Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 12

Health Physics

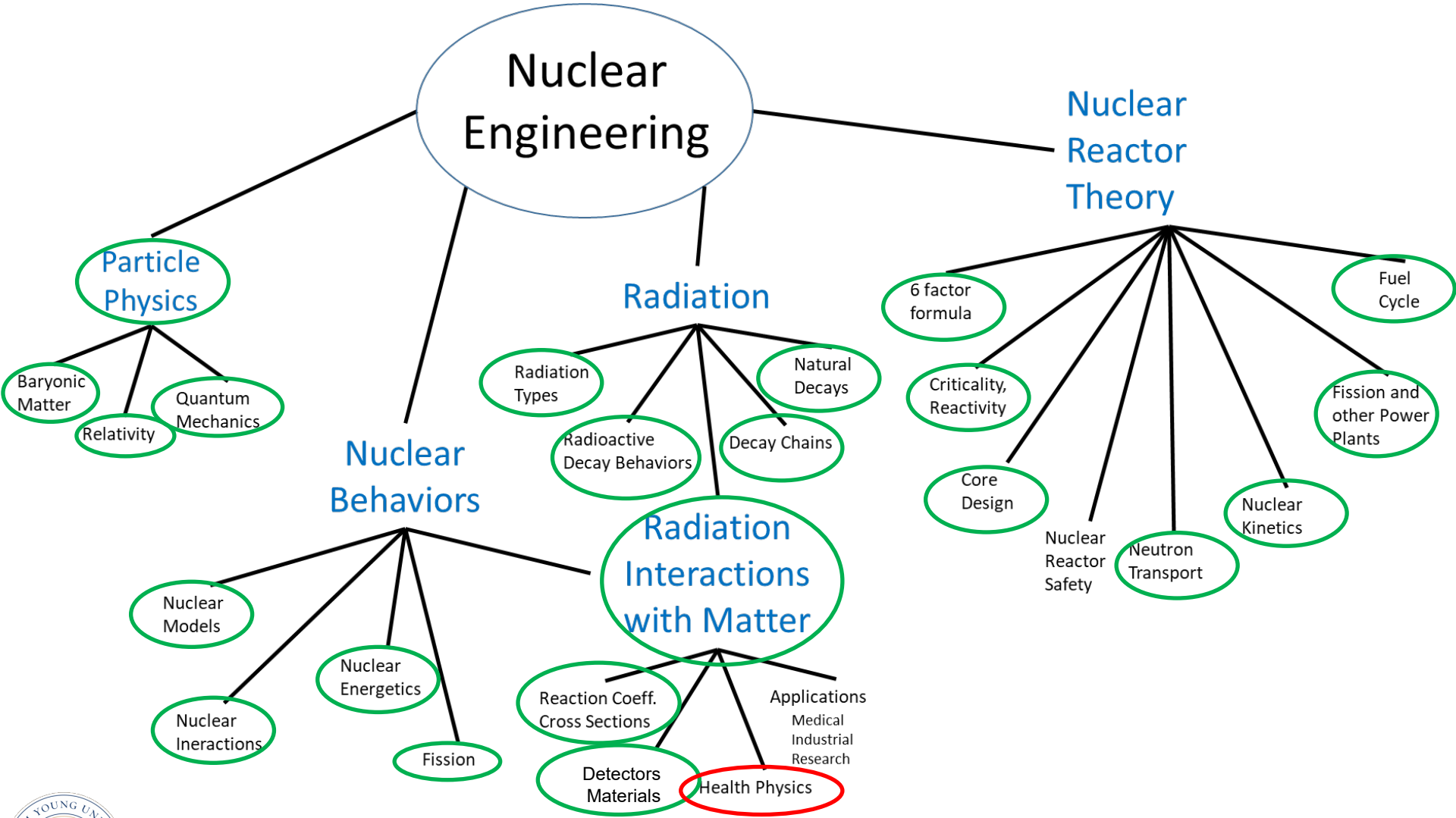
Radiation Hazard Assessment

Spiritual Thought

"I remember well the day [my son] passed away. As Jeanene and I drove from the hospital, we pulled over to the side of the road. I held her in my arms. Each of us cried some, but we realized that we would have him beyond the veil because of the covenants we had made in the temple. That made his loss somewhat easier to accept."

