Odds and Ends You Probably Should Know!

William F. Morgan. Ph.D., D.Sc.

Pacific Northwest National Laboratory

wfmorgan@pnnl.gov

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

Mans Radiation Burden

Air travel

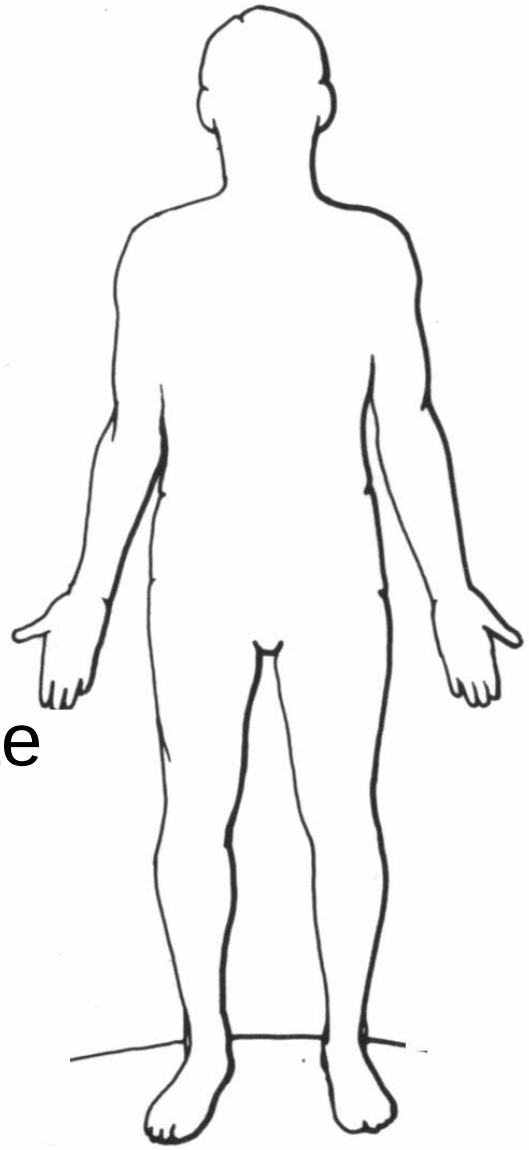
Testing fallout

TV & luminous watches

Nuclear power plants (20%)

Radioactive waste

Diagnostic & therapeutic radiation*



Cosmic rays

Air (radon)

Building material

Water

Food

Earth

*> 200 million procedures/year (USA), 2 billion worldwide

Radiation Dose

One of the most confusing things about understanding radiation effects is visualizing “how much” radiation is involved. It is very difficult to keep the units which measure radiation straight. A number describing the amount of radiation means nothing without evaluating the units, but this is not easy. For example...

...try to match the letter with the amount of radiation involved in each example

- Amount of potassium 40 in the body
- Dose to Atomic bomb survivors
- You can safety hold this amount of alpha radiation
- One coast to coast flight
- A diagnostic X-ray

A. Billions of becquerels

B. ~250 picocuries

C. ~2-10,000 millirem

D. 0-5 Gy

E. ~2 millirads

(Answers: B, D, A, E, C)

Commonly used radiation units

Average natural background in the USA
3.7 mSv/year
370 mrem/year
>50% from radon

*Kerala, India ~10mSv/year
Ramsar, Iran ~0.1Sv/year

EPA life-saving: 0.25Sv

Barium GI fluoroscopy: 85mSv

Full body CT scan: 10-100mSv
(~90 million / year in the USA

Understanding radiation units

Activity

Number of times each second radioactive material decays and releases radiation.

Disintegration/sec = **1 Becquerel (Bq)**

37 billion Bq = **1 curie**

Dose (Absorbed)

The amount of radiation energy absorbed by a given mass of tissue.

1 joule/kg = **1 Gray (Gy)**

1Gray = 100 **rad = 100,000 mrad**

Dose (Equivalent)

Measures the energy per unit mass x adjustments for the type of radiation (quality factor) and the **biological response in the tissue (a weighting factor).**

Equivalent dose converts dose into a measure of risk.

Gray x quality factors = **Sievert (Sv) = SI units**

1 Sievert = **100 rem = 100,000 mrem = Standard units**

What is equivalent dose?

Different types of radiation behave in different ways. In order to compare the amount of risk or biological change that occurs, quality factors are introduced.

For example:

- The damage produced by 1 Gy of x-radiation is equal to that produced by 1 Gy of gamma radiation. Thus, gamma radiation has a quality factor of 1 or 1 Gy gamma rays x 1 =1 Sv.
- The damage produced by 20 Gy of x-radiation is equal to that from 1 Gy of alpha radiation. Alpha radiation has a quality factor of 20 or 1 Gy of alpha radiation x 20 = 20 Sv.
- Quality factors for other types of radiation are between 1 & 20.

Radiation weighting factors

Type and Energy Range	W_R
Photons	1
Electrons	1
Protons	2
α-particles, fission fragments	20
Neutrons	continuous curve max 20 1 MeV neutrons

Tissue weighting factors

Tissue	W_T	$\sum W_T$
Bone marrow, breast colon, lung, stomach	0.12	0.60
Bladder, esophagus gonads, liver, thyroid	0.05	0.25
Bone surface, brain, kidneys, skin, salivary gland	0.01	0.05
Remaining tissues	0.10	0.10

Effectiveness of dose dependent upon dose rate

Dose	Dose Rate	Effect
1 bottle of Aspirin	Over 50 seconds	Death
	Over 50 years	minimal
2500mSv of radiation	Over 50 seconds	Death
	Over 50 years	Minimal

Risk Estimates

Severe mental retardation:

Exposure of embryo/fetus (8-15 weeks)	40%/Sv

Carcinogenesis:

General population (low dose, low dose rate)	5%/Sv

Hereditary effects:

General population	0.2%/Sv

Exposure Limits (stochastic)

