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HEALTH EFFECTS OF IONIZING RADIATION

P89-27E

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Canadian Centre for Occupational Health and Safety

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1. INTRODUCTION

The possible dangers of ionizing radiation concern employees whose workplaces use or produce radioactive materials, x-ray machines or certain types of high-voltage devices. Media reports about the devastating effects of nuclear war and nuclear reactor accidents constantly remind people of these dangers. In this climate of anxiety and fear, it is especially important that employees and employers are aware of the basic facts about the health risk of ionizing radiation.

Ionizing radiation can cause adverse health effects in exposed people (somatic effects), or in their children, grandchildren and subsequent generations (genetic or hereditary effects). Exposed people are at greater risk of cancer, which may appear several years after exposure. Exposure of reproductive organs increases the risk of genetic effects.

All doses of ionizing radiation, no matter how small, pose some risk. As a result, we can only minimize, not eliminate radiation effects. Most radiation protection regulations recognize this fact and recommend that radiation doses be kept as low as reasonably achievable (ALARA) below the allowed exposure limit.

This publication provides basic information on the possible health hazards of ionizing radiation. A glossary of technical terms is included at the end of the text. For more detailed information on methods of reducing worker exposure, or about dose limit regulations, contact your health and safety committee, the Atomic Energy Control Board (AECB), the Canadian Centre for Occupational Health and Safety (CCOHS) or the provincial agency responsible for x-ray safety in your jurisdiction.

2. WHAT IS IONIZING RADIATION?

Radiation is energy in transit. It travels through space either as a wave or as a stream of particles. Radiation from x-ray machines and the emissions from radioactive substances produce electrically charged matter or "ions" when they interact with the human body or other materials. This process of producing ions is known as ionization and the radiation which produces ions is called ionizing radiation.

Heat, light, radio and television broadcast signals and emissions from micro-wave ovens are also called radiation. But they do not, under most conditions, produce ions when they interact with the body or another material. These types of radiation are called nonionizing radiation.

3. WHAT ARE THE SOURCES AND TYPES OF IONIZING RADIATION?

Ionizing radiation is present everywhere as part of the natural environment. It comes to us continuously from the sun and outer space and from naturally occurring radioactive elements in the earth.

Man-made sources of ionizing radiation include x-ray machines; radioactive materials used in medicine, industry, and research; emissions from nuclear power plants; and equipments using high voltage electron and atomic particle beams.

The main sources of radiation exposure are x rays, gamma rays, alpha particles, beta particles and neutrons.

X Rays

X rays are electromagnetic waves just like visible light, but more energetic. They come from x-ray machines, particle accelerators and other equipment that produce high-voltage electron beams. All these devices produce x rays when high speed electrons strike a metal target. X rays penetrate deeply into the human body. This makes them useful in diagnostic procedures of inner body parts. Hospital x-ray machines produce low-energy x rays which cannot penetrate a few-millimeters thick lead sheet or a few-centimeters thick concrete wall. Particle accelerators produce high energy x rays and require thick lead or concrete shielding.

Gamma Rays

Gamma rays are also electromagnetic waves that come from many (but not all) radioactive substances. Gamma rays are highly penetrating and can pass through the human body. Thick barriers of lead and concrete reduce the gamma-ray intensity.

Alpha Particles

Alpha particles are electrically charged helium atoms that move at a very fast speed (several kilometers per second). Radioactive isotopes of heavy elements such as uranium, thorium, polonium, and americium emit alpha particles. Because of their relatively large size and electrical charge, alpha particles have very little penetrating power. The first layer of the skin or a sheet of paper stops alpha particles.

Beta Particles

Beta particles are extremely tiny electrically charged particles also known as electrons. An electron is about seven thousand times lighter than an alpha particle. They can move at speeds very close to the speed of light. Beta particles can penetrate deeper than alpha particles but far less than gamma rays and x rays. An adequately designed shield can stop beta particles.

Neutrons

Neutrons are electrically neutral atomic particles. A neutron weighs one-fourth the weight of an alpha particle and is able to penetrate deep into the body. Nuclear reactors and particle accelerators produce neutrons. A thick layer of plastic or water or other light materials slows down neutrons. Slow neutrons are efficiently absorbed by cadmium and some other elements.

4. HOW DOES IONIZING RADIATION EXPOSURE OCCUR?

Everyone is constantly exposed to natural background radiation from cosmic rays, from radioactive atoms in the earth's crust and from naturally occurring radioactive substances in food and water. The amount of this "natural background radiation" varies from place to place and time to time. Background levels of ionizing radiation continuously expose the general population to an annual dose of about 2 to 3 mSv (millisieverts).

