CHAPTER 3

BIOLOGICAL EFFECTS OF IONIZING RADIATION

$$H_2O \longrightarrow H + OH$$

When radiation splits a chemical bond in this way, it is known as **DIRECT DAMAGE**.

The H and OH components of the fractured water molecule can give a variety of reactions. Three important ones are shown below:

$$H + OH \longrightarrow H_2O$$
no problem, water is formed again.

$$H + H \longrightarrow H_2$$
no damage, a few hydrogen "gas" molecules can be tolerated.

$$OH + OH \longrightarrow H_2O_2$$
hydrogen peroxide is formed; this is poisonous. In fact, chemical poisoning by H_2O_2 resembles radiation sickness in many ways.

The damage produced by the charged H and OH bits drifting around before combining to form H_2O, or combining with other biologically important molecules is known as **INDIRECT DAMAGE**.

An absorbed radiation dose of 1 GRAY corresponds to the deposition of 1 joule of energy in 1 kg of material.

$$1\ \text{Gy} = 10^3\ \text{mGy} = 10^6\ \mu\text{Gy}$$

The QUALITY FACTOR of a particular kind of radiation is defined as the ratio of the biological damage produced by the absorption of 1 gray of that radiation to 1 gray of X- or gamma radiation.

QUALITY FACTORS

Radiation	Energy	Q
gamma	all	1
beta	all	1
neutrons	slow	5
neutrons	fast	20
alpha	all	20

An equivalent dose of one SIEVERT represents that quantity of radiation dose that is equivalent, in terms of specified biological damage, to one gray of X- or gamma rays.