Under 18 years - no occupational exposure

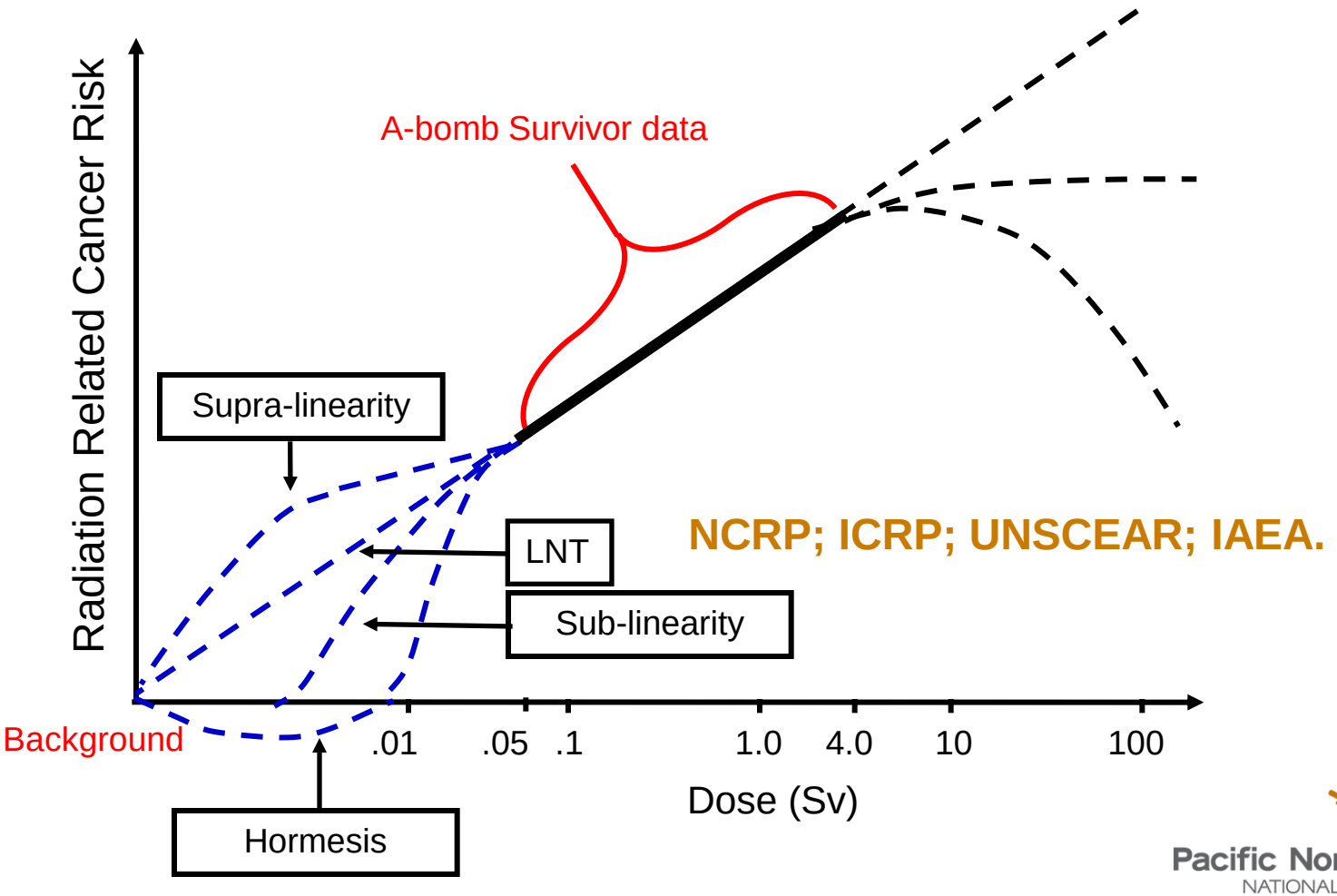
Effective dose in any year not to exceed 50mSv

Worker lifetime effective dose not to exceed age in years x 10mSv

Deterministic: 150mSv/year lens of the eye

500mSv/year hands and feet.

The dilemma for radiation protection: what is the scientific basis for radiation standards to protect the public from exposures to low levels of ionizing radiation (<0.1 Sv) where there are considerable uncertainties in the epidemiological data.



Hereditary Effects

Pacific Northwest
NATIONAL LABORATORY

Proudly Operated by Battelle *Since 1965*

And you don't believe the media ??

Quiz: Which one is the child of the radiation oncologist?

Risks in a pregnant population

Spontaneous abortion	> 15%
incidence of genetic abnormalities	4-10%
intrauterine growth retardation	4%
incidence of major malformation	2-4%

Fetal tissues are sensitive to radiation injury because of fast proliferation.

Biologic effects depends on:

- Stage of gestation
- Radiation dose
- Dose rate

Fetal effects of RT

- Humans 2.75% malformation rate at term
- >6-10% when all malformation and genetic diseases become manifest
- Fetal tissues are extremely sensitive to radiation injury because of fast proliferation.
- Biologic effects depends on:
  - Stage of gestation
  - Radiation dose
  - Dose rate

Dose to the fetus

- Maximal permissible dose to the fetus during the entire gestation period from an occupational exposure of the mother should not exceed 0.5mSv/month (as recommended by NCRP).

  5mSv total.

  - Chernobyl ~ 200,000 pregnancies terminated **(Note; psychological effects)**
  - Epidemiology suggests no effects <0.05Gy

In utero exposure and childhood cancer

- **Controversial, but** an increased risk of childhood solid tumors or leukemia can be the consequence or prenatal exposure at low doses. Some evidence in animal studies.
  - Even a few radiographs during pregnancy > risk
  - Risk exist up to 15 years after *in utero* exposure (factor of 1.5 to 2).
  - However, no evidence of childhood cancers was found among individuals *in utero* in bomb survivors
  - Increases sensitivity to mutagen exposure?

Radiation effects on the embryo and fetus

After cancer, developmental effects are of greatest concern.

Lethal effects:

embryonic, fetal, or neonatal death

Congenital malformations:

High frequency - organogenesis

Growth disturbances:

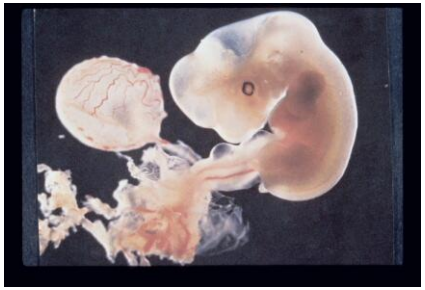
Mental retardation, no malformation

Fetal Radiation Risk

There are radiation-related risks throughout pregnancy which are related to the stage of pregnancy and absorbed dose

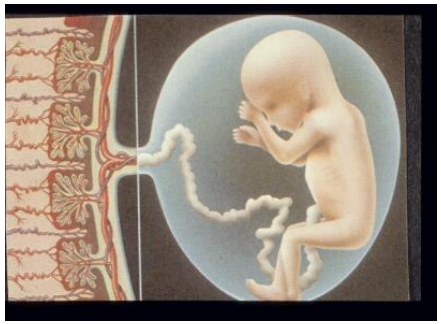
Radiation risks are most significant during organogenesis and in the early fetal period somewhat less in the 2nd trimester and least in the third trimester