Elder Richard G. Scott

Roadmap


Nuclear Engineering
Particle Physics
Baryonic Matter
Relativity
Quantum Mechanics
Nuclear Behaviors
Nuclear Models
Nuclear Ineractions
Nuclear Energetics
Fission
Radiation
Radiation Types
Radioactive Decay Behaviors
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6 factor formula
Criticality, Reactivity
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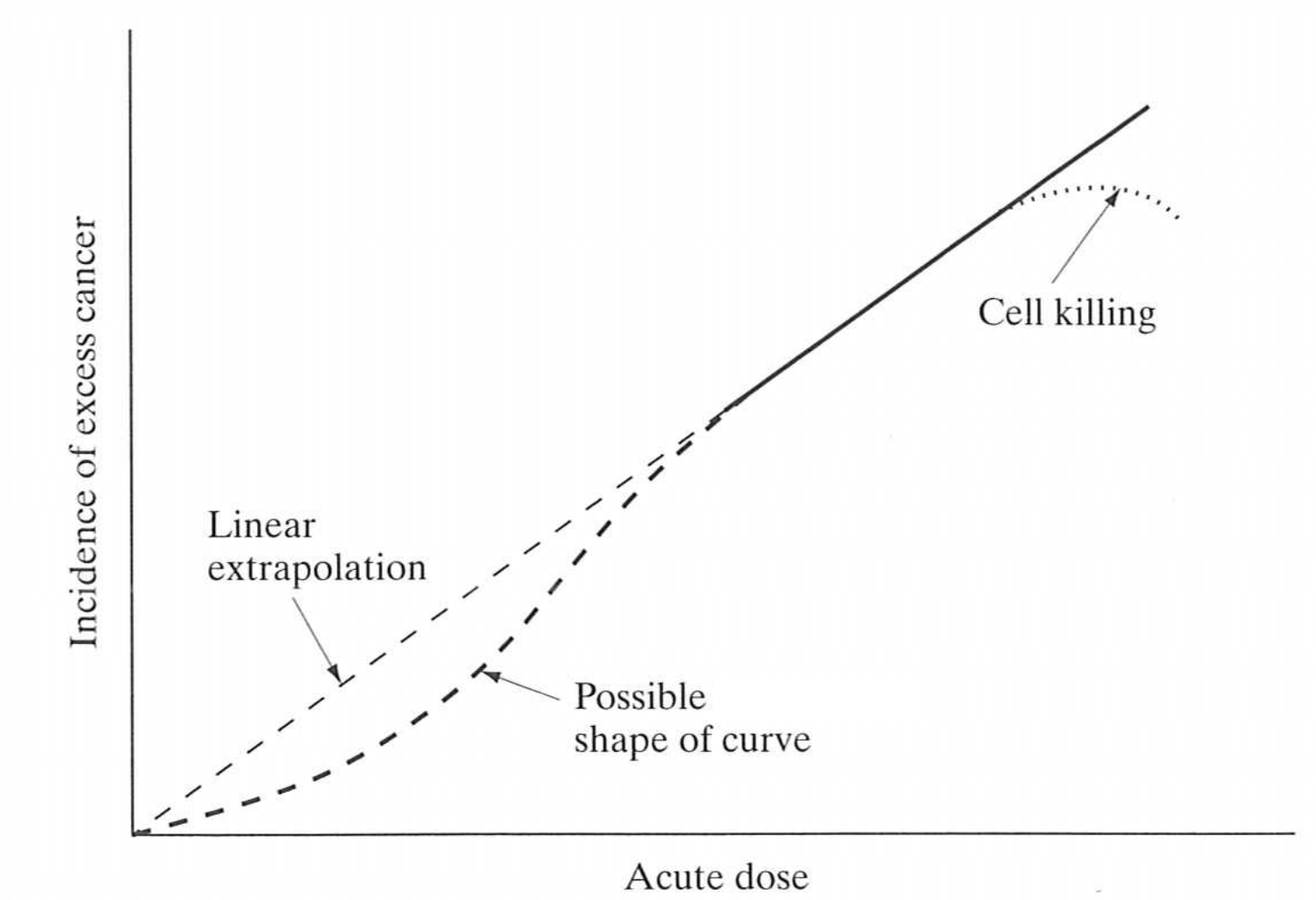
Nuclear Kinetics
Fission and other Power Plants
Fuel Cycle

