Radiation Biology Basics

Living with Radiation Series
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Basic Radiation Biology is one of a series of training CDs designed for staff that use or are exposed to radiation in their daily work. It would be useful to take Basic Radiation Physics presentations before this module is taken.

For some this will act as a review, for many these will be new material. There is a lack of such training in professional education. Also, radiation biology, radiation protection and radiation limits have changed and we need to learn more about risk factors involved.

This course consists of slides, notes and narration. The narration covers the material that is mostly on the slides. They can be heard by selecting the loudspeaker icon when each slide is displayed.

The notes explain principles in more detail or deal with associated material.

Our present knowledge, as expressed in this lecture, is by no means complete, but it is sufficient to act as a guide when we expose humans to ionizing radiations. An understanding of radiobiology and of its ramifications is mandatory for physicians and others who use x-rays, or radioisotopes either directly or indirectly, in their practice.

Radiation Biology Physics

- Why do we need to know haw radiation interacts with the cell?
- What is Radiation Biology, anyway, and how do thy work?

The uses of radiation in medicine and dentistry are unlike the other uses of radiation discussed in other presentations. This is because it involves the irradiation of human beings other than the operator. The reasons may be therapeutic (as in radiation oncology) or diagnostic (as in medical or dental imaging).

The benefit comes from the x-rays producing an image that is useful in the diagnosis of the medical or dental condition under study. X-rays travel outward from the focal spot of the x-ray tube (like light from a light bulb), and they can be blocked out to cast a shadow. But unlike light, x-rays are not stopped at the first surface they encounter. They penetrate materials to a degree depending upon how they are generated and upon the nature of the material. Bone shows up in a radiographic image because it absorbs more x-rays than does soft tissue. Lead and steel absorb x-rays even more effectively and are used as protective barriers to x-rays. This is why we can use x-ray to examine human body. Effects of these on biological cells and its components is considered in this presentation.

Summary: Radiation Biology

1. Introduction
2. What is radiobiology?
3. The structure of DNA molecule
   - The principal target for the biological effects of radiation
4. The sequence of events after radiation exposure
5. The effects of radiation on humans
   - Measurements of radiation dose
   - Deterministic radiation effects
   - Stochastic radiation effects
6. Regulatory limits of radiation dose and exposure
7. Conclusion

The course is roughly divided into these seven general sections.

1. Introduction
2. What is radiobiology?
3. The structure of DNA

   The principal target for the biological effects of radiation

4. The sequence of events
5. The Effects of Radiation on Humans

   Deterministic Radiation Effects

   Stochastic Radiation Effects

6. Regulatory Limits of Radiation Exposure
7. Conclusion

The principles of radiation damage to living cells are explained with some detail. This is done only to help you in understanding why and how to reduce the dose to yourself or your staff. The notes with each slide provide additional information on the topic presented.

Introduction

Ionizing radiation Bermuda is widely used in

- Medicine,
- Research,
- Education, and
- Industry

The use of radiation in Bermuda comes under the mandate of the Ministry of Health, it is a requirement that all users of such radiations have evidence that they have received training in the principles of radiation safety as it applies to themselves, their staff, their patients, and others.

Ionizing radiation is widely used in medicine, research, education and industry.

There is a lack in the knowledge base of basic radiation physics and how it applies to risks.

The use of radiation in Bermuda now comes under the mandate of the Ministry of Health, it is a requirement that all users of such radiations have evidence that they have received training in the principles of radiation safety as it applies to themselves, their staff their patients, and others.

Also various professional societies have formally adopted a policy to encourage the teaching of radiation protection during their training programs.

Opening Questions

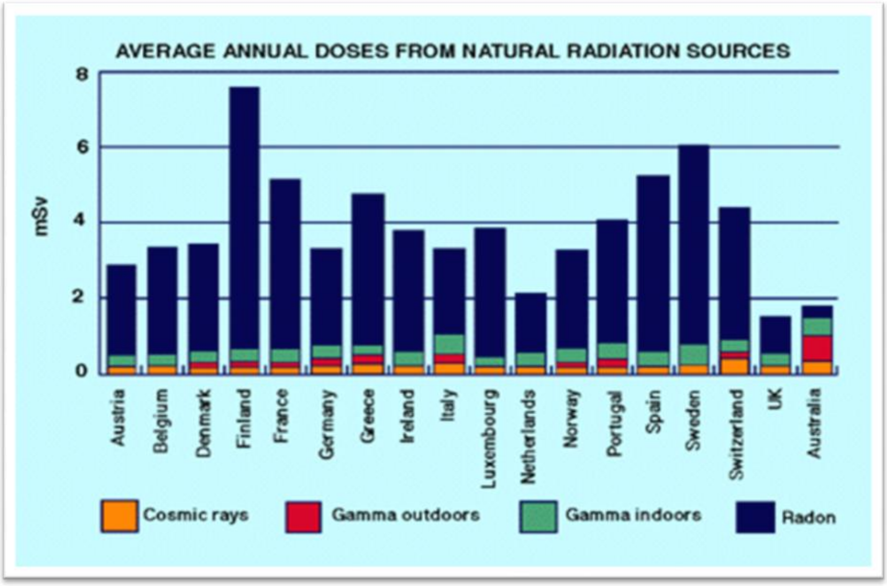
- Why is ‘radiobiology’ a part of this series of lectures?
- Why is it important that we know about this?
- How will this knowledge help us and our patients?

The previous basic physics lecture examined what happens at the atomic level when x-rays impinge upon matter. We saw that atoms were ionized by the removal of one or more orbital electrons, with the result that ‘ion pairs' (consisting of a negatively-charged electron and a positively charged atom) are produced.

What is radiobiology? Radiobiology is the science of the effects of ionizing radiation on the cells and organs of living organisms, in particular those of the human body. It is based on many years of experimental and theoretical study, both of the basic physical interactions and of their biological consequences.

Atoms ionized by radiation may change chemically, becoming free radicals. These free radicals can damage a cell’s DNA.

Background Ionizing radiation



Is that which is naturally and inevitably present in our environmental.

