

# Review of the Harmful Effects of Ionizing Radiation

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Dave Tucker

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## Goal of Radiological Protection

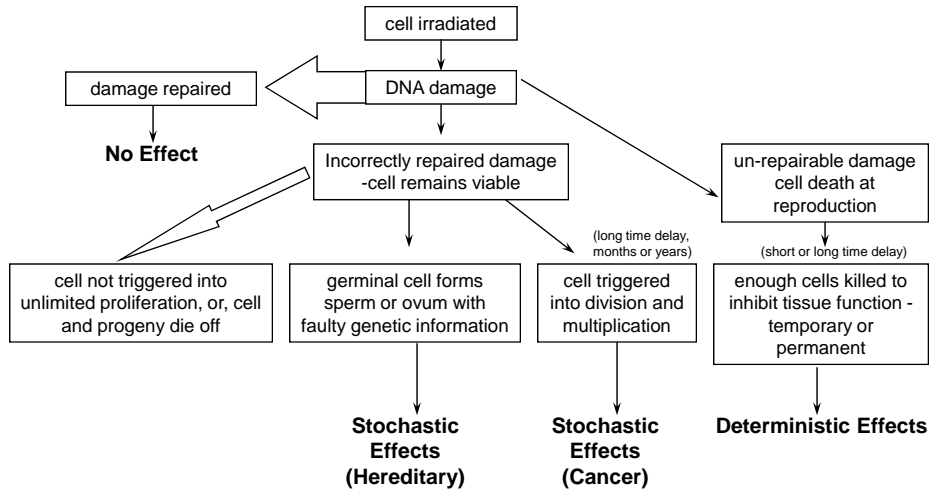
- **ICRP – “Provide an appropriate standard of protection of humans against ionizing radiations without unduly limiting the beneficial practices giving rise to radiation exposures”**
- **Non – human biota recently a focus of interest – outside the scope of this course.**
- **This section – a review of the harmful effects of ionizing radiation as described by (primarily) the ICRP**

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# Harmful Effects - Categories

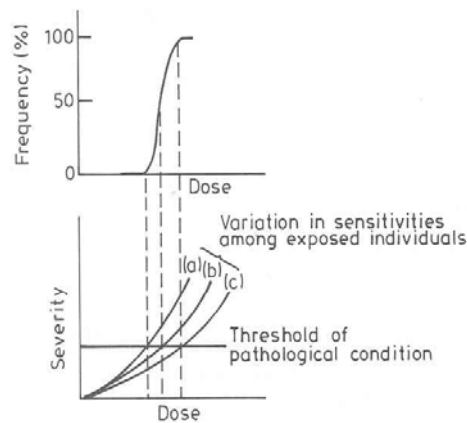


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# Deterministic Effects - Threshold



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## Examples of Deterministic Effect Thresholds

Estimates of Thresholds for Some Deterministic Effects in Adult Humans (from ICRP 60)			
Issue and Effect	Threshold		
	Total dose equivalent received in a single brief exposure (Sv)	Total dose equivalent received in highly fractionated or protected exposures (Sv)	Annual dose rate if received yearly for many years (Sv)
Testes			
Temporary sterility	0.15	NA	0.4
Permanent sterility	3.5-6.0	NA	2.0
Ovaries			
Sterility	2.5-6.0	6.0	>0.2
Lenses			
Detectable opacities	0.5-2.0	5	>0.1
Visual impairment	5.0	>8	>0.15
Bone Marrow			
Depression of hematopoiesis	0.5	NA	>0.4

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## Deterministic Effects in the Skin

Estimates of Thresholds for Deterministic Effects in the Skin of Adult Humans		
Effect	Threshold	Notes
Erythema or dry desquamation	3–5 Gy	Symptoms appear after about three weeks. Early erythematous reaction may be seen within a few hours and will subside in 24–48 hours.
Moist desquamation	20 Gy	Blistering after about four to six weeks
Tissue necrosis	50 Gy	Appears after about 3 weeks

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# Acute Radiation Syndrome

**Table 15.1 Acute Radiation Syndrome**  
(After IAEA 88 1988)

Grouping	Range of Doses (Gy)
1. Hematopoietic	1-10
a. From 0 to 0.25 Gy: No clinical symptoms but a slightly increased frequency of chromosome aberrations may be detected in lymphocytes.	
b. From 0.25 to 1 Gy: Either no symptoms or transient nausea. Biological tests may reveal a lymphopenia accompanied in some cases by slight thrombopenia. Cytogenetic changes in lymphocytes are readily detected. Some studies have shown slight changes in the patient's electroencephalogram.	
2. Gastrointestinal	10-20
3. Cardiovascular or Toxicemic	20-50
4. Nervous System	Above 50 Gy

