Radiation Effects on Humans

Living with Radiation Series

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Radiation Effects on Humans 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 the Basic Radiation Physics and Basic Radiation Biology presentations before this module is taken.

For some this will act as a review, for many this will be new material. There is a lack of such training in professional education. Also, radiation biology, radiation protection and radiation limits have changed as we now learned 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 radiations and how they effect humans, and of its ramifications is mandatory for physicians and others who use x-rays, either directly or indirectly, in their practice.

Summary: Effects on Humans

1. The Effects of Radiation on Humans
2. Relative contribution factors to death
3. Radiation Risks
4. Pregnancy and Medical Radiation
5. Hereditary Effects
6. Radiation Sterility
7. Radiation Carcinogenesis

This course is roughly divided into these seven general sections.

1. The Effects of Radiation on Humans
2. Relative contribution factors to death
3. Radiation Risks
4. Pregnancy and Medical Radiation
5. Hereditary Effects
6. Radiation Sterility
7. Radiation Carcinogenesis

The principles of radiation damage to the human body 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.

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

There is a lack in the knowledge base of the effects of radiation on human body, and how risks are evaluated.

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 radiation 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 effects on humans' 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 first "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. The previous basic radiobiology lecture examined the interactions of radiation on cells and cell components. This presentation will explain how radiation effects the human body and its organs.

What are the effects of radiation on humans? 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.

Relative contribution factors to death

Smoking 10 cigar / day	1 in 200
All natural - aged 40	1 in 850
Flu (all ages)	1 in 5,000
Accidents on the road	1 in 8,000
Radiation dose - 10msv	1 in 10,000

X rays - and gamma rays have been found to be indispensable in diagnostic and therapeutic medicine, and in various aspects of industry and research. It is inevitable, therefore, that people will be exposed to them. The problem is to determine a level of radiation exposure (over the inevitable background) which is acceptable compared to other hazards of everyday life.

A considerable body of knowledge has been accumulated over the years regarding the probability of cancer induced by radiation. This is sufficient to allow us to compare it to other known hazards of everyday life. For example:

1. Smoking 10 cigar / day 1 in 200
2. All natural - aged 40 1 in 850
3. Flu (all ages) 1 in 5,000
4. Accidents on the road 1 in 8,000
5. Radiation dose - 10msv 1 in 10,000

Relative contribution factors to death

Leukaemia	1 in 12,500
Accident at work	1 in 43,000
RW in nuclear industry	1 in 57,000
Being hit by lightning	1 in 10,000,000
Radioactivity release NP	1 in 10,000,000

UK figures (Plaut, 1993)

For example, the following can be associated with the probability of death of one chance in a million:

- ❑ 0.2 mSv - the exposure received from two chest x-rays (cancer)
- ❑ A 10 mile ride on a bicycle (accident)
- ❑ 6 minutes in a canoe (drowning)
- ❑ 300 miles in a car (accident)
- ❑ 1000 miles in a commercial aeroplane (crash)
- ❑ Smoking 1.4 cigarettes (cancer)
- ❑ Drinking 30 12 oz cans of diet soda (saccharin)
- ❑ 20 minutes of life at age 60 (actuarial statistics)

The Effects of Radiation on Humans

- The two effects which may be produced by small amounts of radiation received by people involved in the use of x-rays are genetic changes and cancer induction.
- Genetic change is extremely unlikely, and in fact has never been observed in x-ray personnel.
- The effects of radiation are cumulative.

A great deal is known about the effects of radiation, more than is known about the effects of chemicals such as insecticides, fungicides, etc. The two effects, which may be produced by the small amounts of radiation received by people involved in the use of x-rays, are genetic changes and cancer induction.

Genetic change is extremely unlikely, and in fact, has never been observed in x-ray personnel.

TYPICAL EFFECTIVE DOSES AND BERT VALUES FOR X-RAY STUDIES

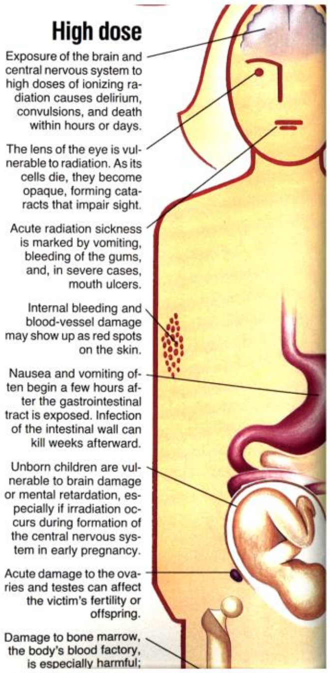
The effectiveness of various types of manmade exposure may be stated in terms of the time necessary to produce an exposure equal to this annual, unavoidable figure. This concept is called the Background Equivalent Radiation Time, or BERT.

X-ray examination	Effective dose (mSv)	BERT (time)
Intraoral dental	0.06	1 week
AP Chest	0.1	12 days
Thoracic spine LAT	1.5	6 months
Lumbar spine	3.0	1 year
Upper GI series	4.5	1.5 years

We have already seen that the average background level of radiation gives an exposure of about 3 mSv/year. The effectiveness of various types of manmade exposure may be stated in terms of the time necessary to produce an exposure equal to this annual, unavoidable figure. This concept is called the Background Equivalent Radiation Time, or BERT, and is easily understood by patients and the general public.