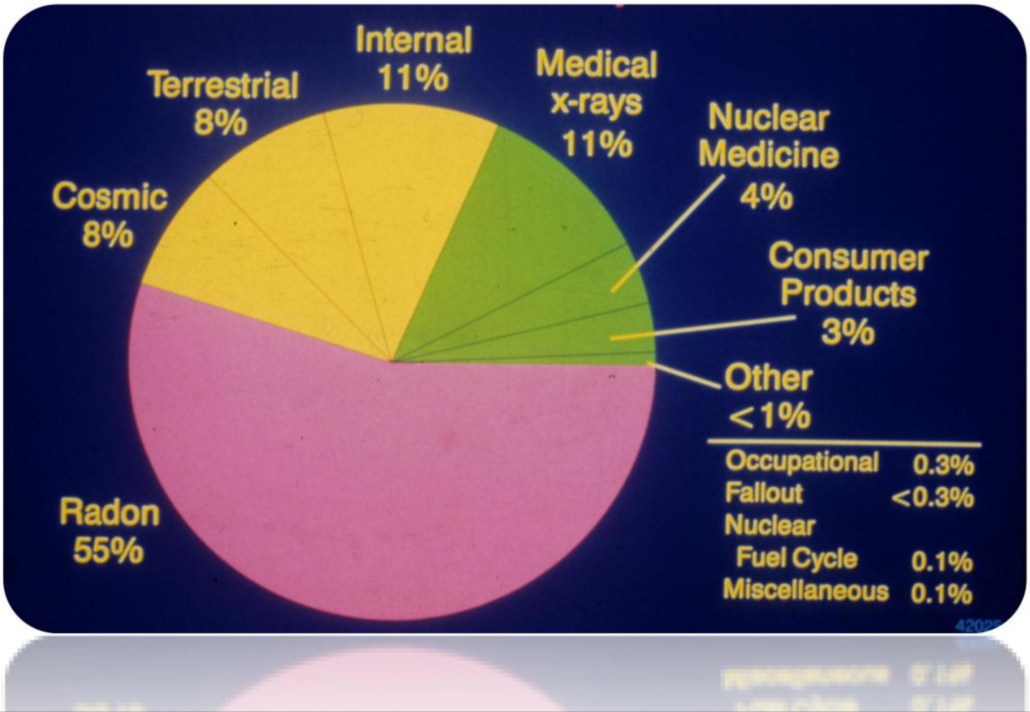
Unavoidable background radiations from natural sources contribute a small, but measurable dose, which cannot be ignored. These sources are cosmic rays, the radioactivity of our surroundings (including that of rocks, buildings and even the bodies of other people). It is against this background that the effects of radiation from man-made sources must be considered.

This slide displays the effective dose received in various parts of the world. The variations from the average dose of s 3.6 mSv/yr are considerable. The contributions to radiation dose from the different sources are presented on the slide.

The large radiation dose received in Finland is because of the mineral content of the soil. The concentrations of these ores vary from place to place.

On the other hand, the low overall dose in Australia is because of the absence of these types of mineral. However, Australia has the largest gamma ray background outdoors. It should also be noted that Switzerland has the largest cosmic ray background because of its average altitude.

Average Effective Dose in U.S. (3.6 mSv/yr)



Irradiation of individuals for medical purpose (including imaging) comprises only part of our exposure to radiation.

This slide displays the percentage of the dose received in the USA. A total average effective dose equivalent from all sources on this slide in U.S. is 3.6 mSv/yr.

The largest contribution to a radiation dose comes from radioactive radon gas (55%). This is a disintegration byproduct of uranium ores in the rocks surrounding the site.

Radon dose is followed by an additional dose received by medical x-rays (11%), and the dose received from internal radioactive materials in the body of 11%.

Terrestrial radiation, coming from naturally radioactive soil, is 8% to the total dose.

Cosmic radiation, coming from space, also contributes 8% to the total dose.

Contribution of Nuclear Medicine to the total dose is 4%.

All other sources of radiation including occupational, fallout, and nuclear energy related exposures would contribute less than 1 % to the total dose of an average person in the U.S.

The Structure of DNA

There is strong circumstantial evidence to indicate that DNA is the principal target for the biological effects of radiation; these include cell killing, mutation and carcinogenesis. The DNA may be altered by the action of free radicals, or directly by the incident radiation.

DNA's backbone (red color) is a chain of alternating phosphate and sugar molecules.

Bases (circles) are information carriers attached to the sugar molecule. There are four bases: thiamine t and cytosine c are small molecules called pyramidines. Adenine A and Guanine G are larger molecules called PURINES.

A gene is a string of bases.

Purines pair up with the pyramidines, and a second strand of DNA, and vice versa (A to T; C to G).

Double helix; Two strands bond to form a double helix. There are ten bases for each complete turn of the helix. When DNA copies itself, the helix unzips, and new , and new strand matches each other.

Within all living cells there are a number of chromosomes, each of which contains a large number of molecules of desoxyribosenucleic acid (DNA) molecules.

The DNA molecule is a tightly-wound double helix which conveys, in an overlapping code, the information which is necessary for an organism to function, and for its cells to replicate as necessary. The backbone of DNA is made up of molecules of sugar and phosphates, which serve as a framework to hold the bases.

Attached to each sugar molecule is one of four bases - cytosine, guanine, adenine or thymine.

It is the order of these bases which forms the genetic code.

There is strong circumstantial evidence to indicate that DNA is the principal target for the biological effects of radiation; these include cell killing, mutation and carcinogenesis. The DNA may be altered by the action of free radicals, or directly by the incident radiation.

DNA Damage

In either case if the DNA is damaged, several things may happen.

The most likely is that the **damage will be repaired** before the end of the cell's mitotic cycle, (which we will look at presently). If repair does not take place **the cell will probably die**.

But there is some chance that **the cell will survive** and behave differently because of the damaged DNA.

For example, it may become malignant. Large radiation doses may kill many cells, causing noticeable damage such as erythema or epilation. Low doses do not cause such significant changes but may produce a malignant change which will become apparent over time. Long term genetic effects are also possible.

