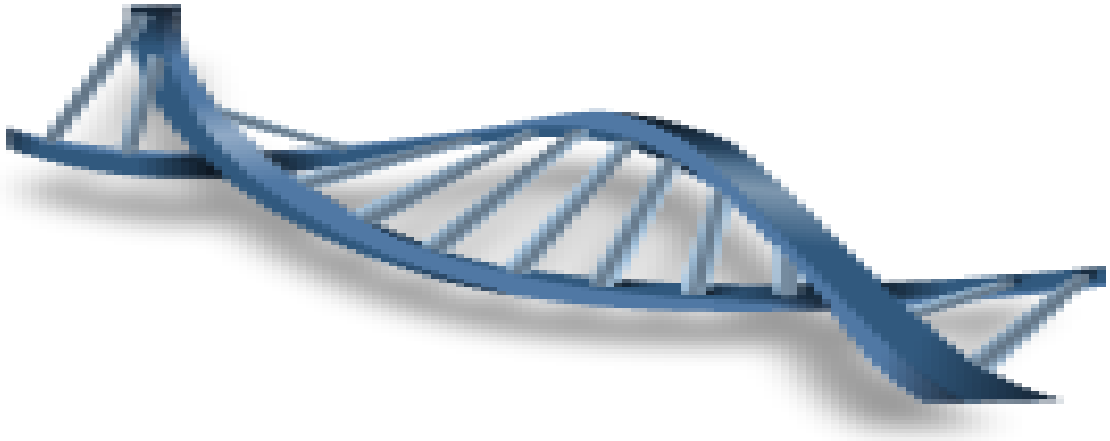
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

HRTD
Human Resources
Training & Development

Chapter 2:
Biological Effects

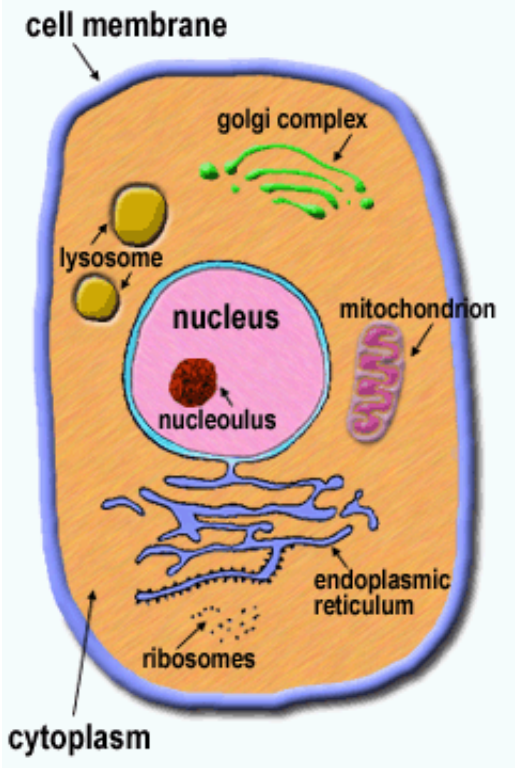


Objectives

- Distinguish between direct and indirect radiation effects.
- Differentiate between stochastic and deterministic effects.
- Discuss high & low dose biological effects.
- Distinguish between the three acute radiation syndromes (ARS).
- Describe the meaning/significance of LD 50/60.
- Describe the LNT concept.
- Discuss the recommended radiation exposure limit for the developing embryo/fetus.

