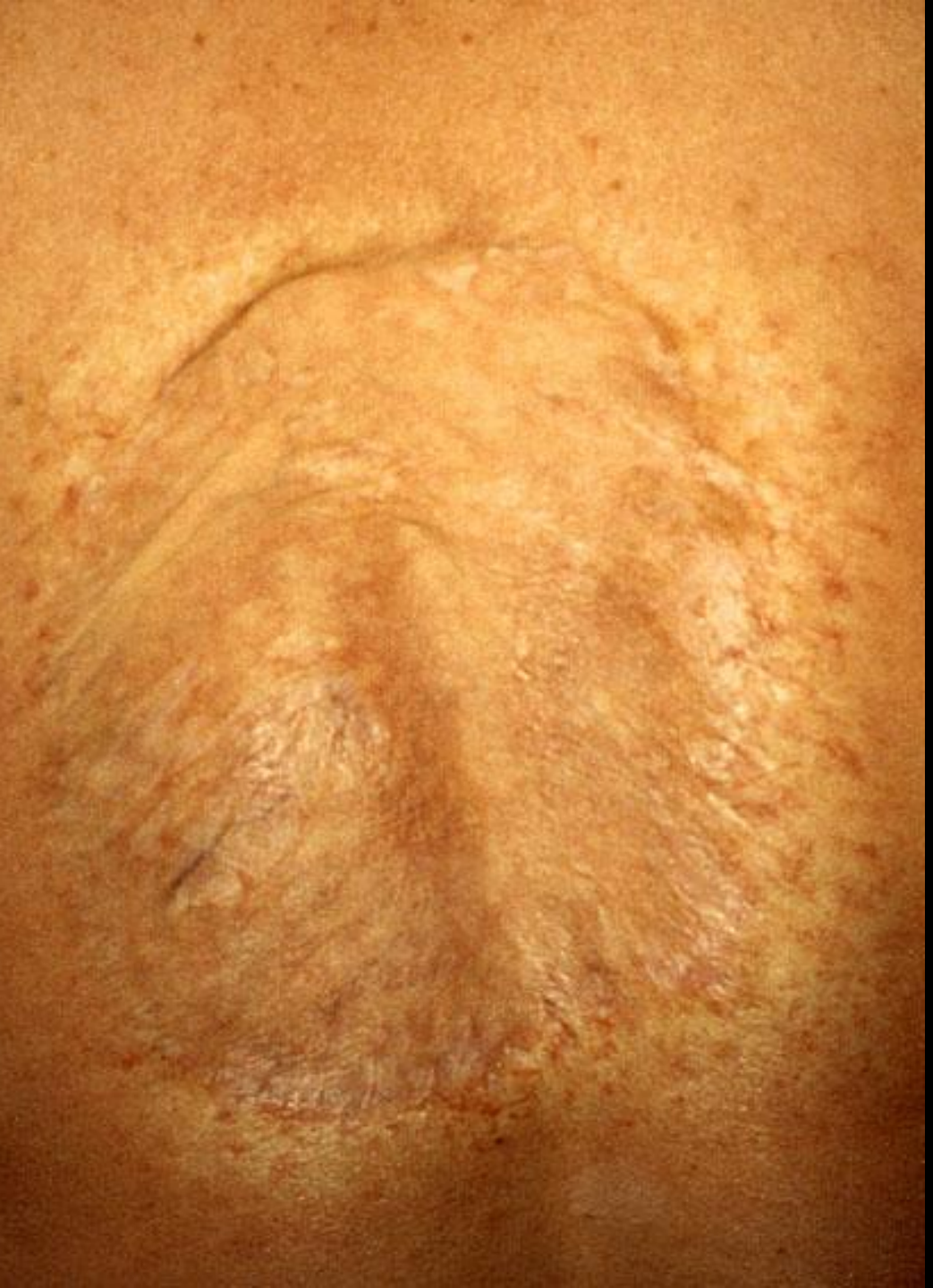
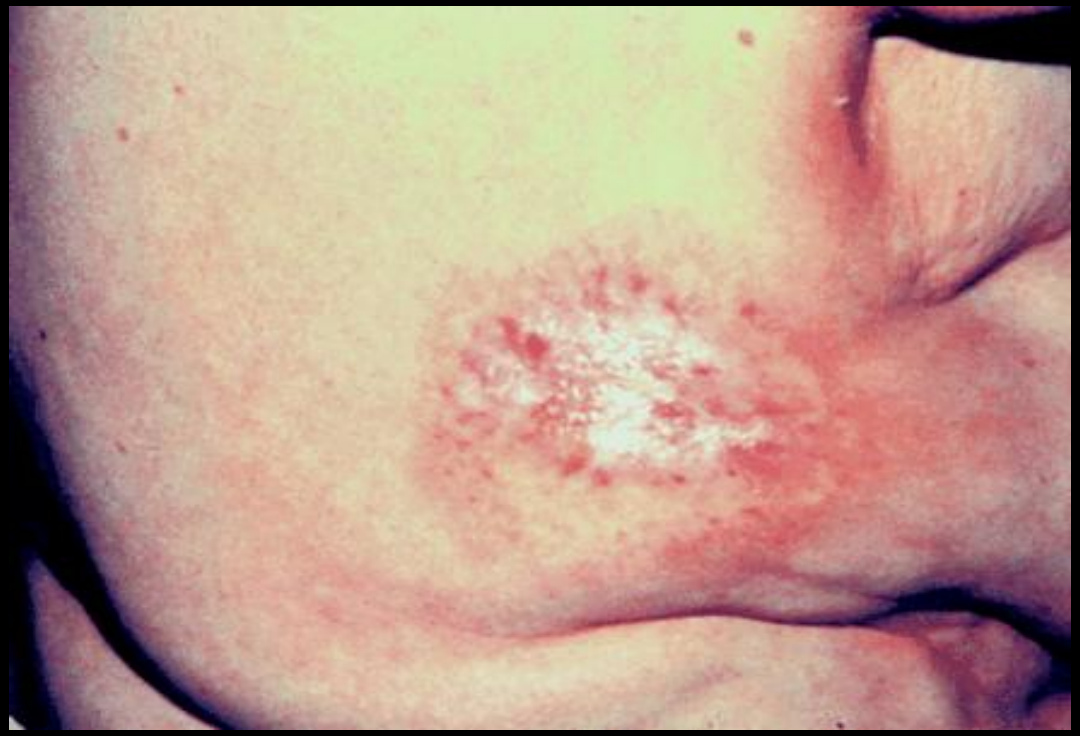
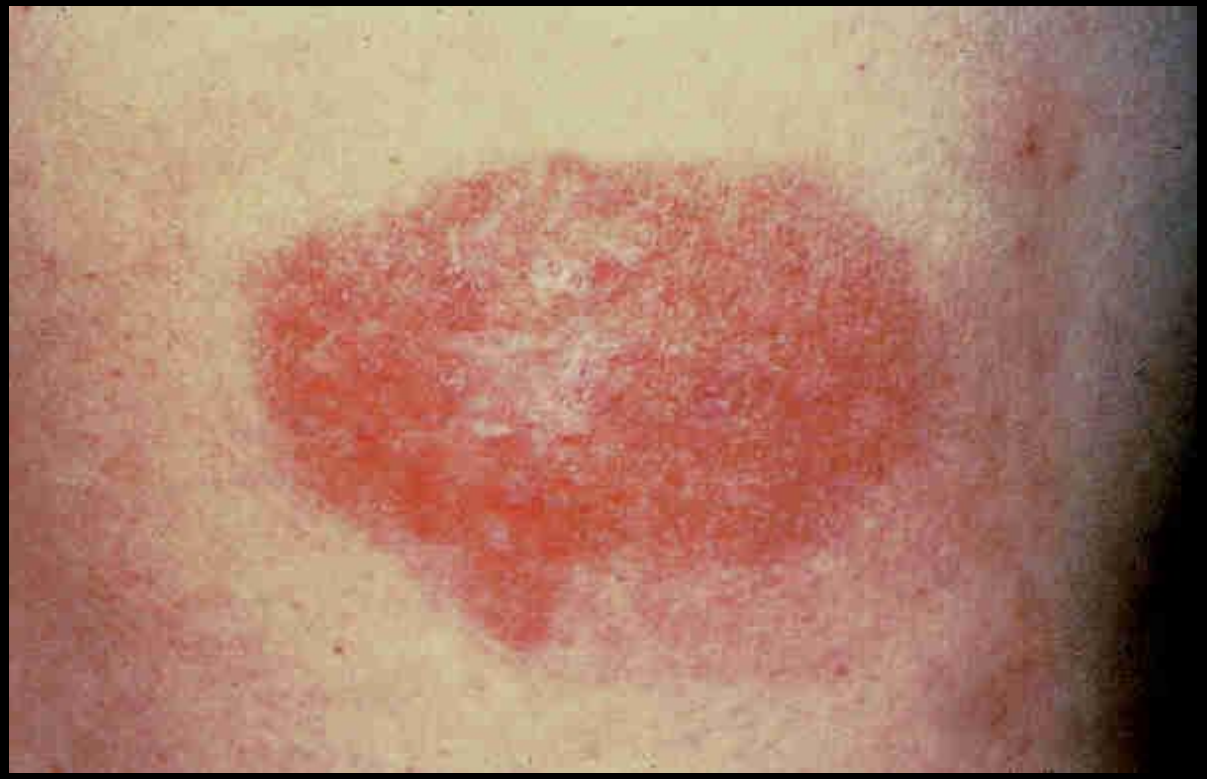