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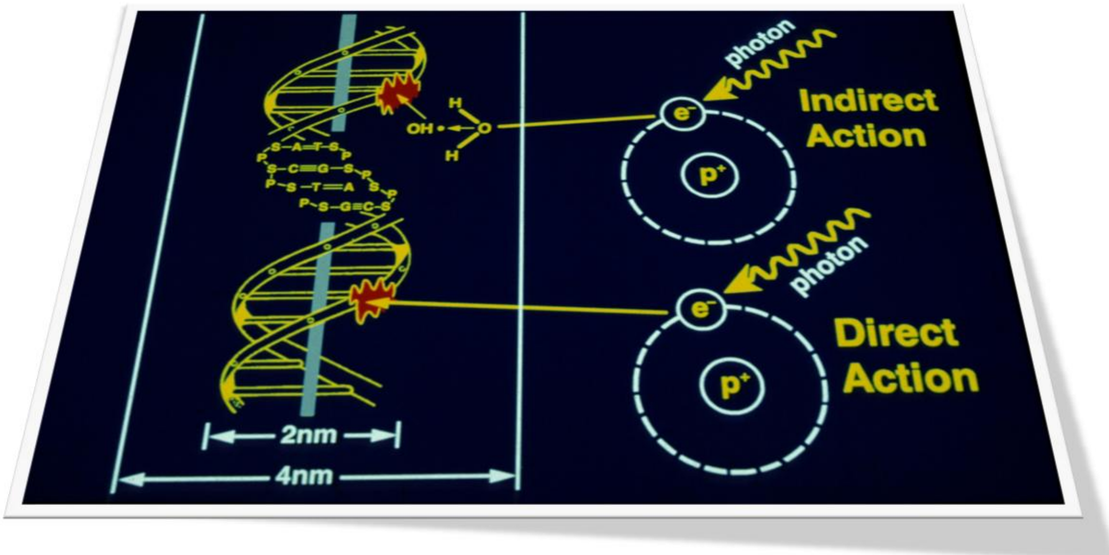
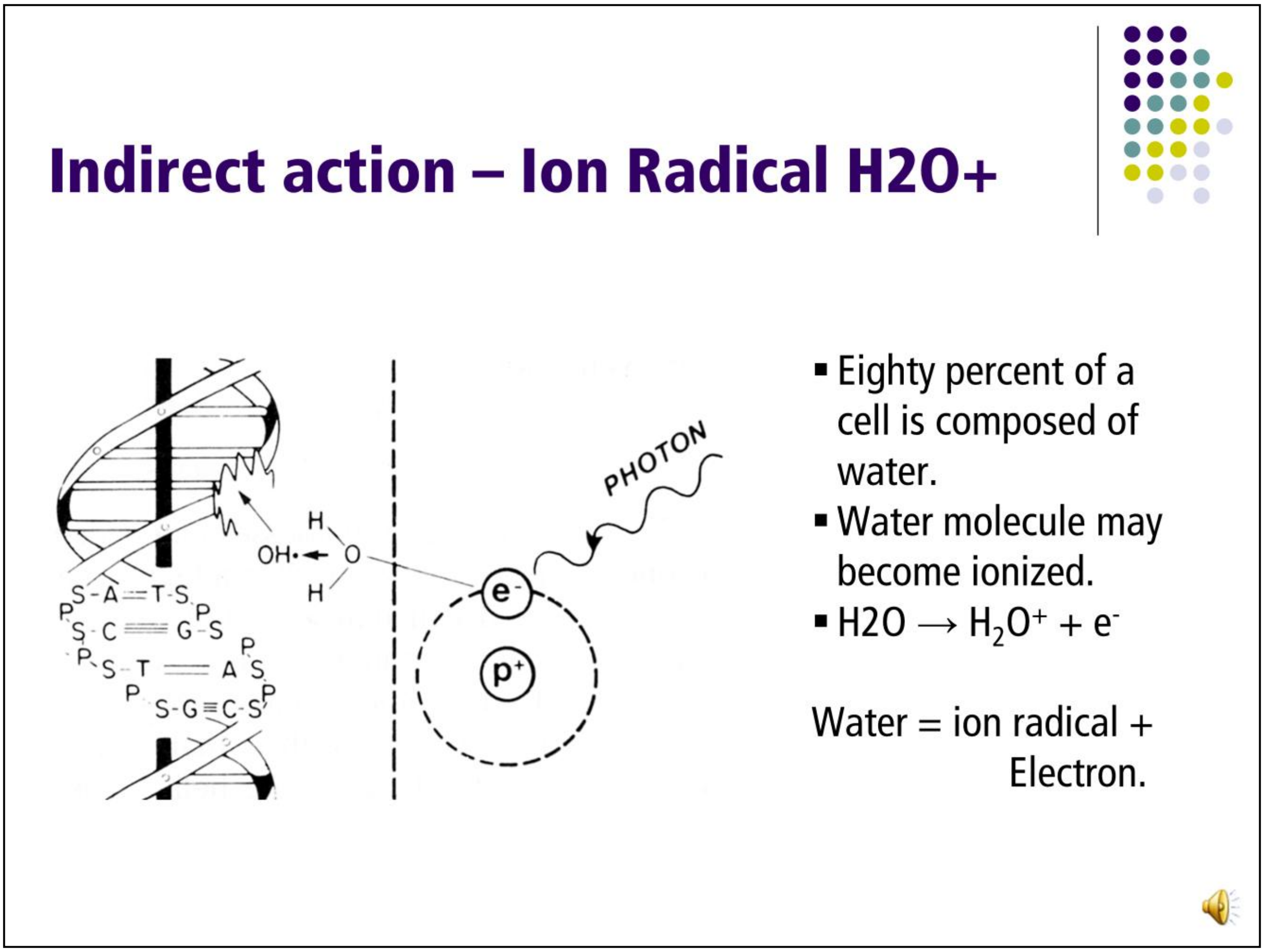
Indirect and Direct Action



Let us now look at the mechanisms by which radiation damages cells.

Direct action: Here the x-ray photon (or its resultant charged or uncharged particle) interacts directly with the critical targets in the cell; the atoms of the target itself may be ionized or excited, which initiates a chain of events leading to biological change. This is an unlikely effect in the case of x-rays; it is most probable when heavy particles (neutrons or alpha particles) are involved.

Indirect action: Eighty percent of a cell is composed of water. As a result of an interaction with an x-ray photon, a water molecule may become ionized.



Indirect action: Eighty percent of a cell is composed of water. As a result of an interaction with an x-ray photon, a water molecule may become ionized. This may be shown as:

$$H_2O \rightarrow H_2O^+ + e^-$$

H_2O^+ is an ion radical, since it has lost an electron and it is also a free radical, since it has an unpaired electron in its outer shell. An ion radical is highly reactive and decays with a lifetime of about 10^{-10} seconds.

Indirect action: hydroxyl radical

The ion radical reacts with another water molecule to form the highly-reactive

hydroxyl radical OH ·

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH\cdot$$

The **hydroxyl radical OH ·** can diffuse a short distance to reach a critical target in a cell, so it can reach the double helix of DNA, and bring about a breakage in one of the arms of the helix.