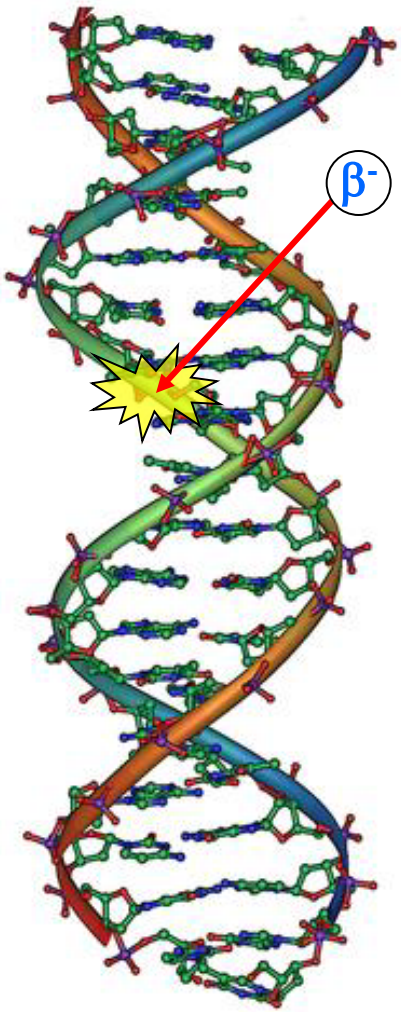
Biology

- Cells are the fundamental working units of every living system. All the instructions needed to direct their activities are contained within the chemical DNA strands.
- DNA from all organisms is made up of the same chemical and physical components. The DNA sequence is the particular side-by-side arrangement of bases along the DNA strand. This order spells out the exact instructions required to create a particular organism with its own unique traits.
- DNA in the human genome is arranged into 23 distinct chromosomes.



Biological Effects of Ionizing Radiation

- Ionizing radiation can disrupt chemical bonds of DNA by breaking the bonds.
- A DIRECT EFFECT would be a disruption or break and can occur directly in the molecular structure, such as the bond between base-pairs.
- This damage could be properly repaired by cellular mechanisms, improperly repaired causing a genetic mutation, or it could result in the death of the cell.



Biological Effects

Direct vs. Indirect Effects:

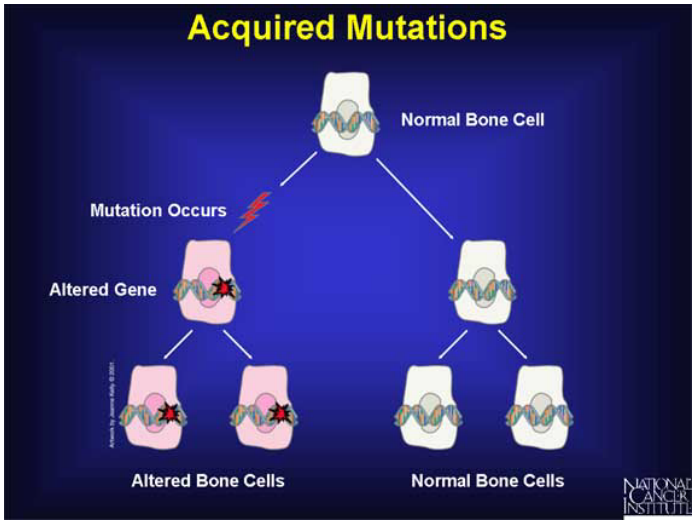
- **Direct - ionizing radiation interacts with DNA, creating immediate damage. The cell could either: die, repair itself, or be altered creating a mutation.**
- **Indirect - ionizing radiation interacts with water molecules within the cell, which produces free radicals and oxidizing agents. These reactive chemical agents can then go on to damage the DNA.**