For example, if the effective dose from a single chest x-ray examination is 0.1 mSv. The equivalence to this is about 12 days ($365 \times 0.1/3.0 = 12$) of natural background radiation. An intraoral dental examination, with an effective dose of about 0.06 mSv, is equivalent to about 1 week of background. It is seen that the BERT values for these various medical examinations vary widely. The value of this BERT concept is that tables of this type can be prepared, from which questions by patients can be readily answered. The tables compare the effects of man-made medical procedures with that of the unavoidable natural radiation background.

Radiation's effects on the body

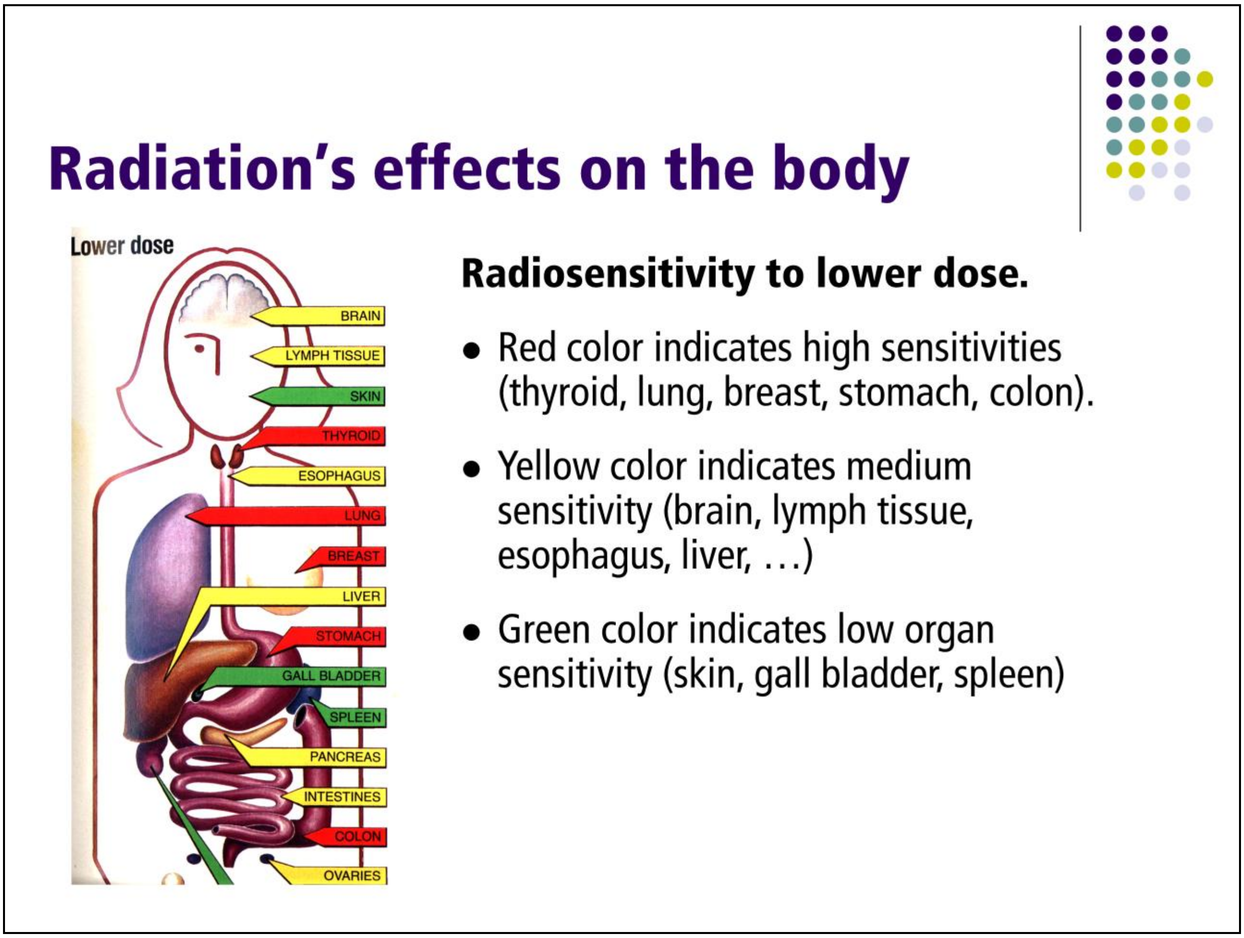


- Radiosensitivity to higher dose.
- Brain and CNS
- Lens of the eye
- Bleeding
- Nausea and vomiting after GI is exposed
- Brain damage or mental retardation in unborn children
- Fertility (ovaries, testes)
- Infections (bone marrow)

Effects of high dose radiation on the body (as explained in National Geographic, April 1998, p 418)

The effects of large amounts of radiation are readily apparent from studies of atomic bomb survivors, uranium miners, and radium watch dial painters. High doses inflict severe damage to organs:

- Exposure of the brain and CNS (Central Nervous System) to high doses of radiation causes delirium, convulsions, and death within hours or days.
- The lens of the eye becomes opaque and cataracts are formed.
- Vomiting, bleeding, mouth ulcer.
- Red spots on the skin indicate internal bleeding and blood vessel damage.
- Nausea, vomiting, infections occur after the GI (Gastro Intestinal) organs are exposed.
- Brain damage and mental retardation is caused by high radiation doses to unborn children.
- Body ability to fight infections and hemorrhaging is decreased when bone marrow is exposed.
- In this presentation we will not consider the radiation effects of such a high doses.