In this case the ion radical reacts with another water molecule to form the highly-reactive **hydroxyl radical OH ·**

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH\cdot$$

The hydroxyl radical can diffuse a short distance to reach a critical target in a cell, so it can reach the double helix of DNA, and bring about a breakage in one of the arms of the helix. About 2/3 of the damage produced by x-rays to the DNA in a cell is caused by the hydroxyl radical.

Direct Effect on DNA

- Here the x-ray photon (or its resultant charged or uncharged particle) interacts directly with the critical targets in the cell.
- The atoms of the target itself may be ionized or excited, which initiates a chain of events leading to biological change.
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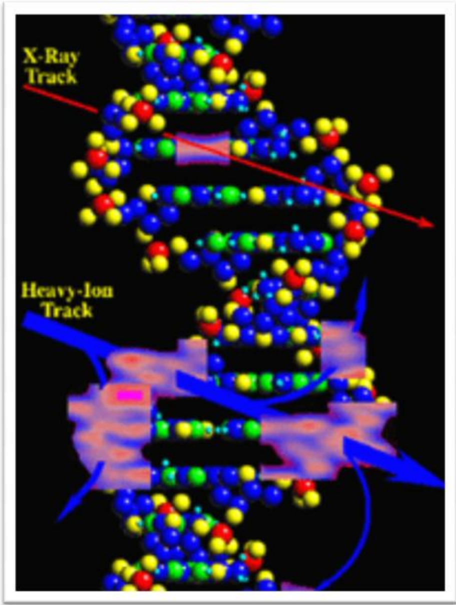


Passage of ionizing radiation can result in direct effect on DNA leading to single strand breaks (SSB), double strand breaks (DSB), associated base damage (BD), or clusters of these damage types.

The initial damage caused by particles at the cell level and to the tissue is unique compared to the damage caused by the terrestrial radiation such as x-rays or gamma rays.

Because of their high ionization density, high mass, high-Z, high-energy (HZE) cosmic particles can also cause clusters of damage where many molecular bonds are broken in the tissue along their trajectory. The cell's ability to repair DNA damage becomes impaired as the severity of clustering increases leading to DNA deletions and other forms of mutations.

Since HZE particles are rare on Earth, the prediction of biological risks to humans in space must rely on fundamental knowledge gathered from biological and medical research. One of the risks of prolonged manned space flight is the exposure of astronauts to radiation from galactic cosmic rays, which contain heavy ions.

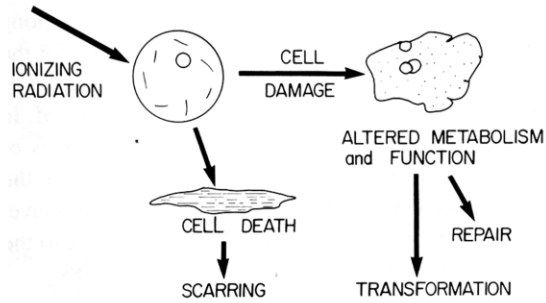
Effects of Radiation on the cell

Cell Killing
- This will cause noticeable damage such as erythema or epilation.
- Relevant in interventential radiology, and to total body irradiation.
- Effects on the embryo & fetus

Mutation in Germ Cells
- Hereditary consequences expressed in later generations

Mutations in Somatic Cells
- Low doses may produce a malignant change (Cancer or Leukemia) which will become apparent over time.

The damage will be repaired



Radiation can affect the cell in two ways. It can bring about the death of the cell or it can initiate mutational changes. The type of mutational change will depend upon the target cell. In germ cells this mutational consequence will be expressed in later generations, while in somatic cells the result can be conversion to malignancy.

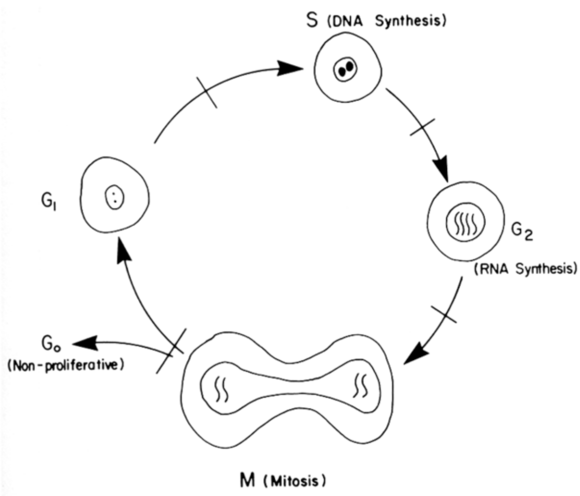
In both cases some repair is possible.

The time scales are approximately as follows:

Incident photon > Fast electron > ion radical > free radical > chemical changes > biological effects

The time step between bond breakage and the expressed biological effects will depend upon the consequences. If cell killing is the result, the time may be hours or days, and becomes apparent when the cell attempts to divide. If the result is oncogenesis, the appearance of an overt cancer may be as long as 40 years. Radiation exposure can cause chromosomal damage that may be "repaired" with an incorrect sequence and subsequently be passed on to the next generation (genetic effects). Radiation does not cause new types of mutations, but simply increases the incidence of certain mutations above their natural rate of occurrence.

The cell cycle for mammalian cells can be divided in four phases



- **M:** mitosis is a sensitive phase.
- **G1:** gap phase of apparent inactivity.
- **S:** DNA synthetic phase is generally the most resistant phase.
- **G2:** gap of apparent inactivity is a sensitive phase.
- **Cycle time:** time from M to G to S to G and back to M varies between 9 and 200 hours.

This brings us to a discussion of the cell cycle. Cells propagate and proliferate by mitosis. At cell division, two daughter cells are produced, each of which carries a DNA complement identical to that of the original cell. After a time (the mitotic interval Tc), the daughter cells will again divide. The major discernable events in the cycle itself are the M (mitosis or division) phase and the S (DNA synthesis) phase. These are separated in time by inactive or resting phases, the G1 (between M and S) and the G2 (between S and M). It is in the S phase that the DNA molecules are reproduced and separated, each of the new pair to one of the daughter cells. Since cell division is a cyclic phenomenon, the cycle is usually represented by a circle.

