

Chemical Engineering 412

Introductory Nuclear Engineering

Lecture 29

Radiation Hazard Assessment



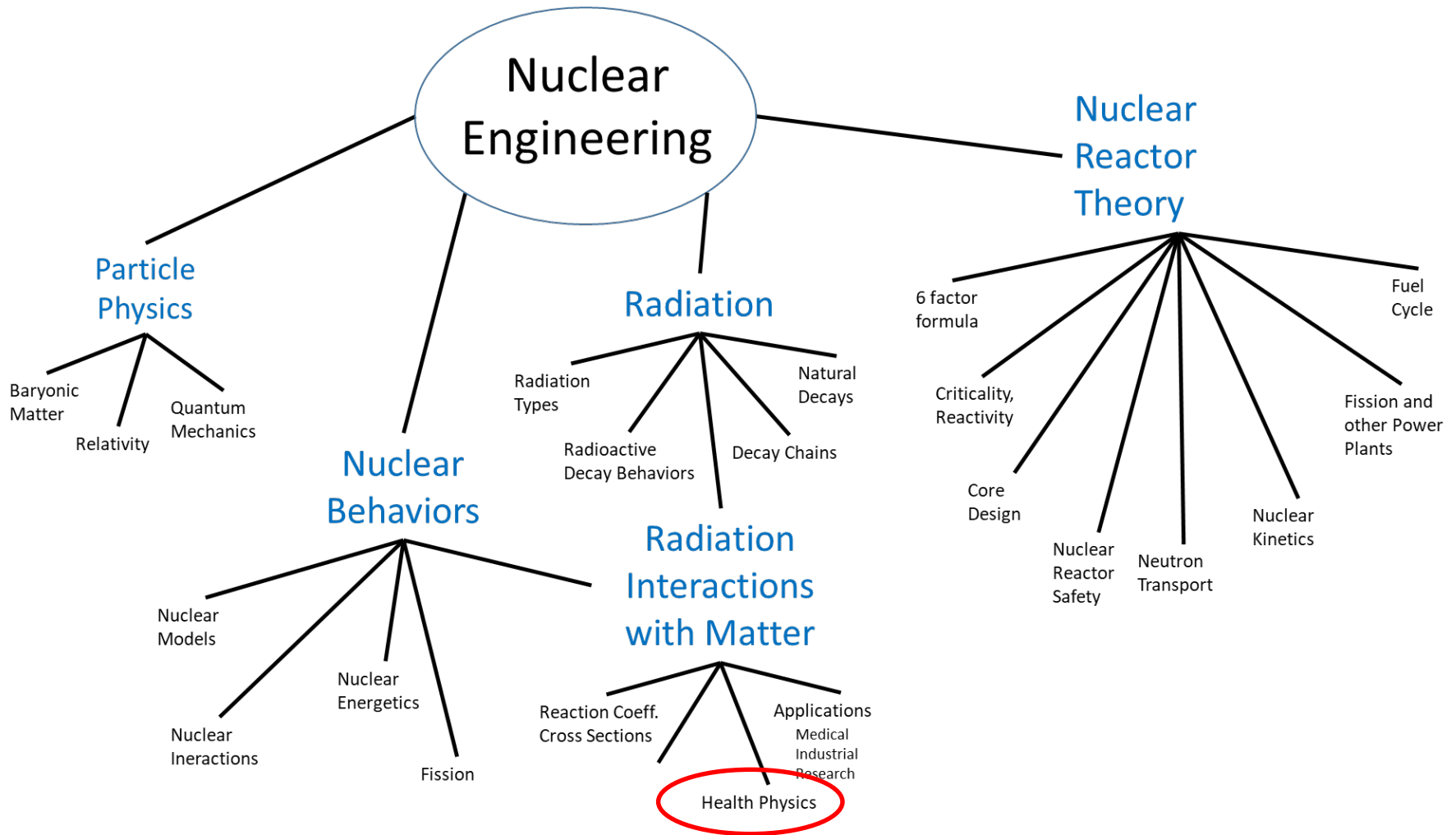
Spiritual Thought

We all live on spiritual credit. In one way or another, the account builds and builds. If you pay it off as you go, you have little need to worry. Soon you begin to learn discipline and know that there is a day of reckoning ahead. Learn to keep your spiritual account paid off at regular intervals rather than allowing it to collect interest and penalties. The gospel teaches us that relief from torment and guilt can be earned through repentance. Save for those few—those very few—who defect to perdition after having known a fullness, there is no habit, no addiction, no rebellion, no transgression, no offense small or large which is exempt from the promise of complete forgiveness. No matter what has happened in your life, the Lord has prepared a way for you to come back if you will heed the promptings of the Holy Spirit.