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**TABLE 1.3C—SUMMARY OF EFFECTS RESULTING FROM ACUTE WHOLE BODY EXTERNAL EXPOSURE OF RADIATION TO MAN**

0-25 rems	25-100 rems	100-200 rems	200-300 rems	300-400 rems	400 or more
No detectable clinical effects.	Slight transient reductions in lymphocytes and neutrophils.	Nausea and fatigue, with possible vomiting above 125 rems.	Nausea and vomiting on first day.	Nausea, vomiting and diarrhea in first few hours.	Nausea, vomiting and diarrhea in first few hours.
Delayed effects may occur.	Disabling sickness not common, exposed individuals should be able to proceed with usual duties.	Reduction in lymphocytes and neutrophils with delayed recovery.	Latent period up to 2 weeks or perhaps longer.	Latent period with no definite symptoms, perhaps as long as 1 week.	Short latent period with no definite symptoms in some cases during first week.
	Delayed effects possible, but serious effects on average individual very improbable.	Delayed effects may shorten life expectancy in the order of 1 percent.	Following latent period symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petechiae, diarrhea, moderate emaciation.	Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petechiae, inflammation of mouth and throat, diarrhea, and emaciation in the third week.	Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week.
			Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries or infections.	Some deaths in 2 to 6 weeks. Possible eventual death to 50 percent of the exposed individuals for about 400 rems.	Rapid emaciation and death as early as the second week with possible eventual death of up to 100 percent of exposed individuals.

SECTION 1

Source – Saenger, Medical Aspects of Radiation Accidents, United States Atomic Energy Commission, 1963

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Range	Subclinical Range 0 -1 Gy	Therapeutic Range			Lethal Range	
		1 to 3 Gy	3 to 5 Gy	5 to 10 Gy	10 to 15 Gy	Over 15 Gy
Vomiting Incidence	NONE	5% to 50%	3Sv, 100%	100%	100%	100%
Delay Time	-----	3 hr	2 hr	1 hr	30 min	
Leading Organ	NONE	Bone Marrow		Bone Marrow GI Tract	GI Tract	Central Nervous System
Characteristic Signs	NONE	Moderate leukopenia	Severe leukopenia, hemorrhage, infection, purpura, epilation Diarrhea > 5 Gy		Diarrhea, fever, electrolyte loss	Convulsions tremor, staxia
Therapy	Reassurance	Blood monitoring	Blood transfusion antibiotics	Marrow transplant? Growth factors?	Maintain electrolytes	Sedatives
Prognosis	Excellent	Excellent	Good	Guarded	Hopeless	
Incidence of Death	NONE	NONE	0 to 80%	80 to 90%	90 to 100%	

Immediate Clinical Effects of acute Radiation - adapted from Gollnick

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## Early Death from Acute Radiation Exposure

- No deaths in a population below 1 Gy
- LD<sub>50,60</sub> about 3 to 5 Gy without medical intervention
- LD<sub>5,60</sub> about 2 Gy
- LD<sub>95,60</sub> about 6 Gy
  
- Review cause of death from ICRP 60 Table B-2

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## Cause of Death after Acute LET Whole Body Exposure (ICRP 60 Table B-2)

WB Dose (Gy)	Principal Effect Contributing to Death	Time of Death (days)
3-5	Damage to bone Marrow	30 - 60
5-15	Damage to GI tract and lungs	10 - 20
> 15	Damage to nervous system	1 - 5

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## Summary of Deterministic Effects

- Effects arising from a high degree of cell killing.
- Threshold for each effect
- Above the threshold, severity of the effect increases with dose
- In occupational settings they are associated with very large acute exposures in an accident
- Regulatory dose limits completely preclude the possibility of deterministic effects

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## Stochastic Effects

- Cancer in the exposed individual
- Severe hereditary disorders in progeny of exposed individuals

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## Hereditary Effects

- Have never been observed in humans
- Extrapolated from (especially) mouse studies
- Current best estimate of "doubling dose" is 1 Gy
- 1 Gy also lower 95% confidence value based on absence of effect in the progeny of the Japanese bomb survivors
- Example of effect from Cember