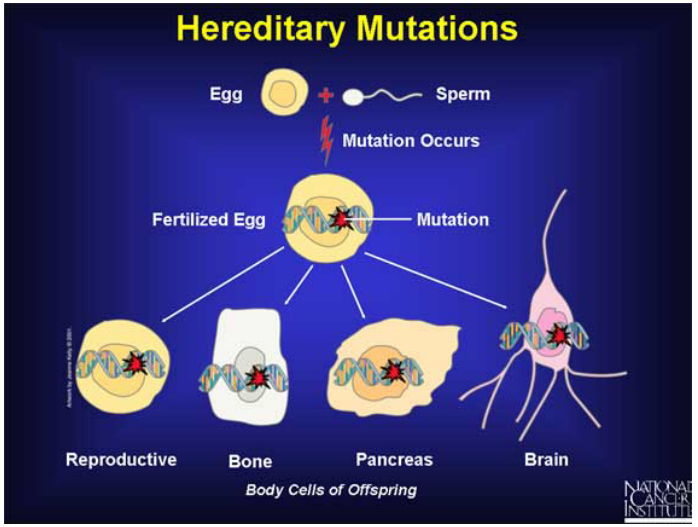
Cell Sensitivity

- Cells that rapidly divide, have a long dividing future, and are less specialized are more sensitive to radiation.
- For this reason, the blood-forming cells in the bone marrow are most sensitive, followed by the cells in the lining of the intestine and the reproductive organs. Muscle and nervous system cells are less sensitive.
- Radiation is used to treat cancer because cancer cells fit this description and are more likely to be sensitive to radiation.
- The developing embryo/fetus also meets this description of sensitivity (more on this later).

Biological Effects of Ionizing Radiation – Genetic Effects

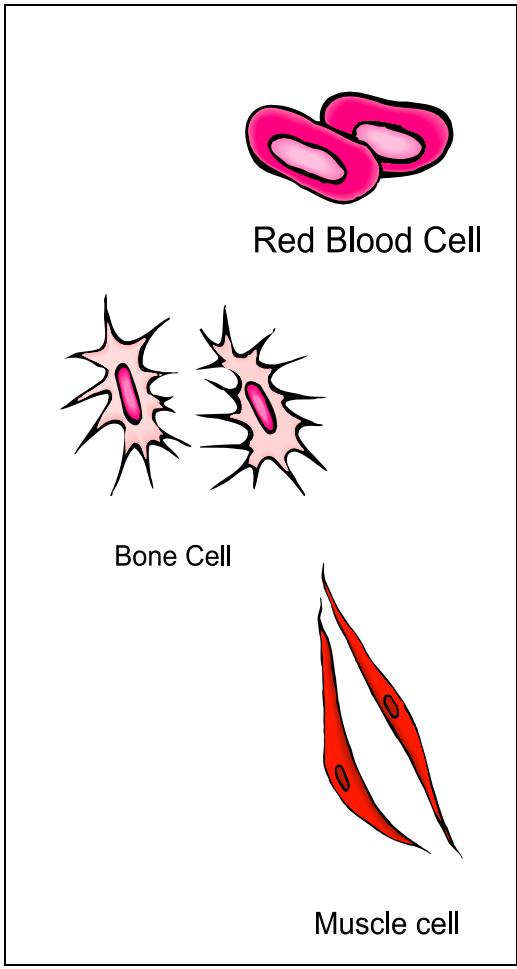
- Mutations caused by ionizing radiation are not unique to radiation.
- Gene mutations can be either inherited from a parent or acquired.
- Acquired mutations are changes in DNA that develop throughout a person's lifetime.
- Genetic effects in humans due to exposure to ionizing radiation have not been observed.





Acute Exposure

- **Exposure of the whole body to a large dose over a short period of time (< 1 hour) may cause effects due to the sensitivity of cells in the body.**
  - **Hematopoietic (or blood) Syndrome – there will be observable decreases in blood cell count at doses of about 100 rad;**
  - **Gastrointestinal (or GI) Syndrome – a dose of about 500 rad will result in nausea, vomiting, and diarrhea; and**
  - **Central Nervous System (CNS) Syndrome – a dose of about 2,000 rad will affect the muscle and brain function of the central nervous system.**



Acute Exposure – LD 50/60

- The dose which is lethal to 50% of the people within 60 days is called the "LD 50/60". The LD 50/60 dose is approximately 400 rad (400 cGy).
- The actual lethal dose varies depending on the health of the individual and whether or not medical intervention is available.