$$H(Sv) = D(Gy) \times Q$$

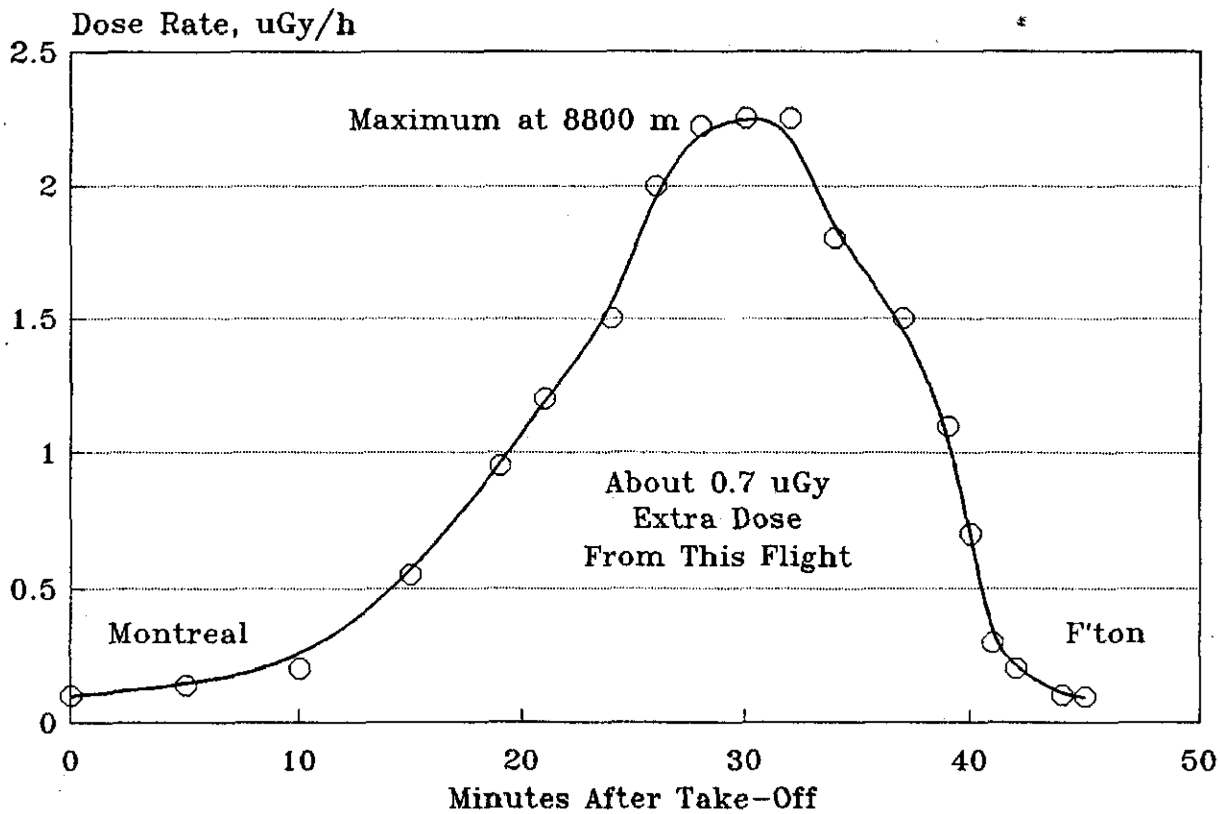

Fig. 3.1. Exposure Rate vs. Time on a Commercial Flight

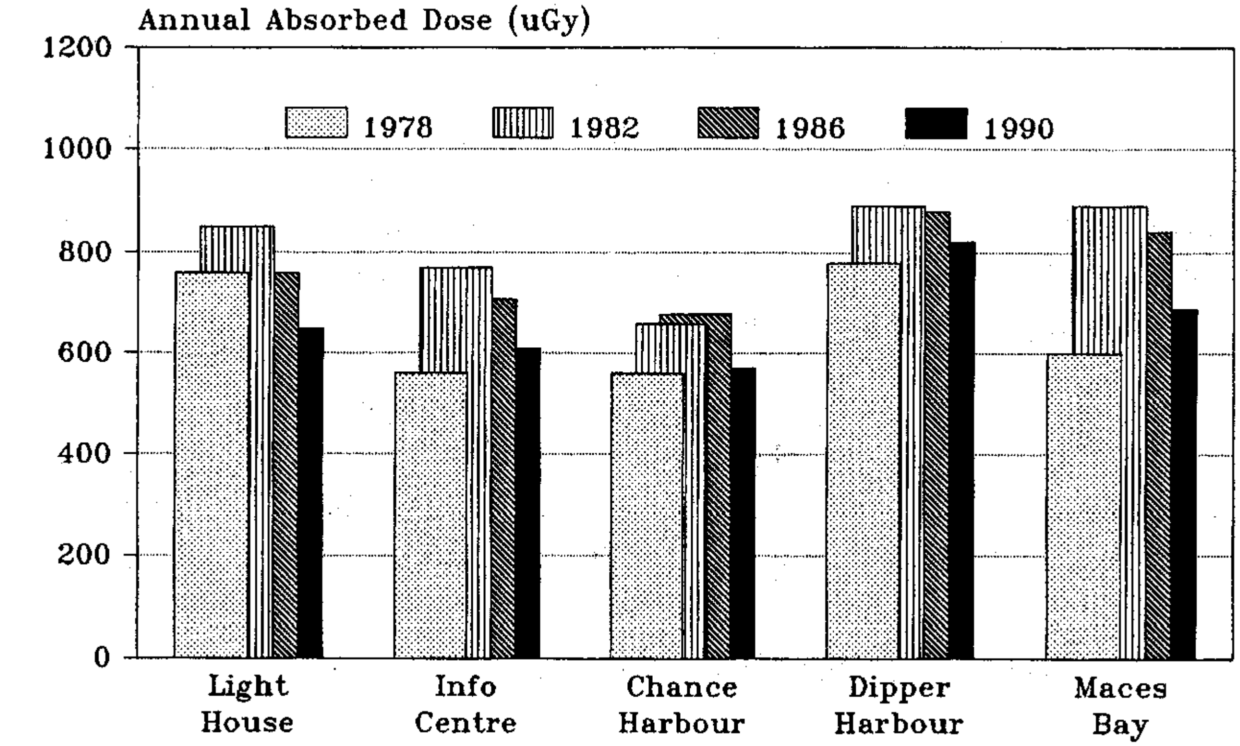

Fig. 3.2. Annual Variation in Background Radiation near Point Lepreau (including Cosmic Rays)