Most risk



Less

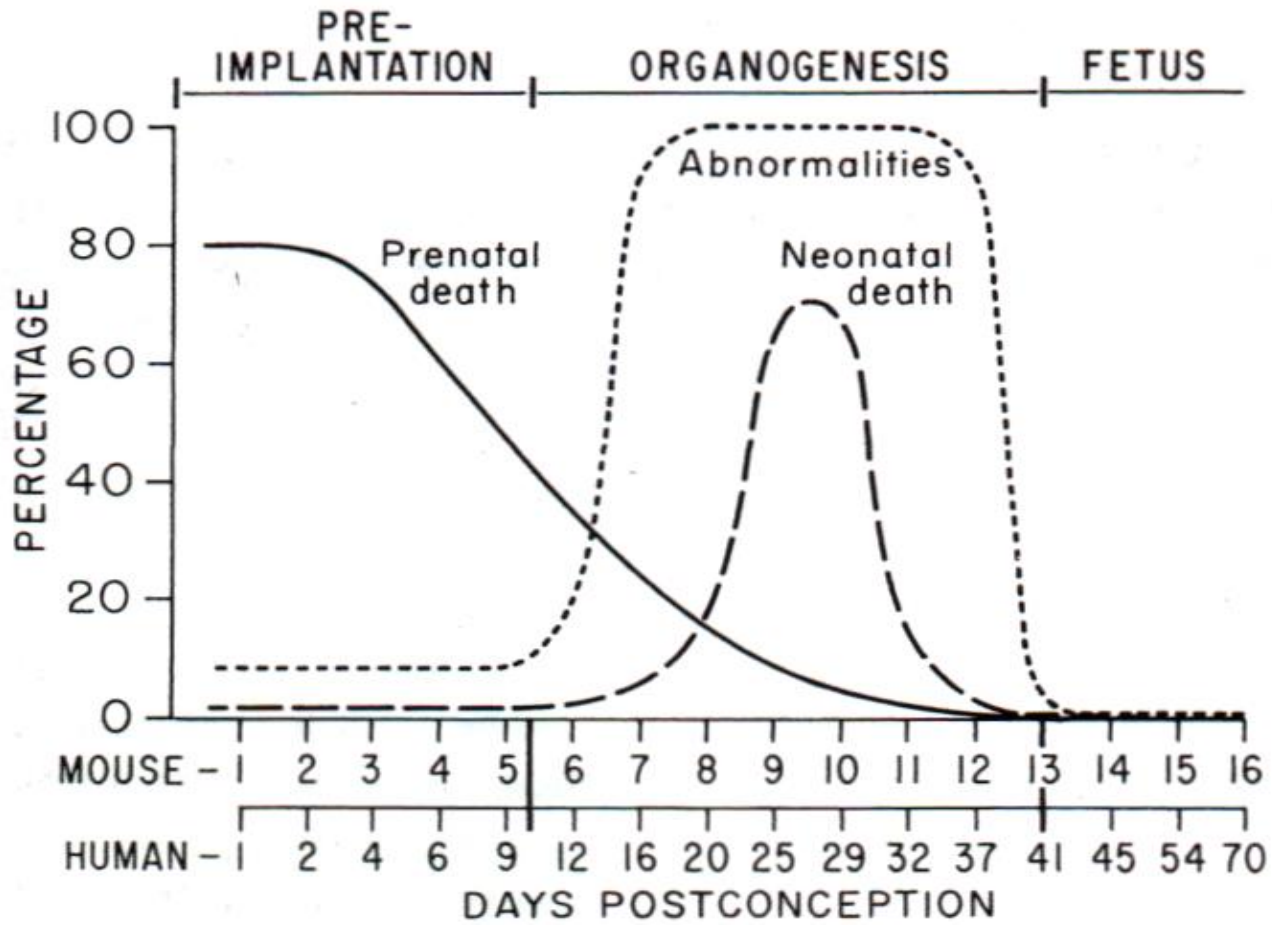
Least



Pacific Northwest
NATIONAL LABORATORY

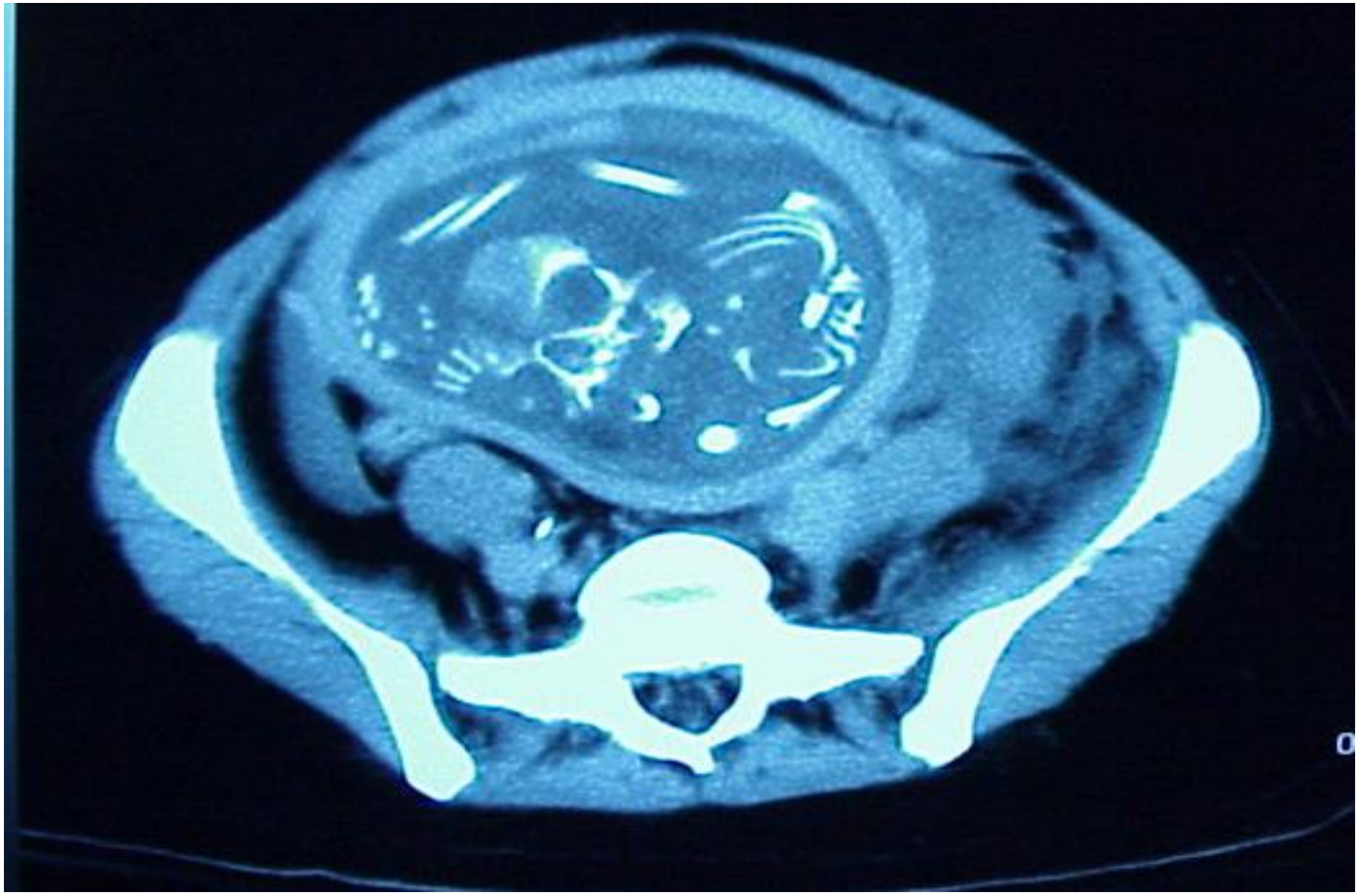
Proudly Operated by Battelle *Since 1965*

2Gy at various times after fertilization



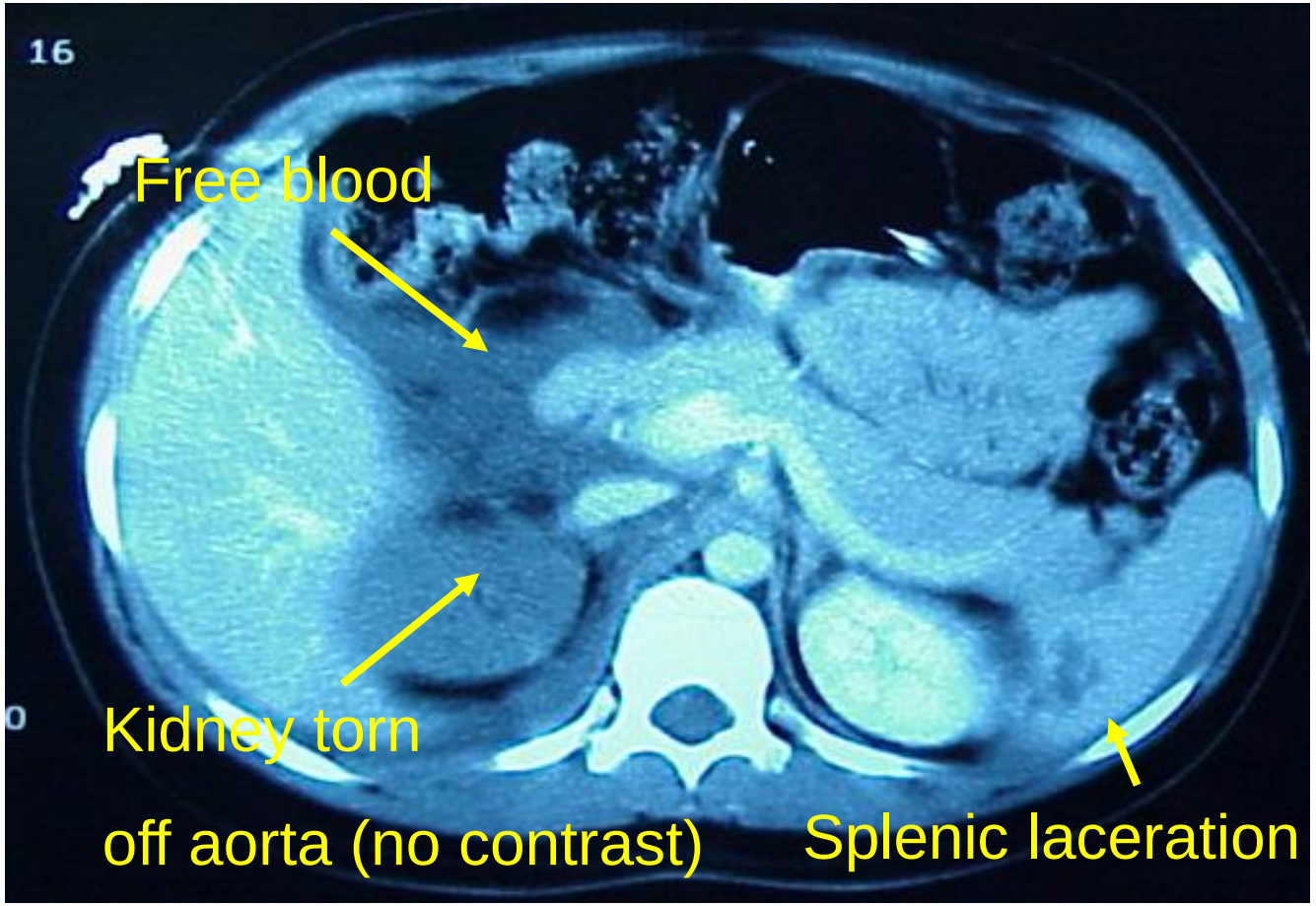
From: Hall, "Radiobiology for the Radiobiologist"