Elder Boyd K. Packer



The BIG Picture

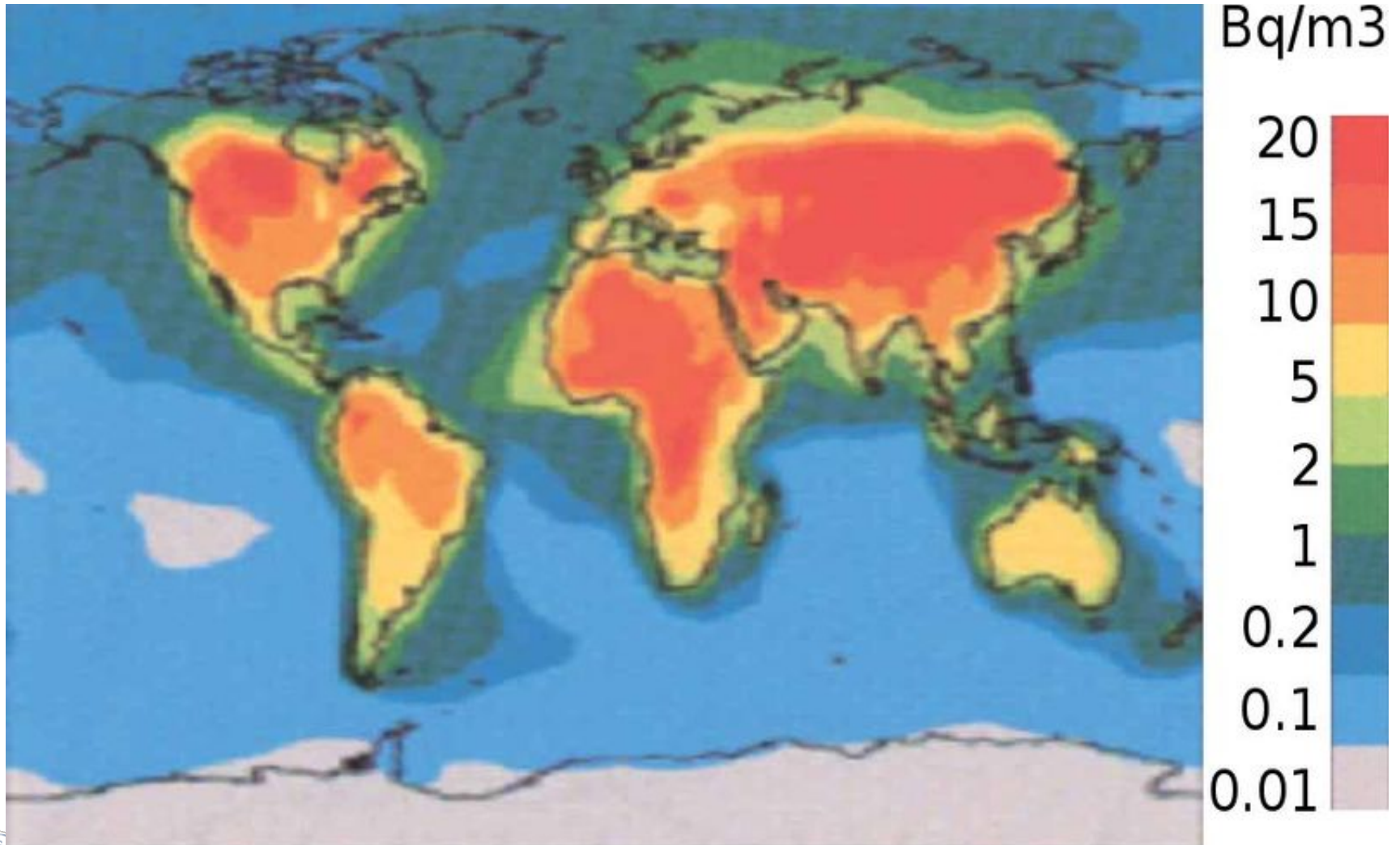


Radiation Exposure

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	



Radon Exposure



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.



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



Effects of absorbed Doses (I)