The total time between the start of mitosis one and that of the next varies from cell type to cell type. Most of this difference lies in Tc (the mitotic interval). Within the cycle for different cells, the time taken by the components M, S and G_2 varies only slightly, but the length of the G_1 period may vary dramatically. All of these times are usually measured in hours or days.

The Relative cellular radiosensitivity

- The following list provides a relative ranking of cellular radiosensitivity

Increasing Sensitivity ↑

Lymphocytes
Erythrocytes, Granulocytes
Epithelial Cells
Connective Tissue Cells
Bone Cells
Nerve Cells
Brain Cells
Muscle Cells

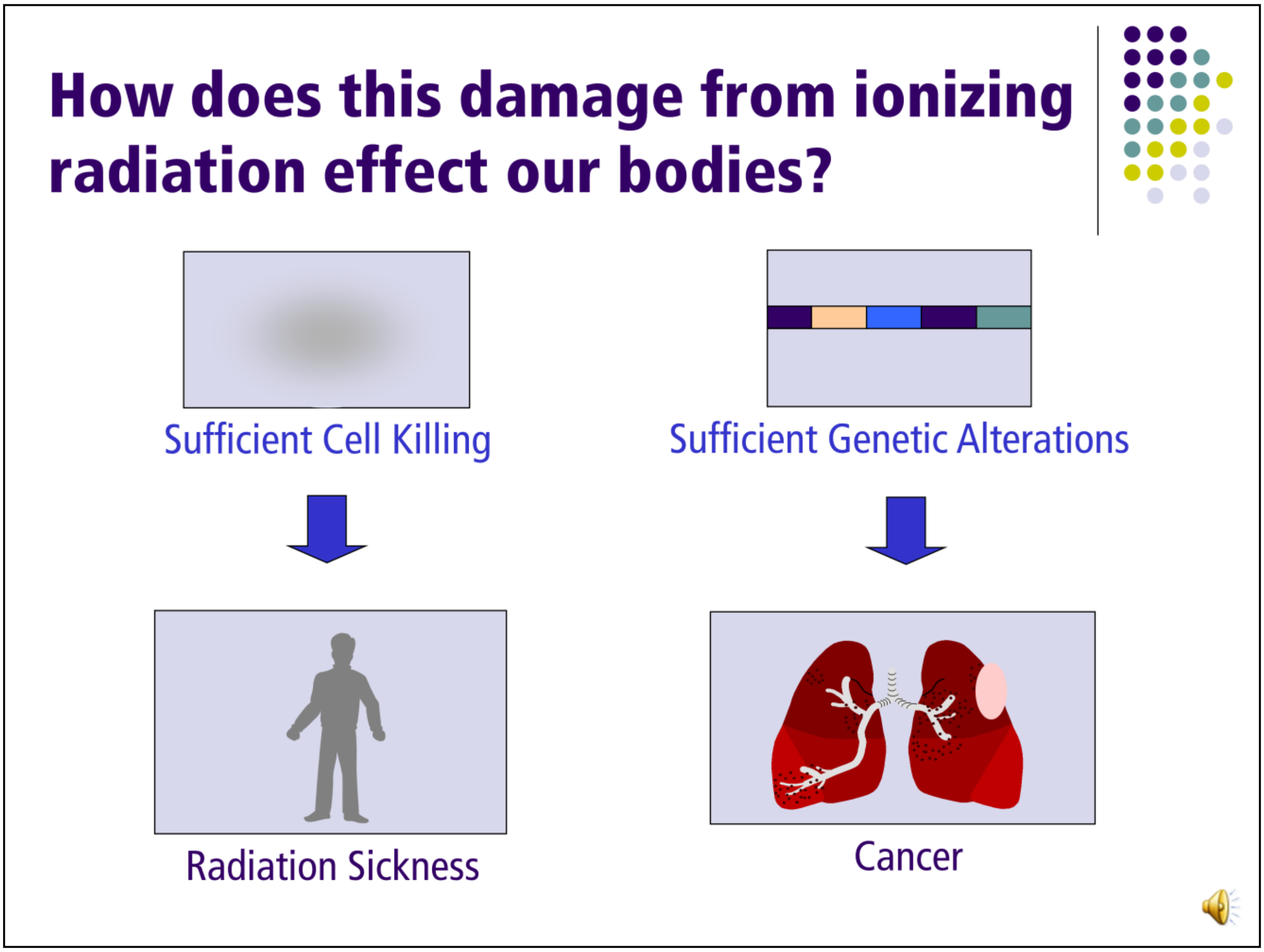
- Radiosensitivity is highest in undifferentiated and actively proliferating cells.
- It is proportionate to the amount of mitotic and developmental activity of the cells.
- Bone marrow is much more sensitive to radiation than nerve cells, which have an extremely long cell cycle.

The Relative ranking of cellular radiosensitivity

Radiosensitivity is a function of the cell cycle with late S phase being the most radioresistant and G1, G2, and especially mitosis M being more radiosensitive.

Radiosensitivity is highest in undifferentiated and actively proliferating cells, proportionate to the amount of mitotic and developmental activity that they must undergo.

For example, bone marrow is much more sensitive to radiation than nerve cells, which have an extremely long cell cycle. The following list provides a relative ranking of cellular radiosensitivity.



In summary, cell killing, genetic aberrations, cancer induction and radiation sickness are all consequences of the irradiation of the human body.

Measurements of Radiation Dose

- **Dose** is a confusing area, many different types
- **Absorbed Dose** - measured in Gray (Gy)
  - amount of energy deposited per kilogram of tissue (1Gy = 1 joule/Kg)
- **Quality Factors** (QF)
  - x-ray, gamma rays & beta particles 1
  - Neutrons .... 5 – 20
  - alpha particles 20

Before discussing the effects of radiation on humans, and the recommendations in detail, we must first introduce the concepts of radiation units.

The biological effect of radiation cannot be measured directly. Instead, we measure its *physical* effect (in units of GRAYS - abbreviated Gy), and we use this to quantitate the biological effect.