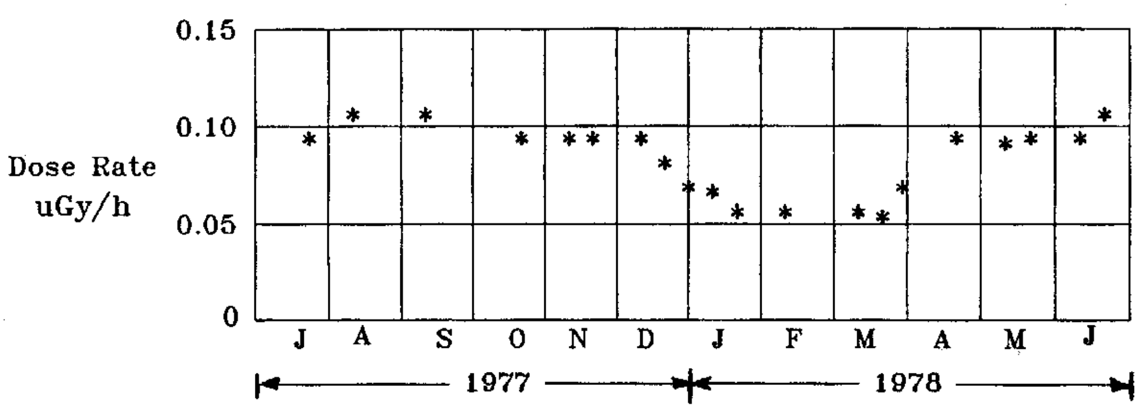

Fig. 3.3. Seasonal Variation in Natural Background Radiation

AVERAGE POPULATION EQUIVALENT DOSE FROM NATURAL AND MAN-MADE SOURCES (μSv /YEAR)

Natural Background	Cosmic Rays	330	
	Radon Daughters	600	
	External Terrestrial	440	
	Internal Sources	200	1570
Medical Exposure (gonad dose)	Diagnostic X-Rays	300	
	Radiotherapy	50	
	Nuclear Medicine	5	355
Fall-out	Weapons Testing	10	10
Occupational Doses (non-nuclear)	Medical	2	
	Dental	0.5	
	Research & Education	0.5	
	Industry (non-nuclear)	0.3	3
Miscellaneous Sources	Colour TV, Air Travel, etc.	3	3
Nuclear Power Generation (projected)	Uranium Mining	1	
	Reactor Operation	15	
	Other Fuel Processes	3	
	Transportation	0.01	
	Accidents	0.5	20

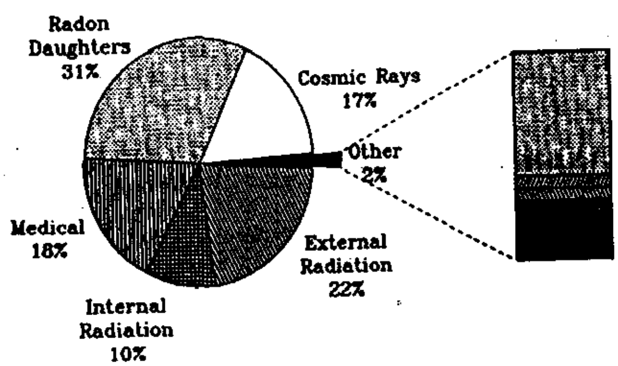

Fig. 3.4. Background Radiation in Canada

mSv	
100,000	Typical dose to the thyroid in radiation therapy
10,000	Hospital leukaemia treatment — 50% successful
	Highest annual radon dose in a UK home (equivalent to 5,000 mSv whole-body)
1,000	
	Dose giving an extra 1% risk of cancer (250 mSv)
	Annual radon dose to Health Spa Workers (200 mSv)
100	Environmental radiation dose in some parts of the world
	Estimated maximum CAT scan dose (40 mSv)
	Annual dose limit for Radiation Workers (20 mSv)
10	
	Typical annual background radiation dose in NB (2 mSv)
	Average annual occupational dose Point Lepreau workers (1.3 mSv)
1	**Annual dose limit for members of the general public (1 mSv)**
	Maximum dose to members of the public from Three Mile Island accident (0.8 mSv)
0.1	Typical chest X-ray dose (0.1 mSv)
	NB Power target for dose to the public from Point Lepreau emissions (50 μSv)
	Dose from one return flight from NB to BC (40 μSv)
0.01	Annual dose from fall-out from past bomb tests (10 μSv)
	Expected annual dose from Point Lepreau at maturity (5 μSv)
	Annual dose from luminous signs, TV, smoke detectors
0.001	**1990 dose to local residents from Point Lepreau emissions (1 μSv)**

A Log Scale of Radiation Doses in Society

SOMATIC EFFECTS are those experienced by the exposed individual.

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Cancer, Radiation Injury

HEREDITARY EFFECTS do not appear until subsequent generations are born.