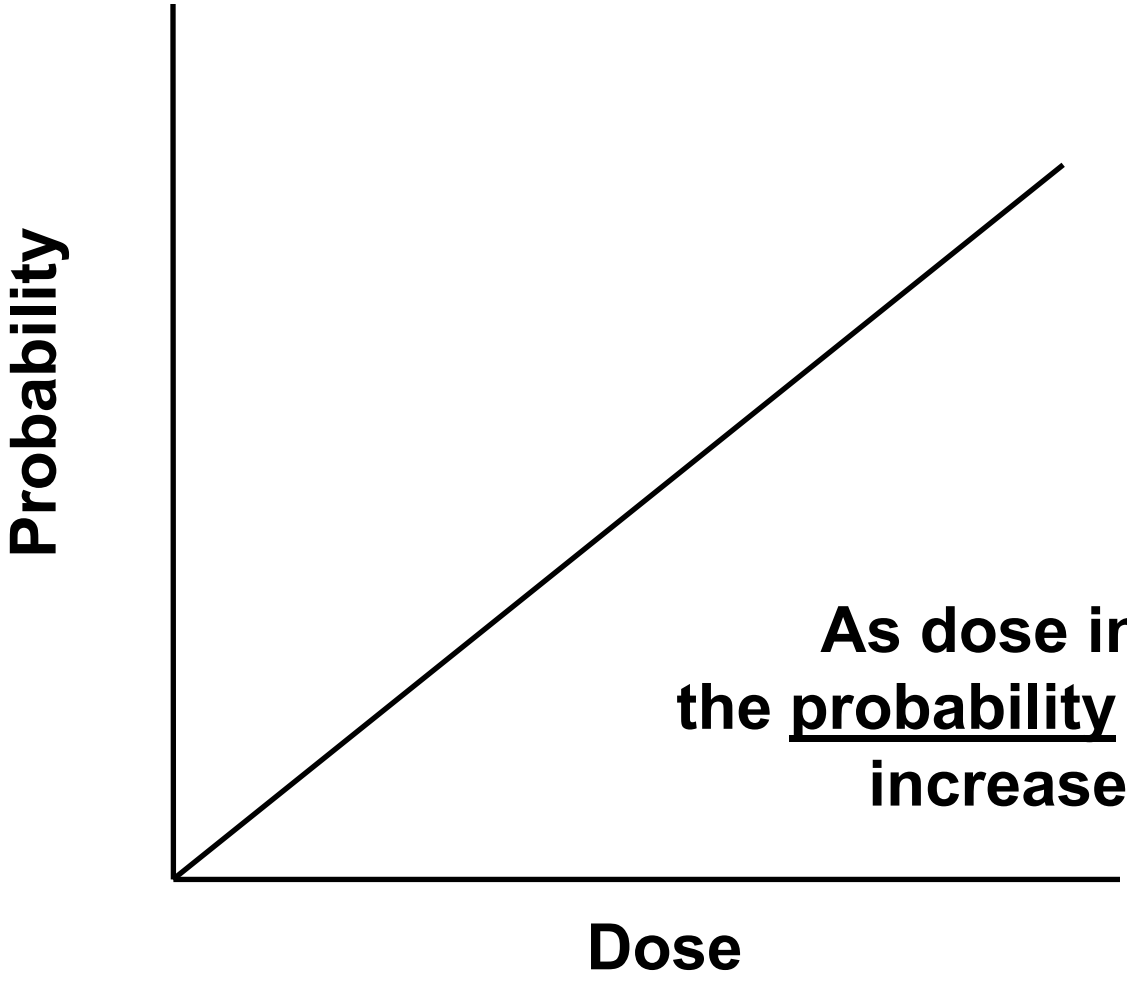


Biological Effects: Stochastic & Deterministic

Two types of effects:

1) Stochastic (random) – health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