Measurements of Radiation Dose

Equivalent Dose - amount of biological damage in Sieverts (Sv)

- gives a measure dose as if received by the whole body (used to equate dose to risk)

Sv = Gy x QF i.e.. for x-rays: 1 Sv = 1 Gy

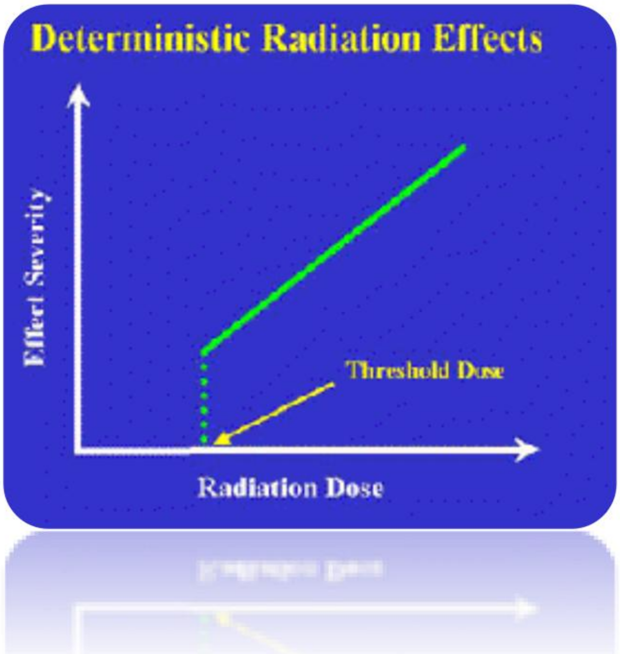
Weighting Factors

- (some organs are more radiosensitive than others) whole body = 1.0

testes and ovaries	0.20	breast	0.05
Bladder	0.05	RB marrow	0.12
Colon	0.12	lung	0.12
Stomach	0.12	thyroid	0.05
oesophagus	0.05	liver	0.05
bone surface	0.02	remainder	0.05

The unit that is used to describe the *biological* effect of radiation is the milliSievert (abbreviated mSv). Using this unit, we can put radiation exposures of humans into some sort of perspective. For instance, at sea level, the average *background* radiation level is about 3 mSv per year, which includes a contribution from radon gas. At higher elevations, it is about 3.5 mSv per year due to the cosmic radiation intensity increasing with altitude. In some parts of the world, background radiation can be as high as 17 mSv per year, because of the radioactivity of the soil in the area. Long-term studies under the auspices of the World Health Organization have found no evident increase in cancer or of genetic effects in the population of these areas. This is in spite of the fact that the people have been living in this radiation environment for thousands of years.

Deterministic Radiation Effects



- A large number of ionizing radiation effects occur at high doses. These all seem to appear only above a threshold dose.
- While the threshold may vary from one person to another, it is about 2 Gy.
- The severity of these effects increases with increasing dose above the threshold.
- They are usually divided into tissue-specific local changes and whole body effects, which lead to acute radiation syndrome.

The biological effects of radiation are usually divided into two classes, *deterministic and stochastic.*

Deterministic Effects: A large number of ionizing radiation effects occur at high doses. These all seem to appear only above a threshold dose. While the threshold may vary from one person to another, it is about 2 Gy. The severity of these effects increases with increasing dose above the threshold. These so-called deterministic effects are usually divided into tissue-specific local changes and whole body effects, which lead to acute radiation syndrome.

Deterministic Radiation Effects

- Organ's response to radiation depends on:
  - The total dose
  - dose rate
  - fractionation scheme
  - volume of irradiated tissue
  - inherent radiation sensitivity
- Less biological damage occurs when the radiation dose is fractionated (delivered over several different events as opposed to all at once), as is the condition of most operator/staff exposures. Dose fractionation allows time for cellular repair.

The total dose, dose rate, fractionation scheme, volume of irradiated tissue and inherent radiation sensitivity all affect a given organ's response to radiation. Generally, a large total dose, high dose rate, small fractionation schedule (as encountered during fluoroscopy), and large irradiated volumes cause a greater degree of damage. Less biological damage occurs when the radiation dose is fractionated (i.e. delivered over several different events as opposed to all at once), as is the condition of most operator/staff exposures. Dose fractionation allows time for cellular repair.

Deterministic Radiation Effects

- Personnel effects include erythema, epilation, sterility, and cataracts.
- The first three of these can be temporary at doses of 2 Gy or permanent at doses greater than 6 Gy.
- Above 0.5 Gy, a decrease in leukocyte counts can be detected.
- Most of these deterministic effects are seen within days or weeks after the exposure, but cataracts may appear a few years after exposure.

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Deterministic Radiation Effects

- Cataract induction is of special interest to fluoroscopy operators since the lens of eye often receives the most significant levels of radiation (provided lead aprons are used).
- Radiation is known to induce cataracts in humans from single doses of 2 Gy.
- Cumulative exposures of up to 7.5 Gy have resulted in no evidence of cataract.
- Personnel exposed to the maximum levels each year would accumulate only 4.5 Sv over 30 years. As such, the risk for cataracts is likely to be small.

Cataract induction is of special interest to fluoroscopy operators since the lens of eye often receives the most significant levels of radiation (provided lead aprons are used). Radiation is known to induce cataracts in humans from single doses of 2 Gy. Higher exposures can be tolerated when accumulated over time. Cumulative exposures of up to 7.5 Gy have resulted in no evidence of cataract.

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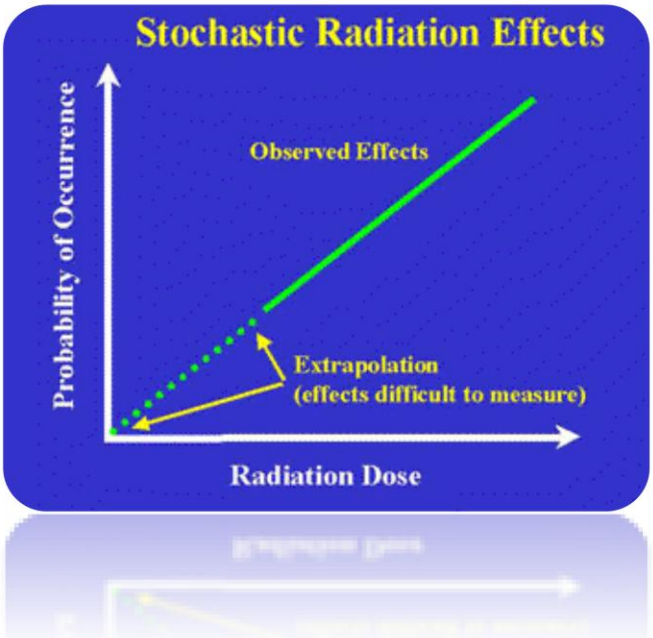
Stochastic or probabilistic phenomena



- Equal increases in dose cause a corresponding equal increase in the incidence of the effects.
- Experimental data suggests a non-threshold linear response to the dose-effect relationship.
- Such effects are also known as stochastic or probabilistic phenomena.