Natural Mutations

Experimental Results with Mice

Hereditary Risk from Radiation
= 1% per Sv to either parent

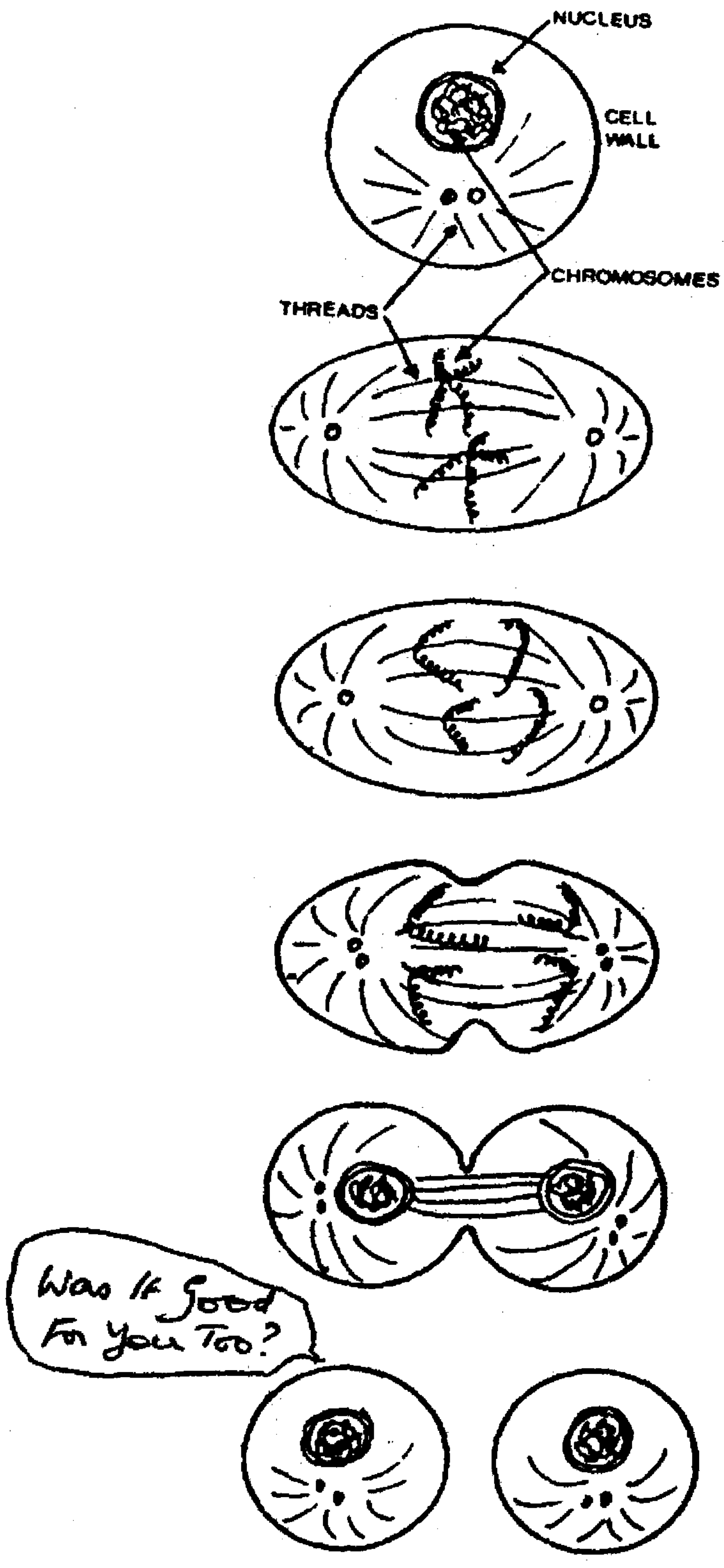

Fig. 3.6. Cell Division

Long-Term Somatic Effects

Cell Mutation and Cancer

Radiation Induced Cancer in Humans:
- Radium Dial Painters
- Ankylosing Spondilitis
- Japanese A-Bomb Survivors

Fatal Cancer Risk for Radiation Workers = 4%/Sv.