Fig. E

Appearance after skin grafting procedure .



75-year-old woman with 90% stenosis of right coronary artery. Photograph of right lateral chest obtained 10 months after percutaneous transluminal coronary angioplasty shows area of hyper- and hypopigmentation, skin atrophy, and telangiectasia (poikiloderma)

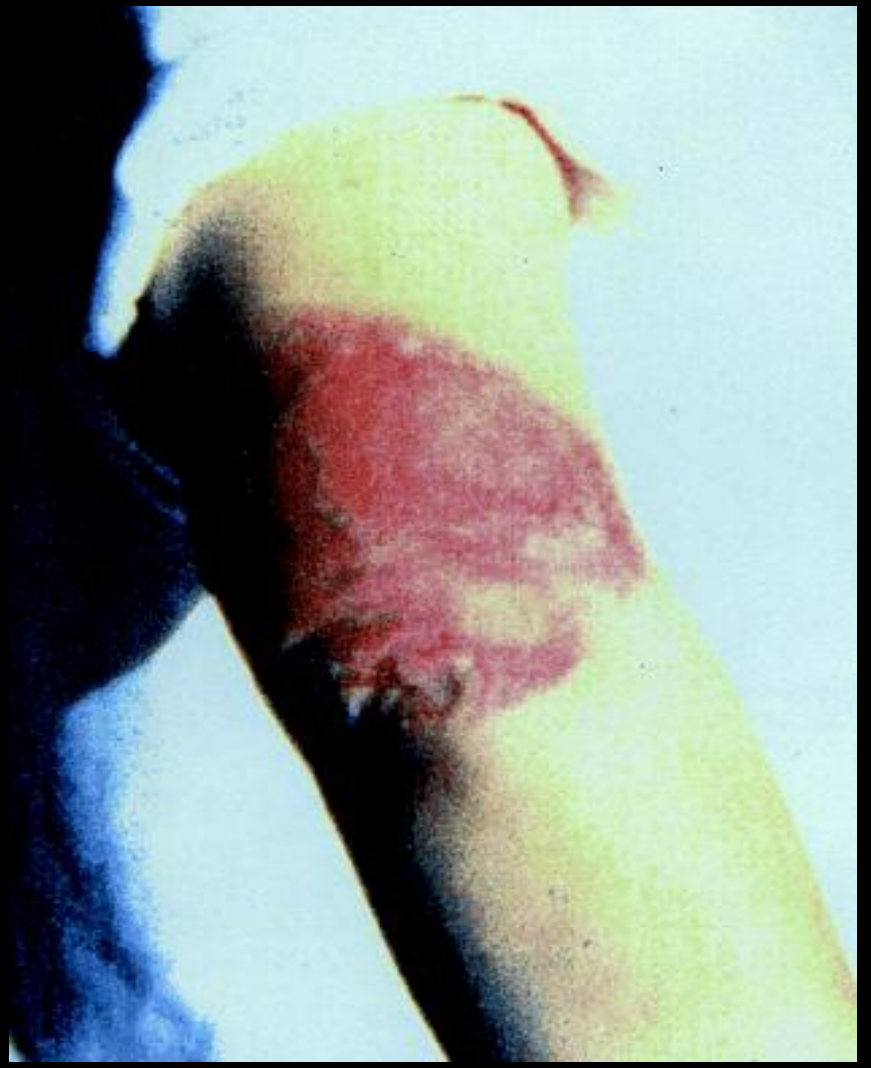


56-year-old man with obstructing lesion of right coronary artery. Photograph of right posterolateral chest wall at 10 weeks after percutaneous transluminal coronary angioplasty shows 12 x 6.5 cm hyperpigmented plaque with hyperkeratosis