Stochastic Dose Response Relationship



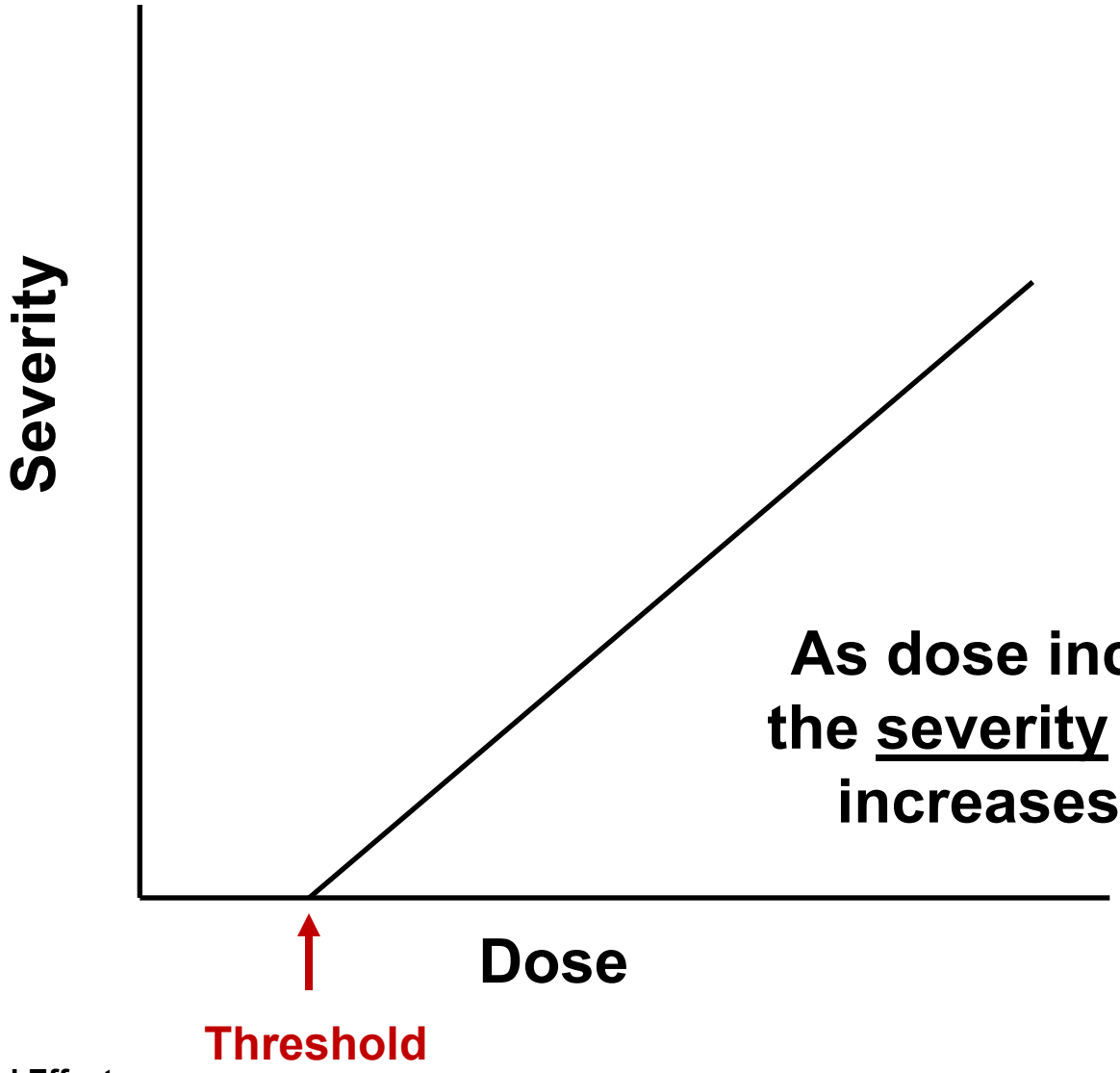
Biological Effects: Stochastic & Deterministic

2) Deterministic (non-stochastic) – health effects, the severity of which varies with the dose and for which a threshold is believed to exist. The severity of these effects (rather than probability) increases with dose.

Examples of these effects are: erythema (skin reddening), cataracts to lens of the eye, sterility (temporary/permanent), & epilation (loss of hair).

The dose required to cause these effects is increased if dose is protracted or fractionated.