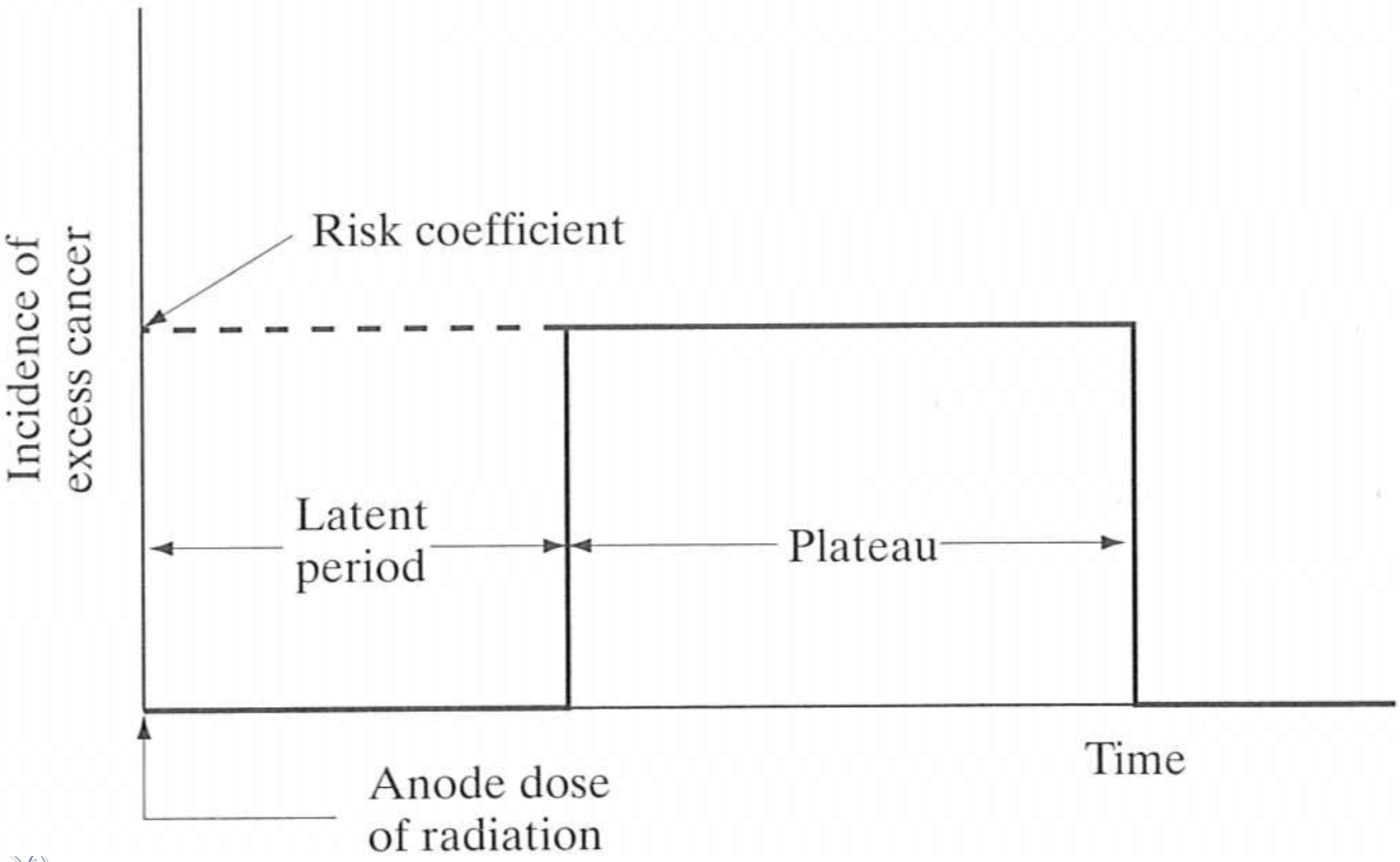
Radiation Exposure

Average annual radiation exposure (millisievert)							
Radiation		United Nations		Princeton	U of Washington	MEXT	
Type	Source	World average	Typical range	USA	USA	Japan	Remark
Natural	Air	1.26	0.2-10.0[a]	2.29	2	0.4	mainly from radon, depends on indoor accumulation of radon gas
	Internal	0.29	0.2-1.0[b]	0.16	0.4	0.4	mainly from food (K-40, C-14, etc.) [(b)]Depend on diets
	Terrestrial	0.48	0.3-1.0[c]	0.19	0.29	0.4	depend on soil and building material
	Cosmic	0.39	0.3-1.0[d]	0.31	0.26	0.3	from sea level to high elevation
	sub total	2.4	1.0-13.0	2.95	2.95	1.5	
Man made	Medical	0.6	0.03-2.0	3	0.53	2.3	
	Fallout	0.007	0 - 1+	-	-	0.01	peak at 1963 and spike at 1986. still high near test and accident sites. US; Fallout is included in others
	others	0.0052	0-20	0.25	0.13	0.001	average occupational exposure 0.7mSv, mining workers are high, population near nuclear plant 0.02mSv
	sub total	0.6	0 to tens	3.25	0.66	2.311	
Total		3	0 to tens	6.2	3.61	3.81	