Effects of low dose radiation on the body (as explained in National Geographic, April 1998, p 419)

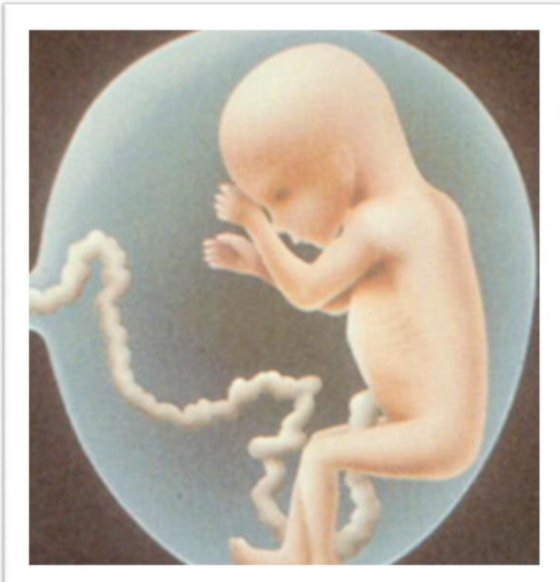
The small amounts that are normally encountered are very difficult to observe.

Red color indicates high sensitivities (thyroid, lung, breast, stomach, colon).

Yellow color indicates medium sensitivity (brain, lymph tissue, esophagus, liver, …)

Green color indicates low organ sensitivity (skin, gall bladder, spleen)

Pregnancy and Medical Radiation



Information abstracted from:

ICRP Publication 84 and 84/466/EURATOM Publication MED97; The revised Medical Exposure Directive

The potential benefit of examination or treatment involving ionizing radiation will, in most cases, be for the mother, and only indirectly for the unborn child, whereas it will incur a risk. This is contradictory to the normal situation where one person, namely the patient, incurs the risk but also derives the benefit of the examination or treatment. It is the aim of this presentation to give some guidance to users of radiation on the instructions and treatments needed for pregnant and breast-feeding women who can be considered as a particular subgroup of patients.

As we presented in previous sessions, radiation can cause the material through which it is passing to become charged (ionized), resulting in damage of cells or DNA in living matter.

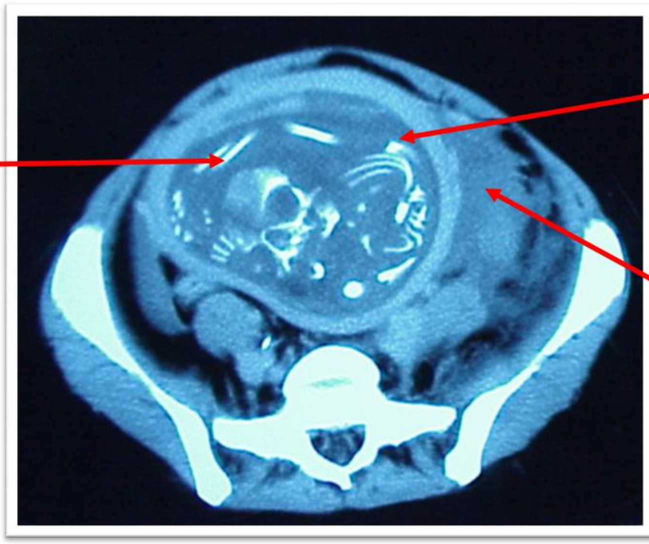
The protection of offspring of pregnant and breast-feeding patients needs particular consideration for several reasons. The unborn child and small children are particularly vulnerable to ionizing radiation. As well as other risks, there is a risk of malformation and mental retardation for the unborn child. For both the unborn child and small children there is a risk of radiation induced cancer, which may be three times as high as for the average population (ICR91).

Radiation Effects on the Embryo & Fetus

- Growth retardation
- Congenital malformations
- Embryonic, fetal, or neonatal death

The protection of offspring of pregnant and breast-feeding patients needs particular consideration for several reasons. The unborn child and small children are particularly vulnerable to ionizing radiation. As well as other risks, there is a risk of malformation and mental retardation for the unborn child and for both the unborn child and small children there is a risk of radiation induced cancer, which may be three times as high as for the average population (ICR91). As the radiological protection of an unborn child (from conception to birth) is required by the EU, and as their protection is of particular concern. Some recommendations are made to: (1) assist in implementing the safety by means of laws, regulations and administrative provisions. (2) to give guidance to physicians for procedures involving ionizing radiation, (3) to help practitioners responsible for the procedures and to staff performing the procedures, (4) to enable these professionals to give advice to pregnant patients on radiological protection matters.

Example: the justified use of a CT Pregnant female, who was in a motor vehicle accident