Deterministic (Non-Stochastic) Dose Response Relationship



Deterministic Effect Thresholds

Effect:	Threshold (cGy)
Cataracts	200
Erythema	600
Sterility (temporary) Sterility (permanent)	50 400

(1 cGy = 1 Rad)

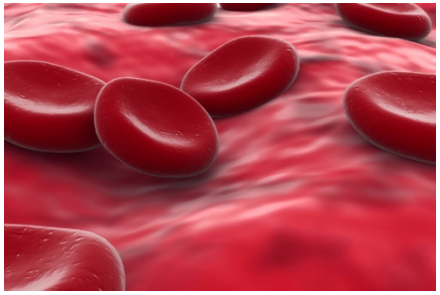
Biological Effects - Cancer

- All cancer is genetic: it's triggered by altered genes. Genes controlling the replication of cells are damaged, allowing the cells to reproduce without restraint. Though all cancer is genetic, only a portion is inherited (familial cancer).
- Cancer usually arises from a single cell mutation.
- Most cancers come from random mutations that develop in body cells during one's lifetime.
- Genetic tests may be able to determine if a particular mutation is present, but finding it is not a guarantee that the disease will develop.

Biological Effects from Chronic Exposures

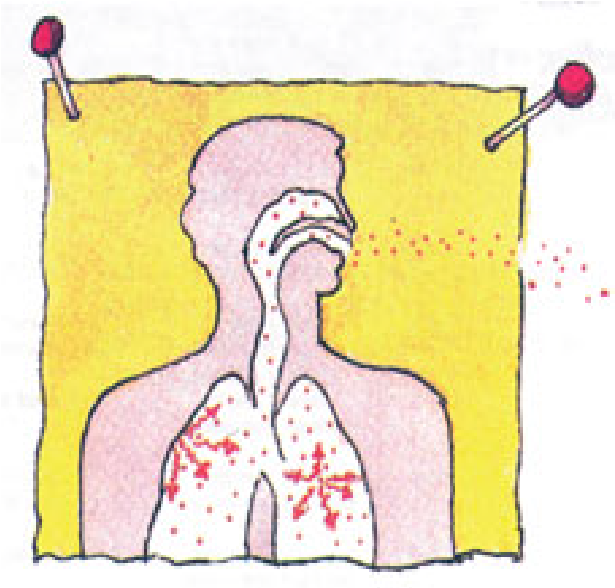
Chronic effects from radiation include:

- **Somatic (cancer) - exposure to radiation increases the risk of cancer; it does not result in new or unique cancers that aren't already observed in the population.**
- **Genetic effects – inherited genetic effects from radiation have not been observed in humans, but it is assumed to contribute an added risk.**



Radiation Risk – Cancer Mortality

- The "baseline" risk of cancer death is ~ 20%. For a population of 10,000 people, approximately 2000 (20% of 10,000) will develop fatal cancers due to the "natural incidence" of cancer.
- Exposure of up to 1 rem may increase the overall risk to 20% + 0.05% = 20.05%



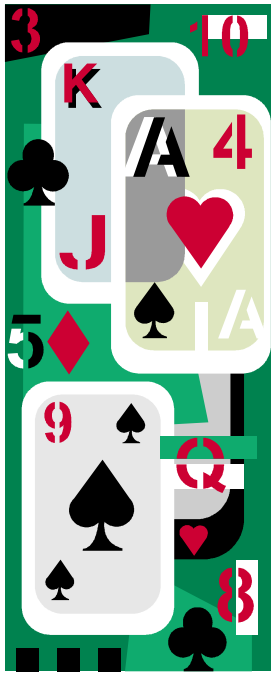
Radiation Risk – Cancer Mortality

- **Collective dose to a population of 10,000 person-rem (1 rem to each person in a population of 10,000) may result in 5 additional cancer fatalities, besides the 2,000 that will occur naturally. That is, there would be 2005 fatal cancers, rather than 2000.**
- **The natural incidence of fatal cancers is not precisely 2,000.**
- **It is not possible to unequivocally distinguish these additional cases from those occurring naturally.**

More information concerning risk from ionizing radiation is available in U.S. NRC Regulatory Guide 8.29, "Instruction Concerning Risks from Occupational Radiation Exposure," Rev. 1, February 1996.

