Radiation Risk

A Critical Look at Real and Perceived Risks from Radiation Exposure

Phil Rutherford

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Agenda

- **Definitions of Risk and Factors Shaping Risk Perception**
- US Mortality Risk
- Background Radiation
- LNT Model of Theoretical Radiation Risk
- Probability of Causation
- Health Studies

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Webster's Dictionary Definition of Risk

- The chance of injury, damage or loss
- Dangerous chance
- Hazard
- Degree of probability of loss

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Scientific Definition of Risk

- Risk is the probability of an undesired consequence during a specified time period
- The specific risks discussed in the subsequent slides will focus on
  - ionizing radiation as the cause
  - cancer mortality as the effect
- Risk is therefore a quantitative function of exposure and biological effect

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Real Measured Risk

- Based on observation
- Reported by US National Center for Health Statistics and other federal agencies
- Risk = $\dfrac{\text{No. of injuries or deaths}}{\text{No. of people exposed to hazard}}$
- Examples
  - number of swimming pool drownings within a population of swimming pool users
  - number of auto fatalities within a population of automobile users and pedestrians
  - no. of cancer fatalities in US population
- Cause of death is stated on death certificate

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Theoretical Risk

- Calculated based on extrapolation or inference from clinical studies or epidemiology studies (cohort or ecological)
- Examples
  - arsenic in drinking water (see later example of new standards recommended by EPA because of new clinical studies)
  - chromium-6 in drinking water (DHS has withdrawn its prior recommendation for lower standards because of faulty clinical studies)
  - radiation exposure (linear-no-threshold model extrapolated from high doses and high dose rates of A-bomb survivors)
- Illness is stated on death certificate but exposure to hazard not usually referenced

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Risk Perception

- Acceptable
  - Voluntary
  - Individual control
  - Clear benefits
  - Trustworthy sources
  - Ethically neutral
  - Natural
  - Familiar
  - No historical associations
  - Less dread
  - Visible
  - Immediate effect
  - Known, understood
  - Little media attention
- Unacceptable
  - Involuntary
  - Others control
  - Unclear benefits
  - Untrustworthy sources
  - Ethically objectionable
  - Artificial
  - Exotic
  - Memorable associations
  - High dread
  - Undetectable
  - Delayed effect
  - Uncertainty, variability
  - High media attention

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US Cancer Rates

- Measured fatal cancer risk in the US population in 1998 was 23% [1]
- Estimated US 2001 cancer deaths = 553,400 [2]
- Estimated US 2001 new cancer incidence = 1,268,000 [2]
- Incidence/mortality rate = 2.29
- Survival rate = 56%
- Estimated cancer incidence risk in the US population is 2.29 x 23% = 53%

(1) US 1998 Cancer Statistics

(2) American Cancer Society estimates based on National Center of Health Statistics data

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1998 Deaths/Mortality (*All figures are for U.S.)*

Number of Deaths Annually: **2,337,258**

Death Rate (age-adjusted): **471.7 deaths per 100,000 population**

Ten Leading Causes of Death in the U.S.:

Heart Disease:	**724,859**
Cancer:	**541,532**
Stroke:	**158,448**
Chronic Obstructive Pulmonary Disease:	**112,584**
Accidents:	**97,835**
Pneumonia/Influenza:	**91,871**
Diabetes:	**64,751**
Suicide:	**30,575**
Nephritis, nephrotic syndrome, and nephrosis:	**26,182**
Chronic Liver Disease and Cirrhosis:	**25,192**

Source: National Vital Statistics Report, Vol. 48, No. 11

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1998 Accidents/Unintentional Injuries

(All figures are for U.S.)

Fatal Accidents:	**97,835**
Fatal Accident Rate:	**36.2 deaths per 100,000**
Fatal Accident Rank:	**5**

Motor Vehicle Deaths:	**43,501**
Motor Vehicle Fatality Rates:	**16.1 deaths per 100,000**

Source: National Vital Statistics Report, Vol. 48, No. 11

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Risk of 1 in a Million Chance of Dying

- Smoking 1.4 cigarettes (lung cancer)
- Eating 40 tablespoons of peanut butter
- Spending 2 days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2,500 miles in a jet (accident)
- Canoeing for 6 minutes
- Receiving 2 mrem of radiation (cancer)

Adapted from DOE Radiation Worker Training, based on work by B.L Cohen, Sc.D.

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Risks of Arsenic in Drinking Water				
Comments	**Concentration (ppb)**	**Cancer Risk**	**Polpulation Potentially Exposed**	**Expected Cancers**
Prior EPA Standard	50	1.5 in 100	280,000,000	4,200,000
Proposed Clinton Administration Standard Accepted Bush Administration Standard	10	3 in 1,000	280,000,000	840,000
Standard preferred by NRDC	3	1 in 1,000	280,000,000	280,000

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Radioactivity vs. Radiation

- Radioactive Source
  - The quantity of radioactivity or radioactive material is measured in curies
  - radioactive material emits energy called ionizing radiation measured in roentgens
  - radiation decreases with distance from the source
- Light bulb
  - The "size" or power of a light bulb is measured in watts
  - a light bulb emits energy called light that is measured in lumens
  - light decreases with distance from the light bulb