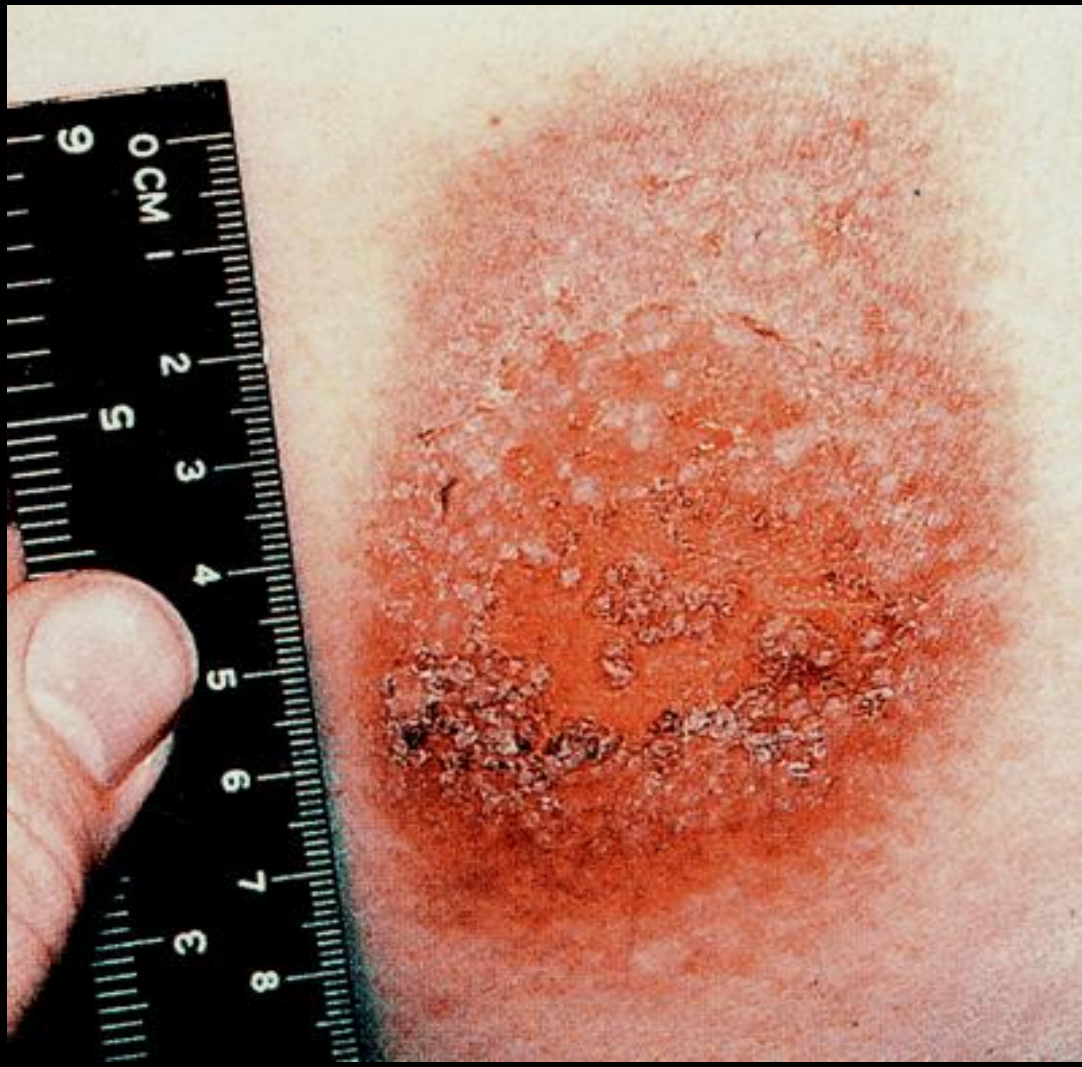
below right axilla

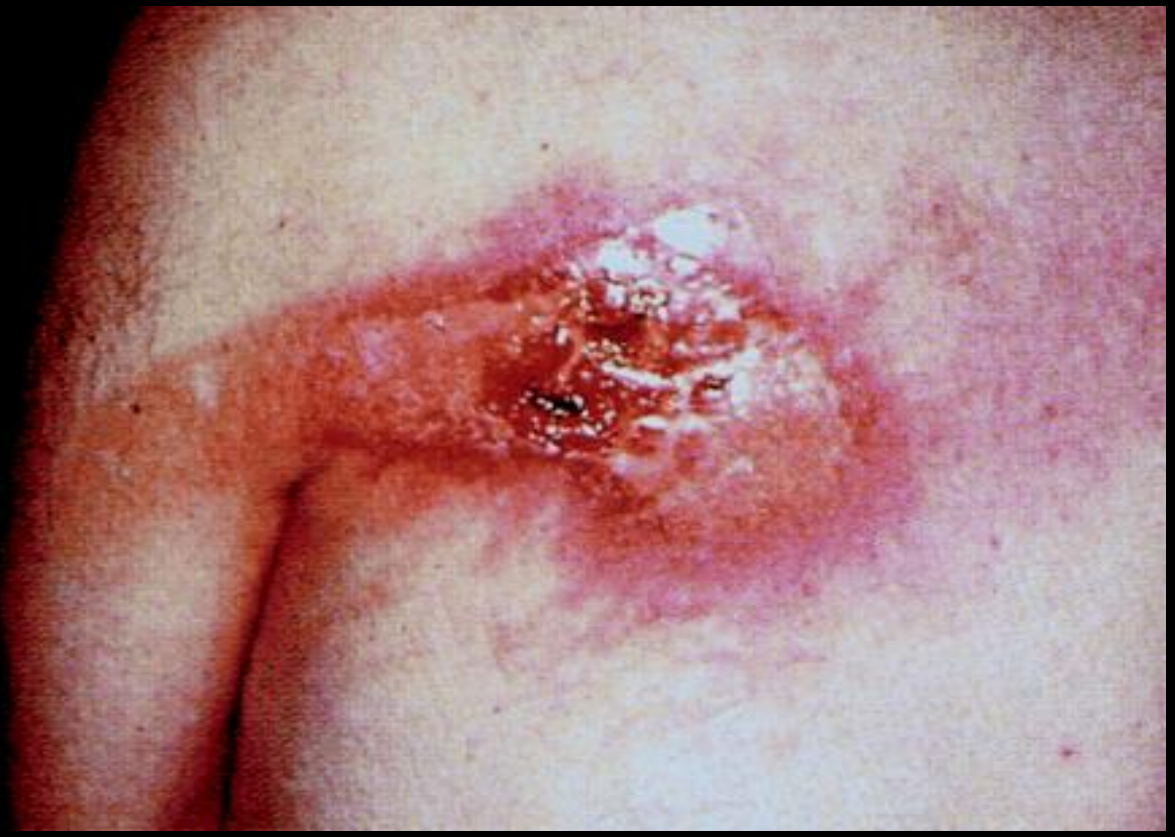
49-year-old woman with 8-year history of refractory supraventricular tachycardia. Photographs show sharply demarcated erythema above right elbow at

3 weeks after radiofrequency cardiac catheter ablation



48-year-old woman with history of diabetes mellitus and severe coronary artery disease who underwent two percutaneous transluminal coronary angioplasties and stent placements within a month. Photograph of left mid back 2 months after last procedure shows well-marginated focal erythema and desquamation





69-year-old man with history of angina who underwent two angioplasties of left coronary artery within 30 hr. Photograph taken 1-2 months after last procedure shows secondary ulceration over left scapula

Stochastic Effects

- Caused by cell mutation leading to
  - cancer or
  - hereditary disease
- Current theory says, no threshold
- The bigger the dose, the more likely effect.

ICRP risk factors

(International Commission on Radiological Protection, ICRP Publication 103, 2007)

ICRP Publication 103

Table 1. Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate.

