Radiation Safety Physics 352

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Introduction

- Introduce biological effects
- some history of radiation protection
- present recent changes in protection criteria
- define some units
- look at what dose limits represent
- Look at some regulatory issues

Introduction con't

- Ionizing radiation is not only useful for diagnosis and treatment of disease but also **harmful to human tissue**.
- Since radioactive substances are natural and permanent feature of our environment, the risk with radiation exposure can **only be restricted**, **not eliminated**.
- Acceptance by society of **risk** associated with radiation is conditional on the **benefits** to be gained

Radiation Exposure

- **Occupational Exposure**
  - All exposures of workers incurred in the course of their work.
- **Medical Exposure**
  - By patient as part of their own medical or dental treatment.
  - By persons voluntarily helping in the support and comfort of patient.
  - Volunteers in a program of research.
- **Public Exposure**
  - Exposure to members of the public from radiation sources excluding any occupational or medical exposure and normal natural background radiation.

Acute whole body irradiation

Early Effects of High Doses

DOSE (Sv)	*EFFECT*
0 – 0.25	No obvious effect
0.25 – 1	Temporary nausea, blood cell changes, sterility in males; no early deaths
1 – 3	Nausea, fatigue, vomiting, blood cell changes, loss of appetite, sterility in males, death possible.
3 – 6	All of the above; early death in 50% of those exposed, sterility and cataracts in survivors

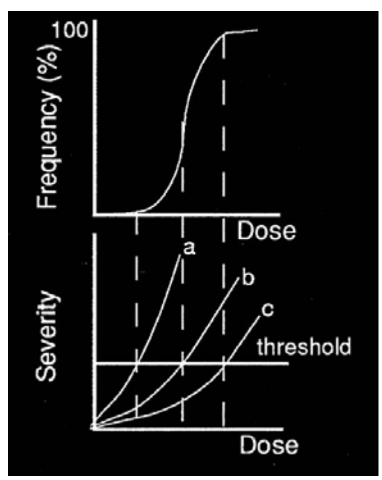
Radiation Effects

Deterministic Effect

- These are effects that are certain to occur beyond a dose threshold level. (e.g. nausea, reddening of skin)
- As a result of cell death or delayed cell division due to the radiation.
- These effect can impair the function of the exposed tissue.
- The severity of a particular effect increases with dose above the threshold dose.

Deterministic effects

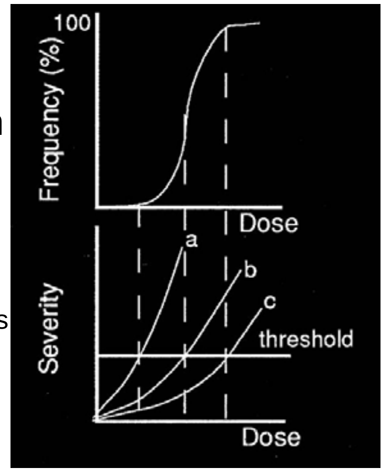
- The upper panel illustrates how the frequency of a particular deterministic effect, defined as some clinically recognizable pathological condition, increases as a function of dose in a population of individuals of varying 100' susceptibilities.



Deterministic effects

- The lower panel represents the dose-severity relationship for a population of mixed sensitivity.

  a) susceptible individuals
  b,c) severity reaches threshold of detectability at a higher dose in less susceptible subgroups.



Radiation Effects

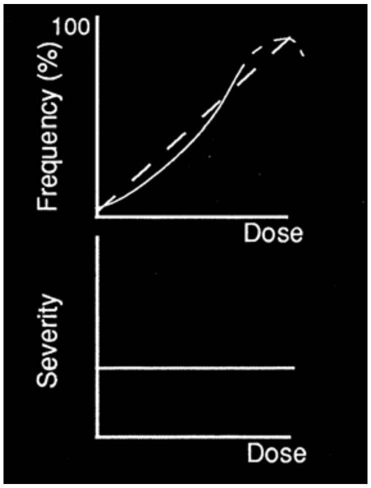
Stochastic Effect

- These are induced delayed effect which are epidemiologically detectable that occur randomly. (e.g. malignancies and hereditary effects nausea, reddening of skin)
- As a result of cell being modified rather than killed which may develop into a cancer.
- No evidence of a threshold dose but probability of occurrence is proportional to dose.
- The severity of effect is independent of dose.