Dose Response for Cancer



Latency


Incidence of excess cancer
Risk coefficient
Latent period
Plateau
Time
Anode dose of radiation

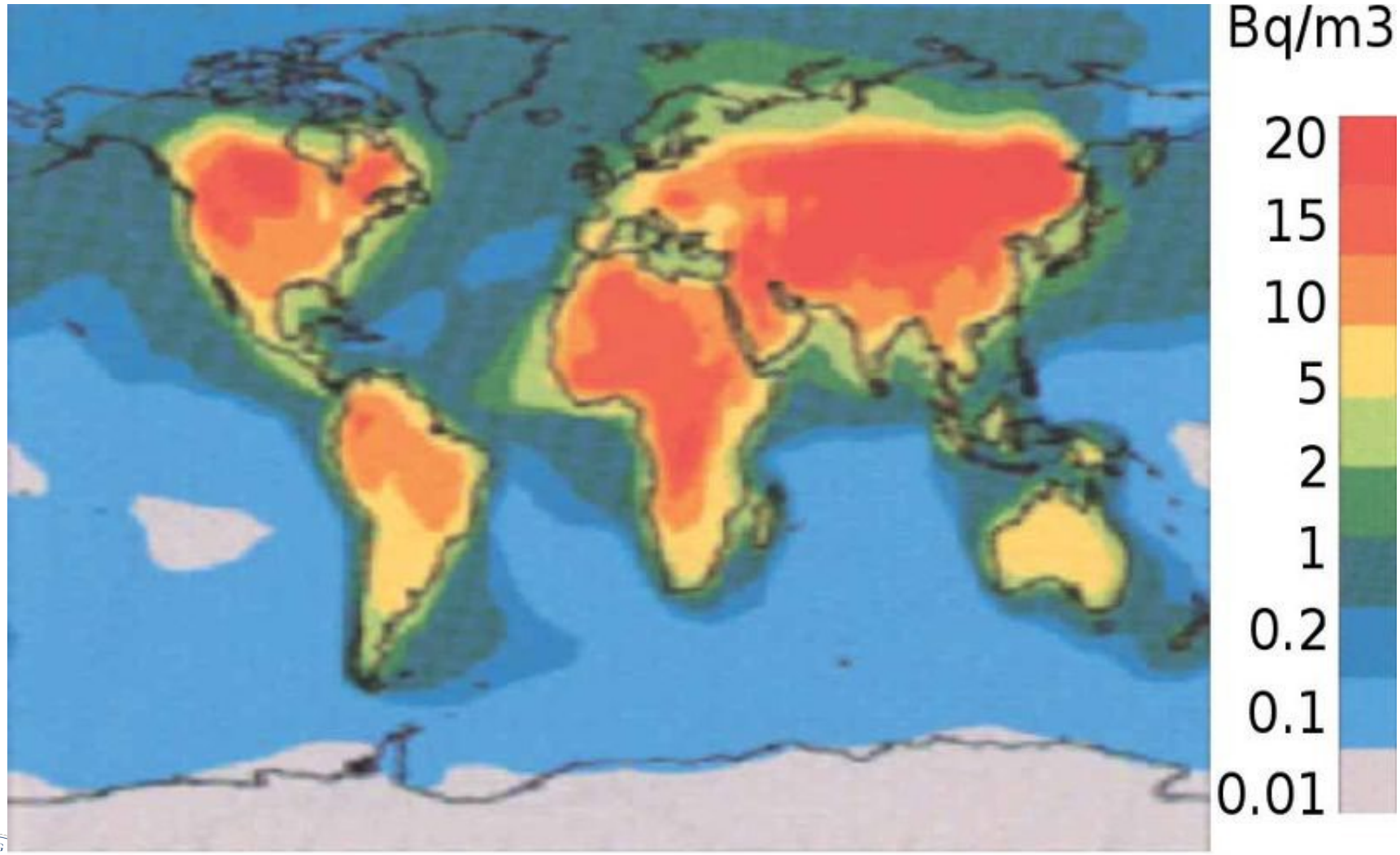
Exposure Limits

Limits for Exposures	Exposure
Occupational Dose limit (US - NRC)	5,000 mrem/year
Occupational Exposure Limits for Minors	500 mrem/year
Occupational Exposure Limits for Fetus	500 mrem
Public dose limits due to licensed activities (NRC)	100 mrem/year
Occupational Limits (eye)	15,000 mrem/year
Occupational Limits (skin)	50,000 mrem/year
Occupational Limits (extremities)	50,000 mrem/year