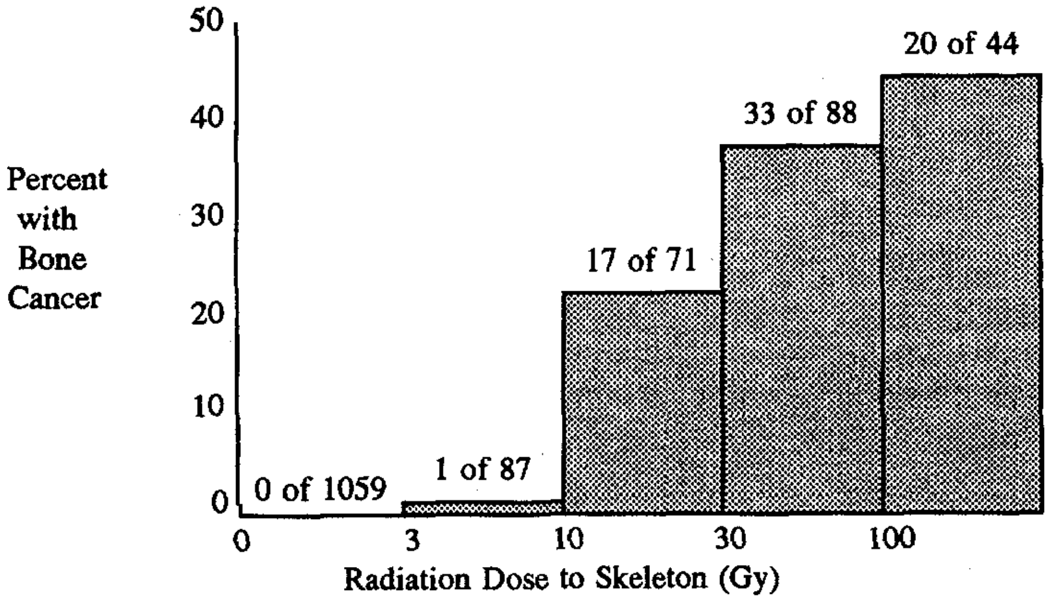

Fig. 3.7. Cancer Cases in Radium Dial Painters

An ACUTE exposure is one that is delivered in a short period of time, i.e., within a day.

A CHRONIC exposure is one that continues over long periods of time,
i.e., months and years.

Short-term somatic effects:

1. **the effects of radiation on living cells,**
2. **the self-renewal tissues in the body,**
3. **the functions of these tissues,**
4. **the effects of damage to these tissues, and**
5. **how we can treat injuries to these tissues.**

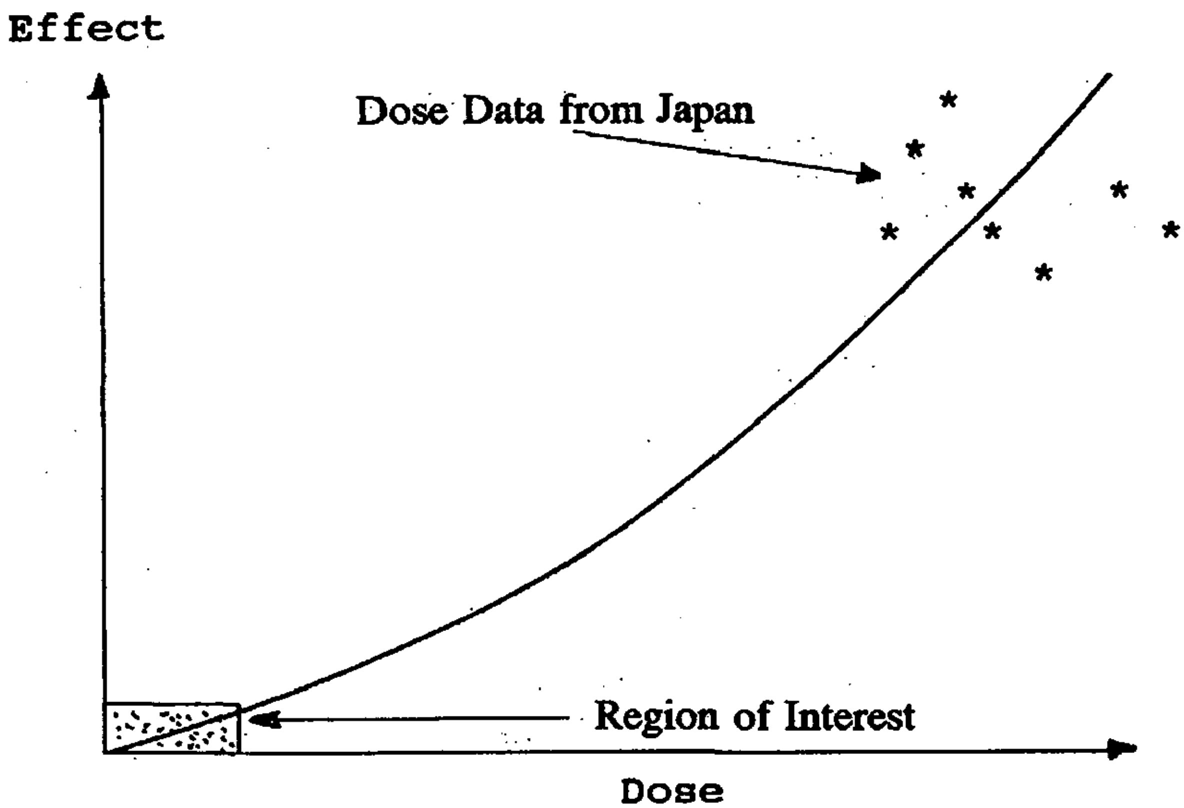

Fig. 3.8. Dose Response Curve

The tissues in our bodies most affected by an acute radiation dose are those in which the cells are reproducing most rapidly. These are the skin, the blood-forming tissues, the gonads and the digestive system lining (called the GI tract).