Exposed population	**Cancer**		**Heritable effects**		**Total**	
	Present[1]	***Publ. 60***	**Present**[1]	***Publ. 60***	**Present**[1]	***Publ. 60***
Whole	5.5	6.0	0.2	1.3	5.7	7.3
Adult	4.1	4.8	0.1	0.8	4.2	5.6

[1] Values from Annex A.

ICRP definition of "detriment"

The total harm to health experienced by an exposed group and its descendants as a result of the group's exposure to a radiation source.

Detriment is a multidimensional concept. Its principal components are the stochastic quantities:

- probability of attributable fatal cancer,
- weighted probability of attributable non-fatal cancer,
- weighted probability of severe heritable effects, and
- length of life lost if the harm occurs.

ICRP risk factors

(International Commission on Radiological Protection, ICRP Publication 103, 2007)

ICRP Publication 103

Table 1. Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate

Exposed						
Whole Adult	4.1	4.8	0.1	0.8	4.2	5.6

[1] Values from Annex A.

$$P(n \geq 1) = 1 - e^{-(E \times \text{risk factor})}$$

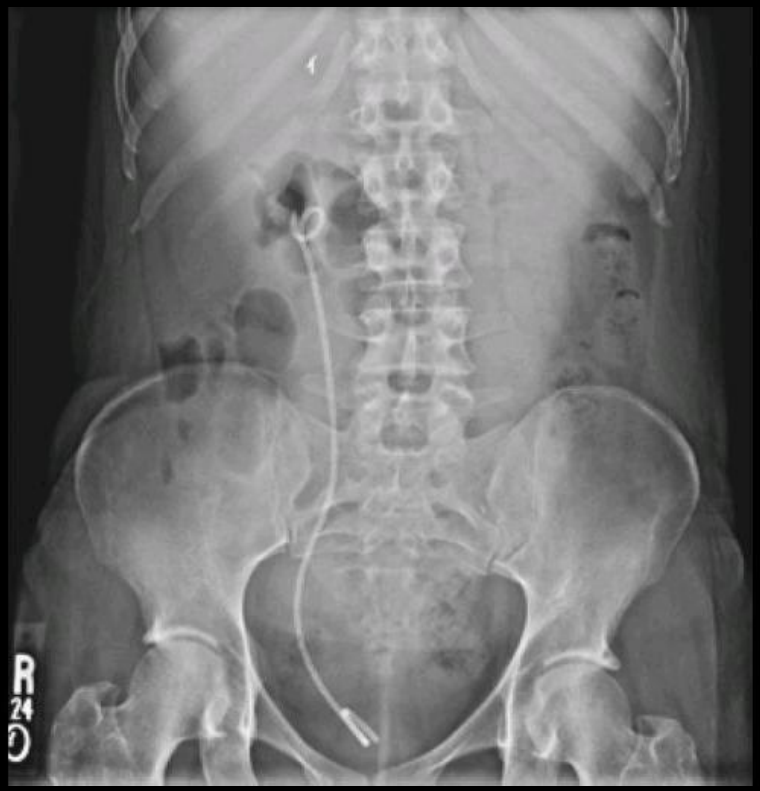
If $E \times \text{risk} \ll 1$ then $P(n \geq 1) \approx E \times \text{risk}$

5.6×10^{-5} per mSv ≡ 1 in 18,000 detriment

(Previous ICRP60 gave risk of fatal cancer

5.0×10^{-5} per mSv ≡ 1 in 20,000 chance).

1 in 20,000 risk

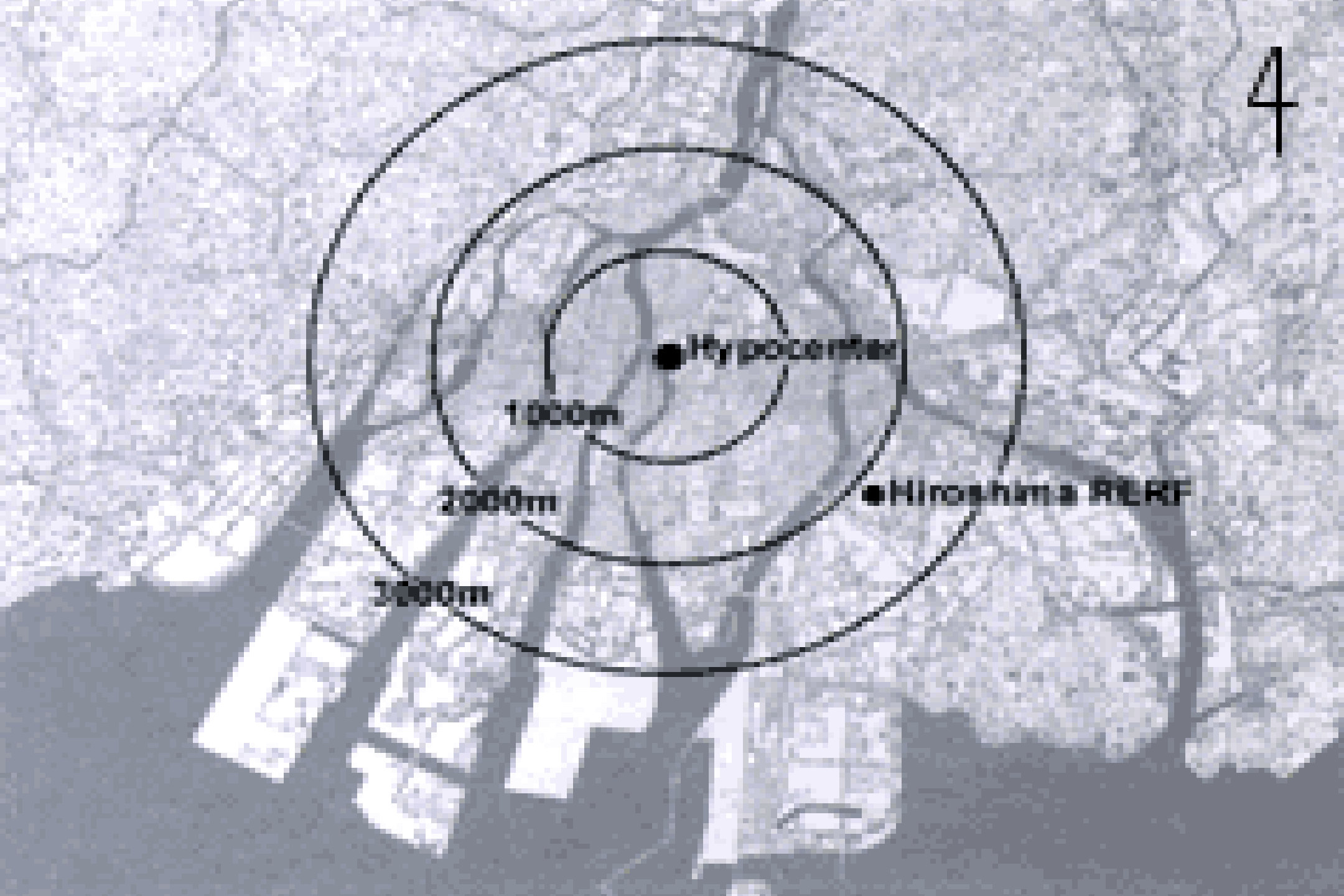


≡

Risk of fatal cancer from 1 mSv

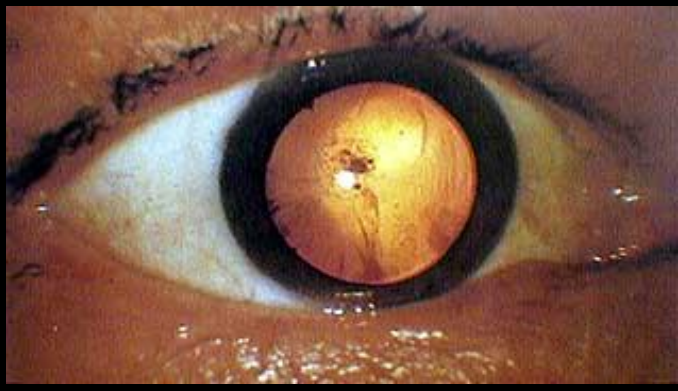
Risk of fatal car accident in UK in 1 year