Somatic effects induced by radiation may include carcinogenesis. Experimental data suggests a non-threshold linear response to the dose-effect relationship. Equal increases in dose cause a corresponding equal increase in the incidence of the effects. Such effects are also known as stochastic or probabilistic phenomena.

Unlike deterministic effects, stochastic effects are assumed to be unaffected by dose fractionation. The total risk to an individual is continually increased with increasing radiation exposure.

Stochastic Effect - definition

- Stochastic:- probability of the effect increases with increasing doses.
  - Genetic effects.
  - Cancer induction.
  - leukaemia, breast cancer, thyroid cancer, bone cancer, skin cancer, lung cancer.
- All or nothing effect, i.E., The severity of the effect does not increase with dose.
- Probability of effect increases with dose.
- No threshold in dose,
- Caused by damage to one, or a few cells.
- Cancer and heritable effects are examples.

Stochastic effect is one where probability of the effect increases with increasing doses. It includes genetic effects and cancer induction (leukaemia, breast cancer, thyroid cancer, bone cancer, skin cancer, lung cancer).

There is limited data on the risk estimates for patients exposed during diagnostic procedures.

Cancer risk estimates from lower radiation exposures are difficult to determine because of the high incidence of malignancy in the general, unexposed population.

The effects from lower radiation exposures (such as those encountered occupationally) are extrapolated from observations made at fairly high doses . The validity of this extrapolation is constantly being re-evaluated. Current guidelines maintain that current risk estimates are the best available for the purpose of establishing acceptable radiation exposure limits.

Stochastic Effects - characteristics

- There is limited data on the risk estimates for patients exposed during diagnostic procedures.
- Cancer risk estimates from lower radiation exposures are difficult to determine because of the high incidence of malignancy in the general, unexposed population.
- The effects from lower radiation exposures are extrapolated from observations made at fairly high doses.
- Current guidelines maintain that current risk estimates are the best available for the purpose of establishing acceptable radiation exposure limits.
- Unaffected by dose fractionation.

Relatively little research has been done on biological effects of low dose exposures as found in diagnostic use of radiation or in occupational environments. Traditionally, the biological effects at low doses are extrapolated linearly from those at high dose level. Biological risks of radiation are also estimated in the whole organism from research on cell models.

Current guidelines maintain that the risk estimates are the best available to establish radiation exposure limits.

Also curable cancers can be induced depending on the organ. For elderly people (older than about 60 years of age) the probability seems to be about 5 - 10 times lower, because their future life span may not be long enough to express the cancer and they would be unlikely to pass genetic damage to offspring. For pregnant women the risk is the same as for the average population (ICRP 91).

Stochastic Effects – Cancer Risk

- For radiological workers, small savings in radiation exposure realized by altering technique can result in significant reductions in personal risk when integrated over a working lifetime.
- The total risk to an individual is continually increased with increasing radiation exposure

Annual Dose (mSv)	30 year total dose (mSv)	Incremental Fatal Cancer Risk
5	150	0.6%
10	300	1.2%
20	600	2.4%
50	1500	6%

For radiation workers small savings in radiation exposure result in significant reductions in personal risk when integrated over a working time.

Risk of fatal cancer per year is small, however over 30 years of exposure to small amounts of radiation will add up to larger risk. The risk of receiving the maximum permissible dose per year of 20 mSv will grow to 2.4 % over 30 years of exposure to this amount of radiation on a regular basis.

The probability of a fatal radiation induced cancer has been estimated (ICR91) at approximately 5 per cent per Sievert effective dose for the low dose, low dose rate, for the whole population with its normal age distribution.

Some examples of doses and eventual effects are: if 100.000 persons are exposed to 1 mSv it is assumed that 5 persons will have a fatal cancer. Equally, if the exposure to those 100.000 is 5 mSv, it is assumed that 25 individuals will get a fatal cancer.

The probability of a fatal radiation induced serious genetic disease has been estimated (ICR91) at approximately 1 per cent per Sievert effective dose for the low dose, low dose rate , for the whole population with its normal age distribution.

Stochastic Effects - Prenatal

- Prenatal Effects
- There are three general prenatal effects observed that are dependent upon the dose and stage of fetal development:
  - Lethality.
  - Congenital abnormalities at birth.
  - Delayed effects, not visible at birth, but manifested later in life.

Animal studies have shown that the embryo and fetus are more sensitive to the effects of radiation than the adult. There are three general prenatal effects observed that are dependent upon the dose and stage of fetal development:

· Lethality.

· Congenital abnormalities at birth.

· Delayed effects, not visible at birth, but manifested later in life.

Irradiation of the human fetus between 4 to 11 weeks of gestation may cause multiple severe abnormalities of many organs. Irradiation during the 11th to 15th week of gestation may result in mental retardation and microcephaly. After the 20th week, the human fetus is more radioresistant, however, functional defects may be observed. In addition, a low incidence (one in 2000) of leukemia has been observed in individuals who received prenatal radiation.

Medically indicated procedures involving radiation are appropriate for pregnant women. However, such procedures should be avoided if alternate techniques are available or measures should be taken to minimize patient/fetal exposure. Considering legal complications resulting from non-optimal prenatal radiation exposure, it is strongly suggested that physicians consult with a Board-Certified Radiologist before performing fluoroscopy on potentially pregnant patients.

Recommended Radiation Limits; Proposed and Continuing Practices: Occupational Exposure; The ICRP System of Radiological Protection

- The ICRP periodically sets “recommended limits of radiation exposure” over medical dose.
- The ALARA principle is applied to all radiation risks and includes patients as well as personnel.
- The ICRP recommendations distinguishes between.
  - The general public.
  - Workers exposed to radiation.
  - Pregnant women working with radiation sources.

Minimize Your Risk

• If you have received more than the usual amount of radiation from diagnostic x-rays, such as abdominal or pelvic, CT or fluoroscopy, discuss the possible risks with your doctor

• If you are pregnant, or think you may be, tell your doctor before having an x-ray, it may be possible to delay it, or to substitute other tests such as ultrasound or MRI

• If you must have an x-ray, tell your doctor about any similar x-rays you have had recently, you may not need to repeat them

The reasons for the distinction between “radiation workers” and “members of the public” is that the exposure of radiation workers is under the supervision of a responsible individual and is capable of being monitored. In fact, if an adequate radiation safety program is in place, no person working with radiation sources should receive more than one-tenth of the amount indicated in the table. At these levels no adverse effect has ever been seen, nor is it likely that it ever will be.