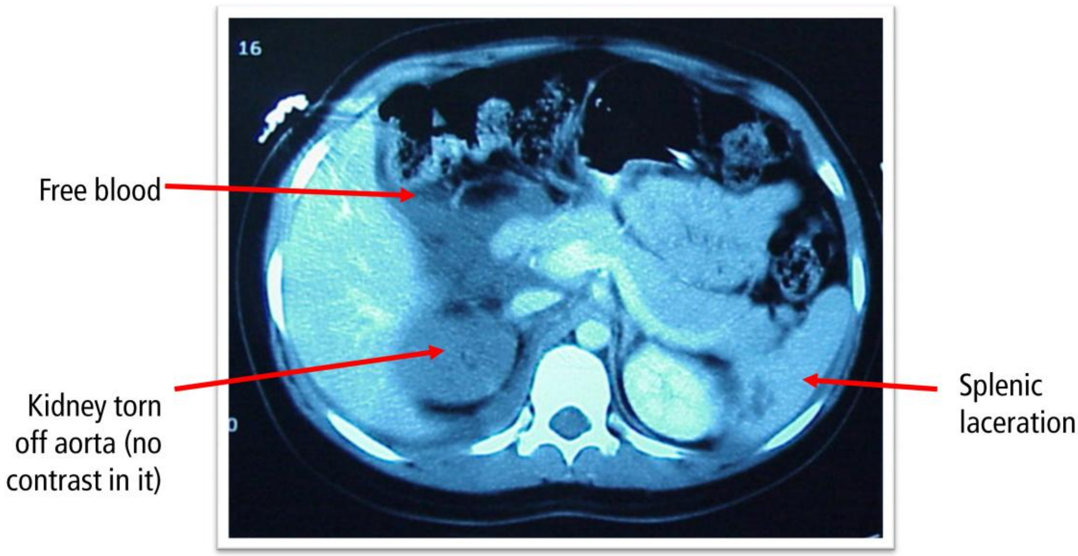
Fetal dose 20 mGy

In the period from the 3rd to the 8th week there is a potential for malformation of organs. The risk of malformation will depend on the period of organogenesis at the time of irradiation, and is probably especially high during the most active phase of cell multiplication and differentiation of the structures being developed. As dose thresholds may apply to these effects, they appear to be deterministic in nature. Thresholds have been observed in animal experiments and on this basis the **threshold in man has been estimated to be of the order of 100 mSv.**

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. In this example the pregnant women was involved in a motor vehicle accident. CT test provided useful information that saved the life of the mother and the child.

3 minute CT exam and taken to the operating room. She and the child survived



Diagnostic x-rays are sometimes needed during pregnancy to provide a doctor with important information about a woman's medical condition.

Fetuses can be unintentionally exposed to x-rays when a woman does not know she is pregnant, or does not inform the doctor or technician of her pregnancy before an x-ray. Whether planned or unintentional, exposure of an unborn child to x-rays can can cause anxiety to the mother, which may be more harmful than the x-rays themselves. Therefore, it is important to understand the issues around x-rays during pregnancy. For most patients, radiation exposure is medically appropriate and the radiation risk to the unborn child is minimal. Like many medical tests, x-rays have risks as well as benefits. Your doctor is trained to determine whether the benefits of an x-ray outweigh the risks to you or your unborn child. The risk of not having a needed x-ray can be much greater than the risk from any exposure to the radiation.

Cell Killing in Radiology

- **Conventional radiology**

  Doses too small to cause significant cell killing
  (~ 100 mGy or ~ 10 cGy)

- **Interventional radiology / fluoroscopy**

  Doses sufficient to cause erythema and occasionally necrosis
  (>1000 mGy)

Doses in conventional radiology are too small to cause significant cell killing (~ 100 mGy or ~ 10 cGy - about 10 centi grays). Plain film radiographic examinations result in small doses to the patient, doses to small to cause significant cell killing.

Doses in Interventional radiology/fluoroscopy are sufficient to cause erythema and occasionally necrosis (>1000 mGy – greater than 1000 milli grays). Interventional radiology involves continuous exposures to the patient, the duration of which is at the choice of the operator. This can result in exposures sufficient to cause erythema and occasional necroses.

Therefore, any radiological examination should be only undertaken to gain information that cannot be obtained in any other way.

Radiation risk to unborn child

- There are radiation-related **risks** throughout pregnancy that are **related to the stage of pregnancy and absorbed dose**
- Radiation risks are most significant during the early organogenesis period, somewhat less in the 2nd trimester, and least in the 3rd trimester

Most risk   Less   Least

Unborn children are more susceptible than adults to the damaging effects of x-rays, partly because their cells are rapidly dividing and growing into specialized cells and tissues. The type of effect on the unborn child depends on the period of the pregnancy when the irradiation is applied. Tissues with developing cells are relatively more radiosensitive. If x-rays cause changes in these cells, there is a slightly increased chance of birth defects or certain illnesses, such as leukemia, later in life. However, most birth defects and childhood diseases are not attributed to exposure to any known harmful agent during pregnancy.

The development of the unborn child may be divided approximately into three major phases:

1. the pre-implantation phase, lasting from conception to implantation. Taking into consideration the frequency of embryonic death, and the low probability that the radiation will affect the live-born, this early period of pregnancy is generally regarded as a period with relatively low radiation risks.
2. the phase of major organogenesis, which extends to approximately the 8th week post-ovulatory (First trimester)
3. the phase of unborn child development, lasting from about 9 weeks until birth, which includes the phase of major formation of the central nervous system from the 8th to 15th (25th) week (UNS93)

Approximate fetal doses from conventional x-ray examinations

Data from the UK, 1998		
Examination / Dose	Mean (mGy)	Maximum (mGy)
Abdomen	**1.4**	**4.2**
Chest	**<0.01**	**<0.01**
Intravenous uro-gram; lumbar spine	**1.7**	**10**
Pelvis	**1.1**	**4**
Skull; thoracic spine	**<0.01**	**<0.01**

The table shows the standard amount of radiation to a fetus from common diagnostic x-rays. An x-ray of the mother's lower body (abdomen, lower back, pelvis, kidneys) may direct radiation near, or through, the fetus. Generally these types of x-rays only involve small amounts of radiation. The amount is given in a unit called a "milligray" or mGy. However, the actual amount of radiation may vary.

The Effects of Diagnostic X-rays Radiation is not directed towards the fetus during an x-ray of the mother's upper body (chest, teeth, neck and limbs). Generally these types of x-rays only involve small amounts of radiation. If an x-ray cannot be delayed until after pregnancy, special techniques are used to minimize the radiation exposure on the fetus. The x-ray beam can be narrowed to expose only a small area, and in fluoroscopy the exposure time can be minimized as well. To understand these figures, you must compare them to the amount of natural background radiation you get every day from the ground, building materials, air, food, even from space (cosmic rays). In the diagnostic field the dose to the unborn child will only in some cases reach level of 0.5 mGy (0.5 milli grays). Hence, **malformation of organs is very unlikely to be caused by diagnostic exposure of the mother** from conventional x-rays.