CT in a female who was in a MVA



Fetal dose 20 mGy

3 minute CT exam and taken to the operating room. She and the child survived



Central Nervous System Effects

During 8-25 weeks post-conception the CNS is particularly sensitive to radiation

Fetal doses in excess of 100 mGy (10 rads) can result in some reduction of IQ (intelligence quotient)

Fetal doses in the range of 1Gy (100 cGy) can result in severe mental retardation and microcephaly particularly during 8-15 weeks and to a lesser extent at 16-25 weeks

Mental Retardation

30 of 1600 bomb survivors

Not observed before 8 weeks

8-15 weeks most sensitive

Critical period of brain development - brain cortex formation and organization occurs: proliferation, differentiation, and migration of neuronal cells/neuroblasts from the proliferative zone to the cerebral cortex.

16 to 25 weeks - risk is 4x lower

Not observed after 25 weeks, effects on IQ???

Microcephaly

(head circumference ~2x smaller)
Relatively frequent after in uterus exposure (<16 weeks gestation).

A. Normal 12 year old
B. 15 year old, exposed *in utero* 1.2km from hypocenter.

From: Atomic Bomb Disease Institute, Nagasaki University.

What do we know about radiation exposures and how do we know it?

Sequence of events by which ionizing radiation affects living systems

Energy absorption (10^{-17} sec)
Ionization and excitation (10^{-5} sec)
Molecular changes (secs)
Biochemical changes (secs - hrs)
Physiologic & anatomic changes (min - hrs)
Biological effects (hrs - yrs)
Death of organism

Lethal effects (radiation syndromes)
Late effects
stochastic v deterministic
RT patients, accidental, medical, occupational, bomb survivors

RADIATION CARCINOGENESIS

Occupational Exposures

- Radium dial painters
- Uranium miners
- Accelerator engineers & physicists

Medical Exposures

- UK ankylosing spondylitis patients
- Children irradiated for enlarged thymus
- Children epilated for *tinea capitis*
- Tuberculosis patients fluoroscoped during artificial pneumothorax

LETHAL EFFECTS

Survival time and mode of death dependent upon dose

Prodromal Radiation Syndrome

rapid onset

persistent

merges with other syndromes

Cerebrovascular Syndrome

high dose (>30Gy)

death rapid (24 - 48 hours)

neurologic & cardiovascular breakdown

Tickling the Dragon's Tail

A graduate student experimenting with criticality (^{239}Pu)

Dropped a brick and pushed it away with his right hand.

Almost immediate numbness and tingling in the hand

Admitted to hospital within 30 minutes

Vomiting at 90 minutes – 24 hours

Day 10 severe abdominal cramping

Day 12-26 continuous diarrhea

Death on day 26 (in a coma)

Estimated dose to hands: 200-400Gy,

Estimated whole body dose >8.4Gy

Accident “LA1” Los Alamos first accident

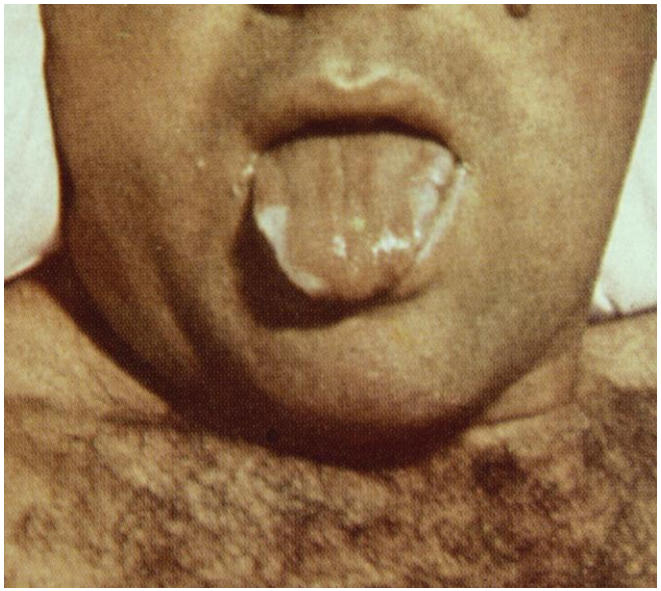
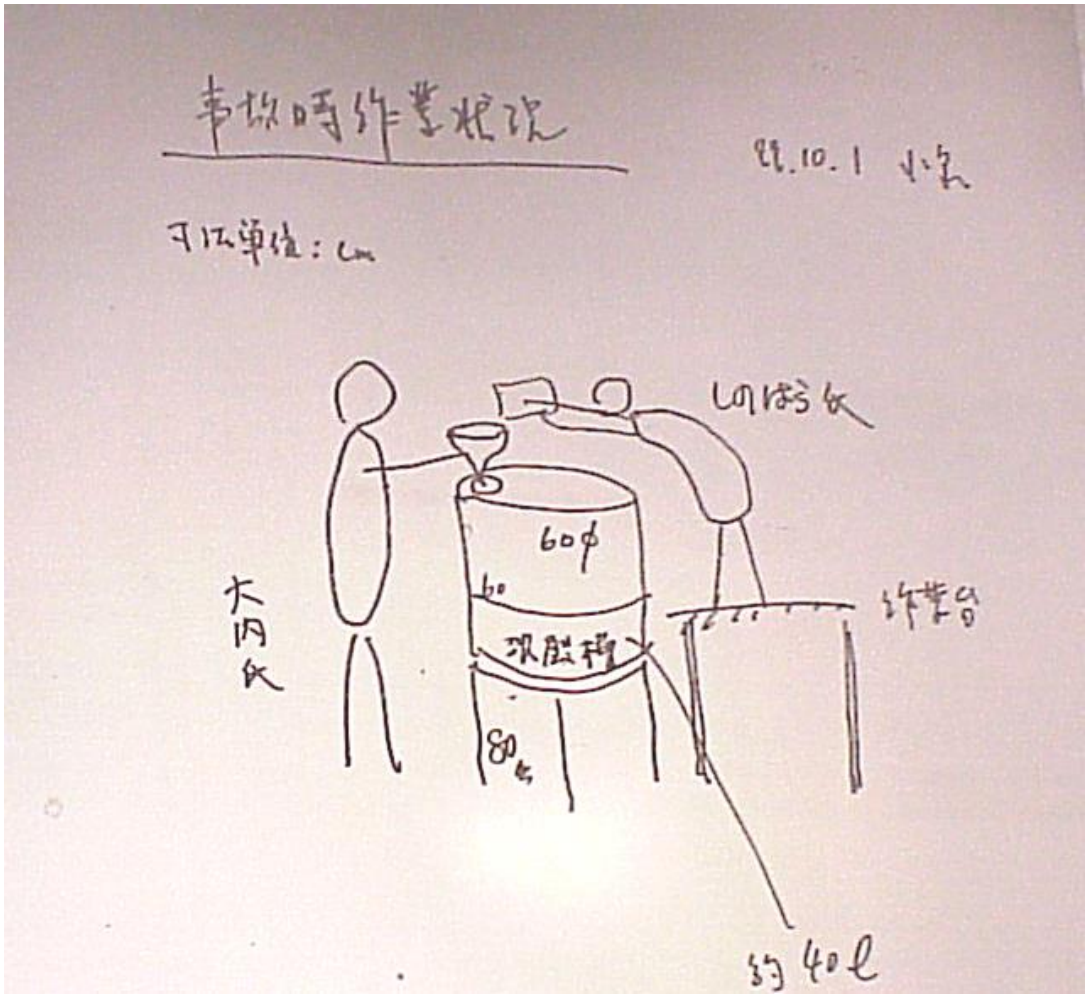