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Hazard vs. Exposure

- Radioactive material is potentially hazardous
- Extent of hazard depends on
  - Quantity (Ci, mCi, μCi, nCi or pCi)
  - Type of radiation (alpha, beta, gamma, neutrons)
  - Energy of radiation (MeV, KeV, eV)
  - Form (sealed source, electroplated, unconfined)
  - Phase (solid, liquid, particulate or gas)
  - Type of contamination (fixed surface, loose surface, volumetric, or airborne)
  - Shielding
  - Distance to receptor
  - Time in proximity
  - Type of exposure (external, inhaled, or ingested)
- Exposure to a receptor is a function of all of these

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37

REVIEW OF QUANTITIES AND UNITS

	Traditional	S.I.
Activity	Ci 3.7×10^{10} dis/sec	Bq 1 dis/sec
Absorbed dose	rad 100 erg gm^{-1}	Gray 1 Joule gm^{-1}
Dose equivalent Equivalent dose	rem rad x QF	Sv Gy x W_R
Effective dose	rem $\sum W_T H_T$	Sv $\sum W_T H_T$
Committed Effective Dose	rem	Sv

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THE UNITS FOR ACTIVITY

Traditional	Activity	S.I.*
1 curie	3.7×10^{10} dis/sec	3.7×10^{10} Bq
1 millicurie	3.7×10^{7} dis/sec	3.7×10^{7} Bq
1 microcurie	3.7×10^{4} dis/sec	3.7×10^{4} Bq
1 nanocurie	3.7×10^{1} dis/sec	3.7×10^{1} Bq
27 picocuries	1 dis/sec	1 Bq

S.I.*	Activity	Traditional
1 Bq	1 dis/sec	27 picocuries
1 KBq	1,000 dis/sec	27 nanocuries
1 MBq	10^{6} dis/sec	27 microcuries
1 GBq	10^{9} dis/sec	27 millicuries
37 GBq	3.7×10^{10} dis/sec	1 curie

*Abbreviation for International System of Units

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Background Radiation

- US EPA, EPA-402-K-92-004, “Radiation: Risks and Realities”, August 1993

Source	**Annual Dose Rate (millirem/year)**
Household Radon	~200
Cosmic Rays	~31
Human Body (food & drink)	~39
Soil & Rock	~28
Total	~300

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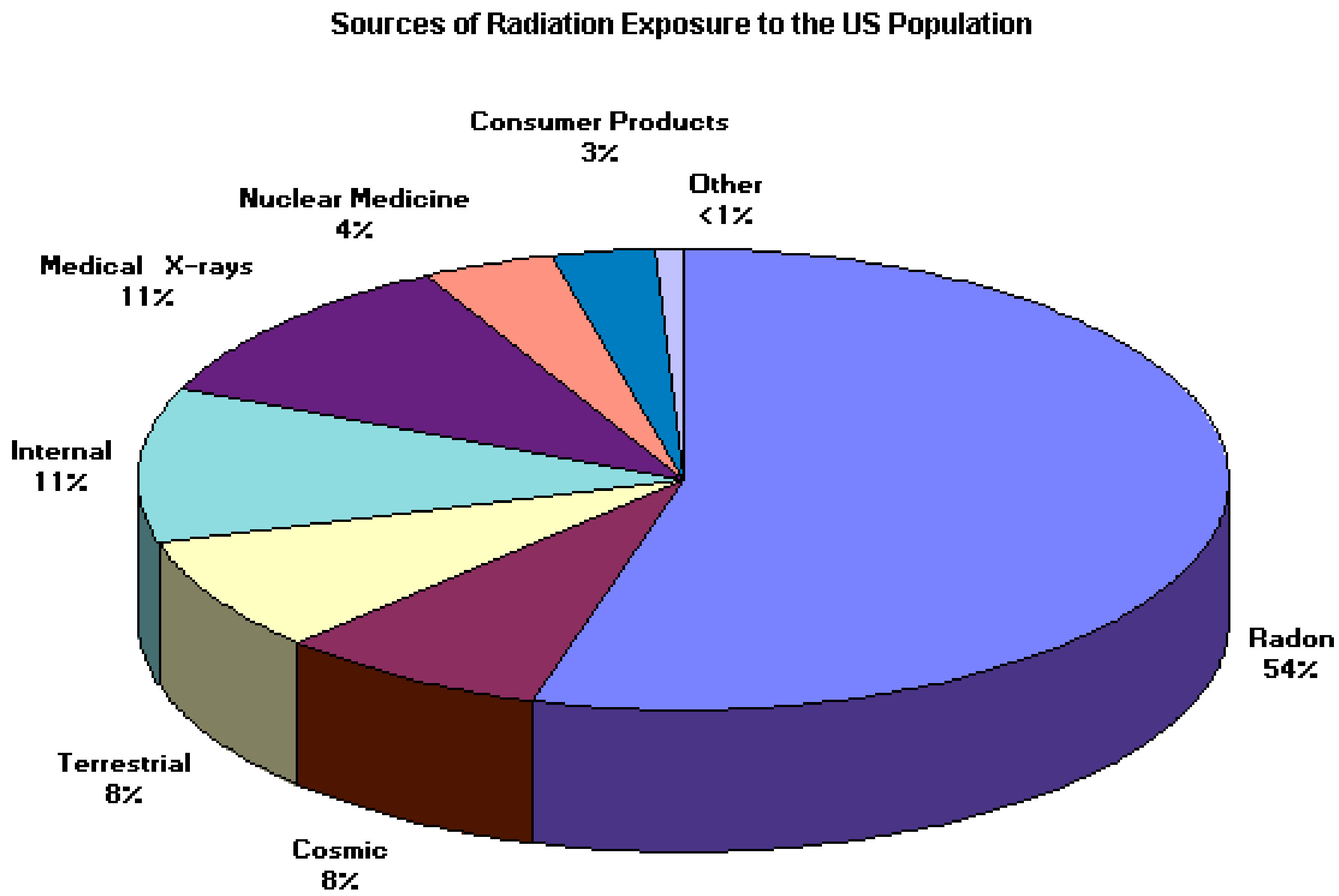