Organ/Tissue	Endpoint	D_{50} (Gy)	$D_{th}(Gy)$
skin	erythema	6 ± 1	3 ± 1
	moist desquamation	30 ± 6	10 ± 2
ovary	permanent ovulation suppression	3 ± 1	0.6 ± 0.4
testes	sperm count suppressed 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.



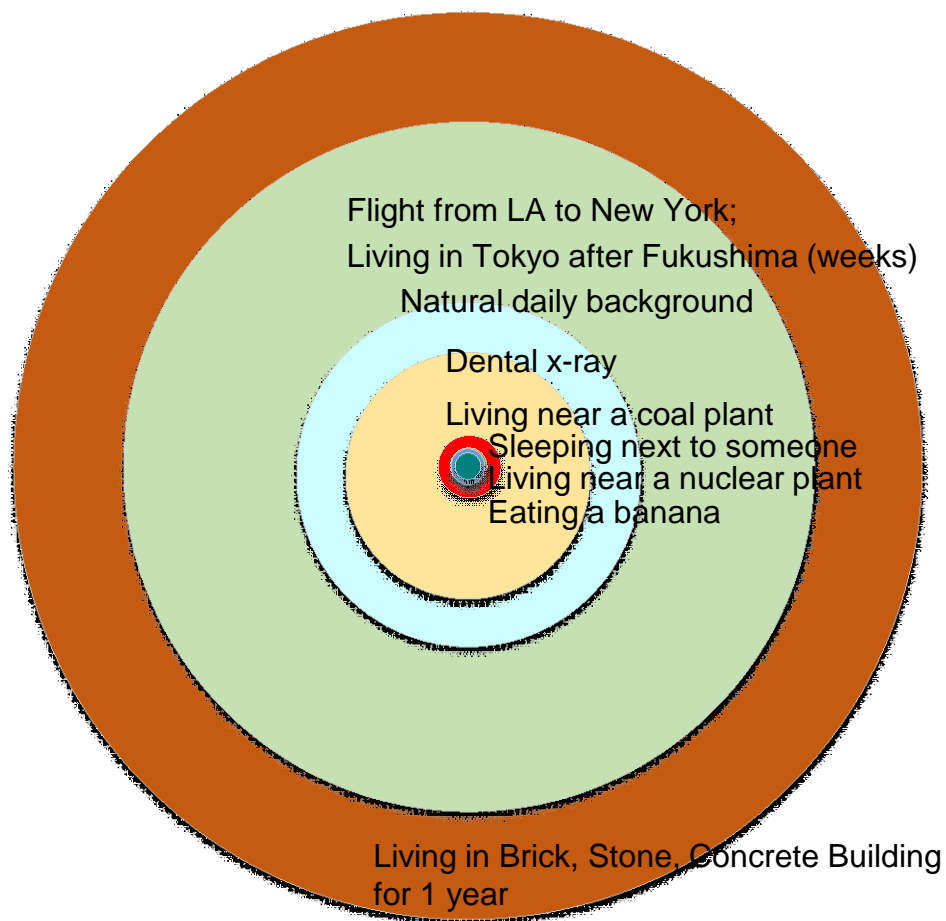
Effects of absorbed Doses (II)