Evidence of Stochastic Effects

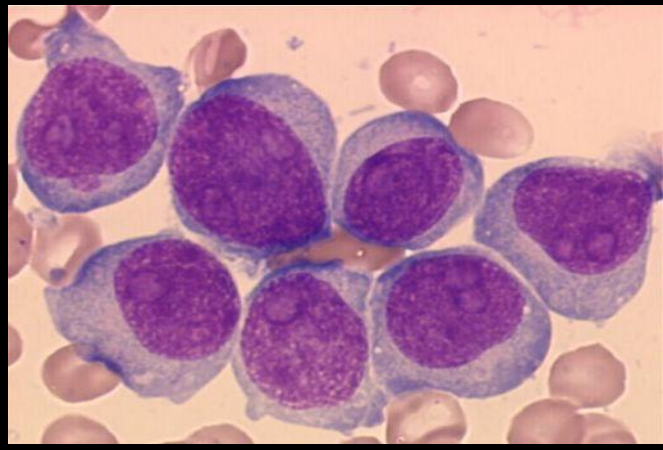

Hypocenter
1000m
2000m
3000m
Hiroshima RERF

Radiation Effects

- Acute radiation syndrome
- Including vomiting, diarrhea, reduction in the number of blood cells, bleeding, epilation (hair loss), temporary sterility in males, and lens opacity (clouding)



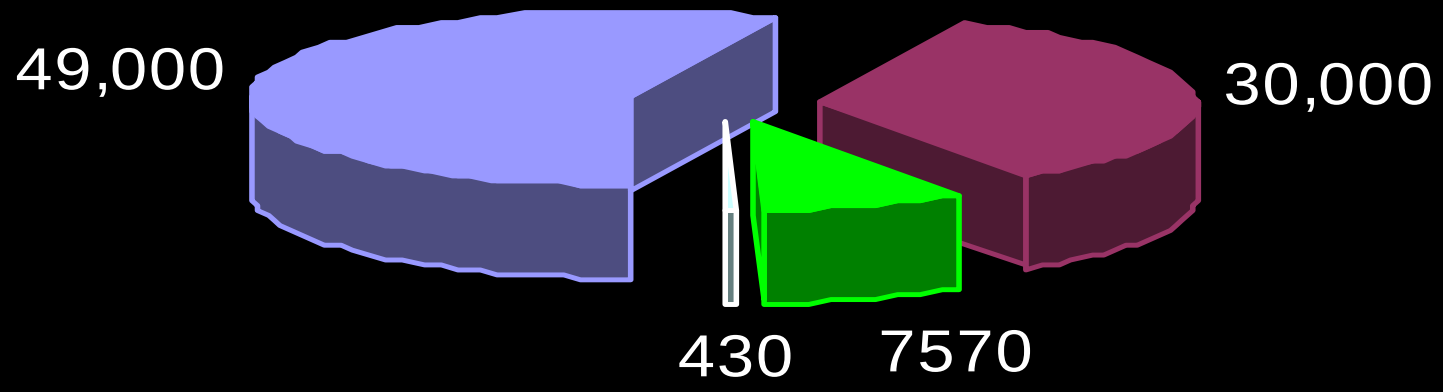
- Late 1940's Dr Takuso Yamawaki noted an increase in leukaemia
- 20% of radiation cancers were leukaemia (normal incidence 4%)
- Incidence peaked at 6-8 years
- Solid cancers – excess seen from 10 years onwards.



Life Span Study

- About 94,000 persons,
- > 50% still alive in 1995
- By 1991 about 8,000 cancer deaths
- ~ 430 of these attributable to radiation
- *(Note – a radiation induced cancer is indistinguishable from a "natural" cancer)*
- 21 out of 800 in utero with dose > 10 mSv severely mentally retarded individuals have been identified
- No increase in hereditary disease
- http://www.rerf.or.jp/eigo/glossary/lsspopul.htm

Atomic Bomb Survivors 1990



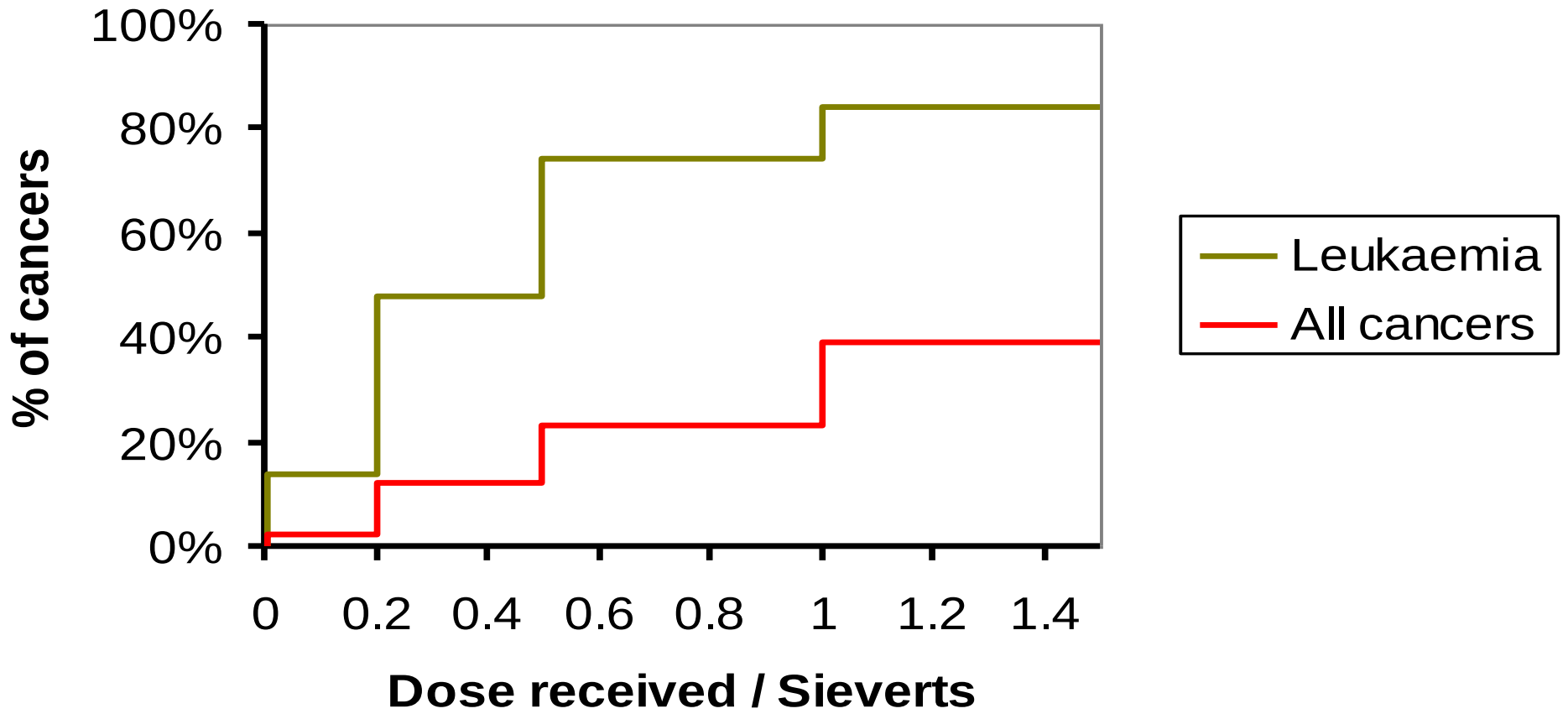
- Still alive in 1990
- Non-cancer death
- "Natural" cancer death
- Radiation induced cancer death