The Present Regulatory Limits of Radiation Exposure in One Year

Body organ or tissue	Radiation workers	Others and public
Whole body	20 mSv	1 mSv
Lens of the eye	150 mSv	15 mSv
Skin	500 mSv	50 mSv
Hands	500 mSv	50 mSv
All other organs	500 mSv	50 mSv

The present annual regulatory limits (as recommended by the ICRP and accepted by the Ministry of Health of Bermuda) are as on this slide.

Proposed and Continuing Practices: Occupational Exposure; The ICRP System of Radiological Protection

The ICRP recommended limit is 20 mSv/y, averaged over 5 years, with the further provision that effective dose shall not exceed 50 mSv in any one year

No special restrictions are required on the subsequent exposure of an individual who has exceeded a dose limit.

Regulatory Limits of Radiation

The distinction between **radiation workers** and **members of the public** exists because the exposure of radiation workers is under supervision of a responsible individual and is capable of being monitored.

Notes:

(a) The reasons for the distinction between "radiation workers" and "members of the public" is that the exposure of radiation workers is under the supervision of a responsible individual and is capable of being monitored.

(b) While the same limits apply to both men and women, more stringent limits apply to a pregnant radiation worker in order to safeguard the fetus.

(c) The exposure of the public is not controlled in the same manner, and so more stringent limitations apply.

(d) The distinction between the various organs arises from the type of damage that might occur and the relative sensitivity of the organ to radiation

In fact, if an adequate radiation safety program is in place, no person working with radiation sources should receive more than one tenth of the amount indicated in the table. At these levels no adverse effect has ever been seen, nor is it likely that it ever will be.

Proposed and Continuing Practices: Occupational Exposure

- The effective dose limit is the boundary of tolerability
- Dose limits for skin and lens of the eye are 500 mSv and 150 mSv, respectively
- Annual limits on intake (ALIs) are based on a committed effective dose of 20 mSv
- Once pregnancy is declared, the conceptus should be protected by applying a supplementary equivalent dose limit to the surface of the woman's abdomen of 2 mSv for the remainder of pregnancy and by limiting intakes of radionuclides to about 1/20 of the ALI

Minimize Your Risk (If you think you may be pregnant)

- have a pregnancy test before undergoing an x-ray
- If you are pregnant, inform the x-ray technologist so that protective measures, such as using a lead apron, can be taken. If you must hold a child needing an x-ray, ask to wear a lead apron. After a pregnant woman has been examined or treated with ionizing radiation the dose to the unborn child should be evaluated by a medical physics expert or by the practitioner. If the uterus was not in the X-ray beam or the dose is estimated to be below 1 mSv, this evaluation is not necessary.

Proposed and Existing Practices: Public Exposure

- Dose limits and dose constraints are applicable in relation to the mean dose to the critical group
- The dose limits relate only to radiation practice received in the work environment, and not to radiation in the natural environment.
- The limit for public exposure is 1 mSv in a year
- Dose limits for skin and lens of the eye are 50 mSv and 15 mSv per year, respectively.

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Proposed and Existing Practices: Potential Exposure

- Where doses, should they occur, will not be in excess of dose limits, it is adequate to use the product of the expected dose and its probability of occurrence as if this were a dose that is certain to occur
- If the dose is in excess of dose limits, this simple approach is inadequate
- Risk constraints should be defined applicable to the attributable probability of death

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Protection in Intervention

- Exposures of emergency teams following accidents should be limited by operational controls and the doses should be treated separately from normal doses
- Exposures in the control of an accident and in immediate and urgent remedial work should not result in effective doses of more than about 0.5 Sv, except for life-saving actions
- Once the emergency is under control, remedial work should be treated as part of occupational exposure

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The Rules

- Doses should not exceed about 30 mSv and this level should be approached only if there is benefit to the individual or the dose is difficult to reduce or prevent.
- At around 3 mSv, there may be a need to reduce or prevent doses, particularly if there is no benefit to the individual.
- A dose of 0.3 mSv should be the maximum to an individual who receives no direct benefit from one source of radiation.
- A dose of 0.03 mSv presents a trivial risk to an individual.

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Regulatory Limits of Radiation Exposure

- While the same limits apply to both men and women, more stringent limits apply to a pregnant radiation worker.
- The exposure to the public is not so controlled, and so more stringent limitations apply.
- The distinction between the various organs arises from the type of damage that might occur and the relative sensitivity of the organ to radiation.

Radiation safety applies to the following medical exposures:

the exposure of individuals as part of their own medical diagnosis or treatment; the exposure of individuals as part of occupational health; the exposure of individuals as part of health screening programs; the exposure of healthy individuals or patients voluntarily participating in medical or biomedical, diagnostic or therapeutic, research; the exposure of individuals as part of medico-legal procedures.

X-rays may involve risks to an unborn child. When the medical profession communicates risks from exposure to ionizing radiation to patients, these risks should be explained and put in context so that they can be easily understood. If pregnancy cannot be excluded, depending on the type of medical exposures, special attention shall be given to the justification, particularly the urgency, and to the optimization of the medical exposure taking into account the exposure both of the expectant mother and the unborn child.

SUMMARY

- Both early and late effects and risks from high levels of radiation are well defined and understood.
- The radiation risks associated with exposure to low levels of radiation are difficult to measure and still have major uncertainties associated with them.
- Rapid advances in technology, techniques in cell and molecular biology are now making it possible to detect and understand biological changes after low doses of radiation.

Closing Questions - Quiz

- ✓ Why there is closing 'radiation protection quiz' a part of this series of lectures?
- ✓ Why is it important that we have certification process in Bermuda?
- ✓ How will this process help us and our patients?

Please send answers to the questions below to the Bermuda MOH if you wish to be included on the list of certified radiation users:

Conclusion: Radiation Health Basics

1. Introduction
2. What is radiobiology?
3. The structure of DNA
   - The principal target for the biological effects of radiation
4. The sequence of events
5. The effects of radiation on humans
   - Deterministic radiation effects
   - Stochastic radiation effects
6. Regulatory limits of radiation exposure
7. Conclusion