Allowed exposure above background (300 mrem)

- 25,000 mrem/yr
  - Astronauts, per Space Shuttle mission
  - Annual occupational limit for adults through 1950.
- 15,000 mrem/yr
  - 1950 to 1957 occupational limit per year for adults,
  - changed in 1957 to 5,000 millirems.
- 5,000 mrem/yr
  - Occupational limit per year for adult radiation workers
  - ALARA – "as low as reasonably achievable"
  - lifetime cumulative exposure not to exceed the age multiplied by 1,000 millirems.
- 500 mrem/yr
  - Occupational limit per year for a minor under 18 exposed
  - Cumulative total for Embryo or fetus of a pregnant worker (Jan. 1, 1994)
  - Fetus should be limited to 50 millirems above background levels per month.

Radon Exposure



Radiation Health Risks

Health Risk	Est. life expectancy lost
Smoking 20 cigs a day	6 years
Overweight (15%)	2 years
Alcohol (US Ave)	1 year
All Accidents	207 days
All Natural Hazards	7 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

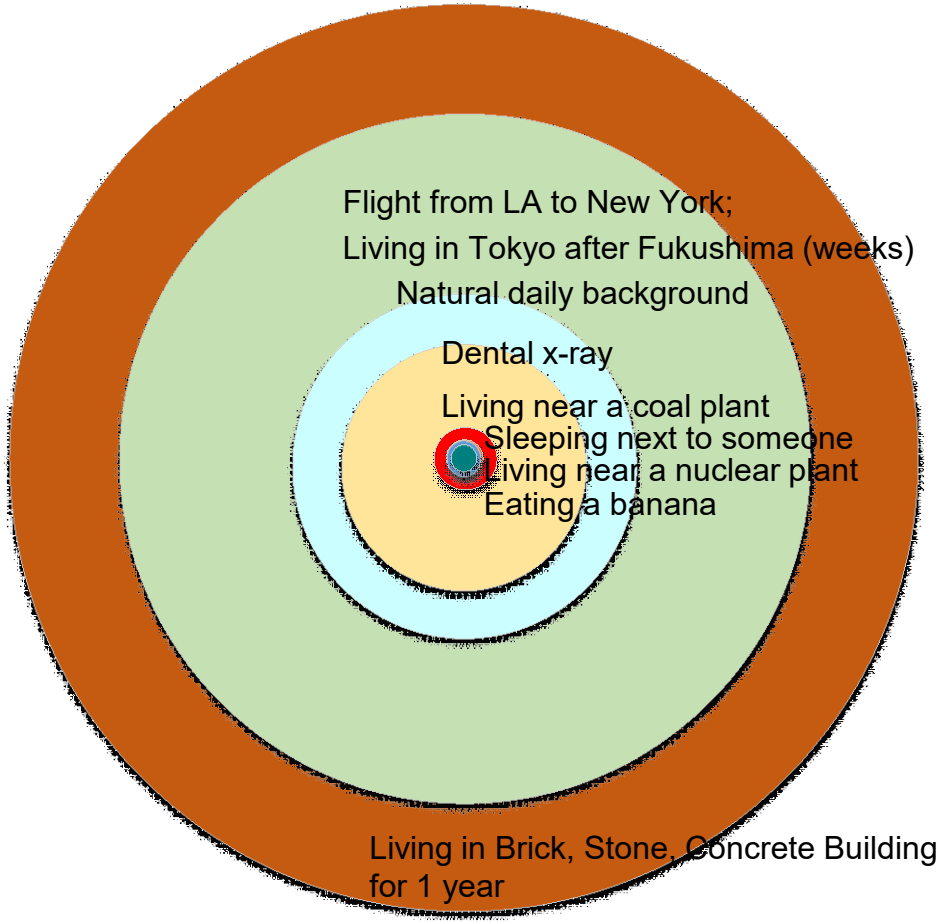
Occupational Health Risks

Industry type	Est. life expectancy lost
All Industries	60 days
Agriculture	320 days
Construction	227 days
Mining and quarrying	167 days
Manufacturing	40 days
Occupational dose (300 mrem/yr)	15 days
Occupational dose (1 rem/yr)	51 days