Cancer deaths between 1950 and 1990 among Life Span Study survivors with significant exposure

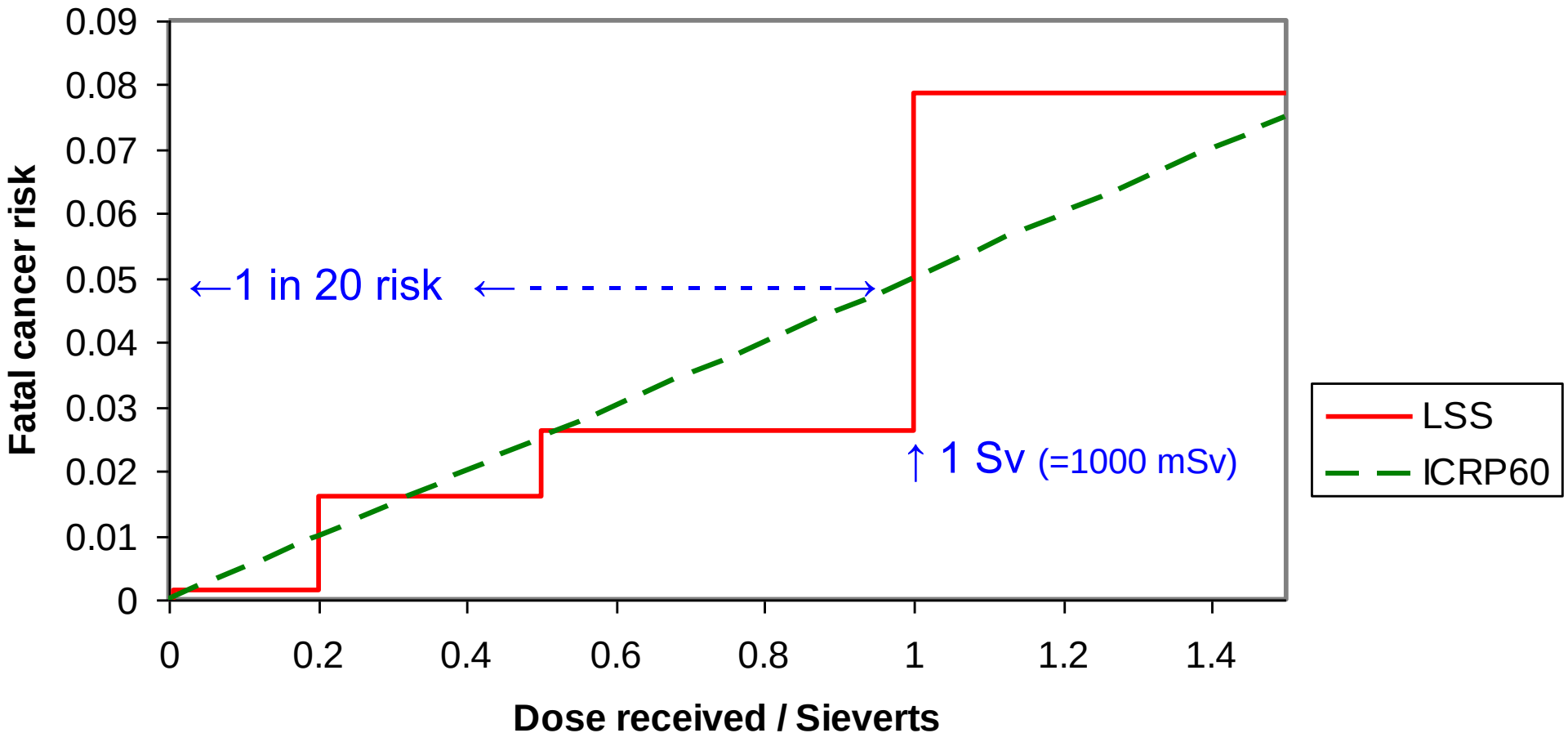
(i.e. > 5 mSv or within 2.5 km of the hypercentre)

Dose range	Number of cancer deaths	Estimated excess death	Attributable fraction
5 - 200 mSv	3391	63	2 %
200 - 500 mSv	646	76	12 %
0.5 - 1 Sv	342	79	23 %
> 1 Sv	308	121	39 %
All	4687	339	7 %

Atom Bomb Survivors
- % of cancers induced by radiation -



Atom Bomb Survivors (LSS) results & ICRP recommended risk factor



Linear Non-Threshold (LNT) model

Data Sources for Risk Estimates

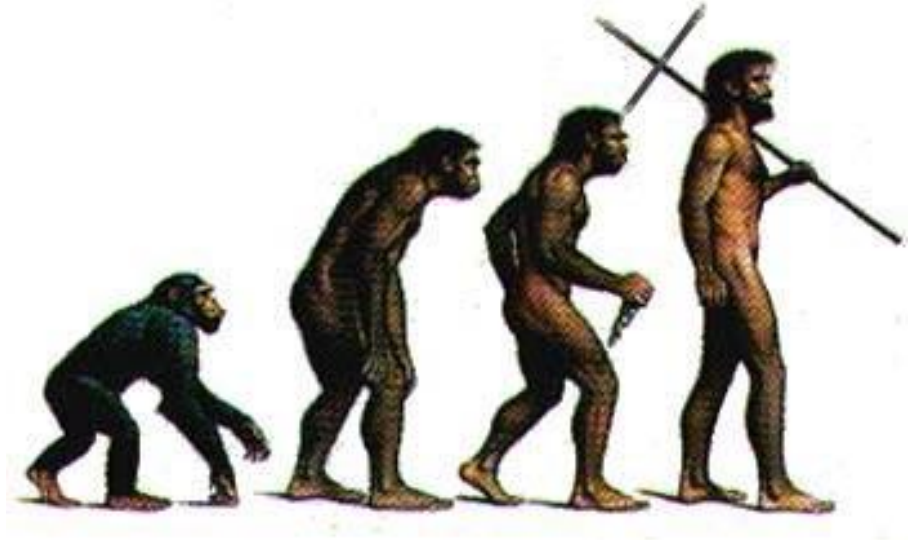
- North American TB patients - *breast, thyroid, skin*
- German patients with Ra-224 - *bone*
- Euro. Patients with Thorotrast - *liver*
- Oxford study - *in utero induced cancer*
- Atomic bomb survivors - *leukaemia, lung, colon, stomach, remainder* .