Stochastic effects

- There is no threshold in curve of frequency versus dose (top panel).

- Also the severity is not dose dependent (bottom panel).



Radiation Effects

Effect on embryo and fetus

- Effect to infants due to exposure of the embryo or fetus to radiation.

- Likelihood of **leukemia** (Stochastic effect)

- **Severe mental retardation** and **congenital malformation** (deterministic effect).

Radiation protection concerns

Stochastic effects drive radiation protection concerns

At low levels of radiation main concerns are:

- Induction of cancer
- Induction of genetic effects in later generations
- Damage to embryo/fetus

Radiation Protection Standards

- In 1921 the first recommendations for radiation exposure control were set by the British x-ray and Radium Protection Committee:
  - No more than 7 working hours/day
  - Sundays and two half days off per week
  - As much leisure time as possible spent out-of-doors
  - Annual holiday of 1 month or 2 fortnights
  - Sisters and nurses working full-time in x-ray and radium depts. should not be expected to perform other hospital services.

Radiation Protection Standards

- In 1930's, with the definition of exposure, limits became quantitative.
  - They were set to avoid deterministic effects such as skin erythema.
- In 1950's reports of excess leukemias in Japan atom bomb survivors began to emerge.
  - early radiation risk assessment used controversial models
  - established possibility of stochastic effects

Radiation Protection Standards

- Dose Limits
  - In 1977 ICRP (in Report #26) established dose limits for radiation protection based on risk assessment
  - In 1991 ICRP (in Report #60) revised these limits (based on analysis in BEIR V Report 1990, UNSCEAR 1988).

Dose Limits

- In the spirit of a International Commission on Radiological Protection's 1991 report (ICRP 60) the Canadian government adopted:
  - for occupationally-exposed persons:
    - 20 mSv per year (whole body) averaged over 5 years with 50 mSv permitted in a single year.

Dose Limits

- In the spirit of a International Commission on Radiological Protection's 1991 report (ICRP 60) the Canadian government adopted:
  - members of the public:
    - 1 mSv per year.

Dose Limits

- Why the difference
  - Risks (different comparators)
  - Populations (different sensitivity, benefits, awareness…)

The Descent of Dose Recommendations*

1926	tolerance dose	1560	mSv/yr
1931	USACXRP	720	mSv/yr
1936	USACXRP	300	mSv/yr
1948	ICRP?	150	mSv/yr
1958	ICRP?	50	mSv/yr
1990	ICRP	20	mSv/yr
(Typical natural background is		~3	mSv/yr)

* For the purpose of showing the trend, some liberties have been taken with the units of radiation dose which have changed over the century. The values shown represent international recommendations, not legal limits.

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Dosimetry: Units

- Exposure: X

$$X = \frac{dQ}{dm}$$

– the SI unit of exposure is C kg^{-1}, a special unit of exposure is the roentgen (R) defined as

1 R = 2.58 x 10^{-4} C kg^{-1}.

Dosimetry: Units

- Absorbed Dose, D
- the fundamental dosimetric quantity in radiological protection
- defined as the energy absorbed per unit mass of material

$$D = \frac{dE}{dm}$$

Dosimetry: Units

- Absorbed Dose, D
- its SI unit is the joule per kilogram, which is given the special name gray (Gy).
- the old unit of dose is the rad = 100 ergs of energy absorbed per gram of material:

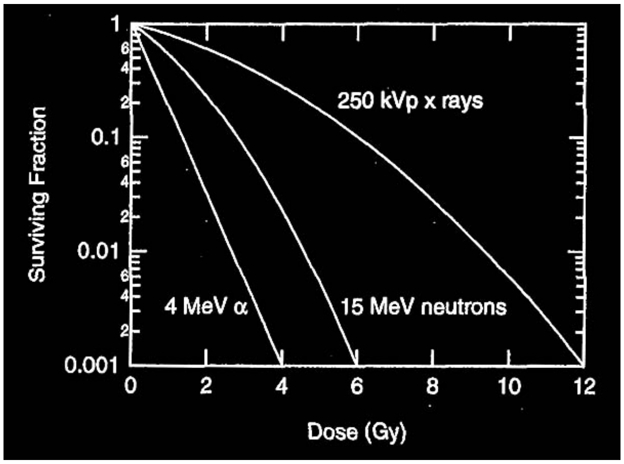
$$1 \text{ rad} \equiv 1 \text{ cGy}$$

Dosimetry: Units

- Equivalent Dose, H_T
  - Biological Effect
    - depends on the type and energy of the radiation concerned.
    - The induced damage from 10 Gy from neutrons is found to be several times greater than that from 10 Gy of X rays.