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## Induction of Cancer

- Cannot be directly observed in occupationally exposed persons other than Uranium miners and early high dose workers
  - risk is small compared to other risk factors and variation
  - (N.B. Recent study by Cardis et al purports to show dose response)
- Risk factors extrapolated down from high dose – high dose rate exposure situations – most important is Japanese bomb survivors
- Statistically significant effects (95% confidence) only observed over about 0.2 Sv
- Allowance made in extrapolation for presumed lower effectiveness at low dose/low dose rates – the Dose-Dose Rate Effectiveness Factor (DDREF)
- DDREF reasonable range of values thought to be 2 to 10 – so 2 was chosen
- Latency periods – vary for different types of cancer

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## Cancer Risk

### Fatal Cancer Risk

- Adult Workers

- 4.0 % per Sv

- Whole Population

- 5.0 % per Sv

Example – 100 000 workers each given 10 mSv  
 expect  $(4/100) \times (10E-3/1) \times 100\ 000 = 40$  additional cancer fatalities

Baseline risk of fatal cancer in the whole population is about 25% or 25 000 in the example population

### Non-Fatal Cancer Risk

- Adult Workers

- 0.8 % per Sv

- Whole Population

- 1.0 % per Sv

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## Linear No-Threshold Theory

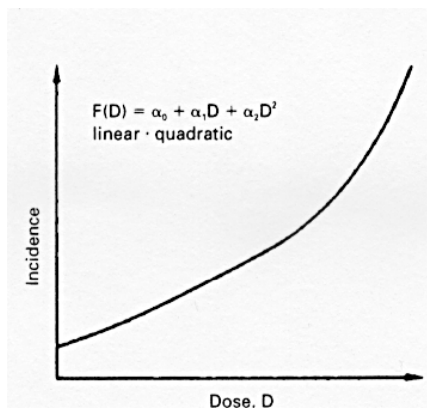
- There is no threshold associated with the induction of stochastic effects
- The risk of stochastic effects increases linearly with exposure
- There is controversy regarding the LNT theory – however, ICRP UNSCEAR and BEIR all identify it as best current model
- Appropriate forum for debate is the scientific community – not in occupational and public radiological protection

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## Linear Quadratic Curve for Stochastic Effects



- Interpretation:
- Each small increment of dose has an associated small increment of risk
- Therefore – doses are to be maintained  
As  
Low  
As  
Reasonably  
Achievable

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## Effects

•Stochastic Effects	Deterministic Effects
<ul style="list-style-type: none"> <li>•no threshold (statistical probability)</li> <li>•possibility of stochastic effect with any dose – probability increases with dose</li> <li>•severity of effect is not related to dose received</li> </ul>	<ul style="list-style-type: none"> <li>•threshold               <ul style="list-style-type: none"> <li>•no effect will be seen for doses below threshold</li> <li>•above threshold severity of effect depends on dose</li> </ul> </li> <li>•effect is seen due to death of cells → enough cells to affect/impair this function of a tissue or organ</li> </ul>
<ul style="list-style-type: none"> <li>•cancer</li> <li>•genetic effects</li> </ul>	<ul style="list-style-type: none"> <li>•radiation burns</li> <li>•blood effects</li> <li>•cataracts (lens of eye)</li> <li>•Acute Radiation Syndromes</li> </ul>

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## Risks and Hazards of Prenatal Exposure to Ionizing Radiation (ICRP 60 and ICRP 84)

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**Acknowledgement:**  
The information in this presentation is a summary of the relevant sections of ICRP 60 and ICRP 84

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## Principal Effects

- a) Lethal effects in the embryo
- b) Malformations and other growth/structural changes
- c) Mental Retardation
- d) Cancer Induction including leukemia
- e) Hereditary effects

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## Lethal Effects

- Can be induced in animals at fairly low doses (0.1 Gy) around the time of implantation. Can be induced by higher doses at other stages of development.
- Pregnancy loss following exposure is known to occur for humans.
- Insufficient data to develop projections of risk of fetal death at particular stages.