Figure 3. At 3½ days, blisters of the hands were very tense. They ruptured by day five.

Figure 4. Top of the right hand after debridement on day nine. The large amount of edema can be appreciated by the indentation made by the caregiver’s thumb, called “pitting” edema.

Figure 5. By day 24, ischemia (decreased blood supply) and necrosis (tissue death) of the fingers is evident.

Tokaimura uranium criticality accident



Tokaimura criticality accident (20 days post exposure)

36 days post exposure, despite intensive care both individuals died in months

Gastrointestinal Syndrome

Intermediate dose 5 - 12Gy

Death in days

Destruction of GI mucosa

Hematopoietic Syndrome

Low dose < 5Gy

Death in 3 - 4 weeks

Effect on blood forming organs

Death by depletion of stem cells of critical self-renewing tissue

LD_{50} man ~4Gy, **medical care significant**

RADIATION CARCINOGENESIS

Cancer is the most important somatic effect of radiation

Latency

Leukemia ~5 years

Solid tumors >20 years

Factors affecting carcinogenesis

Dose

Dose rate (DREF or DDREF)

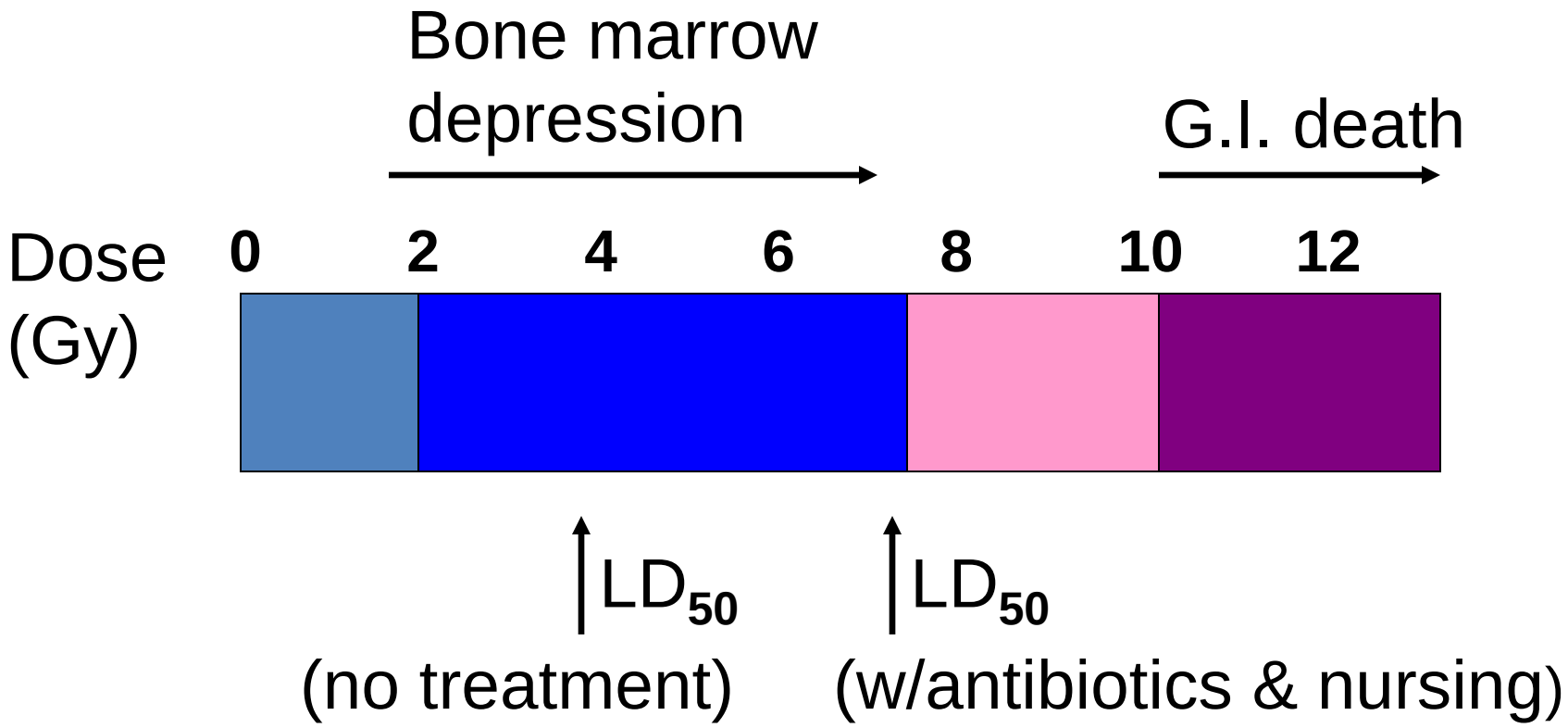
Gender

Age at exposure

Time since exposure

Gorlin's Syndrome: (Nevoid basal cell carcinoma syndrome)

