Radiation Risk and its Uncertainties

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What We Know, Can Measure or "Accurately" Estimate

- System radiation output
  - Air Kerma
- Radiation absorbed dose in a material
  - TLD, OSL, MOSFET, scintillators, etc.
- Modelling
  - Extrapolate output or measured dose to materials, e.g. tissue
    - Monte Carlo calculations

Tissue Functional Subunits

- If the radiation ***absorbed dose*** to any tissue is large enough tissue damage ***will*** occur
- In most tissues the damage is greater and the morbidity is greater if the amount of tissue irradiated is larger
  - e.g. whole organ irradiation produces a greater morbidity
- Due to structure of tissues and organs into functional subunits (FSU)
  - A FSU is a set of tissues or organs whose ultimate function is dependent on the overall workings of each subunit
    - e.g. proper digestion of food requires the entire digestive tract to function properly

Deterministic Effects

- Outcome can be pre-determined, i.e. they are predictable
- Amount of energy required is different for different tissues
  - i.e. there is a "**threshold dose"** for tissue damage
  - Threshold dose has been derived from studies in experimental cell cultures, animal studies, as well as effects seen in humans
- For deterministic effects as absorbed energy increases, the severity of damage also increases and the potential for repair decreases

Deterministic Effects

- Thresholds where effect is observed in 1% of a population

e.g. if 100 people were exposed to this threshold level of radiation, only a single individual would experience this effect

Tissue	Acute dose threshold (Gy)	Latency Period
Lens of eye		
Detectable opacities	0.5 – 2	**> 1 year**
Cataract formation	5.0	**> 1 year**
Skin		
Erythema	3 – 6	**1 – 4 weeks**
Temporary hair loss	4	**2 - 3 weeks**
Skin death and scarring	5 - 10	**1 - 4 weeks**
Reproductive Organs		
Testes - Temporary sterility	0.15	**3 - 9 weeks**
Testes - Permanent sterility	3.5 – 6	**3 weeks**
Ovaries - Permanent sterility	2.5 – 6	**< 1 week**
Gastrointestinal		
Mucosa lining loss	6	**6 - 9 days**
Bone Marrow		
Reduction of blood cell production	0.5	**1 - 2 months**

based on ICRP publication 103 - 2007

Deterministic Effects

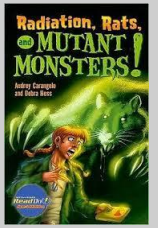
- All biological and clinical studies have shown that ***below 0.1 Gy no deterministic effects*** from radiation exposure have been proven
  - Most diagnostic and interventional studies are under 0.1 Gy
  - Some cardiology, electro-physiology and surgical studies can exceed 0.1 Gy
- It is known that some syndromes and some genetic traits result in increased sensitivity to radiation
  - e.g. Down syndrome, Fanconi's anemia, Ataxia-telangiectasia

Stochastic Effects

- Effects are random or probabilistic in nature
  - Genetic effects
  - Carcinogenesis
- Whether an effect will occur cannot be determined absolutely, regardless of the amount of energy absorbed
  - Only the probability or the likelihood can be ascertained
  - There isn't a threshold dose above which these effects will definitely occur
- Some cellular and animal studies have suggested that there are thresholds for stochastic effects

Genetic changes

- Damage in germ cells that may ultimately result in mutations in the exposed fetus
  - Mutations are not radiation-specific
    - Only produces DNA sequencing errors that might have occurred naturally



- There is no ***direct*** evidence ***at any radiation dose*** that exposure of parents leads to excess genetic disease in their offspring

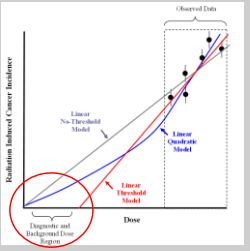
Conservatively many organizations use 50 mSv level as a limit

Carcinogenesis

- Cancer induction is arguably the most important and most feared radiation effect
- Human experiences were all at high radiation dose levels
  - At high radiation doses there is clear evidence of increased cancer incidence

Stochastic Effects

- Currently at low radiation exposure levels no study has been comprehensive enough to demonstrate stochastic effects conclusively
- Estimation of risk for cancer induction at low radiation exposure must be extrapolated from the high exposure data
- Linear No-Threshold (LNT) most commonly used extrapolation



Relative Risk Model

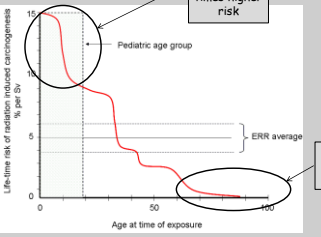
- Assumes radiation increases natural incidence of a cancer
  - Expressed as a fraction or multiple of the naturally occurring risk

Exposed Population	Excess Relative Risk of Cancer (per Sv)
entire population	5.5% – 6.0%
adult only	4.1% – 4.8%