Lethality	Mid-line absorbed dose (Gy)
<i>LD</i> _{5/60}	2.0 - 2.5
<i>LD</i> _{10/60}	2.5 - 3.0
<i>LD</i> _{50/60}	3.0 - 3.5
<i>LD</i> _{90/60}	3.5 - 4.5
<i>LD</i> _{99/60}	4.5 - 5.5

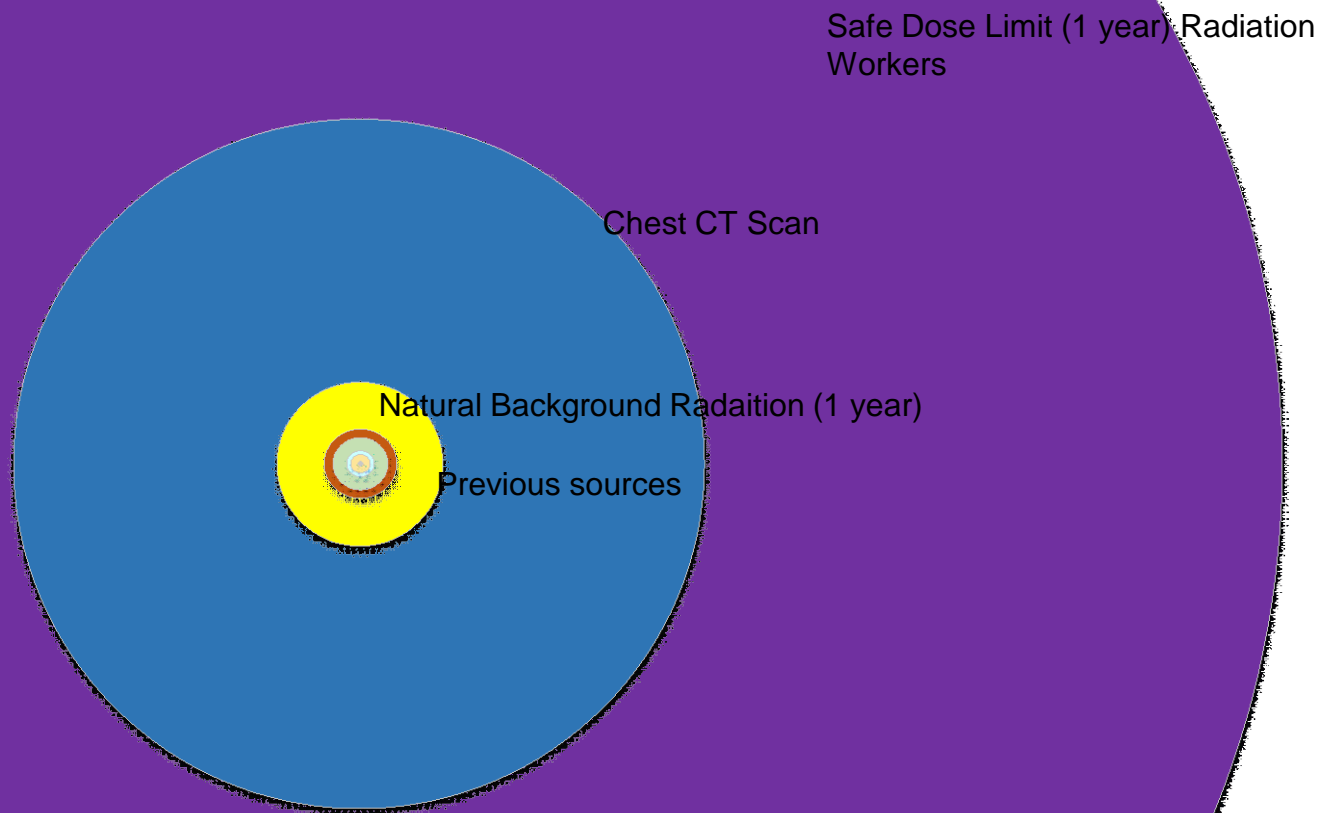
Minimal dose detectable by chromosome analysis	0.05-0.25 Gy
Minimal dose detectable in groups by change in white-blood cell count	0.25-0.50 Gy
Minimal acute dose readily detectable in a specific individual	0.50-0.75 Gy
Mild effects only during first day post-exposure with slight depression of blood counts	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 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.