Doses in Interventional Radiology

Taken from "*Real-time quantification and display of skin radiation during coronary angiography and intervention*", den Boer A, et al., Oct 2001

- 332 patients
- 25 - 99 Gy.cm^2 dose-area product
- 4 - 18 mGy effective dose
- 1:5000 - 1:1100 risk of inducing fatal cancer .

Hereditary Effects

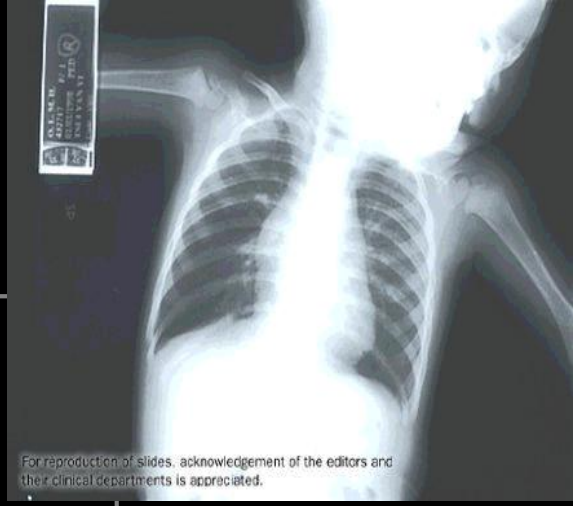


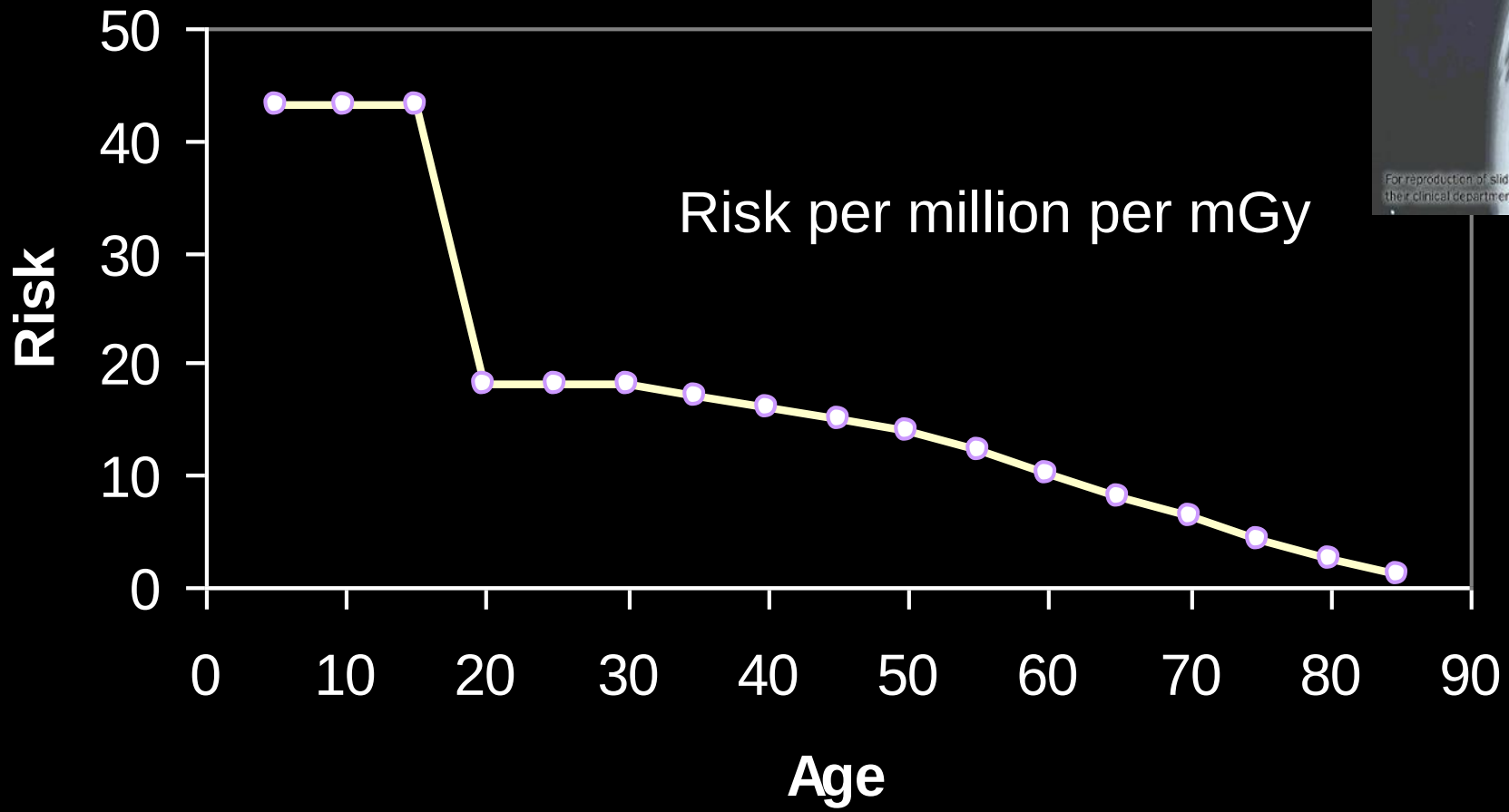
- Observed in animal experiments
- Not observed in A-bomb victims
- ICRP 103 Detriment for severe hereditary disease = 0.2×10^{-5} per mSv *(i.e. < 3% of total detriment).*

Here on 28 Sept

Probability of fatal cancer

(Atom bomb “survivors”)





- i.e. children risk ≈ 3 x adult risk

Radiation Risks to the Fetus

Age	Minimal dose (mGy) for:		
(weeks)	Lethality	Gross malformation	Mental retardation
0-1	No threshold at day 1?	No threshold at day 1?	
	100 mGy thereafter		No effects observed to
2-5	250-500 mGy	200 mGy	about 8 weeks
5-7	500 mGy	500 mGy	
7-21	> 500 mGy	Very few observed	Weeks 8-15: no threshold? 300 mGy
			Weeks 16-25: threshold dose 600-700 mGy
To term	> 1000 mGy	Very few observed	Weeks 25-term: no effects observed

UK 1998 Guidance on Stochastic Risks

Total risk of cancer up to age 15 years following *in utero* exposure (per mGy)