Sources of radiation exposure to US population. Adapted from NCRP 93

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Natural Radioactivity in your Body

Nuclide	Total Activity of Nuclide Found in the Body
Uranium	30 pCi
Thorium	3 pCi
Potassium 40	120,000 pCi
Radium	30 pCi
Carbon 14	400,000 pCi
Tritium	600 pCi
Polonium	1,000 pCi

Estimated concentrations of radionuclides calculated
for a 70 kilogram adult based ICRP 30 data:

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Natural Radioactivity in Food

Food	^{40}K (pCi/g)	^{226}Ra (pCi/g)
Banana	3.52	0.001
Brazil Nuts	5.6	1 - 7
Carrot	3.4	0.0006 - 0.002
White Potatoes	3.4	0.001 - 0.0025
Beer	0.39	---
Red Meat	3.0	0.0005
Lima Bean	4.64	0.002 - 0.005
Drinking water	---	0.0 - 0.00017

Ref: Handbook of Radiation Measurement and Protection, Brodsky, A. CRC Press 1978 and Environmental Radioactivity from Natural, Industrial and Military Sources, Eisenbud, M and Gesell T. Academic Press, Inc. 1997.

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Typical Radioactivity in Common Building Materials

Material	Uranium (pCi/g)	Thorium (pCi/g)	Potassium (pCi/g)
Granite	1.7	0.22	32
Sandstone	0.2	0.19	11
Cement	1.2	0.57	6.4
Limestone concrete	0.8	0.23	2.4
Sandstone concrete	0.3	0.23	10
Dry wallboard	0.4	0.32	2.4
By-product gypsum	5.0	1.8	0.2
Natural gypsum	0.4	0.2	4
Wood	-	-	90
Clay Brick	3	1.2	18

Estimates of concentrations of uranium, thorium and potassium in building materials (NCRP 94, 1987)

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Potassium-40 Concentrations

Item	**Potassium-40 (pCi/g)**
Potassium Chloride (Salt Substitute)	400
Clean Soil	20
Human Body	1.4
Clean Seawater	0.3
EPA's Preliminary Remediation Goal at 10^{-6} risk level*	0.013*

* EPA's Preliminary Remediation Goal for Agricultural Soil. http://epa-prgs.ornl.gov/radionuclides/

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Potassium-40 in Food*

Specific activity (picocuries of potassium-40 per gram of potassium) = 818 pCi/g
1 picocurie (pCi) = one trillionth part of a curie = 0.000000000001 curie

	Potassium (mg)	Item	Serving or Item Size (g)	Potassium Content (g-K/g)	Potassium-40 concentration (pCi/g)	Potassium-40 content (pCi/serving)
Dried Fruits					**10.2 - 2.5**	
Apricots	500	Serving	40	0.013	10.2	409
Peaches	370	Serving	40	0.009	7.6	303
Raisins	310	Serving	40	0.008	6.3	254
Prunes	290	Serving	40	0.007	5.9	237
Figs	260	Serving	42	0.006	5.1	213
Dates	240	Serving	40	0.006	4.9	196
Cranberry/Orange	190	Serving	40	0.005	3.9	155
Apples	180	Serving	40	0.005	3.7	147
Bananas	93	Serving	30	0.003	2.5	76
Fresh Fruit					**2.5 - 0.7**	
Banana	450	1 medium	150	0.003	2.5	368
Cantaloupe	494	I cup	226	0.002	1.8	404
Orange	250	1 medium	227	0.001	0.9	205
Watermelon	186	1 cup	226	0.001	0.7	152
Fruit Juice					**1.8 - 1.0**	
Orange Juice	500	Serving	226	0.002	1.8	409
Grapefruit juice	320	Serving	240	0.001	1.1	262
Apple Juice	280	Serving	240	0.001	1.0	229
Cerials					**8.8 - 2.5**	
Wheat germ	140	Serving	13	0.011	8.8	115
Soy Protein	390	Serving	55	0.007	5.8	319
Bran Flakes	190	Serving	30	0.006	5.2	155
Oat Bran	230	Serving	49	0.005	3.8	188
Mueslix	240	Serving	55	0.004	3.6	196
Raisin Almond Crunch	220	Serving	58	0.004	3.1	180
Grapenuts	180	Serving	58	0.003	2.5	147