SKIN	Contains body fluids, protects underlying tissues, prevents bacterial invasion
GONADS	Procreation, recreation
BLOOD:	
Red Blood Cells	Transport oxygen
White Blood Cells	Gobble up bacteria and germs
Antibodies	Destroy or immobilize foreign molecules and bacteria
Platelets	Assist in blood-clotting mechanism
GI TRACT LINING	Secretes digestive enzymes, absorbs nourishment from food, prevents bacterial invasion

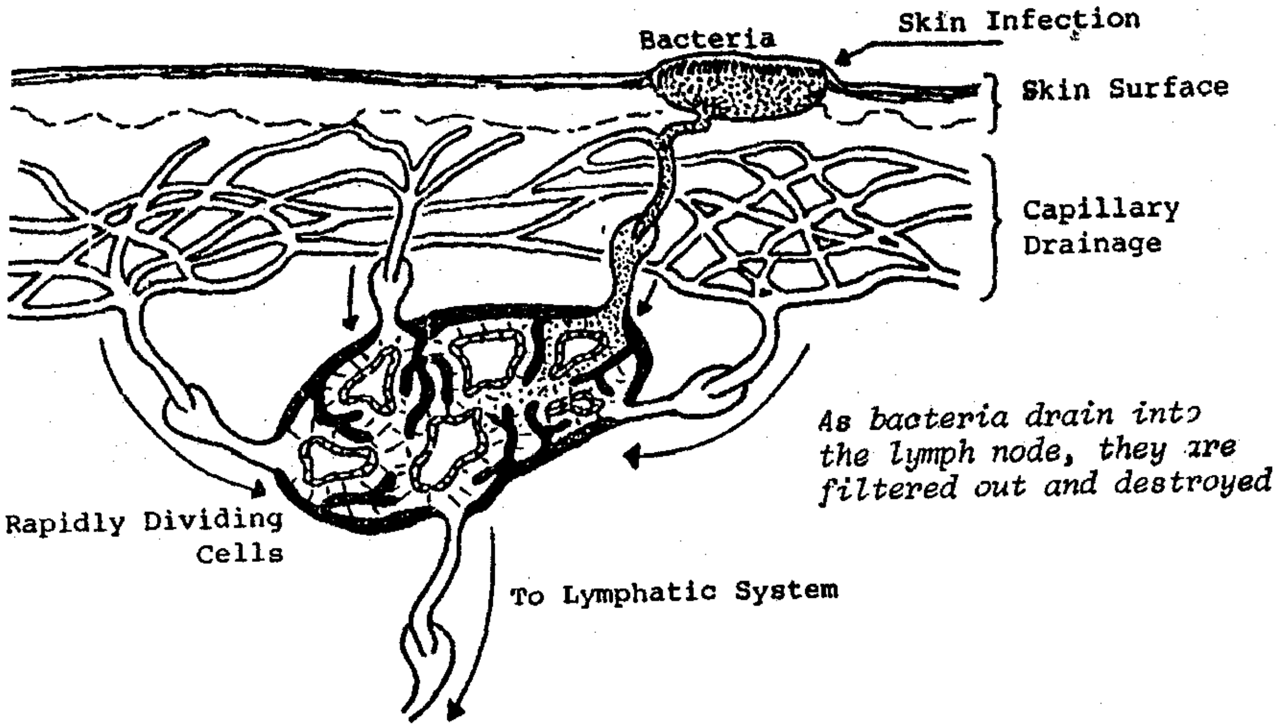

Fig. 3.9. Cross-Section of Lymph Node

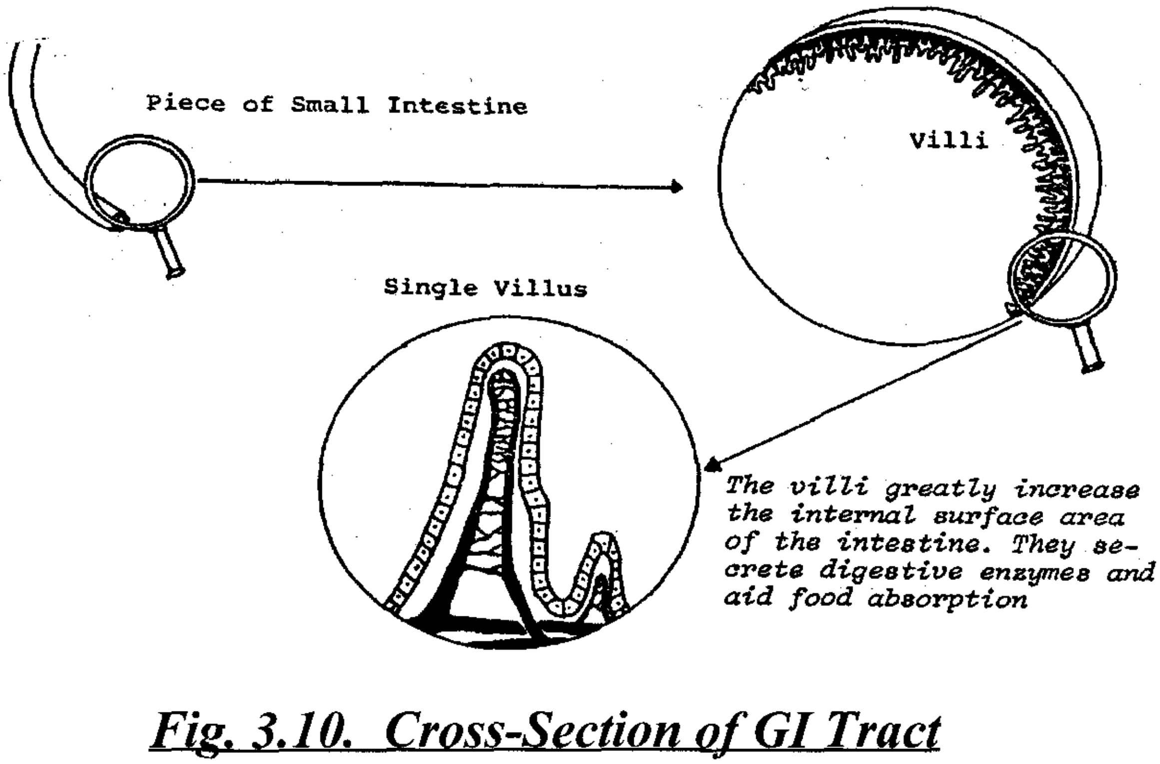

Fig. 3.10. Cross-Section of GI Tract

PROBABLE EFFECTS OF ACUTE WHOLE-BODY GAMMA DOSES (mGy)

0-250	No detectable clinical effects. Delayed effects may occur, but are highly unlikely.
250-1000	Slight blood changes with later recovery. Possible nausea. Serious delayed effects are possible but unlikely.
1000-2000	Nausea and fatigue, possible vomiting. Reduction in certain blood cells with delayed recovery.
2000-3000	Nausea and vomiting probable on first day. Two week latent period followed by general malaise, loss of appetite, diarrhoea, moderate loss of weight. Possible death in 2-6 weeks but for most healthy individuals recovery likely.
3000-6000	Nausea, vomiting and diarrhoea probable in first few hours. Short latent period followed by loss of appetite, general malaise, then haemorrhage, loss of weight, skin blotchiness, diarrhoea, inflammation of throat. Some deaths in first weeks, possible eventual death to 50% of individuals receiving about 3500 mGy without medical treatment.