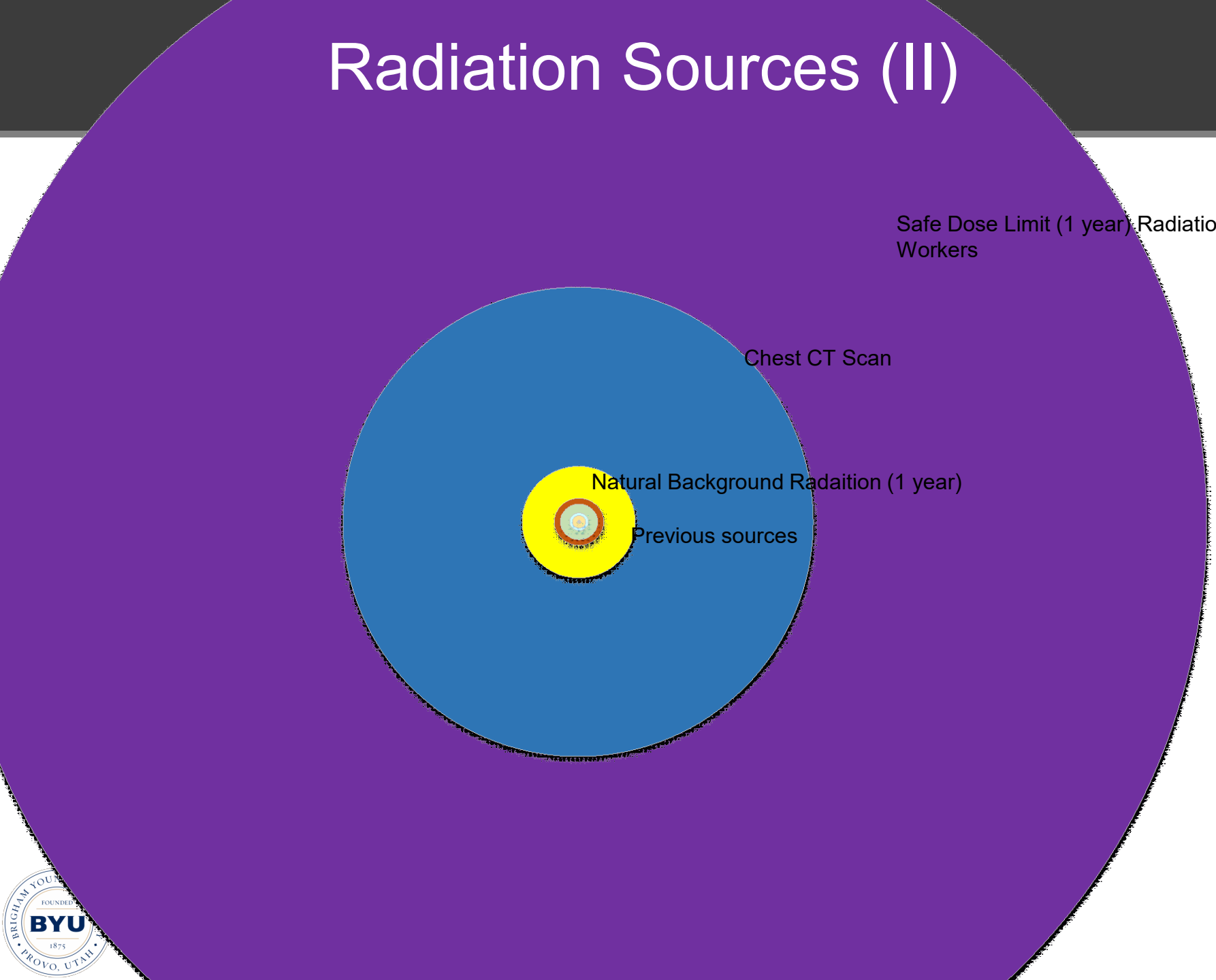
Comparison of Risks

Procedure	Effective Dose (Sv)	Effective Dose (mrem)	Risk of Fatal Cancer	Equivalent to Number of Cigarettes Smoked	Equivalent to Number of Highway Miles Driven
Chest Radiograph	3.2×10^{-5}	3.2	1.3×10^{-6}	9	23
Skull Exam	1.5×10^{-4}	15	6×10^{-6}	44	104
Barium Enema	5.4×10^{-4}	54	2×10^{-5}	148	357
Bone Scan	4.4×10^{-3}	440	1.8×10^{-4}	1300	3200

Radiation Sources (I)



Radiation Sources (II)



Biological Effect Classification

- Stochastic
  - Probability of occurrence (not severity) depends on equivalent dose
  - Cancer and genetic mutations are examples
  - Has minimum threshold (contested)
- Non-stochastic
  - Deterministic effects with severity that scales with dose
  - Skin damage (erythema), cataracts, blood composition are examples.
  - May have threshold

Human Physiology

- Wide ranges in active cell division rates in mature adults.
  - Intestinal lining, bone marrow, skin, and reproductive systems – most active
  - Other organs and tissues – low rates in adults.
  - Developing embryo, children, and youth
    - many regions of cell division
    - activity level varying greatly depending on system and age
    - But all much higher than in adults.