Based on LNT model, ICRP publication 103 – 2007 and 60 - 1990

Cancer Risk and Age

- Lifetime risk is age dependent



- Cannot simply use the average relative risk of 5%/Sv to estimate increased incidence of cancer

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Effective Dose and Cancer Risk

- Effective Dose was created to provide a dose quantity linked to health detriment due to stochastic effects
  - ICRP states that Effective Dose is intended for use as a protection quantity
- LNT Model should not be used for determining risk of cancer from low radiation dose levels

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Effective Dose, LNT and Epidemiology

- Over last several years many published studies stating low dose radiation exposures in humans will cause cancer

Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007

" … out of approximately 600,000 … CT examinations annually performed … 500 of these individuals might ultimately die from cancer attributable to the CT radiation"

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Effective Dose, LNT and Epidemiology

- "… combined reduction in volume and dose per procedure reduced estimated induced cancers by 63%"

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Uncertainties in Estimates of Cancer Risk

- There is no unique feature of radiation induced cancer to distinguish a cancer due to radiation from ***"naturally occurring"*** cancer
- This problem is made even more difficult due to many competing risks for cancer in our environment.
- When discussing estimates of cancer induction from radiation the uncertainty in the estimate should always be discussed

Sources of Error in Epidemiology Studies

- Known sources of errors
  - Extrapolation to low dose
  - Lifetime projection
  - Transfer to US population
  - Statistical uncertainties
  - Dosimetry uncertainties
  - Misclassification of cancer death

Sources of Error in Epidemiology Studies

Type of Uncertainty	% of Total Uncertainty
Extrapolation to low dose	37%
Unspecified uncertainties	29%
Transfer to US population	18%
Lifetime projection	7%
Statistical uncertainties	4%
Dosimetry uncertainties	4%
Misclassification of cancer death	1%

Adapted from NCRP Report 126 (1997)

Unaccounted for errors in the model

Uncertainty of Risk for Cancer Types

- Sampling = variation in observed cancer cases or deaths
  - Includes low dose extrapolation
- Risk Transfer = projection of risks to the U.S. population
- Dose and Dose Rate Effectiveness Factor (DDREF) = Correction of risk determined at acute, high dose rates to low fractionated doses

Cancer Type	Sampling	Risk Transfer	DDREF	Other
Stomach	7.5%	76.5%	9%	7%
Lung	26.5%	15%	33%	25.5%
Breast	16%	0%	47%	37%
Uterus/Prostate	82.5%	11%	3.5%	2.5%
Thyroid	75%	0%	14%	11%
Leukemia	80.5%	15.5%	0%	4.5%
Residual (i.e. all other cancer)	51.5%	4%	24.5%	11%

*Averaged for Males and Females (REF-EPA April 2011)

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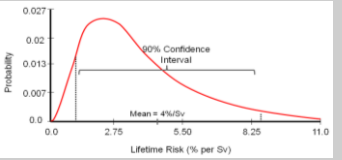
Uncertainties in Estimates of Cancer Risk

- Mean lifetime risk is 4% per Sv
- 90% confidence interval is 1.2% - 8.8% per Sv
- Lifetime risk per Sv is skewed to values lower than the linear extrapolation model estimates

Higher probability for values lower than 5% per Sv



Perception of Risk

- There is risk in all aspects of life
- Best that can be hoped for is to minimize the risks that have the greatest potential of disrupting your life
- When a risk has a benefit to an individual or to society the risk may be justified with respect to the benefit
- **But how do you convey both risks and benefits to people?**
- Requires knowledge of how people perceive risk and how to communicate the risk and the benefit to different populations

How do you Convey Technical Information to the Public?

- Avoid using technical/medical jargon
  - Translate technical/medical terms (e.g. dose) into everyday language
- Write short sentences that convey a single point
  - Use headings and other formatting techniques to provide a clear and organized structure to the presentation of information
- "… it is easier for the world to accept a simple lie than a complex truth …"

*Alexis de Tocqueville

Risk Communication vs. Risk Education

- Risk communication differs from risk education in that when you are attempting to discuss risk you need to understand the value systems of the people you are talking to
- This requires an understanding of how different groups may interpret risk

Risk Ranking

- Differences between how scientists and non-scientists rank risk is one of the major problems of risk communication
- In general, if scientists and non-scientists are asked to rank a series of health risks the rank orders of the lists are considerably different