Approximate fetal doses from fluoroscopic and computed tomography procedures

Dose Data from the UK, 1998		
Examination	Mean (mGy)	Maximum (mGy)
Barium meal (UGI)	**1.1**	**5.8**
Barium enema	**6.8**	**24**
Head CT	**<0.005**	**<0.005**
Chest CT	**0.06**	**1.0**
Abdomen CT	**8.0**	**49**
Pelvis CT	**25.0**	**80**

Higher amounts of radiation are from the abdominal or pelvic CT (computerized tomography) and fluoroscopy. If an x-ray cannot be delayed until after pregnancy, special techniques are used to minimize the radiation exposure on the fetus. The x-ray beam can be narrowed to expose only a small area, and in fluoroscopy the exposure time can be minimized as well.

You must compare above doses to the amount of natural background radiation you get every day from the ground, building materials, air, food, even from space (cosmic rays). In Canada, a fetus encounters about 0.5 mGy during pregnancy. Natural background radiation increases when you fly because cosmic radiation levels are higher than those at ground level. (For example, a round- trip flight between Toronto and Vancouver might expose the fetus to 0.05 mGy).

The risks are higher during the first three months of pregnancy (first trimester). It is important to note that most of these effects do not usually occur below 100 mGy – more radiation than three pelvic CT scans or 20 abdominal x-rays.

For comparison purposes the spontaneous non radiation induced incidence of such effects in live-born can be taken as a few per cent (ICRP 92). Congenital anomalies visible at birth are observed with as many as 5 - 6 per cent of all newborn children (UNS86). This levels **can be reached in interventional fluoroscopy and in radiation therapy.**

Approximate whole body fetal dose (mGy) from common radioisotope procedures

Procedure	Activity (MBq)	Early pregnancy	9 months
Tc-99^{m}			
Bone scan	**750**	**4.7**	**1.8**
Lung scan	**240**	**0.9**	**0.9**
Liver colloid scan	**300**	**0.6**	**1.1**
Thyroid scan	**400**	**4.4**	**3.7**
Renal DTPA	**300**	**9.0**	**3.5**
Red blood cell	**930**	**6.0**	**2.5**
I-123 thyroid uptake	**30**	**0.6**	**0.3**
I-131 thyroid uptake	**0.55**	**0.04**	**0.15**

Examples for radioisotope procedures are given in Table together with an indication of the doses to the unborn child.

A new-born child may be exposed to ionizing radiation if the mother has undergone a nuclear medicine examination or treatment. This is due to the fact that the radionuclide administered to the mother will remain in her body for a certain time depending on the type of radionuclide and on biological factors. If the radionuclide at the same time emits penetrating radiation, the new-born child will be exposed to the external radiation from the mother when close to her, i.e. during feeding or cuddling. The dose will depend on the time the child is held, the distance from the mother's body etc. Patients with radioactive substances in their body may present a contamination problem in that they excrete radioactivity, via perspiration, saliva, breath and urine, which can be inhaled or ingested by a new-born child. Great care and attention to hygiene will in general mean that the dose to the child will be small.

Growth Retardation at Hiroshima by *In Utero* Irradiation

- 80% of 1,613 children exposed *in utero* followed to age 17 years.
- Those exposed within 1500 m (*average kerma 25 mGy* BEIR III report) of the hypocenter compared with those more than 3000 m:
  - 2.25cm – shorter
  - 3.0kg – lighter
  - 1.1cm – smaller head diameter

The type of effect on the unborn child depends on the period of the pregnancy when the irradiation is applied. Tissues with developing cells are relatively more radiosensitive. If x-rays cause changes in these cells, there is a slightly increased chance of birth defects or certain illnesses, such as leukemia, later in life. Most birth defects and childhood diseases are not attributed to x-ray exposure during pregnancy.

Example: Growth Retardation found at Hiroshima following In Utero Irradiation. 80% of 1,613 children studied were exposed in utero and were followed up to age of 17 years. Those exposed within 1500 m (average dose 25 mGy BEIR III report) of the hypocenter compared with those more than 3000 m were smaller, shorter and with smaller heads:

2.25	cm	–	shorter
3.0	kg	–	lighter
1.1	cm	–	smaller head diameter

Termination of pregnancy…

- High fetal doses (100-1000 mGy) during late pregnancy are not likely to result in malformations or birth defects since all the organs have been formed
- A fetal dose of 100 mGy has a small individual risk of radiation-induced cancer. There is over a 99% chance that the exposed fetus will **NOT** develop childhood cancer or leukaemia
- Termination of pregnancy at fetal doses of less than 100 mGy is **NOT** justified based upon radiation risk
- Fetal doses in excess of 500 mGy can cause significant fetal damage; the magnitude and type is a function of dose and stage of pregnancy
- For fetal doses between 100 and 500 mGy, decisions should be based upon individual circumstances

The dose and the time of pregnancy when the exposure occurred should be taken into account when discussing possible actions with the patient. The risk of everyday life compared with the risk due to the exposure should be discussed with the mother to be.

It must be emphasized that abortion is a very drastic decision that should not be taken without very serious reasons.

Below 100 mSv (BIR73), abortion on the ground of radiation alone should not be considered. Above 100 mSv individual circumstances should be taken into account. However, even a dose to the unborn child as high as several hundreds of milligray may not in all circumstances lead to advice for abortion.