Effects of absorbed Doses (I)

Organ/Tissue	Endpoint	D_{50} (Gy)	$D_{\mathrm{th}}(Gy)$
skin	erythema	6 ± 1	3 ± 1
	moist desquamation	30 ± 6	10 ± 2
ovary	permanent ovulation supression	3 ± 1	0.6 ± 0.4
testes	sperm count supressed for 2 y	0.6 ± 0.1	0.3 ± 0.1
eye lens	cataract	3.1 ± 0.9	0.5 ± 0.5
lung	death[a]	70 ± 30	40 ± 20
GI system	vomiting	2 ± 0.5	0.5
	diarrhea	3 ± 0.8	1
	death	10 ± 5	8
bone marrow	death	3.8 ± 0.6	1.8 ± 0.3

[a] dose rate 0.5 Gy/h.

Erythema

Effects of absorbed Doses (II)

Lethality	Mid-line absorbed dose (Gy)
$LD_{5/60}$	2.0 - 2.5
$LD_{10/60}$	2.5 - 3.0
$LD_{50/60}$	3.0 - 3.5
$LD_{90/60}$	3.5 - 4.5
$LD_{99/60}$	4.5 - 5.5

Minimal dose detectable by chromosome analysis	0.05-0.25 Gy
Minimal dose detectable in groups by change in white-blood cell count	0.25-0.50 Gy
Minimal acute dose readily detectable in a specific individual	0.50-0.75 Gy
Mild effects only during first day post-exposure with slight depression of blood counts	0.50-1.00 Gy
Minimal acute dose to produce vomiting in 10 percent of exposed individuals	0.75-1.25 Gy
Nausea and vomiting in 20 to 70% of persons exposed fatigue and weakness in 30 to 60%; 20 to 35% drop in blood cell production due to loss of bone marrow stem cells	1.00-2.00 Gy
Acute dose likely to produce transient disability and clear hematological changes in a majority of individuals so exposed.	1.50-2.00 Gy

Radiation Sickness

- General dose radiation damage is most severe in activity reproducing cells
  - Broad exposure generally affects reproductive cycles (can be temporary at modest exposure), intestinal lining (can recover), and bone marrow (can recovery – sometimes with surgery)
  - Common symptoms of non-lethal exposures are changes in reproduction fertility and virility, nausea an diarrhea, and leukemia.
  - Cancers are long-term, stochastic issues.
- Specific dose radiation damage has fewer general trends
  - Thyroid cancers common because of radio-iodine
  - Basal cell cancers common but can have long latencies
  - Very little reliable data on humans

Cancer rates

TABLE 9.3 US CANCER MORTALITY RATES IN 1992–1996 (DEATHS PER HUNDRED THOUSAND PERSONS PER YEAR)*

Cancer type	Mortality
Breast	14.2
Leukemia	6.3
Lung, respiratory system	49.5
Pancreas	8.4
Stomach	4.2
Prostate	25.6
Thyroid	0.3
All sites	170.1

0.1 Gy dose (Low LET) Excess Cancers

Age at Exposure	Females					
	total	leukemia	breast	respiratory	digestive	other
5	1532	75	129	48	655	625
15	1566	72	295	70	653	476
25	1178	29	52	125	679	293
35	557	46	43	208	73	187
45	541	73	20	277	71	100
55	505	117	6	273	64	45
65	386	146	-	172	52	16
75	227	127	-	72	26	3
85	90	73	-	15	4	-
average[a]	810	80	70	150	290	220