Cancer type	Fatal	Non-fatal	Total
Leukaemia	1.25×10^{-5}	1.25×10^{-5}	2.5×10^{-5}
Other	1.75×10^{-5}	1.75×10^{-5}	3.5×10^{-5}
Total	3.0×10^{-5}	3.0×10^{-5}	6.0×10^{-5}

- at 8-15 weeks it is estimated that 30 IQ points are lost per 1000 mGy.
- Risk of heritable effects estimated at 2.4×10^{-5} per mGy

"Natural Risks"

Heritable disease	1×10^{-2} to 6×10^{-2}
Fatal cancer to age 15 years	7.7×10^{-4}
Lifetime cancer risk	20×10^{-2} to 25×10^{-2}

Fetal Doses from Medical Exposure (mGy)

Examination	Mean	Max.
Conventional X-ray		
Abdomen (AP only)	1.4	4.2
Barium enema	6.8	24
Barium meal	1.1	5.8
Chest	< 0.01	< 0.01
Intravenous urography	1.7	10
Lumbar spine	1.7	10
Pelvis	1.1	4
Skull	< 0.01	< 0.01
Thoracic spine	< 0.01	< 0.01
CT		
Abdomen	8	49
Chest	0.06	0.96
Head	< 0.005	< 0.005
Pelvis	25	79
Pelvimetry	0.2	0.4

Fetal Doses from Medical Exposure (mGy)

Examination	Mean	Max.
Nuclear Medicine		
^{99m}Tc bone scan (phosphate)	3.3	4.6
^{99m}Tc lung perfusion (MAA)	0.2	0.4
^{99m}Tc lung ventilation (aerosol)	0.3	1.2
^{99m}Tc kidney scan (DTPA)	1.5	4
^{99m}Tc thyroid scan (pertechnetate)	0.7	1.6
^{99m}Tc dynamic cardiac scan (RBC)	3.4	3.7
^{51}Cr glomerular filtration (EDTA)	< 0.01	0.01
^{201}Tl myocardial perfusion (thallium)	3.7	4
^{99m}Tc brain scan (pertechnetate)	4.3	6.5
^{75}Seleno-cholesterol	-	14
^{67}Ga tumours and abscesses	-	12
^{131}I thyroid metastases	-	22

Examples of Risk of Childhood Cancer

- "Natural" risk: 1 in 1,300

• Abdomen	mean: 1.4 mGy → 1 in 24,000
	max.: 4.2 mGy → 1 in 8,000
• CT Abdomen	mean: 8 mGy → 1 in 4,000
	max.: 49 mGy → 1 in 700
• Pelvis	mean: 1.1 mGy → 1 in 30,000
	max.: 4.0 mGy → 1 in 8,000
• CT Pelvis	mean: 8 mGy → 1 in 4,000
	max.: 79 mGy → 1 in 400

TABLE Typical fetal doses and risks of childhood cancer for some common diagnostic medical exposures

Examination		Typical fetal dose range (mGy)*	Risk of childhood cancer per examination
X-ray	Skull	0.001–0.01	< 1 in 1,000,000
X-ray	Teeth		
X-ray	Chest		
X-ray	Thoracic spine		
X-ray	Breast (mammography)		
X-ray CT	Head and/or neck		
^{51}Cr	GFR measurement		
^{81m}Kr	Lung ventilation scan		
X-ray CT	Pulmonary angiogram	0.01–0.1	1 in 1,000,000 to 1 in 100,000
^{99m}Tc	Lung ventilation scan (Technegas)		
X-ray	Abdomen	0.1–1.0	1 in 100,000 to 1 in 10,000
X-ray	Barium meal		
X-ray	Pelvis		
X-ray	Hip		
X-ray CT	Pelvimetry		
X-ray CT	Chest and liver		
^{99m}Tc	Lung perfusion scan		
^{99m}Tc	Thyroid scan		
^{99m}Tc	Lung ventilation scan (DTPA)		
^{99m}Tc	Renal scan (MAG3, DMSA)		
^{99m}Tc	White cell scan		

Examination		Typical fetal dose range (mGy)*	Risk of childhood cancer per examination
X-ray	Barium enema	1.0–10	1 in 10,000 to 1 in 1,000
X-ray	Intravenous urography		
X-ray	Lumbar spine		
X-ray CT	Lumbar spine		
X-ray CT	Abdomen		
^{99m}Tc	Bone scan		
^{99m}Tc	Cardiac blood pool scan		
^{99m}Tc	Myocardial scan		
^{99m}Tc	Cerebral blood flow scan (Exametazine)		
^{99m}Tc	Renal scan (DTPA)		
^{201}Tl	Myocardial scan		
^{18}F PET	Tumour scan		
X-ray CT	Pelvis	10–50	1 in 1,000 to 1 in 200 *Natural childhood cancer risk ~ 1 in 500*
X-ray CT	Pelvis and abdomen		
X-ray CT	Pelvis, abdomen and chest		
^{99m}Tc	Myocardial (SPECT rest-exercise protocol)		
^{18}F PET/CT	Whole body scan		

* Fetal doses derived from doses to the uterus seen in recent UK surveys (Hart et al, 2007; Shrimpton et al, 2005) and the ARSAC Notes for Guidance (ARSAC, 2006), so only apply to early stages of pregnancy when the fetus is small.

ICRP 103 (2007)

- The Commission considers that it is prudent to assume that life-time cancer risk following in-utero exposure will be similar to that following irradiation in early childhood,
- i.e., at most, about three times that of the population as a whole.

Do not adjust your set

1990 Recommendations of the International Commission on Radiological Protection

ICRP Publication 103

Principles of Radiation Protection

- Justification
- Optimisation
- Limitation

The Justification of a practice

- "*Any decision that alters the radiation exposure situation should do more good than harm*."
- i.e. must be a net benefit.

The Optimisation of Protection

- *"The **likelihood** of incurring exposures, the **number of people** exposed, and the **magnitude of their individual d**
  a
  fa

ALARA

as low as reasonably achievable

Individual Dose and Risk Limits

- *"The total dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission."*
- Prevent deterministic effects
- Limit risk of stochastic effects to acceptable level.

ICRP's Three Types of Exposure

- Occupational
- Medical
- Public

Occupational Exposure

- "exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating manager."
  - 20 mSv a year effective dose (averaged over 5 years, but <50mSv in a single year)
  - 150 mSv a year to lens of eye
  - 500 mSv a year to 1 cm^2 of skin, hands and feet

- Fetus: from declaration of pregnancy
  - 1 mSv to the embryo/fetus.

Medical Exposure

- “exposures incurred by individuals as part of their own medical diagnosis and treatment .”
- “and . . . individuals helping in the support and comfort of patients undergoing diagnosis and treatment *(not occupationally) . .* .”
- No dose limits apply
- Consider dose constraints.

Public Exposure

- Limits apply to exposures from human activities
- 1 mSv a year effective dose
  - in special circumstances, average over 5 years
- 15 mSv a year to lens of eye
- 50 mSv a year to 1 cm^2 of skin.

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