With doses normally involved in diagnostic examinations there will therefore be no need for abortion, with therapy procedures it may be considered.

Termination of pregnancy at fetal doses of less than 100 mGy is NOT justified based upon radiation risk

Fetal doses in excess of 500 mGy can cause significant fetal damage; the magnitude and type is a function of dose and stage of pregnancy

For fetal doses between 100 and 500 mGy, decisions should be based upon individual circumstances

Hereditary Effects

- Adverse health effects in descendants due to mutations induced in germ cells.

Values of intelligence quotient (IQ) lower than expected have been reported in some children exposed at Hiroshima and Nagasaki. The data are consistent with a general downward shift in the distribution of IQ with increasing dose. It is assumed that this shift is proportional to dose. **A figure of about 30 IQ points per Sievert** relates to the dose to the unborn child in the period from 8 to 15 weeks after conception. On this basis, the change in the IQ of an individual that can be caused by a dose as large as 100 mSv will be no more than three IQ points. Small shifts in IQ cannot be identified clinically. The effects on IQ are less marked following exposure in the period from 16 to 25 weeks after conception and have not been observed for other periods. All observations on IQ relate to high doses and high dose rates. (ICR96). A second finding is the dose-related increase in the frequency of children classified as "severely retarded". The number is small, but the data indicate an **excess probability of severe mental retardation of 0.4 at 1 Sievert**. The effect observed following exposures in the 8th to 15th week after conception, is less marked than effects following exposures in the period from the 16th to 25th week and has not been observed for other periods.

Hereditary Effects of Radiation

- Radiation *does not* produce *new unique mutations*, but increases the incidence of the *same mutations* that occur *spontaneously*.
- Information on the genetic effects of radiation comes almost *entirely* from animal experiments.

Damage to fetal cells may result in mental impairment or in some other problem as in miscarriage, birth defects, depending on the amount of radiation and the stage of pregnancy.

Radiation does not produce new unique mutations, but increases the incidence of the same mutations that occur spontaneously.

Information on the genetic effects of radiation comes almost entirely from animal experiments.

Hereditary Effects of Radiation

- The **doubling dose** is the dose required to double the spontaneous mutation incidence; i.e., The dose required to produce an incidence of mutations equal to the spontaneous rate.
- BEIR III estimate: 0.5 to 2.5 Gy (i.e. 50 to 250 rem).
- UNSCEAR (1986) estimate: 1 Gy (i.e. 100 rad).

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.

Hereditary Effects - ICRP

Basis: doubling dose approx. 1 Sv

(1000 mSv)

Risk: probability/caput of severe hereditary disorder in a working population

0.6 x 10-2/sv

Basis: doubling dose according to ICRP for hereditary effects is approx. 1 Sv (1000 mSv)

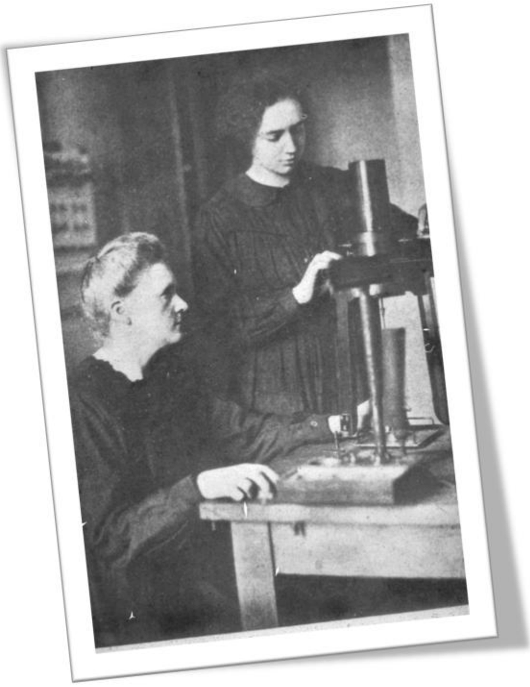
Risk: probability/caput of severe hereditary disorder in a working population is 0.6×10^{-2}/Sv (0.6 %)

Radiation Carcinogenesis

Most studies show no increase in childhood cancer from small amounts of radiation. However, one study identifies the chance of a childhood cancer from abdominal x-rays (in the 10 mGy range) at about one in 1,000 births. In comparison, the chance of a childhood cancer in the general population is about two to three in 1,000 births. The risk of induction of cancers either in childhood or in adult life following irradiation throughout pregnancy is considered to be the same as for children up to the age of 10, i.e. it may be a factor of two to three times higher than that for the average population.

The probability of a fatal radiation induced serious genetic diseases 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. 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.

Radiation Carcinogenesis - Examples



Marie Curie and her daughter Irene are thought to have died of Leukemia

The effects of large amounts of radiation are readily apparent. But those from the small amounts that are normally encountered are very difficult to observe. Furthermore, they may only appear after a latent period of many years. Since we cannot perform experiments on human beings that will clarify this situation, we have to work downward from the effects of large amounts in order to decide on safe limits.

We do know that the effects of radiation are cumulative: That is, the more radiation that an individual is exposed to over a period of time, the more likely the effects are to appear.

In the early days of radiology, when little was known about radiation, and when x-ray equipment was very primitive, some cancers in radiologists were found to be due to their exposure to radiation. It is the results of these "after-the-fact" calculations of the radiation exposures received by these individuals (and by people exposed to radiation from the atomic bombs detonated at Hiroshima and Nagasaki) that form the basis of our present-day regulatory limits of occupational exposure.