Radiation Risk – Cancer Incidence

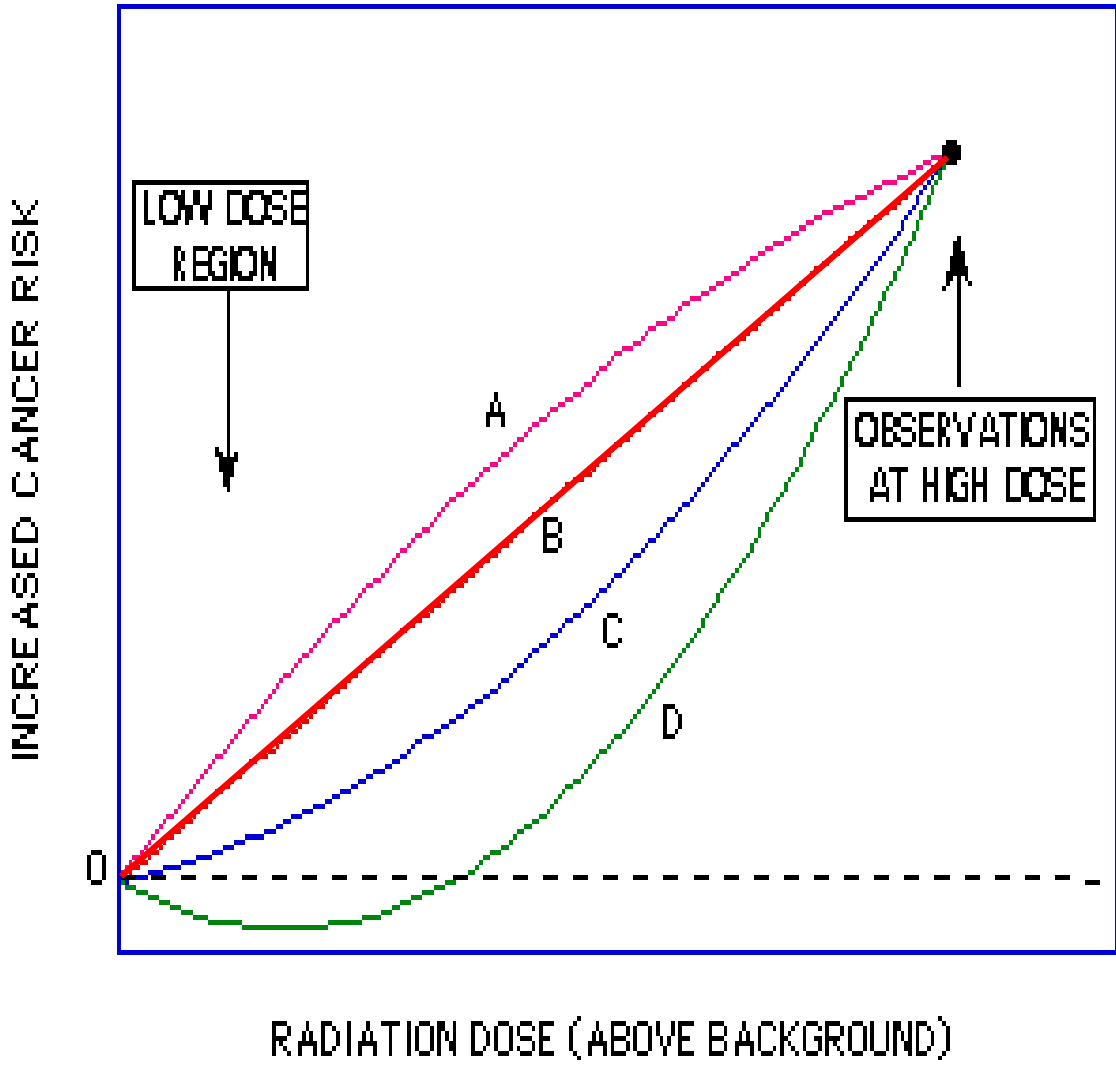
- Collective dose in a lifetime, approximately 42 out of 100 people will be diagnosed with cancer from causes unrelated to radiation. From a previous slide note that about 20% of the population dies from some form of cancer. So of the 42% of the people who develop cancer, half will survive.
- If 100 people received a dose of 0.1 Sv (10 rem), it is estimated that there will be one additional cancer incidence in this group for a total of 43 cancer incidents.