Dosimetry: Units

- Equivalent Dose, H_T



Dosimetry: Units

- Equivalent Dose

$$H_T = \sum_R w_R \cdot D_{T,R}$$

- H_T has same physical dimensions as D (J kg^{-1})
- to avoid confusion between H_T and D , H_T is expressed as a special unit,
  - the Sievert (Sv) = 1 J kg^{-1},
- Similarly, for non-SI units, 1 rem = 1 rad x Q
  - 1 Sv = 100 rem.

Radiation Weighting Factors

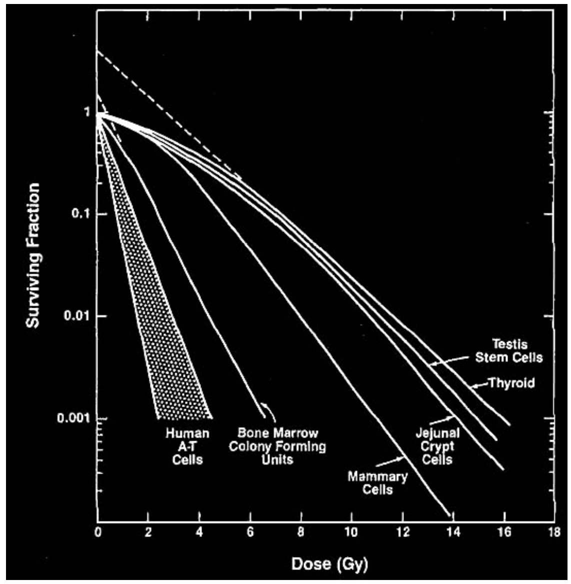
Type and energy range	Radiation weighting factor, w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons, energy < 10 keV	5
10 keV to 100 keV	10
>100 keV to 2 MeV	20
>2 MeV to 20 MeV	10
>20 MeV	5
Protons, other than recoil protons, energy >2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Dosimetry: Units

- Effective Dose, E
  - Biological Effect
    - The relationship between the probability of stochastic effects and equivalent dose also depends on the organ or tissue irradiated.

Dosimetry: Units

- Effective Dose, E



Dosimetry: Units

- Effective Dose, E
  - Tissue weighting factors, w_T
    - The factor by which the equivalent dose in tissue or organ T is weighted is called the tissue weighting factor, w_T
  - w_T represents the relative contribution of that organ or tissue to the total detriment due to these effects resulting from uniform irradiation of the whole body.

Dosimetry: Units

- Effective Dose

$$E = \sum_T w_T \cdot H_T$$

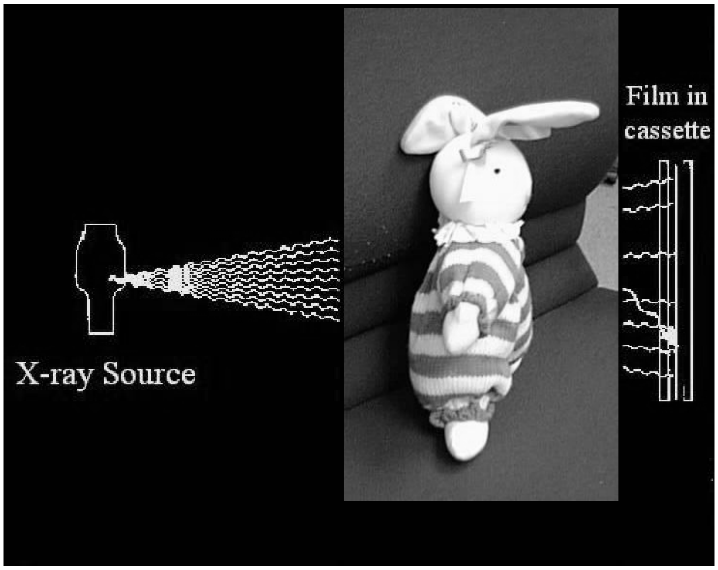
- H_T is also expressed as
  - the Sievert (Sv) = 1 J kg^{-1},

- Again;
  - 1 Sv = 100 rem.