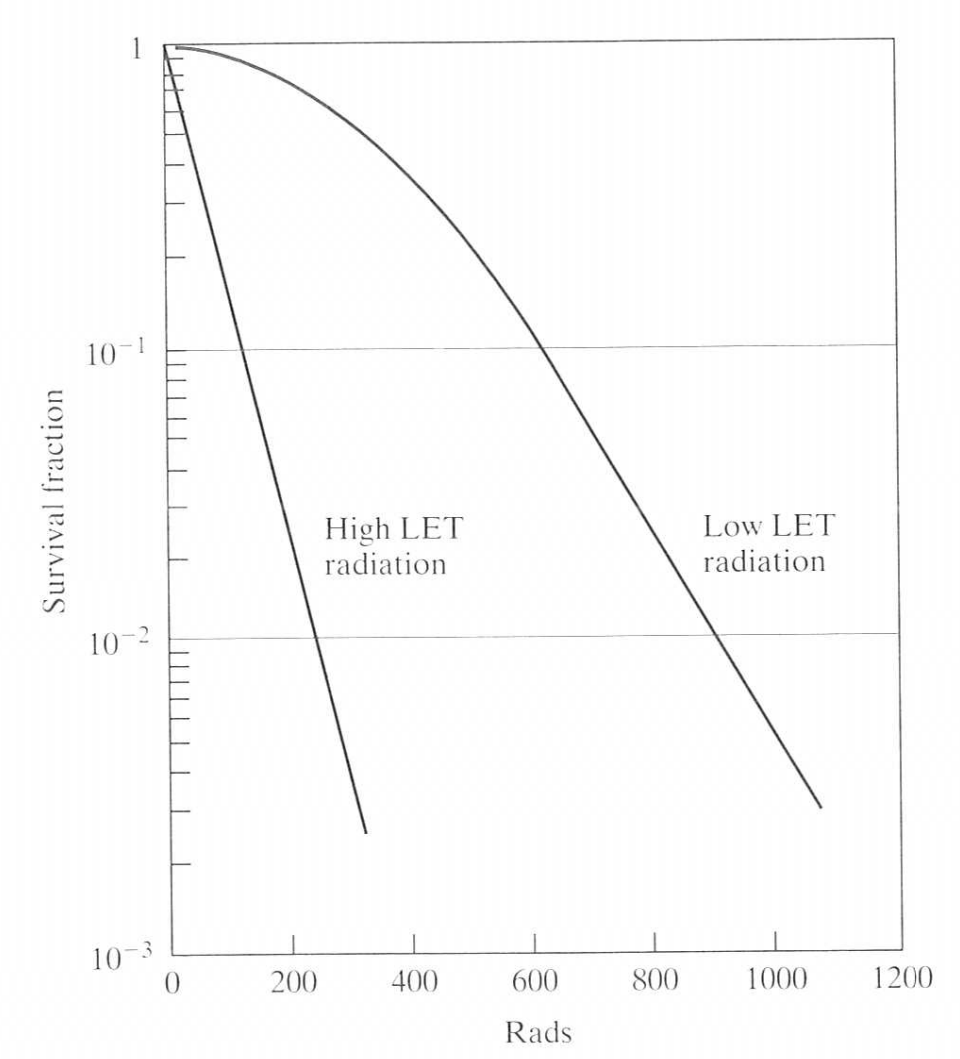
Age at Exposure	Males					
	total	leukemia	nonleukemia	respiratory	digestive	other
5	1276	111	1165	17	361	787
15	1144	109	1035	54	369	612
25	921	36	885	124	389	372
35	566	62	504	243	28	233
45	600	108	492	353	22	117
55	616	166	450	393	15	42
65	481	191	290	272	11	7
75	258	165	93	90	5	-
85	110	96	14	17	-	-
average[a]	770	110	660	190	170	300

[a] weighted average based on a static population.

Example Problem

What are the probabilities a 25-yr old male who receives a sudden accidental gamma-ray exposure of 2 rad (0.02 Gy) will eventually die from (1) radiogenic leukemia and from (2) any cancer caused by his exposure?

LET impacts on cells



Dose responses

TABLE 9.4 PROBABLE EARLY EFFECTS OF ACUTE WHOLE-BODY RADIATION DOSES*†

Acute dose (rems)	Probable observed effect
5 to 75	Chromosomal aberrations and temporary depression of white blood cell levels in some individuals. No other observable effects.
75 to 200	Vomiting in 5 to 50% of exposed individuals within a few hours, with fatigue and loss of appetite. Moderate blood changes. Recovery within a few weeks for most symptoms.
200 to 600	For doses of 300 rems or more, all exposed individuals will exhibit vomiting within 2 hours. Severe blood changes, with hemorrhage and increased susceptibility to infection, particularly at the higher doses. Loss of hair after 2 weeks for doses over 300 rems. Recovery from 1 month to a year for most individuals at the lower end of the dose range; only 20% survive at the upper end of the range.
600 to 1,000	Vomiting within 1 hour. Severe blood changes, hemorrhage, infection, and loss of hair. From 80% to 100% of exposed individuals will succumb within 2 months; those who survive will be convalescent over a long period.

Blood effects

TABLE 9.5 AVERAGE CONCENTRATIONS OF FORMED ELEMENTS OF HUMAN BLOOD

Formed elements	Concentration (per cubic millimeter)
Erythrocytes	$(4.5–5.5) \times 10^6$
Leukocytes	6,000–10,000
Platelets	$(2–8) \times 10^5$

Blood response