***potassium is not regulated in food or drinking water**

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	Potassium (mg)	Item	Serving or Item Size (g)	Potassium Content (g-K/g)	Potassium-40 concentration (pCi/g)	Potassium-40 content (pCi/serving)
Dairy Products					**1.5 - 1.3**	
Yogurt	500	1 container	277	0.002	1.5	409
Skim Milk	406	1 cup	226	0.002	1.5	332
Low Fat milk	348	1 cup	226	0.002	1.3	285
Vegetables					**4.3 - 0.9**	
Potato	844	1 medium	159	0.005	4.3	690
Acorn Squash (cooked)	896	1 cup	226	0.004	3.2	733
Spinach (cooked)	838	1 cup	226	0.004	3.0	685
Lentils (cooked)	731	1 cup	226	0.003	2.6	598
Kidney Beans (cooked)	713	1 cup	226	0.003	2.6	583
Split Peas (cooked)	710	1 cup	226	0.003	2.6	581
White Navy Beans (cooked)	669	1 cup	226	0.003	2.4	547
Butternut Squash (cooked)	583	1 cup	226	0.003	2.1	477
Tomato	273	1 medium	114	0.002	2.0	223
Carrot	233	1 medium	100	0.002	1.9	191
Brussel Sprouts (cooked)	494	1 cup	226	0.002	1.8	404
Zucchini (cooked)	456	1 cup	226	0.002	1.7	373
Green Beans)cooked)	185	1/2 cup	113	0.002	1.3	151
Broccoli (cooked)	332	1 cup	226	0.001	1.2	272
Spinach (fresh)	119	1/2 cup	113	0.001	0.9	97
Meat & Fish					**4.3 - 2.1**	
Cod	449	3 oz. Fillet	85	0.005	4.3	367
Chicken	220	3 oz. Breast	85	0.003	2.1	180

***potassium is not regulated in food or drinking water**

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Potassium-40*

Specific activity (picocuries of potassium-40 per gram of potassium) = 818 pCi/g

1 picocurie (pCi) = one trillionth part of a curie = 0.000000000001 curie

	Potassium (mg)	Item	Serving or Item Size (g)	Potassium Content (g-K/g)	Potassium-40 concentration (pCi/g)	Potassium-40 content (pCi/serving)
Miscellaneous						
Daily potassium intake. Recommended Daily Allowance (RDA)	3,500	3.5 g/day	3.5	1.0	818	2,863
Annual potassium intake. Recommended Annual Allowance (RAA)	1,277,500	3.5 g/day for 1 year	1,278	1.0	818	1,044,995
Salt substitute (KCl)	610	Condiment serving	1.2	0.51	416	499
Clean Soil	-	-	-	0.024	20	-
Human Body	122,249	150 lb adult	68,182	0.002	1.5	100,000
Clean Seawater	-	-	-	0.00037	0.3	-
EPA 10^{-6} cleanup standard in soil	-	-	-	0.000016	0.013	-
Daily DWP Drinking Water	7	2 liters/day	2,000	0.000004	0.003	6
Annual DWP Drinking Water	2,555	2 liters/day for 1 year	730,000	0.000004	0.003	2,090

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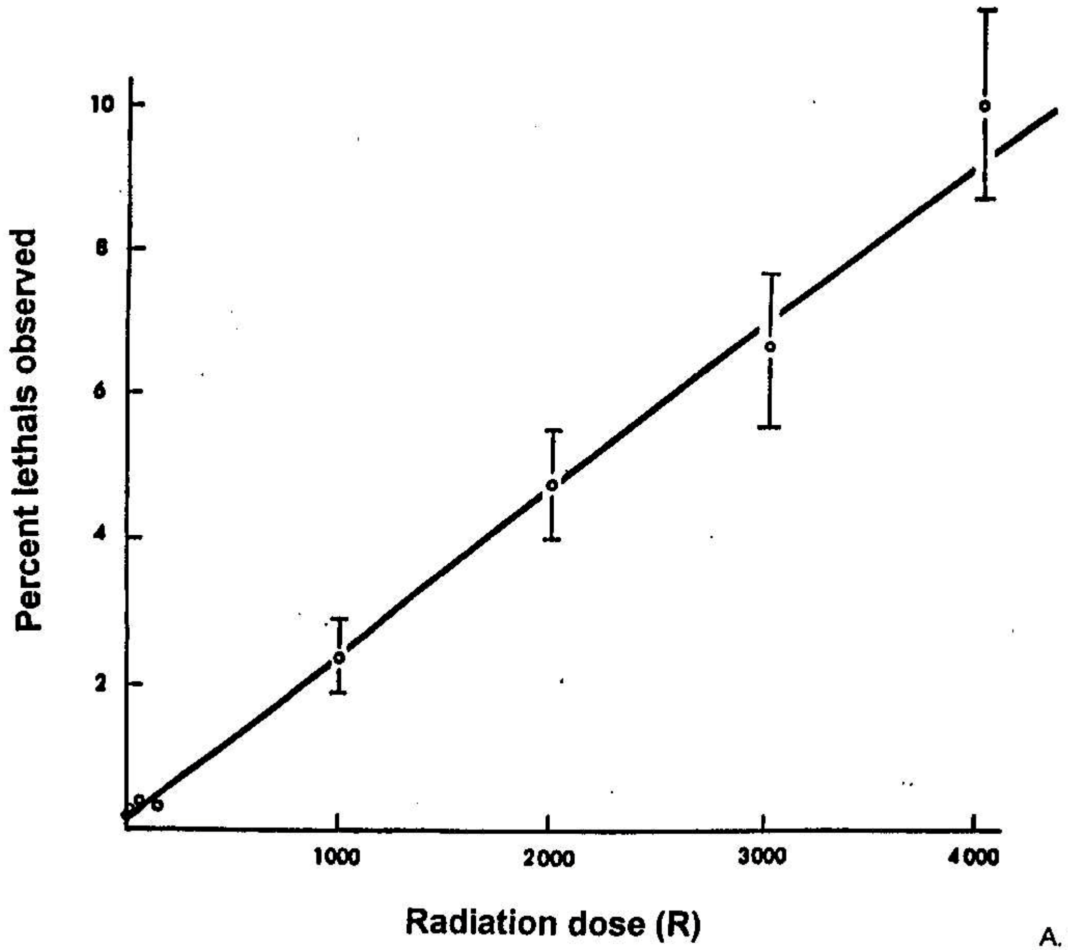
Relationship between mutation rate and radiation dose to *Drosophila* spermatozoa. (Data from Spencer and Stern, 1948)