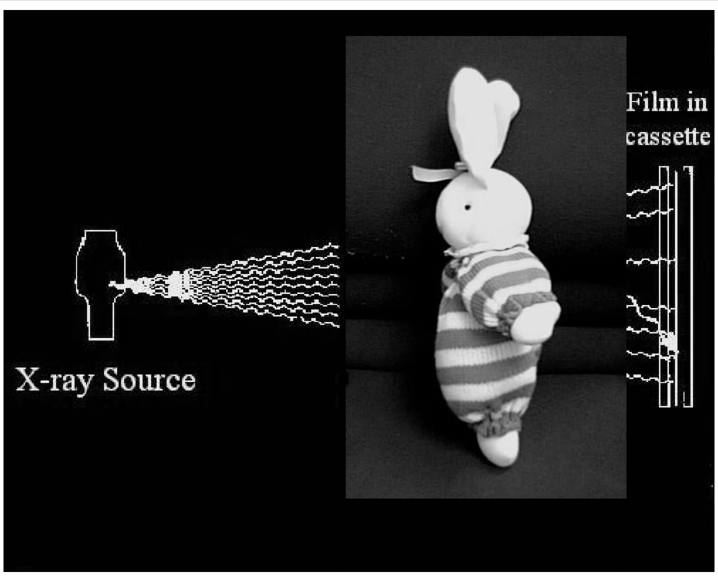
Tissue Weighting Factors, w_T

	ICRP 60	ICRP26
Bladder	0.05	----
Bone marrow (red)	0.12	0.12
Bone surface	0.01	0.03
Breast	0.05	0.15
Colon	0.12	----
Liver	0.05	----
Lung	0.12	0.12
Oesophagus	0.05	----
Skin	0.01	----
Stomach	0.12	----
Thyroid	0.05	0.03
Gonads including ovaries *	0.20	0.25
Remainder	0.05	0.30

Practical Example: Chest x-ray



Practical Example: Chest x-ray



Background Exposure

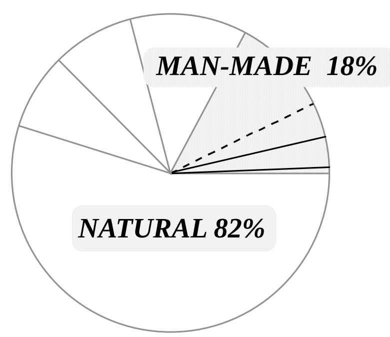
- The base-line for radiation dose is provided by natural background radiation to which the whole population is exposed.

- The annual effective dose, for the whole body, is about 3 mSv (300 mrem) for natural background radiation.

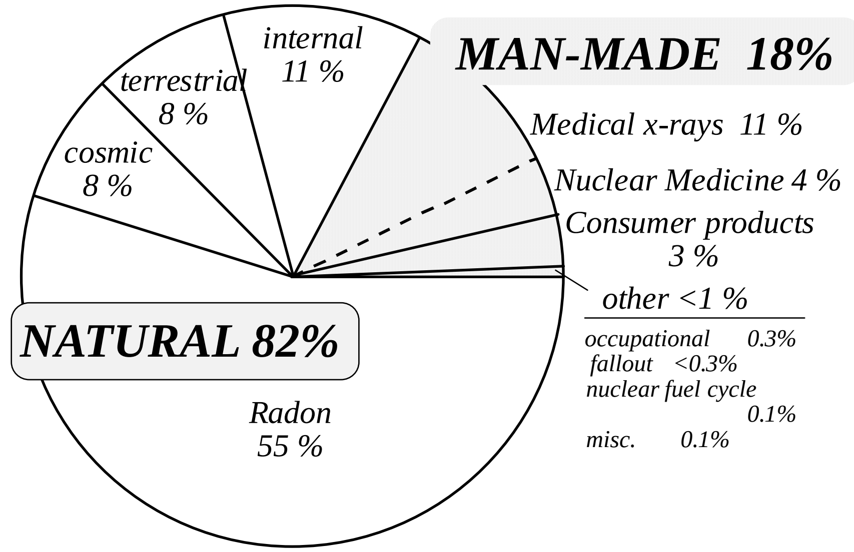
- Additional exposure from man-made sources:
  - contribute an additional effective dose of ~ 0.6 mSv.