High frequency, rapid onset



No treatment

Antibiotics, transfusions, nursing

Potential for bone marrow transplants

LATE EFFECTS

If cellular damage not adequately repaired

- Germ cell - mutation in offspring
- Somatic cell - leukemia or cancer

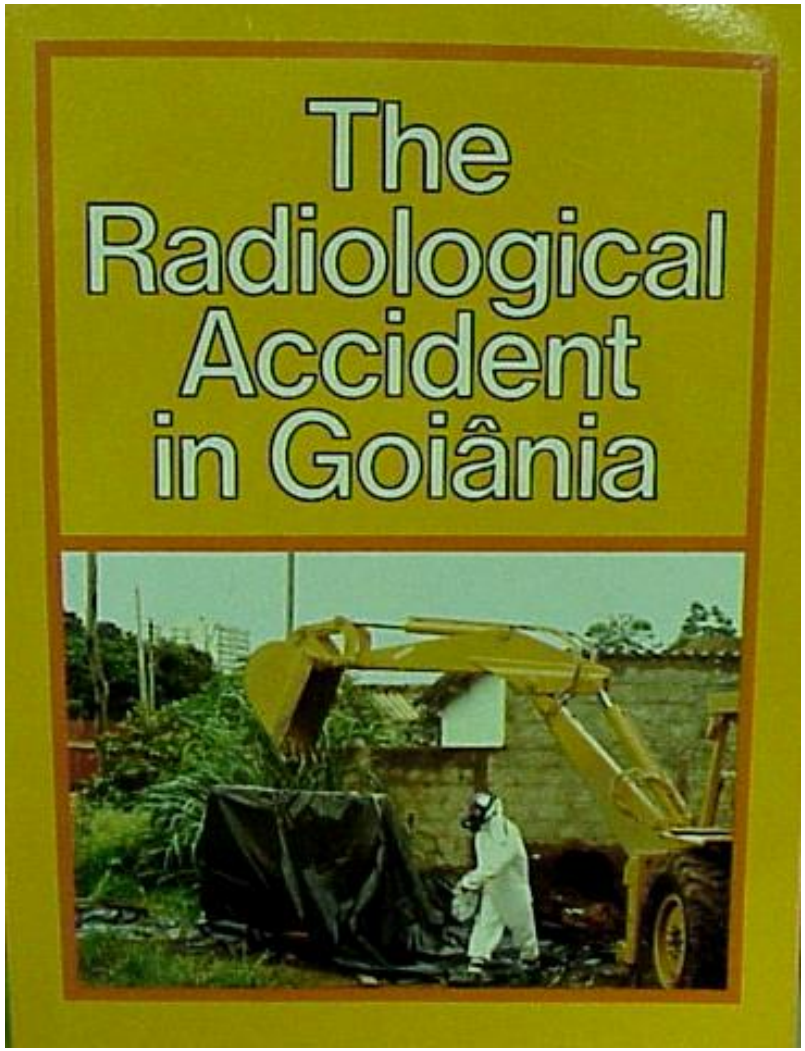
STOCHASTIC EFFECTS

- Genetic and carcinogenic effects
- No threshold with dose
- Severity independent of dose
- Probability of an effect > as dose >

DETERMINISTIC (NON-STOCHASTIC) EFFECTS

- Practical threshold e.g., cataract
- Severity dependent upon dose
- Usually requires larger doses than required to produce mutations and cancer

Local radiation injuries from handling extremely high activities of radionuclides



Historical Lesson:
Goiania Brazil (relatively small accident)

Powdered cesium-137 from abandoned radiotherapy source

Dispersed by ignorance, not explosives

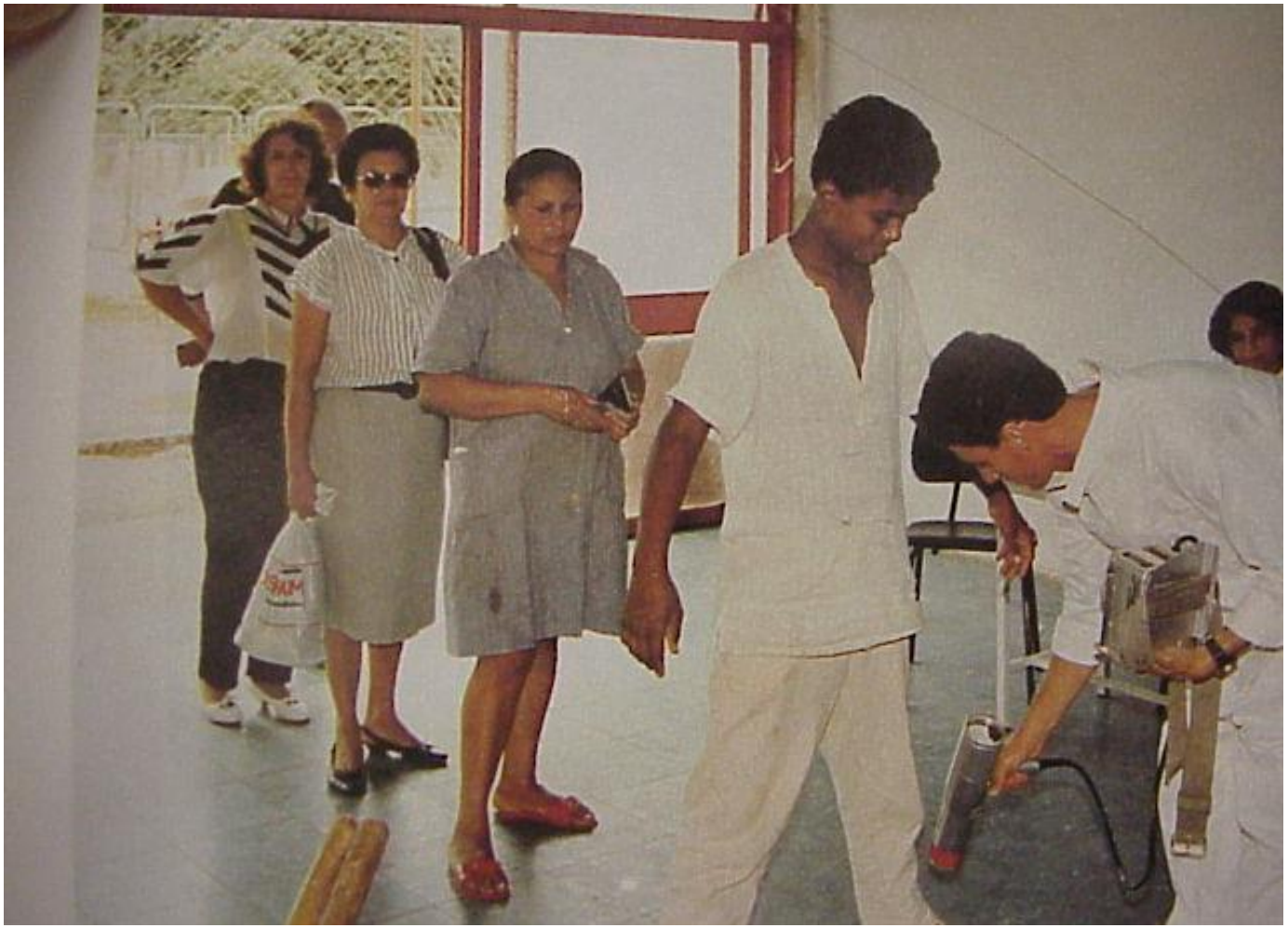
Some areas 2 Sv (200 rem)/hr at 1 m above ground

249 contaminated with powder

28 with serious radiation burns

4 deaths

Lesson: Lots of people to deal with. 110,000 persons monitored in the Olympic Stadium (secondary assessment center)



Radiation therapy injuries

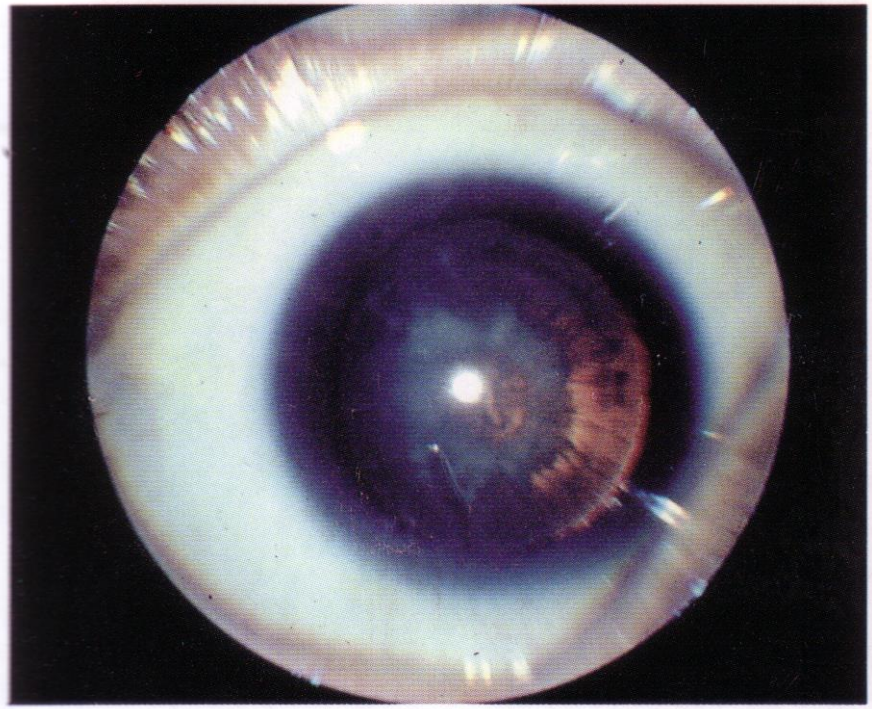
More deaths in the last decade from radiotherapy accidents than from Chernobyl