BEIR VII Report, June 2005.

Radiation Risk

The dose response curve is based on information from high doses and extrapolated to lower doses. There are different theories on the shape of the curve. The NRC assumes that the relationship is linear and without a threshold: Linear No Threshold (LNT) - this is represented by line "B" in the diagram.



Biological Effects - Teratogenic

- Cells that rapidly divide and are less specialized are more sensitive to ionizing radiation (e.g., the developing embryo/fetus).
- As a teratogen, radiation is capable of causing malformation of organs during fetal development. This is a deterministic effect, with a conservative threshold estimated to be 0.1 Gy (10 rad). This is not an inherited genetic effect; it is due to exposure after conception; therefore after the transfer of genetic information.
- Severe mental retardation is associated with doses to the brain, particularly between Weeks 8 – 15 of fetal development. A reduction of 30 IQ units per 1 Gy is postulated during this interval.

Reference: "Teratogen Update: Radiation and Chernobyl," Teratology 60:100-106 (1999).

Declared Pregnant Woman (DPW)

- Exposure *in Utero* presents a greater lifetime risk for developing leukemia/other cancers of 2 to 3 times that for an adult. Same risk for dose in first decade of life.
- There is a provision to enable women who are pregnant to limit the dose to the developing embryo/fetus on a voluntary basis. This is called a "declared pregnant woman," or DPW. It is the woman's choice whether she wants to invoke this provision, or not. She may rescind the declaration at any time.
- The dose limit to the embryo/fetus of a DPW is 500 mrem (0.5 rem) during the entire gestation. This is 1/10th the annual adult occupational dose limit. This dose is to be uniformly distributed during the pregnancy; about 50 mrem per month.

(Reference: Reg. Guide 8.36, "Radiation Dose to the Embryo/Fetus," 1992.)

Biological Effects - Summary

Ionizing radiation has biological effects. The biological effects from ionizing radiation are not unique to radiation.

Because ionizing radiation has biological effects, it is important to limit the amount of radiation (dose) received by a person. Dose limits are established to minimize probabilistic effects and to avoid deterministic effects.

Radiation effects may be stochastic, such as causing cancer or genetic effects. The probability of stochastic effects increases with dose. The NRC has adopted the LNT (linear-no-threshold) concept as a means of reducing the chance or risk of stochastic effects.

Biological Effects - Summary

There is no scientific evidence of inherited genetic effects in human resulting from exposure to ionizing radiation.

Deterministic effects have a threshold dose that must be exceeded for the effects to occur. The severity of deterministic effects increases with dose. Examples are: cataracts, erythema, and sterility. Dose limits have been established to avoid the deterministic effects.

Acute radiation syndrome is for whole body exposures in a short time. Effects may include blood changes, nausea, vomiting, diarrhea, and, CNS damage. The LD 50/60 is approximately 400 rad.

Biological Effects - Summary

Average occupational doses are approximately 150 mrem which results in a slight increase in the risk of getting cancer. (Data from NUREG-0713 Rev 30, Year = 2008)

Developing embryo-fetuses are more sensitive to radiation so women can invoke a dose limitation restricting the dose to 500 mrem during the pregnancy (about 50 mrem per month).

The incidence of FATAL cancer is about 20%.

The incidence of ANY type of cancer is about 42%.