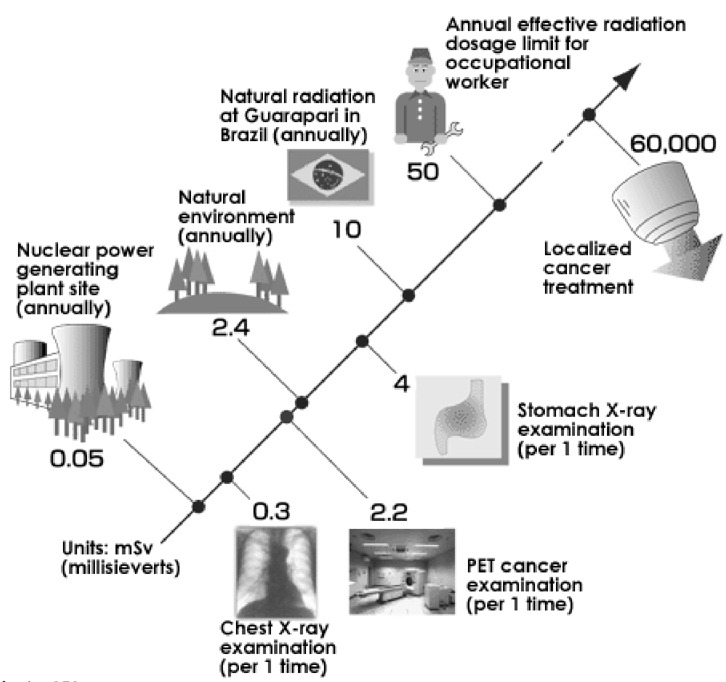
Sources of Exposure

- The relative contribution of various radiation sources to the total average effective dose in the US population. (NCRP Report No. 93)



- Note that the data are averaged over the whole population and so the significance of some contributions (e.g., occupational) may be less than expected since population exposed is small).


MAN-MADE 18%
Medical x-rays 11 %
Nuclear Medicine 4 %
Consumer products 3 %
other <1 %
occupational 0.3%
fallout <0.3%
nuclear fuel cycle 0.1%
misc. 0.1%
internal 11 %
terrestrial 8 %
cosmic 8 %
NATURAL 82%
Radon 55 %


Annual effective radiation dosage limit for occupational worker
50
Natural radiation at Guarapari in Brazil (annually)
10
60,000
Localized cancer treatment
Natural environment (annually)
2.4
Nuclear power generating plant site (annually)
0.05
4
Stomach X-ray examination (per 1 time)
0.3
2.2
Units: mSv (millisieverts)
Chest X-ray examination (per 1 time)
PET cancer examination (per 1 time)

Estimates of Probability for Cancer Death

- Estimates of the probability of cancer death for the period 1950 to 1985 changed for 4 main reasons :

  a) the new dosimetry of Japanese data
  b) more cancers observed over the years
  c) different radiation effects modelling,
  d) different risk modelling accounting for age

Japanese A-bomb Survivors

- Most important single group studied because of their large number, the care with which they have been followed, and the fact that people of all ages and both sexes received a wide range of doses.

- out of a population of about 560 000 approximately 150 000 to 220 00 people died within 4 months of bombing.

Japanese A-bomb Survivors

- ~ 280,000 survived the immediate effects of the two weapons,

of those:

- ~ 90,000 have been followed up carefully (76,000 with DS86 dosimetry).

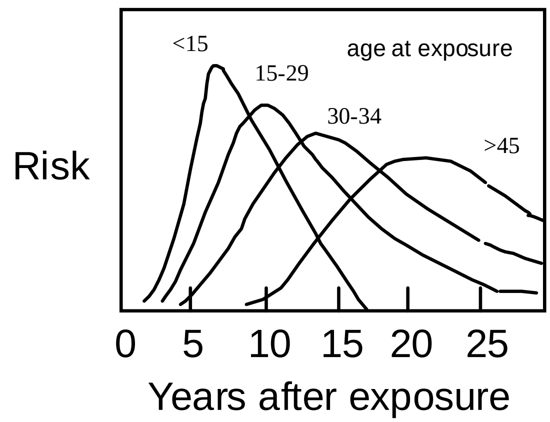
Japanese A-bomb Survivors

- of the ~ 280,000 survivors and ~ 90,000 followed up:
  - ~ 24,000 had died by late 1980's,

  - ~ 5000 deaths were caused by cancer
    - (from ~10 to ~2000 in various particular organs)
    - an estimated 250 being in excess of expectations
    - these are attributable to radiation.