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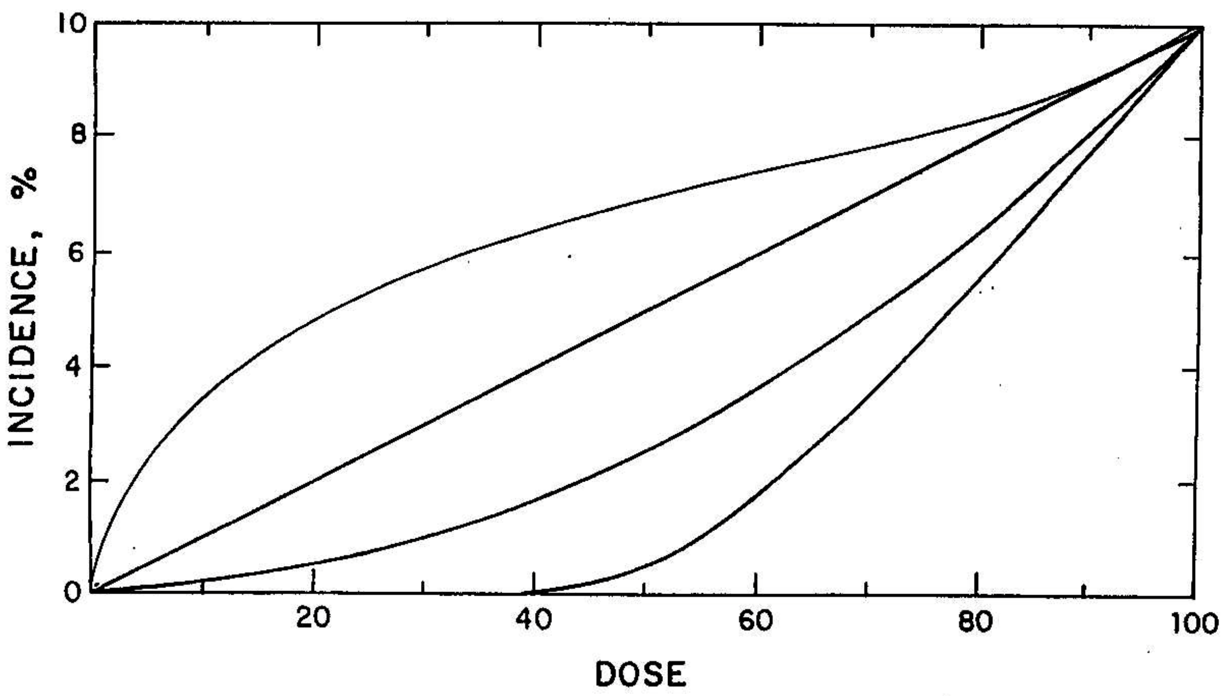
DOSE RESPONSE MODELS



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Risk per Exposure (LNT)

- Linear-no-threshold (LNT) model relates risk to exposure
- Non cancer specific
- Non organ dose specific
- Risk = risk of dying from fatal cancer
- Exposure = cumulative exposure to whole body
- 0.0004 risk per rem = 1 in 2,500 chance of fatal cancer per rem of exposure (occupational workers)
- 0.0005 risk per rem = 1 in 2,000 chance of fatal cancer per rem of exposure (general population)
- International Commission on Radiological Protection, ICRP 60 (1991)

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Risk per Exposure (LNT)

- 0.0005 fatal cancer risk per rem
- NRC cleanup standard (10 CFR 20 Subpart E) is
  - 25 mrem/year or
  - 25 mrem/year x 40 years x 0.0005 risk/rem x 0.001 rem/millirem = 5×10^{-4} fatal cancer risk

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Background Radiation

- Exposure to background radiation during and average lifetime
- ~ 0.3 rem/year x 80 years = ~ 24 rem per lifetime
- Using the assumption that theoretical risk of 0.0005 per rem applies at background exposure levels,
- Individual theoretical risk is 0.0005 x 24 = 0.012,
  or over 1 in a hundred,
  or over 1%

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Collective Dose
(Person-rem)

- The stochastic nature of LNT model allows inappropriate exposure of large populations to trivially small doses to achieve high fatalities
- 0.0005 risk per rem = 0.0005 fatalities per person-rem
- 1 fatality per 2,000 person-rem

Fatalities	**Dose (mrem)**	**Persons Exposed**	**Person-rem**
1	1,000	2,000	2,000
1	100	20,000	2,000
1	10	200,000	2,000
1	1	2,000,000	2,000
1	0.1	20,000,000	2,000
1	0.01	200,000,000	2,000

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Collective Risk to Large Populations

- Background exposure of 300 mrem/y to US population of 285,000,000 people would result in 42,750 theoretical deaths per year
  - 1.8% of all deaths
  - 8% of all cancer deaths
- Background exposure of 300 mrem/y to world population of 6,186,000,000 people would result in 927,900 theoretical deaths per year
- If LNT is valid at background levels

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Radiation Risk in Perspective

Health Physics Society Position Statement

March, 1996

In accordance with current knowledge of radiation health risks, the Health Physics Society recommends against quantitative estimation of health risk below an individual dose of 5 rem[(1)] in one year, or a lifetime dose of 10 rem in addition to background radiation. Risk estimation in this dose range should be strictly qualitative accentuating a range of hypothetical health outcomes with an emphasis on the likely possibility of zero adverse health effects. The current philosophy of radiation protection is based on the assumption that any radiation dose, no matter how small, may result in human health effects, such as cancer and hereditary genetic damage. There is substantial and convincing scientific evidence for health risks at high dose. Below 10 rem (which includes occupational and environmental exposures) risks of health effects are either too small to be observed or are non-existent.