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## Malformations

- Induced malformations are characteristic of the period of organogenesis at time of exposure.
  - Highest sensitivity during most active phase of cell multiplication and specialization in structure of concern
- Growth disturbances without malformation may also occur especially later in pregnancy – cell killing
- Malformations have a threshold of 100-200 mGy or higher and are typically associated with central nervous system problems (ICRP 84)

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## Mental Retardation

- Modified development of the human brain  
-> dose related increases in rate of mental impairment. Has been observed.
- Time sensitive.
  - Has not been observed prior to 8 weeks or after 25 weeks
  - 8 – 15 weeks highest sensitivity
    - Fraction becoming severely mentally retarded increased by  $0.4 \text{ Sv}^{-1}$ .
  - 16 – 25 weeks
    - Fraction increased by  $0.1 \text{ Sv}^{-1}$ .
- Probably a threshold of 0.12 – 0.2 Gy.

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## Mental Retardation cont.

- Also – less severe effects and impairments observed
- Manifests as shift in IQ curve
- At 8 – 15 weeks – 30 IQ points  $\text{Sv}^{-1}$ .
- Probably same risk observed different ways

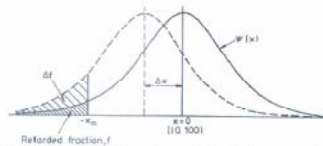


Fig. 18-1. The shift of the IQ curve by 30 IQ units or  $3\sigma$  per Sv, i.e.  $\Delta x = 2.7 \text{ IQ per Sv}$  is the dose equivalent expressed in Sv. The variable  $x$  is the number of standard deviations below ( $-$ ) or above ( $+$ ) IQ 100.  $\infty$  denotes the number of standard deviations below IQ 100 so clearly an individual is mentally retarded.

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## Cancer Induction including Leukemia

- *In utero* exposure leads to increased risk of childhood cancer during first 10 years of life
- Observed from medically exposed mothers and A-bomb survivors
- Risk estimated at  $2.8 \times 10^{-1} \text{ Sv}^{-1}$ . Relative risk may be as high as 1.4 for 10 mGy fetal dose
- Risk for development of cancer in later life similar to exposure for postnatal irradiation
- Individuals exposed *in utero* to 10 mGy results in absolute risk of about one excess death per 1700 (ICRP 84)

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## Risks in a pregnant population *not* exposed to radiation (ICRP 84)

- Risks:
 

- Spontaneous abortion	> 15%
- Incidence of genetic abnormalities	4-10%
- Intrauterine growth retardation	4%
- Incidence of major malformation	2-4%

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## How to Protect?

- Remember the goal – appropriate standard of protection without undue limitation
- Myriad of potential exposure scenarios in occupational, public and medical exposures
  - Whole body external
  - Partial body external
  - Internally deposited radionuclides
  - Etcetera
  - How to compare types of exposure?
- Answer lies in a uniform expression of risk – concept of Detriment

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## Detriment

- Conceptual value to reflect the overall harm to an exposed population arising from Stochastic Effects
- Four components
  - Risk of fatal cancer in all relevant organs
  - Allowance for different values of latency leading to different values of life lost
  - Allowance for morbidity resulting from induced non-fatal cancer
  - Allowance for the risk of serious hereditary disease in all future generations

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## Contribution to Detriment

Organ	Prob. of fatal cancer F per $10^4$ people/Sv	Relative length of life lost ( $\ell/L$ )	Relative non-fatal contribution (2-k)	Product $F(\ell/L)(2-k)$ per $10^4$ people/Sv	Relative contribution
Bladder	30	0.65	1.50	29.4	0.040
Bone Marrow	50	2.06	1.01	104.0	0.143
Bone Surface	5	1.00	1.30	6.5	0.009
Breast	20	1.21	1.50	36.4	0.050
Colon	85	0.83	1.45	102.7	0.141
Liver	15	1.00	1.05	15.8	0.022
Lung	85	0.90	1.05	80.3	0.111
Oesophagus	30	0.77	1.05	24.2	0.034
Ovary	10	1.12	1.30	14.6	0.020
Gonads <sup>1</sup>	100	1.33		133.3	0.183
Skin	2	1.00	2.00	4.0	0.006
Stomach	110	0.83	1.10	100.0	0.139
Thyroid	8	1.00	1.90	15.2	0.021
Remainder <sup>2</sup>	50	0.91	1.29	58.9	0.081
Total	500			725.3	1.000

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## Overall Risk Factors Adopted by the ICRP

(nominal probability coefficients)

	Detriment ( $10^{-2} \text{ Sv}^{-1}$ )			
	Fatal cancer	Non-fatal cancer	Severe hereditary effects	Total
Exposed population				
Adult workers	4.0	0.8	0.8	5.6
Whole population	5.0	1.0	1.3	7.3

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