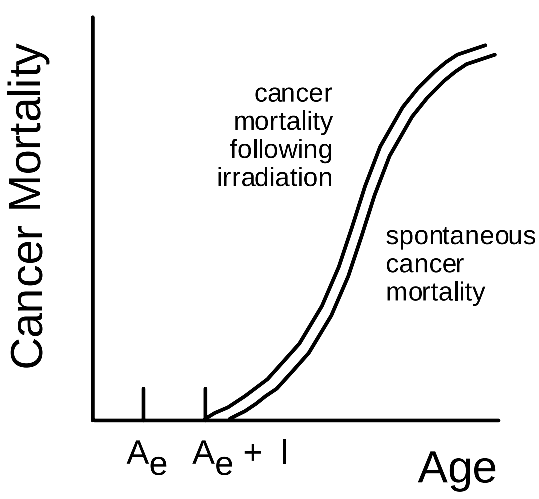
Latency Period

e.g., Leukaemia
(all forms)

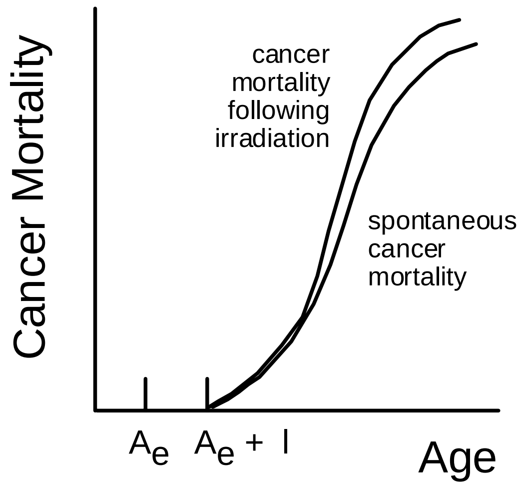


- There is a time course in cancer induction with a latency period between the exposure to radiation and the onset of observable cancers.

Additive Model



Multiplicative Model



Framework

Radiation Protection

- Exposure to radiation only if it yield sufficient benefit to exposed individual.
- Individual doses should not exceed specified dose limit.
- Radiation sources and installations should be provided with the best available protection and safety measures under the prevailing circumstances so that the likelihood of exposure is **a**s **l**ow **a**s **r**easonable **a**chievable, economic and social factors being taken into account (i.e. protection and safety be optimized). – the **ALARA** principle.

Risk Estimates for Cancer & Hereditary Effects
Detriment per Sv

	Workers	Whole Population
Fatal CA	.04	.05
Non-Fatal CA	.008	.010
Severe Hereditary	.008	.013
Total	.056	.073