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EEOICPA

- Under EEOICPA, claimants will need to to demonstrate a "probability of causation (PC)" of 50%, or more.
- Online software IREP-NIOSH calculates PC
- Risk of radiation cancer => inherent risk of cancer
- Radrisk => Baserisk

$$PC = Radrisk / (Radrisk + Baserisk) => 0.5$$

- Radrisk is the risk of contracting cancer (incidence) due to occupational radiation exposure
- Baserisk is the inherent risk of contracting cancer with no occupational radiation exposure

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Probability of Causation for Non-specific Cancer

- Baserisk of non-specific cancer = 0.23
- Radrisk of occupational radiation induced non-specific cancer = 0.0004 x Exposure (rem)
- Exposure (rem) = 0.23 / 0.0004 = 575 rem
- 575 rem would be the threshold at which the “probability of causation” exceeds 50%
- 575 rem would be the doubling dose

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Probability of Causation for Specific Cancers

- The same process can be used with organ cancer risk factors (e.g. from ICRP-60)
- The data on the next slide are median (50%) risk factors for organ specific cancers
- Median threshold exposures (50th percentile) for PC=0.5 are shown in the subsequent slide
- NIOSH-IREP uses a more sophisticated algorithm and calculates 99 percentile thresholds which will be used in EEOICPA

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160 LIFETIME MORTALITY IN A POPULATION OF ALL AGES FROM SPECIFIC FATAL CANCER AFTER EXPOSURE TO LOW DOSES

	Fatal probability coefficient (10^{-4} Sv^{-1})	
	ICRP (1977)	ICRP (1990)
Bladder	-	30
Bone marrow	20	50
Bone surface	5	5
Breast	25	20
Colon	0	85
Liver	-	15
Lung	20	85
Oesophagus	-	30
Ovary	-	10
Skin	-	2
Stomach	-	110
Thyroid	5	8
Remainder[1]	50	50
Total	125[2]	500[3]

[1]The composition of the remainder is quite different in two cases.
[2]This total was used for both workers and the general public.
[3]General public only. The total fatal cancer risk for a working population is taken to be 400 x 10^{-4} Sv^{-1}.

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NCHS Estimated Data for 2001

Cancer	Estimated 2001 Deaths	Estimated 2001 New Cases	Base Mortality Risk[1]	Base Incidence Risk[2]
Bladder	12,400	54,300	0.0052	0.0227
Bone surface	1,400	2,900	0.0006	0.0012
Brain	13,100	17,200	0.0055	0.0072
Breast (Female)	40,200	192,200	0.0168	0.0805
Cervix	4,400	12,900	0.0018	0.0054
Colon	48,100	98,200	0.0201	0.0411
Kidney	12,100	30,800	0.0051	0.0129
Leukemia (bone marrow)	21,500	31,500	0.0090	0.0132
Liver	14,100	16,200	0.0059	0.0068
Lung and Bronchus	157,400	169,500	0.0659	0.0710
Oesophagus	12,500	13,200	0.0052	0.0055
Ovary	13,900	23,400	0.0058	0.0098
Pancreas	28,900	29,200	0.0121	0.0122
Prostate	31,500	198,100	0.0132	0.0829
Skin	9,800	56,400	0.0041	0.0236
Stomach	12,800	21,700	0.0054	0.0091
Thyroid	1,300	19,500	0.0005	0.0082
Uterus	6,600	38,300	0.0028	0.0160
Remainder	111,400	242,500	0.0466	0.1015
Total Cancers 2001	553,400	1,268,000	0.2317	0.5309
Total Cancer Deaths 1998	541,532			
Total Deaths 1998	2,337,258			

1. Base mortality risk is (2001 specific cancer deaths / 2001 total cancer deaths) x (1998 total cancer deaths / 1998 total deaths)