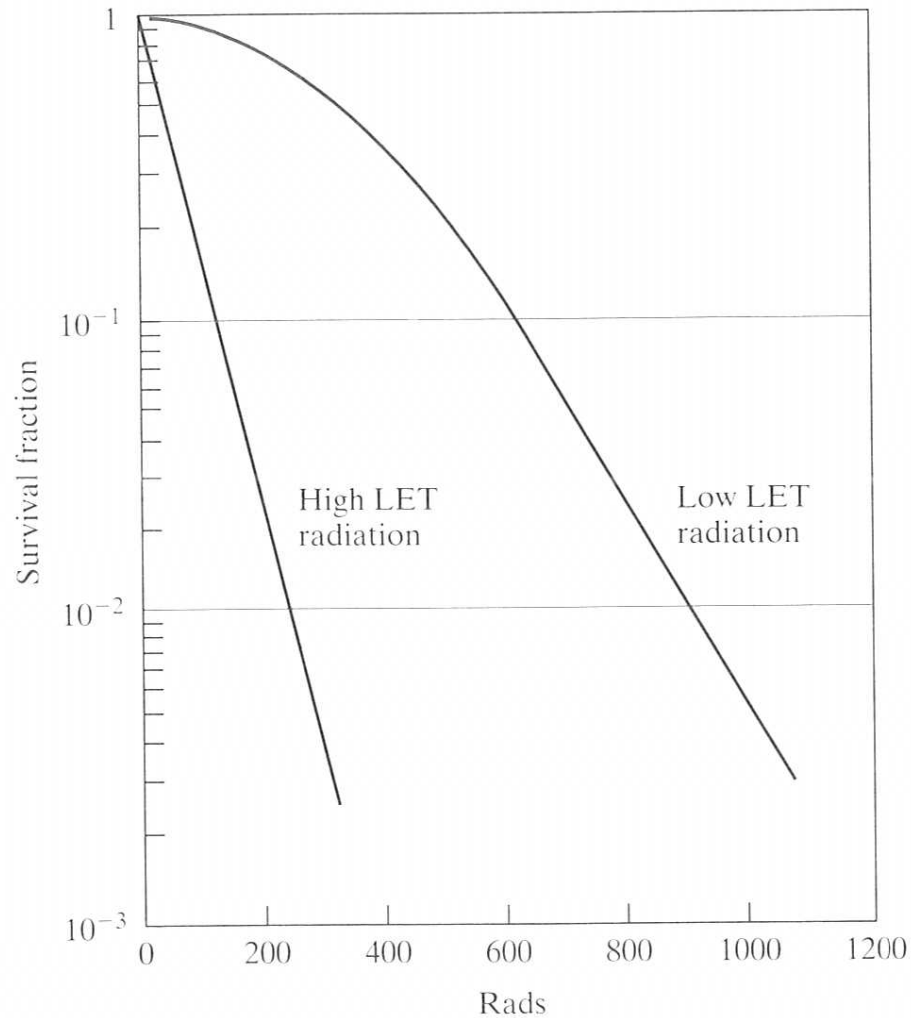


Radiation Sickness

- 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 and 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



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.