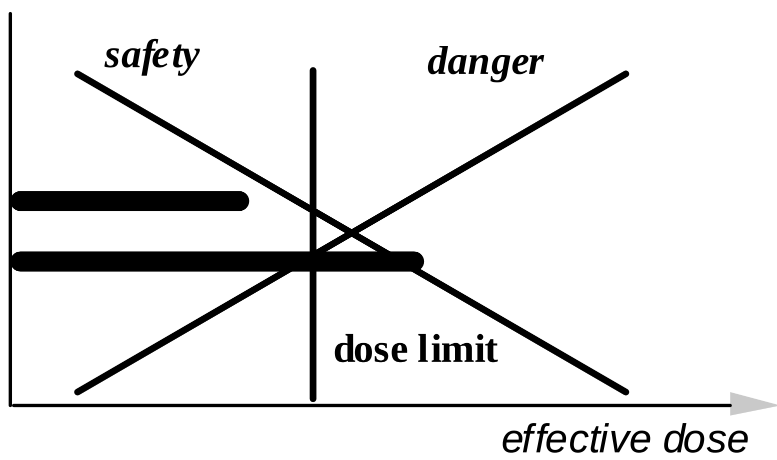
Ref Hill Table 25-5

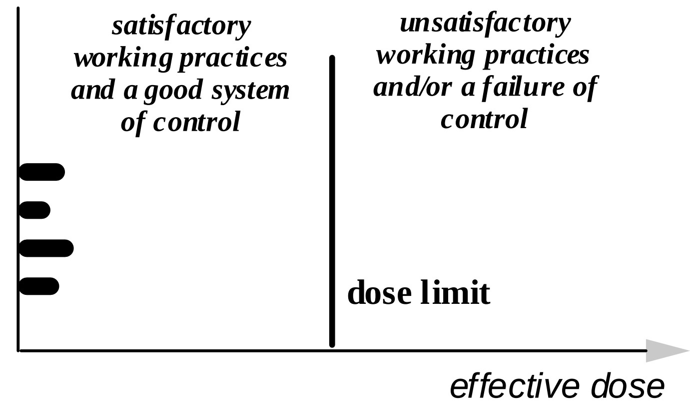
nomin prob coef

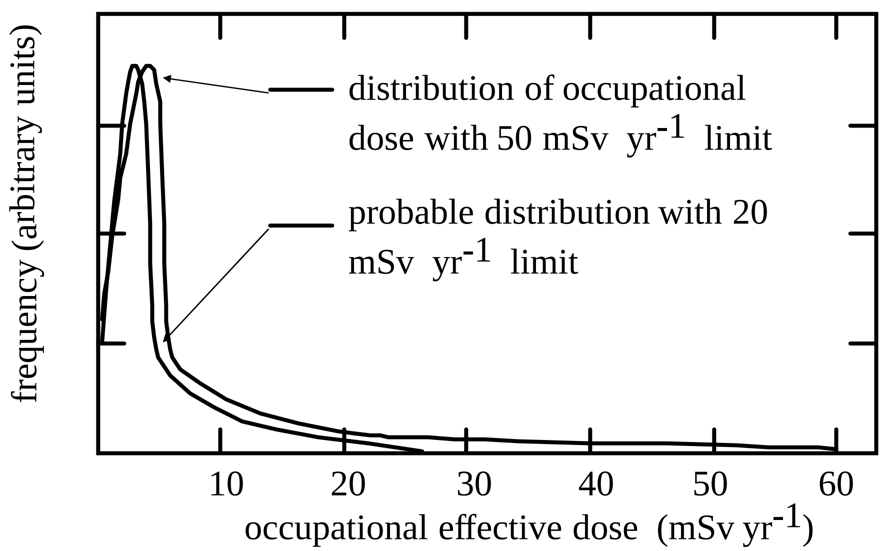
Framework

Radiation Protection

- In occupational exposure, pregnant worker shall be protected; embryo or fetus considered as member of the public.
- Safety culture should be inculcated that governs the attitudes and behavior in relation to protection and safety of all individuals and organizations dealing with sources of radiation.
- Sound management, good engineering, quality assurance, training, and qualification of personnel, comprehensive safety assessments and attention to lessons learned from experience and research.
- Dose limits do not apply to medical exposure.




satisfactory working practices and a good system of control
unsatisfactory working practices and/or a failure of control
dose limit
effective dose


frequency (arbitrary units)
distribution of occupational dose with 50 mSv yr-1 limit
probable distribution with 20 mSv yr-1 limit
10
20
30
40
50
60
occupational effective dose (mSv yr-1)

Medical Radiation Worker doses in 2000:

Job Category	# of Workers	Avg. Dose (mSv)
Dental Worker	25,099	0.01
NM Technologist	1261	1.41
Rad'n Therapist	1153	0.07
Radiologist	1562	0.09
Med. Physicist	274	0.22
Reactor - Fuel Handling	*52*	*5.64*

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Medical Radiation- Accidents

Date	Place	Equipment	Consequences	Cause
1976	Ohio	Co-60 teletherapy	450 patients over-exposed in 2 years	Incorrect calibration
1985	Texas	Linear accelerator (Therac-25)	6 patients affected, 2 died	Design error in accelerator control software
1986	Goiania, Brazil	Cs-137 teletherapy	4 persons died 54 persons > .25 Gy	Machine abandoned, weak reg. oversight
1990	Zaragosa, Spain	Linear accelerator	27 patients over-exposed, 14 died	Equipment malfunction - mishandled
1993	Indiana Regional Cancer Centre	^{192}Ir HDR brachytherapy	Patient received 16000 Gy instead of 18 Gy and died	Source wire broke, source in patient for 4 days, not surveyed
1996	Costa Rica	Co-60 teletherapy	115 patients over-exposed	Continued use of old equipment
2000	Thailand	Co-60 teletherapy	4 workers died	4 machines stolen
2001	Panama	Co-60 teletherapy	28 patients over-exposed, 6 died	Wrong treatment planning software

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Part 2
Agencies involved in Radiation Protection