2. Base incidence risk is (base mortality risk) x (2001 new specific cancer cases / 2001 specific cancer deaths)

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Probability of Causation

Cancer	Radiation Mortality Risk per Rem[1]	Radiation Incidence Risk per Rem[2]	Base Mortality Risk[3]	Base Incidence Risk[4]	Lethality[5]	Survivability[6]	Exposure for PC = 0.5[7] (Rem)	Exposure for PC = 0.5 (Rem) (Using NIOSH-IREP)[8]	
							Median	Median	99th %
Bladder	0.00003	0.00006	0.0052	0.0227	0.5	0.5	379		
Bone surface	0.000005	0.00001	0.0006	0.0012	0.7	0.3	170		
Brain	-	-	0.0055	0.0072	0.8	0.2	-		
Breast	0.00002	0.00004	0.0168	0.0805	0.5	0.5	2,012		
Cervix	-	-	0.0018	0.0054	0.45	0.55	-		
Colon	0.000085	0.00015	0.0201	0.0411	0.55	0.45	266		
Kidney	-	-	0.0051	0.0129	0.65	0.35	-		
Leukemia (bone marrow)	0.00005	0.00005	0.0090	0.0132	0.99	0.01	261		
Liver	0.000015	0.00002	0.0059	0.0068	0.95	0.05	430		
Lung and Bronchus	0.000085	0.00009	0.0659	0.0710	0.95	0.05	793		
Oesophagus	0.00003	0.00003	0.0052	0.0055	0.95	0.05	175		
Ovary	0.00001	0.00001	0.0058	0.0098	0.7	0.3	686		
Pancreas	-	-	0.0121	0.0122	0.99	0.01	-		
Prostate	-	-	0.0132	0.0829	0.55	0.45	-		
Skin	0.000002	0.00100	0.0041	0.0236	0.002	0.998	24		
Stomach	0.00011	0.00012	0.0054	0.0091	0.9	0.1	74		
Thyroid	0.000008	0.00008	0.0005	0.0082	0.1	0.9	102		
Uterus	-	-	0.0028	0.0160	0.3	0.7	-		
Remainder	0.00005		0.0466	0.1015			-		
Total[9]	0.0005		0.2317	0.5309			463		

1. Radiation mortality risk per rem from ICRP-60 (1990)
2. Radiation incidence risk per rem = Radiation mortality risk per rem / (1 - Survivability)
3. Base mortality risk fro the US. Estimated data for 2001 from the National Center for Health Statistics
4. Base incidence risk data for the US. Estimated data for 2001 from the National center for Health Statistics
5. Lethality is that fraction of cancer incidence that results in a fatality
6. Survivablity is that fraction of cancer incidence that does not result in a fatality. Survivability = 1 - Lethality
7. Median exposure at which the risk of radiation induced cancer incidence equals the base risk of cancer incidence (using table data)
8. Median and 99th percentile exposure at which the risk of radiation induced cancer incidence equals the base risk of cancer incidence (using NIOSH-IREP)
9. Exposure for PC = 0.5 for total cancer is based on ratioing mortality risks not incidence risks

Agenda

- Definitions
- Factors Shaping Risk Perception
- US Mortality Risk
- Background Radiation
- LNT Model of Theoretical Radiation Risk
- Probability of Causation
- Health Studies

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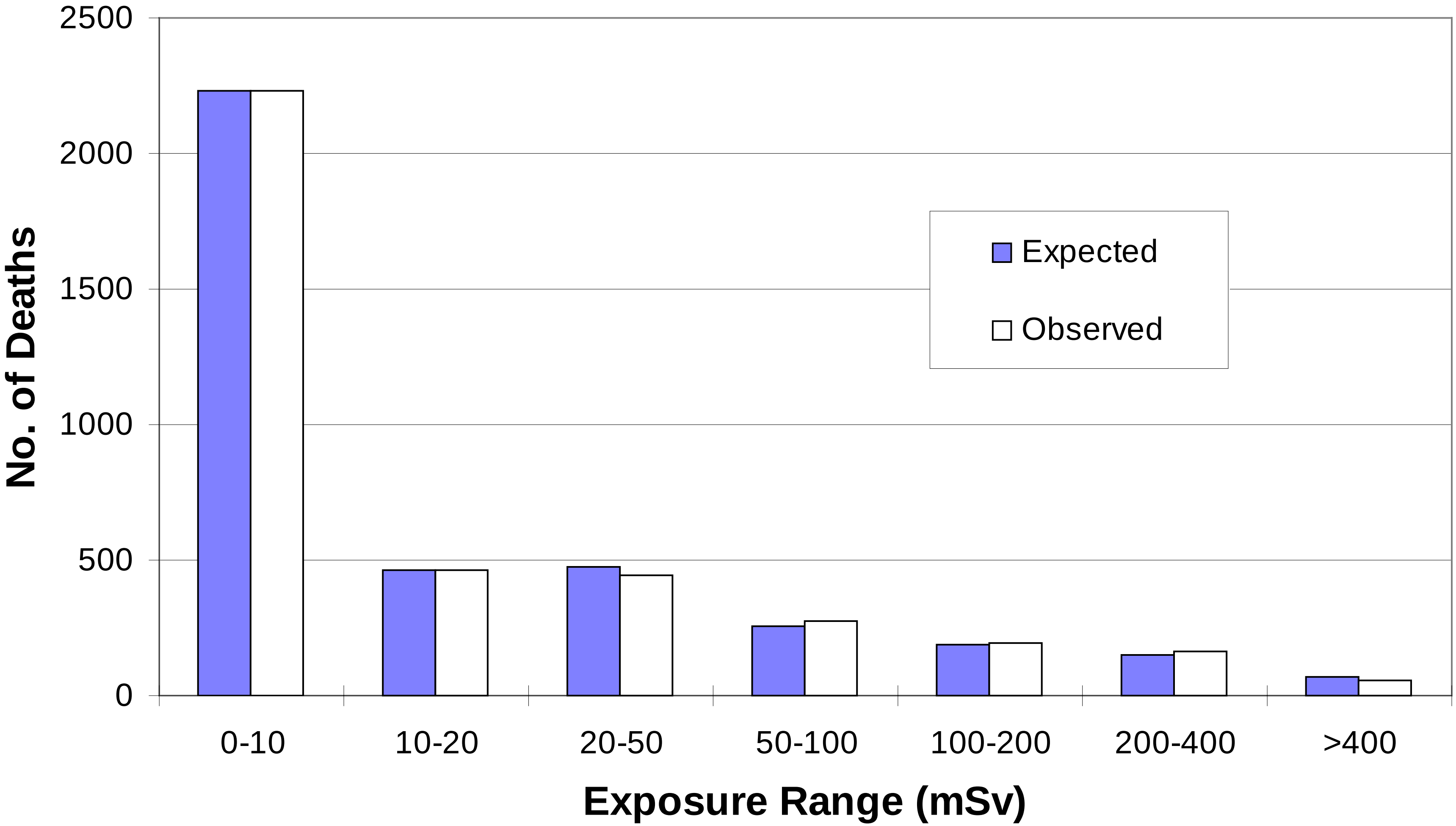
Compilation of 105,314 radiation workers from the US, UK and Canada shows no elevated rates for non-leukemia cancer deaths.