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



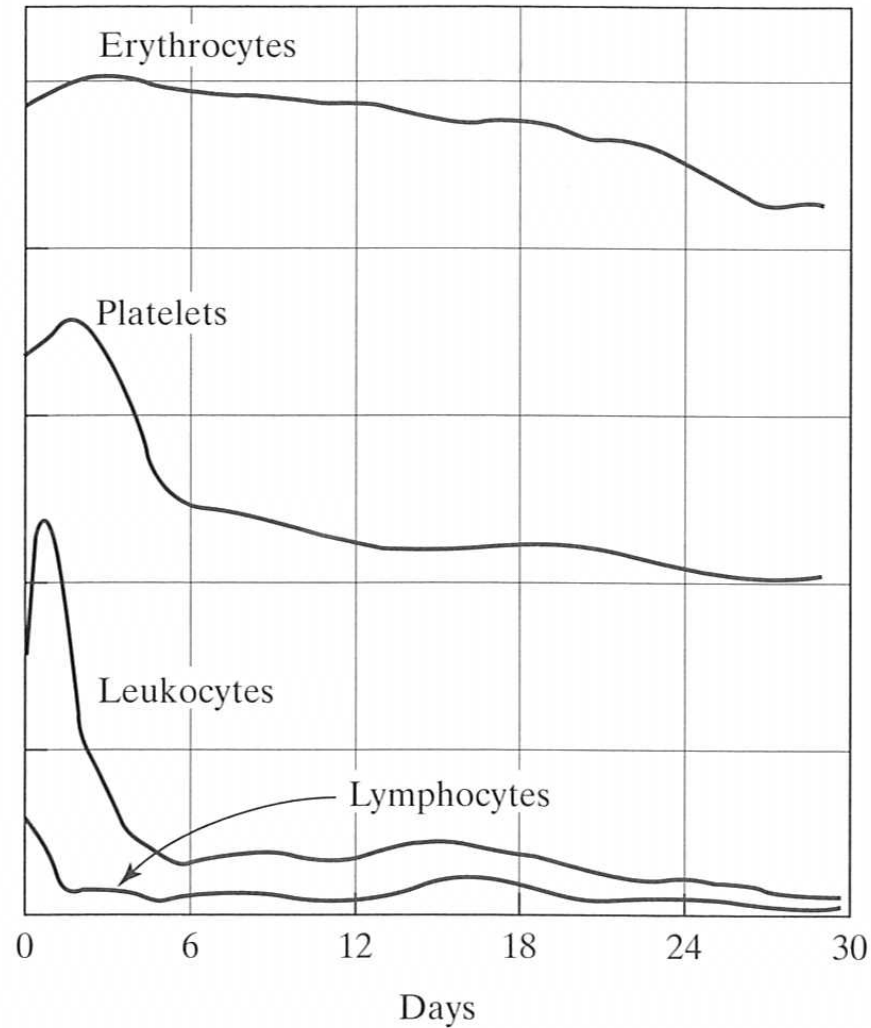
Blood effects

TABLE 9.5 AVERAGE CONCENTRATIONS OF FORMED ELEMENTS OF HUMAN BLOOD

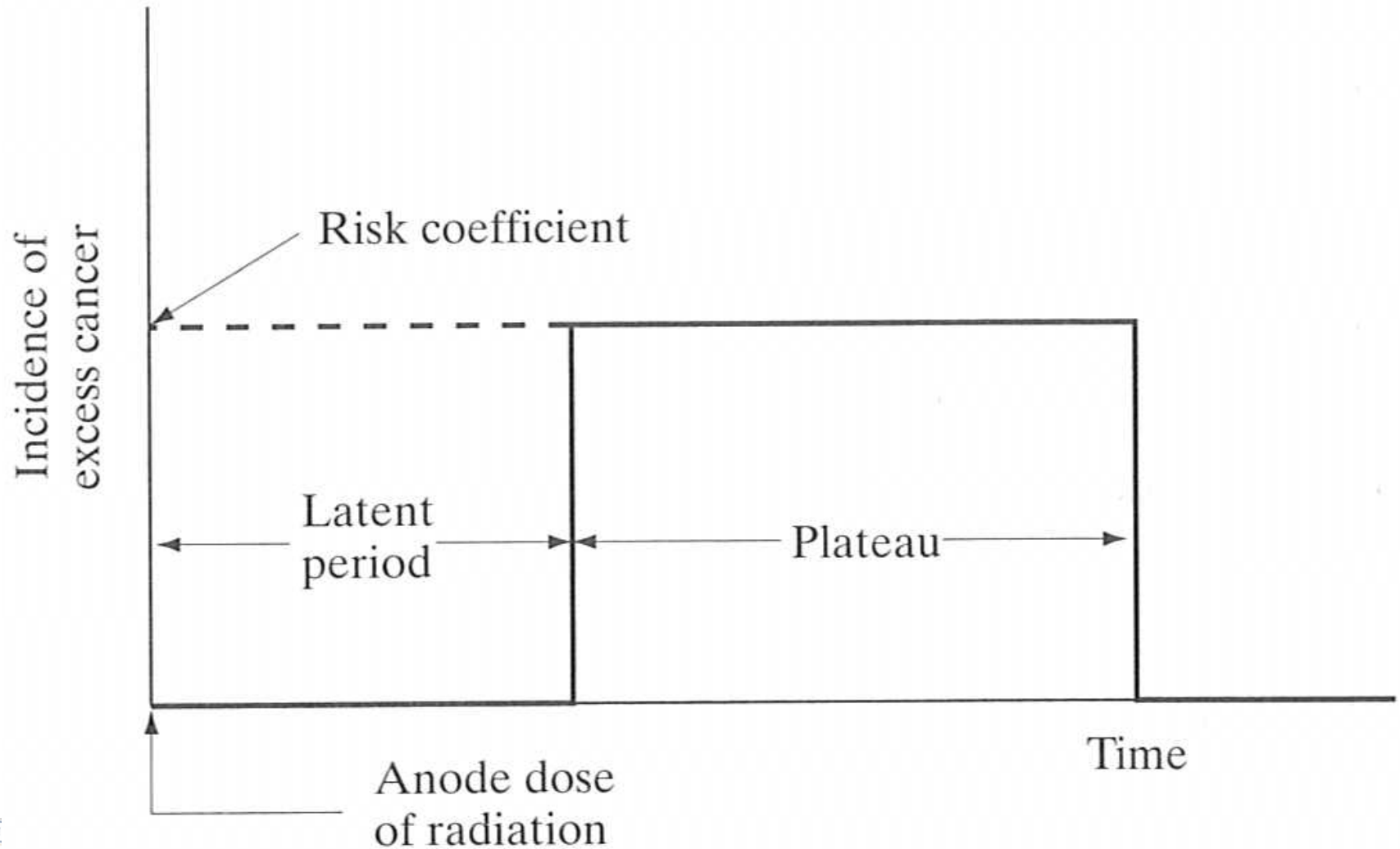
Formed elements	Concentration (per cubic millimeter)
Erythrocytes	$(4.5-5.5) \times 10^6$
Leukocytes	6,000–10,000
Platelets	$(2-8) \times 10^5$



Blood response



Latency



Dose-induced Cancer

TABLE 9.6 DATA ON RADIATION-INDUCED CANCER*

Type of cancer	Age at time of irradiation	Latent period years	Plateau period (years)	Risk coefficient (deaths/10 ⁶ /yr/rem)
Bone	0–19.9	10	30	0.4
	20+	10	30	0.2
Breast	10+	15	30	1.5
Leukemia	<i>In utero</i>	0	10	15
	0–9.9	2	25	2
	10+	2	25	1
Lung, respiratory system	10+	15	30	1.3
Pancreas	10+	15	30	0.2
Stomach	10+	15	30	0.6
Rest of alimentary canal	10+	15	30	0.2
Thyroid	0+	10	30	0.43
All other	<i>In utero</i>	0	10	15
	0–9.9	15	30	0.6†
	10+	15	30	1‡

*From Reactor Safety Study, WASH-1400, US Nuclear Regulatory Commission, October 1975,



Dose Response for Cancer