over 6000	Nausea, vomiting and diarrhoea in first hours. Short latent period followed by diarrhoea, haemorrhage, skin blotchiness, inflammation of throat, fever by end of first week. Rapid weight loss and death as early as second week with possible eventual death of 100% of exposed individuals.

Effects of Acute Radiation Dose of 4 - 6 Gy

Time from Exposure	Biological Effects	Symptoms Observed
Stage I 0-48 hours	Body cells killed by the radiation disintegrate, releasing irritants into the blood system. The body senses this and assumes the last meal to be at fault.	Vomiting, nausea, loss of appetite, fatigue.
Stage II 2 days - 3 weeks	Following the removal of the irritants, there is a period during which the concentrations of all blood constituents are falling.	Symptoms disappear, and patient feels well.
Stage III after 2 weeks	There is now a severe shortage of blood constituents. Shortage of red cells: - poor oxygen transport. Lack of white cells: - open to infection. Lack of platelets: - no clotting of damaged blood vessels.	Severe lethargy, fever, bleeding, and blotchy skin. Fatalities occur here.
Stage IV after 8 weeks	For the radiation victim to survive Stage III, he must have sufficient blood-forming tissue to sustain life, perhaps aided by medical treatment consisting of massive doses of antibiotics, massive blood transfusions and possibly bone marrow transplants. The patient's condition will improve but up to six months are required before full recovery.	