Activity (ranked by experts)	League of Women Voters	College Students	Professional Society Members
Motor Vehicles	2	3	2
Smoking	4	2	4
Alcohol	6	7	5
Handguns	3	2	1
Surgery	10	11	9
Motorcycles	5	6	3
X-Rays	22	17	24
Pesticides	9	4	15
Electric Power	18	19	19
Swimming	19	30	17
Contraceptives	20	9	22
Private Aviation	7	15	11
Large Construction	12	14	13
Food Preservatives	25	12	28
Bicycles	16	24	14
Commercial Aviation	17	16	18
Police Work	8	8	7
Fire Fighting	11	10	6
Railroads	24	23	29
Nuclear Power	1	1	8
Food Coloring	26	20	30
Home Appliances	29	27	27
Hunting	13	18	10
Antibiotics	28	21	26
Vaccinations	30	29	29
Spray Cans	14	13	23
Football	23	26	21
Power mowers	27	28	25
Mountain Climbing	15	22	12
Skiing	21	25	16

Adapted from Slovic P. Science Vol. 236 No. 4799 (1987)

Objective Risks vs. Subjective Risks

- Scientific community "normally" interprets risk objectively
- General public usually interprets it subjectively
  - May be getting information from "less technical" sources
    - The National Enquirer
    - Television shows (e.g. Gray's Anatomy)
    - Personal communication (e.g. discussion in the pub)
    - Wikipedia
  - Unlikely to recall where a fact was presented
    - Unable to recall whether the National Enquirer or the proceedings of the National Academy of Sciences presented the fact
- Equal weight may be given to data presented by any source

Risk Communication

- People often have difficulty processing information under stress and ***do not "hear"*** what is being said to them
- People often become distrustful of anything a person is saying, leading them ***to not "listen"*** to what is being said
- People often give ***greater weight to negative*** information than to positive information

In Risk Perception Theory

Perception = Reality

Risk Communication

Category	Things to do	Things NOT to do
Truthfulness	Tell the truth	**Do not lie or avoid the truth**
Absolutes	Avoid absolutes, "nothing" is absolute	**Do not use the terms "never", or "always"**
Jargon	Define all terms and acronyms	**Do not use standard medical terminology**
Negative	Use positive or neutral terms	**Do not use negative terms or negative associations**
Temper	Remain calm	**Do not let your feelings interfere with your ability to communicate**
Clarity	Ask whether you are being understood	**Do not assume understanding**
Abstraction	Use examples, metaphors and analogies to aid understanding	**Do not talk of theoretical concepts without using clear non-technical justification**
Attack	Only attack the issue	**Do not attack the person or organization that may have made incorrect statements**
Promise	Promise only what you are certain will occur	**Do not make promises that you cannot backup and follow-thru on to ensure they occur**
Speculation	Provide information only on what is being done and what you know	**Do not discuss "worst case" scenarios and unintended possible outcomes, unless required by protocol**
Risk/Benefit comparison	Make risk and benefit statements separately	**Do not discuss the risk, relative to the benefit**
Risk comparisons	Use "tested" comparison messages, cite trustworthy data/groups	**Do not compare unrelated risks**

adapted from EPA Workbook on Risk Communication in Action (2007)

Risk Comparison

Odds of Death From Injury*

Type of Incident / Manner of Injury	Number of Deaths in 2005	Probability of occurrence
All causes of mortality from injuries	176,406	4.5%
Transport accidents	48,441	1.3%
Automobile	14,584	0.4%
Pedestrian	6,074	0.2%
Air travel		2%
Non-transport		%
Falls		%
Being struck by objects	2,845	0.07%
Intentional self harm	32,637	0.9%
Assault	18,124	0.5%
Complications from medical care	2,653	0.07%

*adapted from National Safety Council, http://www.nsc.org/research/odds.aspx.

Poor comparison for radiation risk!

Risk Comparison

- Make comparison of the same risk at two different times or in different circumstances
- Make comparison with a standard that is understood by the listener
- Make comparison with different estimates of the same risk

Risk Comparison

Comparison of adult exam dose to background radiation level

Exam	Reference Level (time to receive equivalent background radiation)
Chest X-Ray PA / LAT	2.4 days / 12 days
Mammography	1 ½ months
Abdomen / Pelvis X-ray	3 months
Head CT	8 months
Lung Perfusion (Tc^{99m})	8 months
Thyroid scan (Tc^{99m})	1 ½ years
Brain (Tc^{99m})	2 years
Abdominal CT	2 ½ years
Cardiac Stress Test (depending on isotope/protocol)	3 years – 13 ½ years
Cardiac PET (^{18}F-FDG)	5 years
High resolution Chest CT (e.g. pulmonary embolism, angiogram)	5 years

* Using an average background radiation level of 3 mSv/yr

Benefits vs. Risk of Not Using Radiation

- Risks of NOT performing an exam include missing a diagnosis and/or initiating treatment too late to improve the medical outcome
- Potential of reducing a patient's overall life expectancy due to a disease must be considered in conjunction with the latency period for radiation induced cancer and patient's age
- There are no hard/fast rules to provide a clinician when making a decision to use radiation or not
- The best that can be done is for them to understand the risks associated with the disease and the potential risks from radiation to assist in making a well-informed decision