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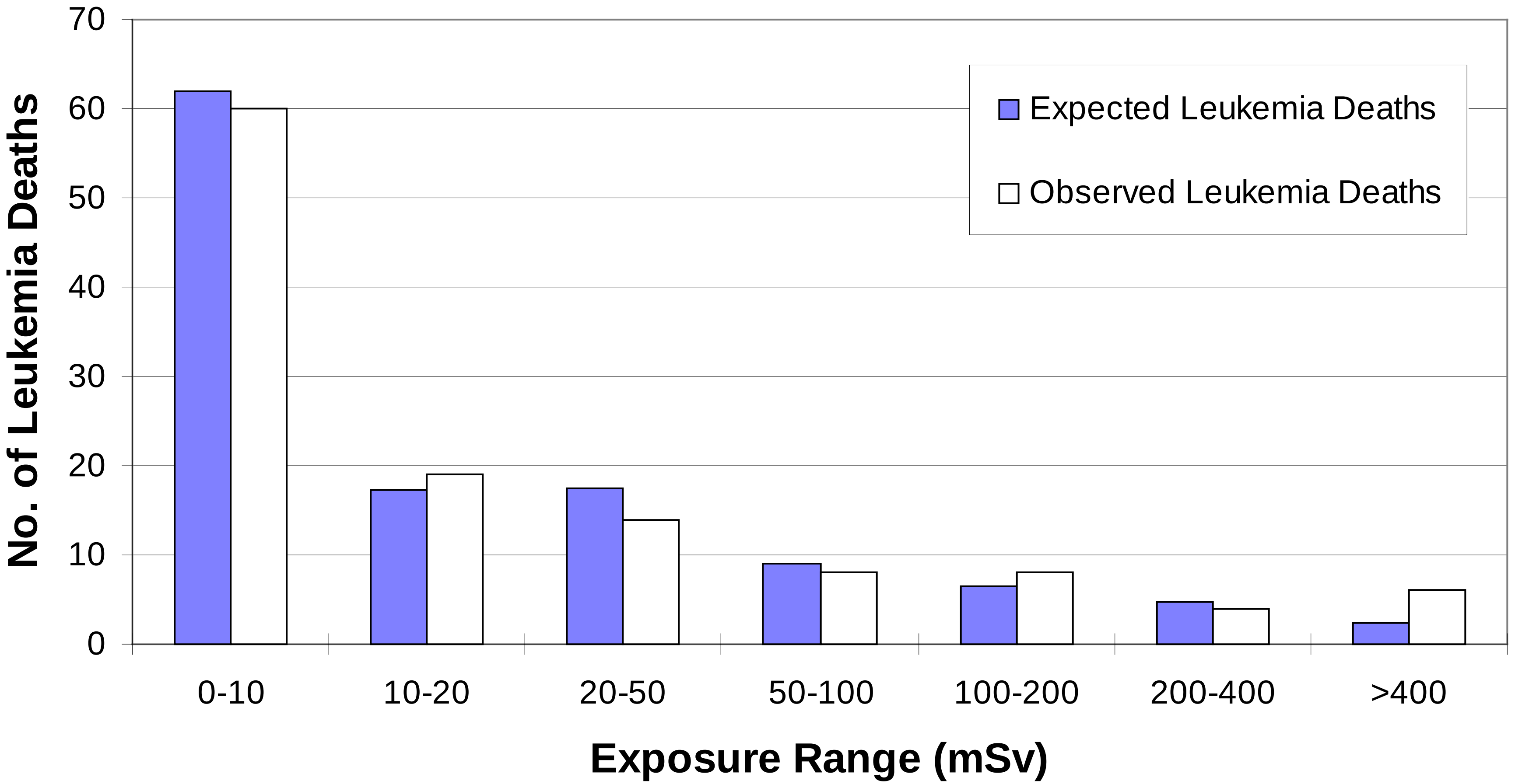
Compilation of 105,314 radiation workers from the US, UK, and Canada shows elevated leukemia rates for only the upper >400 mSv exposure range. 6 cases observed compared to 2.3 expected from a population of 105,314



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Conclusions

- Use of the LNT model at exposures comparable to or less than background is inappropriate
  - Health Physics Society advises against use of LNT less than 10 rem
  - American Nuclear Society advises against use of LNT at low dose rates
  - National Academy of Science says there is no evidence of health risk as a result of variability in natural background
  - BEIR VII Committee is investigating validity of LNT at low doses

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