TREATMENT	REASON
Complete rest	Conservation of the blood constituents
Strict environ-mental sterility	Reduction of bacteria contact
Antibiotics	To aid body's bug-fighting equipment
Blood transfusions	Restoration of blood constituents
Intravenous feeding	To aid or replace normal digestive processes

Localised Doses to Specific Organs or Tissues

Skin

Blood-Forming System

GI Tract

Reproductive System

Thyroid

Eye

Central Nervous System

Developing Embryo and Foetus

- Mortality
- Malformations
- Mental Retardation
- Reduced Intelligence
- Childhood Cancer

Lethal Acute Doses

3 - 5 Gy LD_{50}

> 5 Gy	Severe GI Damage = Death
> 10 Gy	Inflammation of Lungs: Death
> 15 Gy	Nervous System Damage Death within few days
> 100 Gy	Death within few hours

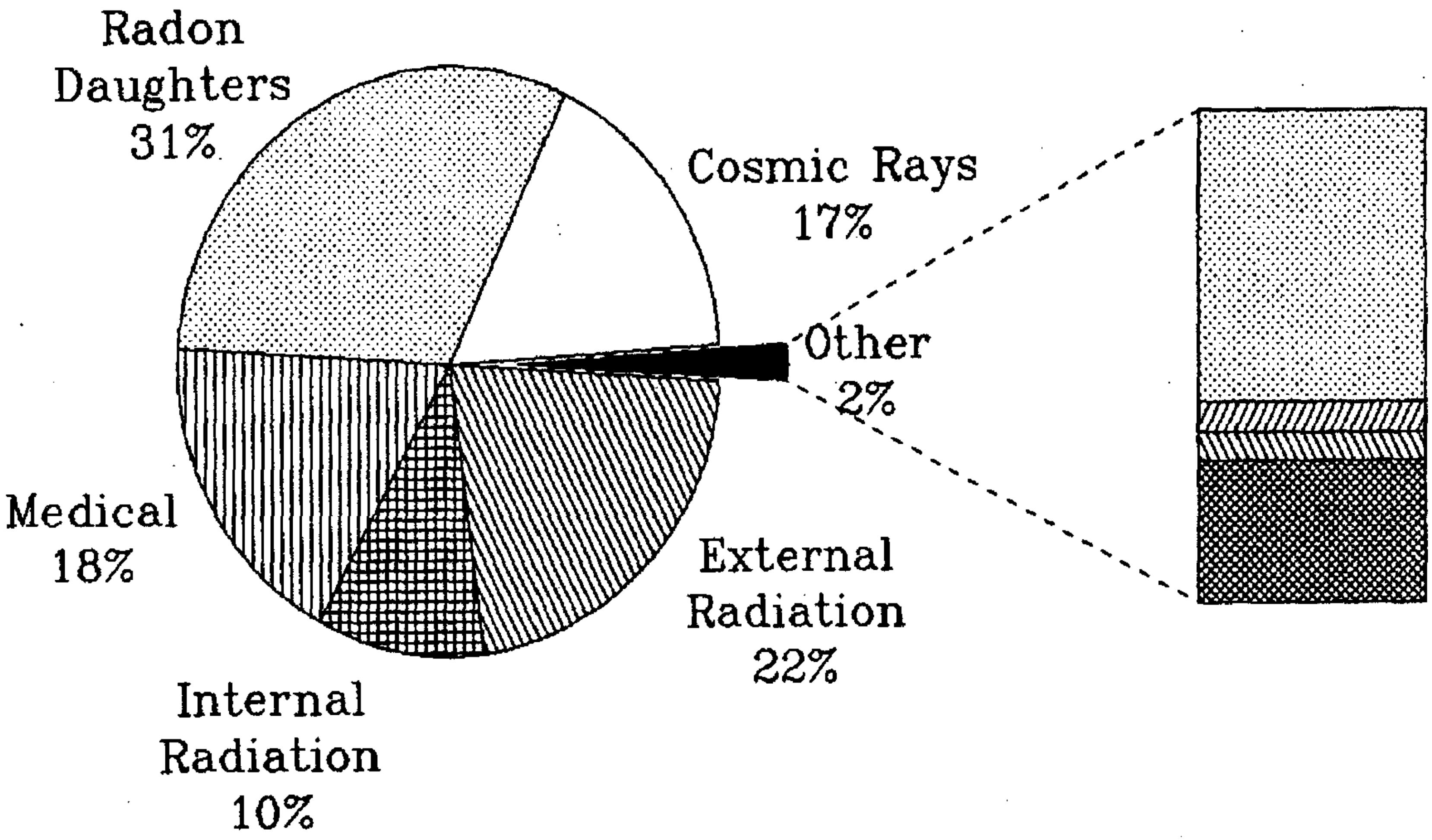

Fig. 3.4. Background Radiation in Canada