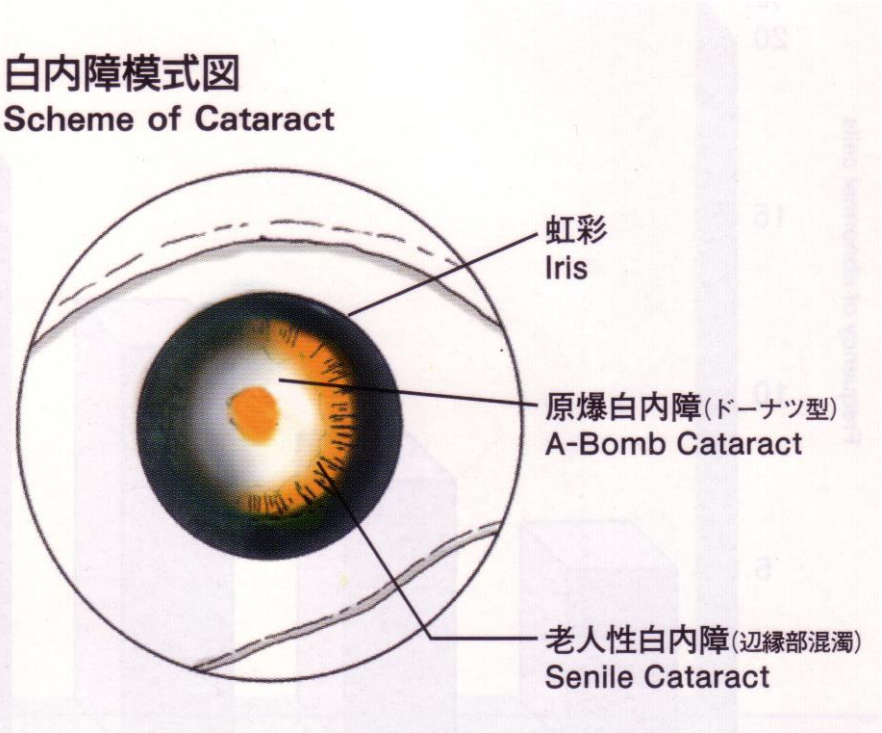
Typically involve central body parts

May not be obvious due to rotational nature of the beam or if multiple ports are used

Post coronary angioplasty and stenting

Radiation induced cataract

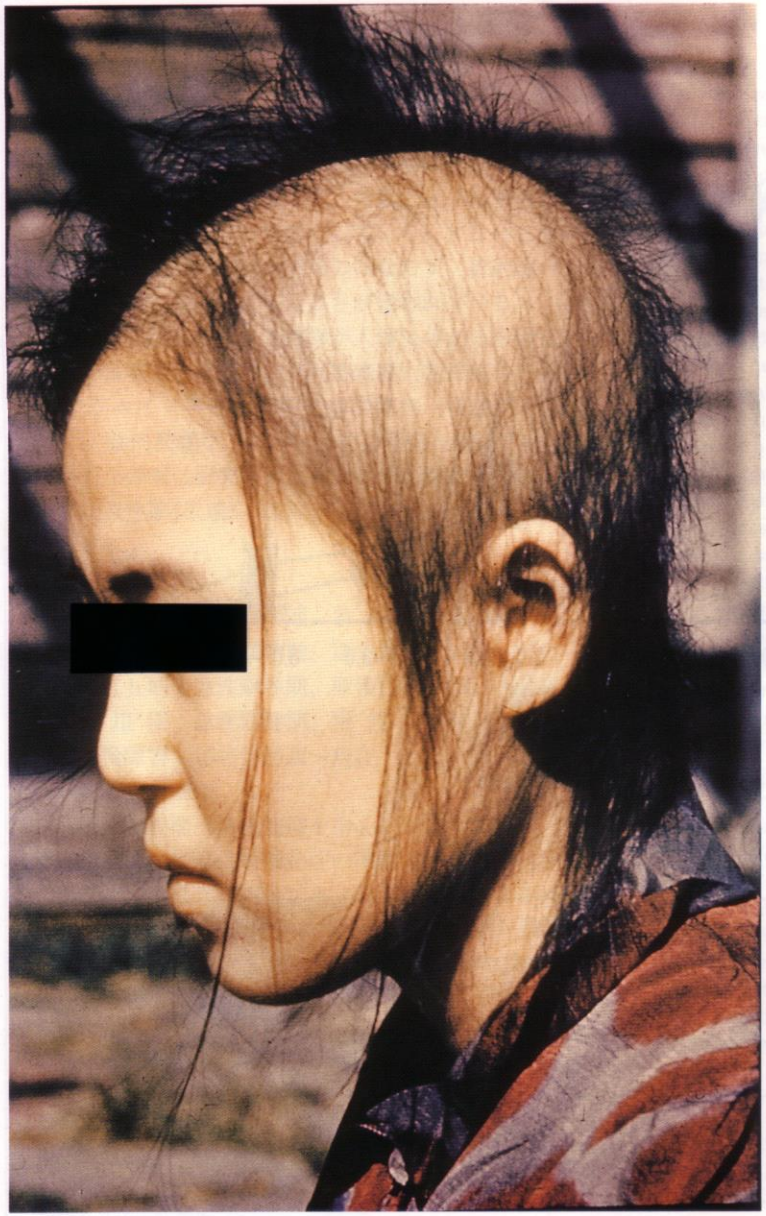




21 year old female, 0.8km from hypocenter
Cataract a donut-shaped opacity (in posterior pole of lens) appeared 3 months - 10 years after the bombing

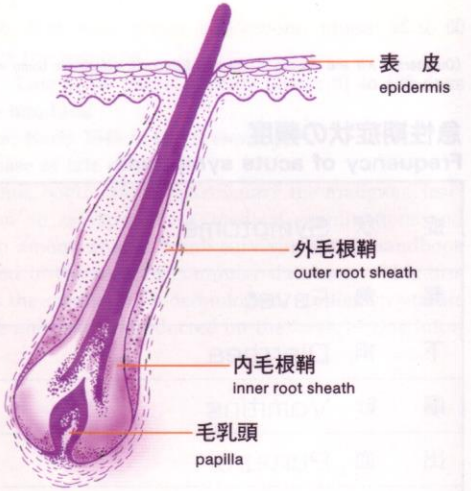
From: Atomic Bomb Disease Institute, Nagasaki University.