Basis for calculating cancer risk using LNT

single particle of radiation → single DNA molecule → cancer initiation

probability of cancer initiation ∝ number of hits ∝ number of particles ∝ the dose

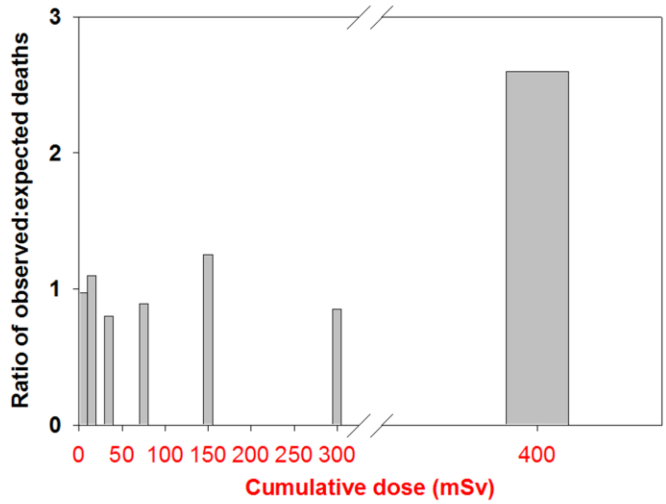
Cancer risk is therefore linearly dependent on dose with no mention of a threshold

Thus the cancer risk from *0.001* Sv is *0.001* the risk from 1 Sv

Cancer Mortality among Nuclear Industry Workers

(all leukaemias except chronic lymphocytic leukaemias)

Ratio of observed death to excepted deaths vs. cumulative dose (mSv)



Risk and Weighting Factors for Tissues at risk for Stochastic Effects (1 Sv = 1000 mSv).

Tissue	Risk	Comments	Weighting
Gonads	***4×10^{-3}***	Genetic risk,first two generations	0.25
Breast	***2×10^{-3}***	Average for all ages and sexes	0.15
Bone Marrow	***$2x\ 10^{-3}$***	Leukemia	0.12
Lung	***2×10^{-3}***	Cancer	0.12
Thyroid	***5×10^{-4}***	Cancer	0.03
Bone Surfave	***5×10^{-4}***	Osteosacorma	0.03
Remainder	***5×10^{-4}***	Caner	0.30
Total	***$2x\ 10^{-2}$***		

Risk and Weighting Factors for Tissues at risk for Stochastic Effects (1 Sv = 1000 mSv).

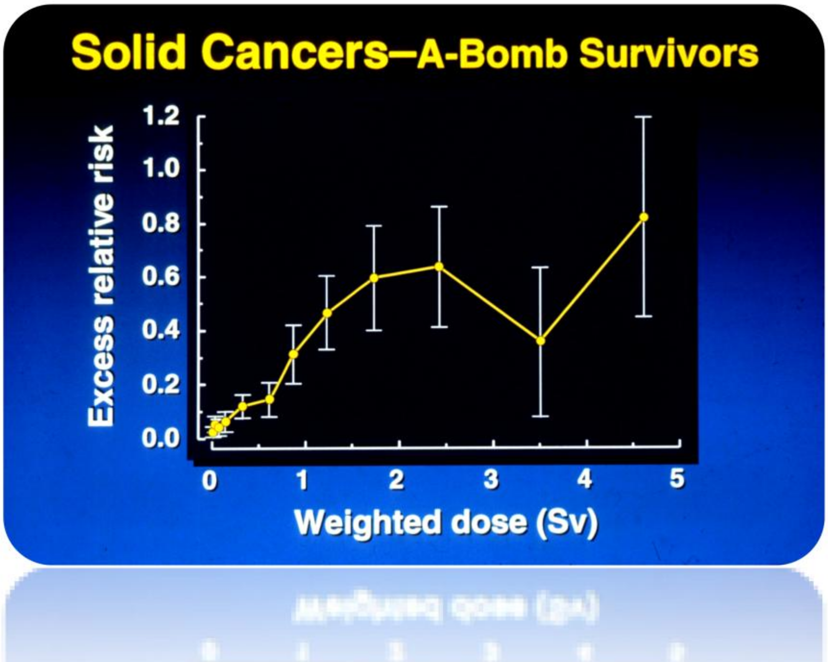
Radiation Carcinogenesis in Humans

Leukemia & Solid Tumors	**Japanese survivors.**
Leukemia	**Patients irradiated for alkylosing spondylitis.**
Thyroid	**Children irradiated for enlarged thymus** **Children epilated for *tinea capitis.***
Breast	**Patients treated with x-rays for postpartum mastitis.** **Fluoroscopy during management of tuberculosis.**
Lung	**Uranium miners.**
Bone	**Dial painters who ingested radium.** **Injections of radium for tuberculosis or ankylosing spondylitis.**

Radiation Carcinogenesis in Humans

Dependence of a risk of getting cancer as relates to work with radioactiva material and x-rays.