A



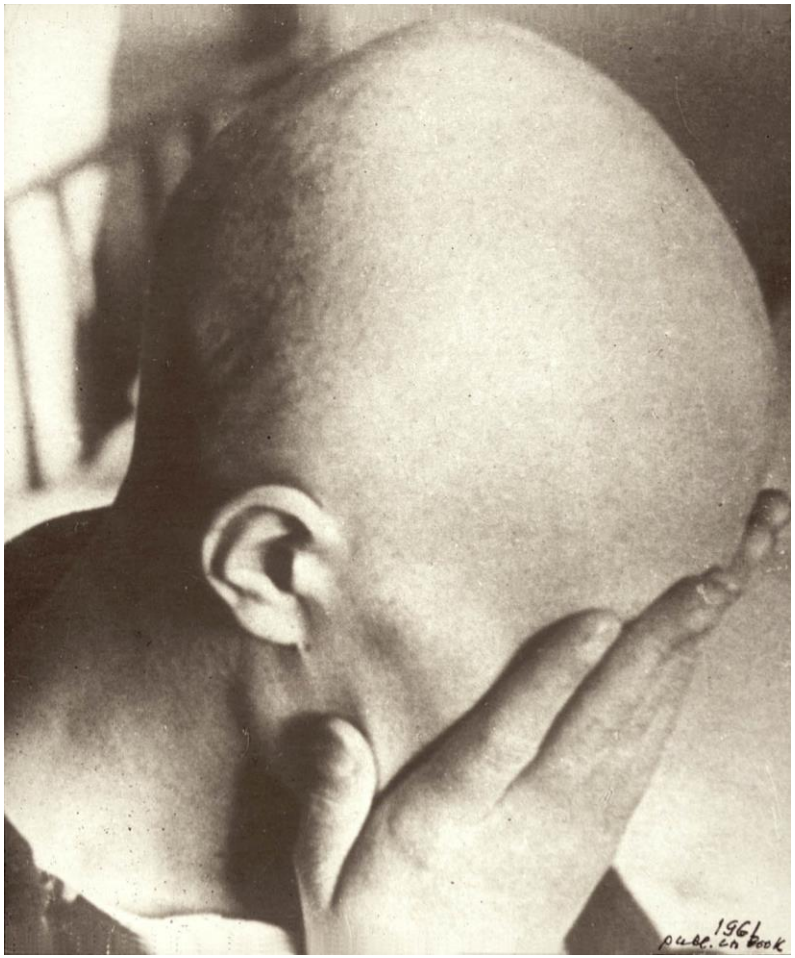
18 year old female
1.1km from hypocenter
Dermal hair papilla, connecting inner and outer root sheaths severely affected

B：毛根とその基部の縦断
Longitudinal section of the hair and hair follicle



From: Atomic Bomb Disease Institute, Nagasaki University.

Russian radiochemistry accident in a weapons plant in the Urals (~5 Gy)



Second malignancies in RT patients

- Controversial
- “Patient selection”
- Suitable control group
- Limited patient numbers
  - statistical limitations
- Sufficient follow up period (latency)

Large studies

- Small, but statistically significant increase in relative risk

Second Malignancies in prostate Cancer Patients

NCI's SEER program (1973 - 1993)

	RT	Surgery
Number of patients	51,584	70,539
Mean survival time (yrs)	4.2	4.4
Ave. age at diagnosis (yrs)	70.3	71.4
Ave. age at 2nd malignancy	75.3	77.0

Small but statistically significant increased relative risk of second cancer after radiotherapy.

Risk increased with time

Bladder and rectum largest increase

No increase in rate of leukemia

Brenner et al. Cancer 88, 398-406 (2000)

Which of the following are SI units: True or False:
A.Rad
B.Rem
C.Sievert
D.Curie
E.Gray

The likelihood of late stochastic effects following exposure to radiation is influenced by: True or False
A.Radiation dose
B.Linear energy transfer (LET) of the radiation
C.Radiation dose rate
D.Types of tissues exposed

Know your radiation sensitive syndromes
AT, NBS, Gorlin's syndrome

Which of the following are SI units. True or False

A. Rad False
B. Rem False
C. Sievert True
D. Curie False
E. Gray True

The likelihood of late stochastic effects following exposure to radiation is influenced by: True or False

A. Radiation dose
B. Linear energy transfer (LET) of the radiation
C. Radiation dose rate
D. Types of tissues exposed

All of the above are True

Which of the following effects would be seen as a consequence of a total body exposure to 1.5Gy of x rays

A. Vision impairing cataracts of the ocular lens
B. Dicentric chromosomes in blood lymphocytes
C. Skin erythema
D. Ataxia
E. A 25-50% increase in carcinogenesis

Which of the following statements concerning radiation-induced **heritable** effects are true?

A. Changes are different than those occurring spontaneously
B. Humans are more sensitive than mice
C. Risk estimates are based on mouse data
D. 10-20% of changes in the population are due to radiation
E. Doubling dose in humans is estimated to be 0.5-2.5SV

Which of the following effects would be seen as a consequence of a total body exposure to 1.5Gy of x rays

A.	Vision impairing cataracts of the ocular lens	??
B.	Dicentric chromosomes in blood lymphocytes	True
C.	Skin erythema	False (2-6Gy)
D.	Ataxia	False
E.	A 25-50% increase in carcinogenesis	False

Which of the following statements concerning radiation-induced **heritable** effects are true?

A.	Changes are different than those occurring spontaneously	F
B.	Humans are more sensitive than mice	F
C.	Risk estimates are based on mouse data	T
D.	10-20% of changes in the population are due to radiation	F
E.	Doubling dose in humans is estimated to be 0.5-2.5Sv	T

Following irradiation which of the following organs in children is the most sensitive to the induction of tumors by x-rays?

A. Bone marrow
B. Breast
C. Thyroid
D. Lung
E. Brain

Match the consequence with stage of pregnancy:

A. Congenital malformations
B. Death
C. Increased risk of cancer

D. Preimplantation
E. Organogenesis
F. Fetal period

Following irradiation which of the following organs in children is the most sensitive to the induction of tumors by x-rays?

A. Bone marrow
B. Breast
C. Thyroid C
D. Lung
E. Brain

Match the consequence with stage of pregnancy:

A. Congenital malformations B
B. Death A
C. Increased risk of cancer C

D. Preimplantation
E. Organogenesis
F. Fetal period

A 2Gy exposure to a developing embryo when radiation is administered during (True or False)

A. Weeks 8-18 of gestation is likely to induce abortions
B. Weeks 0-2 of gestation produces congenital abnormalities
C. Weeks 15-25 can produce mental retardation
D. Weeks 2-6 is likely to induce congenital abnormalities

Match the exposure with the type of radiation induced cancer:

A. Patients treated with alkylosing spondylitis
B. Fluoroscopy patients treated for tuberculosis
C. Uranium workers
D. Radium dial painters
E. Marshall island inhabitants

F. Leukemia
G. Breast cancer
H. Thyroid cancer
I. Lung cancer

A 2Gy exposure to a developing embryo when radiation is administered during (True or False)

A. Weeks 8-18 of gestation is likely to induce abortions
B. Weeks 0-2 of gestation produces congenital abnormalities
C. Weeks 15-25 can produce mental retardation
D. Weeks 2-6 is likely to induce congenital abnormalities

Match the exposure with the type of radiation induced cancer:

A. Patients treated with alkylosing spondylitis
B. Fluoroscopy patients treated for tuberculosis
C. Uranium workers
D. Radium dial painters
E. Marshall island inhabitants

F. Leukemia
G. Breast cancer
H. Thyroid cancer
I. Lung cancer

A 2Gy exposure to a developing embryo when radiation is administered during (True or False)

A. Weeks 8-18 of gestation is likely to induce abortions
B. Weeks 0-2 of gestation produces congenital abnormalities
C. Weeks 15-25 can produce mental retardation
D. Weeks 2-6 is likely to induce congenital abnormalities

Match the exposure with the type of radiation induced cancer:

A. Patients treated with alkylosing spondylitis	F
B. Fluoroscopy patients treated for tuberculosis	G
C. Uranium workers	I
D. Radium dial painters	
E. Marshall island inhabitants	H

F. Leukemia
G. Breast cancer
H. Thyroid cancer
I. Lung cancer