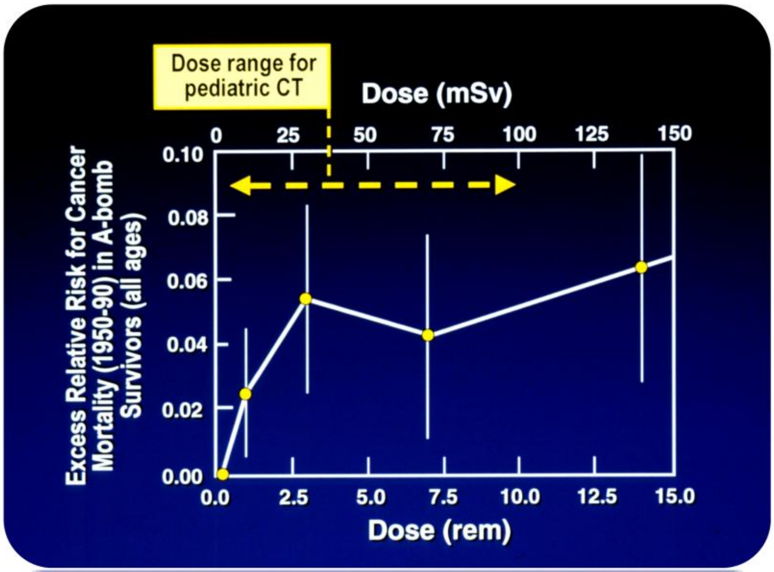
Radiation Carcinogenesis in Humans



The significantly different A-bomb survivor data (much higher risk at all doses) can be explained by the difference between a very high dose rate in the A-bomb survivors and the lower dose rate from fluoroscopic exams extending over many weeks.

It must give pause for thought before using A-bomb survivor data to predict risks from LLR, which is the method normally used.

Radiation Carcinogenesis in Humans



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.

Total Excess Fatal Cancer (ICRP) %/Sv

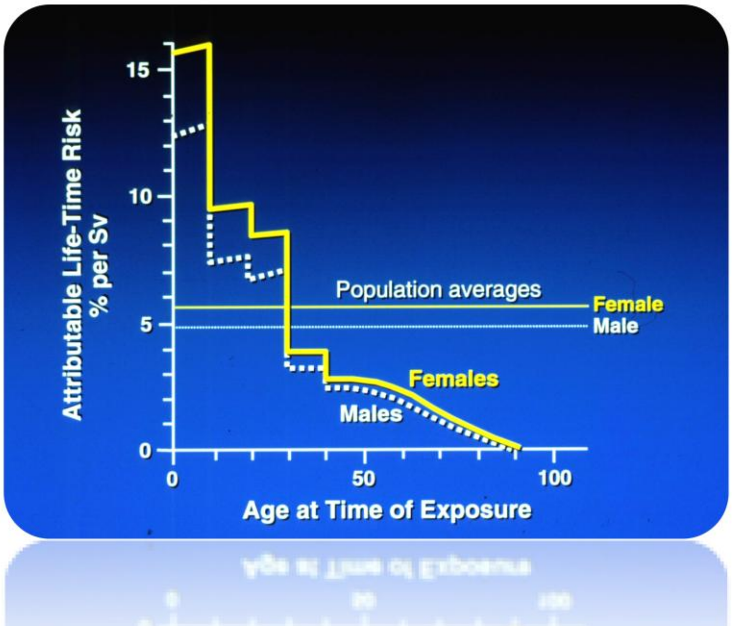
	High dose high d/r	low dose low d/r
General population:	10%	5%
Working population:	8%	4%

Total Excess Fatal Cancer (ICRP) %/Sv

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. Also curable cancers can be induced depending on the organ.

For pregnant women the risk is the same as for the average population (ICRP91).

Radiation Carcinogenesis in Humans



Radiation Carcinogenesis in Humans

This graph shows life time risks as a function of the age at radiation exposure. The risk is higher for children (15 %/Sv received, and 12 %/Sv for female- yellow line- and male- doted line children respectively), and decreases with age. 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.

Risk of cancer due various factors

1.	Poor diet	35%
2.	Tobacco	30%
3.	Infections inc. Aids	10%
4.	Sexual practice	7%
5.	Occupation	4%
6.	Geophysical eg sun	3%
7.	Alcohol	3%
8.	Pollution	2%
9.	Food additives	< 1%

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From Plaut (1993)

Childhood Cancer from Fetal X-Rays

- Low dose irradiation of the fetus in utero, particularly in last trimester, causes an increased risk of childhood cancer.
- 40% increase in risk from an obstetric x-ray examination.
- Radiation doses of ~10 mGy increases the risk.
- Excess absolute risk is about 6% per Gy.

- Doll & Wakeford 1997

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Cataractogenesis

- A cataract is an opacity in the normally transparent lens of the eye.
- An acute x-ray dose of 2 Gy will produce a cataract: bigger doses are needed in a protracted exposure to get the same effect.
- A radiation-induced cataract is a deterministic effect – i.E., There is a dose threshold and the severity increases with dose.

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Conclusion: Radiation Effects on Humans

1. The Effects of Radiation on Humans
2. Relative contribution factors to death
3. Radiation Risks
4. Pregnancy and Medical Radiation
5. Hereditary Effects
6. Radiation Sterility
7. Radiation Carcinogenesis

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Radiation effects on Humans Closing QUIZ

- ✓ Why do we use x-rays to examine internal structure and functioning of the body?
- ✓ What are x-rays, anyway, and how do thy work to damage organs of the body?
- ✓ Which use poses the greatest radiation risk to the operator or patient?

Radiation effects on Humans Closing QUIZ:

1. Which poses the greatest radiation risk to the patient (Radiography, Fluoroscopy, CT, Mammography)?
2. Which poses the greatest radiation risk to the operator (Radiograph, Fluoroscopy, CT, Mammography)?
3. In what unit do we express the physical effect of radiation?
4. In what unit do we express the biological effect of radiation?
5. For medical x-rays, how are these two units related?
6. List three contributors to background radiation?
7. What is a BERT value? Why is it useful to you?
8. What is the difference between acceptance testing and quality control in medical radiology?