In the workplace, radiation exposure can occur in two ways--externally and internally. External exposure occurs from radiation sources in the surroundings. Internal exposure occurs from radioactive substances deposited inside the body by inhalation, ingestion and contamination of wounds and cuts.

External Exposure

Gamma rays and x rays are the main concern since they can penetrate deeply into the human body. The body tissues absorb radiation energy, which causes radiation damage.

Beta particles can pose an external radiation hazard in some situations. The risk is greatest when the eyes are exposed or when radioactive material is deposited on the skin.

Beta particles may indirectly cause external exposure. When beta particles slow down inside metals such as tantalum, tungsten, they produce x rays called bremsstrahlung. Bremsstrahlung poses an external radiation hazard just like x rays and gamma rays.

Alpha particles are the least penetrating. A few centimeters of the atmospheric air and less than a fraction of a millimeter thickness of other material absorb alpha particles.

Neutrons pose an external hazard because they can penetrate deeply into the body.

Internal Exposure

Internal exposure occurs when a radioactive substance is swallowed, inhaled or absorbed through skin, or through cuts and wounds. The body eventually excretes such foreign material mainly in urine and feces. The time needed to completely eliminate the radioactive substance varies widely. Some radioactive [illegible] may remain inside the body for several years while others remain inside the body for only hours. The radiation dose continues to accumulate until the radioactivity fades out or the body clears out the radioactive substance.

Alpha emitters pose the maximum internal hazard because of their extremely poor penetrating capability. A thin layer (less than 1 millimeter in thickness) of tissue around the site of emission absorbs the alpha particles causing localized radiation damage.

Beta particles and gamma rays from the internally deposited emitters cause radiation damage over a larger tissue volume.

5. WHAT IS RADIATION DOSE?

When ionizing radiation interacts with the body, it gives its energy to the body tissues. The amount of energy absorbed per unit weight of the body organ or tissue is called absorbed dose. It is expressed in units of gray (Gy). One gray dose is equivalent to one joule of energy per kilogram of body or tissue weight. Rad was the old unit of absorbed dose. One gray is equivalent to 100 rads.

Some studies report x-ray and gamma-ray exposure in units of roentgens (R). This refers to the amount of ionization present in the air. One roentgen of gamma or x-ray exposure produces a tissue dose of about 1 rad (0.01 Gy).

Equal doses of all types of radiation are not equally harmful. For a given absorbed dose, alpha particles produce greater harm than do beta, gamma and x rays. To allow for this difference, we express radiation dose as a dose equivalent or simply "dose" in units of sievert (Sv). Dose in Sv is equal to absorbed dose multiplied by a quality factor (see Table 1). One Sv dose produces a constant biological effect regardless of the type of radiation. The old unit of dose equivalent was rem.

Dose in Sv = Absorbed Dose in Gy x quality factor (QF)
Dose in rem = Dose in rad x QF
1 Sv = 100 rem
1 rem = 10 mSv (millisievert = one thousandth of a Sv)

Table 1 - Quality factors

Radiation	Quality Factor
Gamma and X rays	1
Beta particles	1
Slow Neutrons	2
Fast Neutrons	10
Alpha particles	20

Table 2 shows SI units (International System of units) together with their symbols, corresponding non-SI units and the conversion factors.

Table 2 - Units of radioactivity and radiation dose

Quantity	SI unit and symbol	Non-SI unit	Conversion factor
Radioactivity	becquerel, Bq	curie, Ci	1 Ci = 3.7 x 10^{10} Bq (37 GBq)
Absorbed dose	gray, Gy	rad	1 rad = 0.01 Gy
"Dose" (Dose equivalent)	sievert, Sv	rem	1 rem = 0.01 Sv

Working Level and Working Level Month

In underground uranium mines, as well in some other mines, radiation exposure occurs mainly due to radon gas and its solid short-lived decay products, called radon daughters. Radon daughters enter the body when air is inhaled. The unit for measuring the concentration of radon daughters in the air is working level (WL). This is a measure of the concentration of potential alpha particle energy per litre of air. The worker's exposure to radon daughters is expressed in units of Working Level Months (WLM). One WLM is equivalent to 1 WL exposure for 170 hours. For more information on radon, see the CCOHS publication (P89-3E) "Radon in Buildings."

6. WHAT ARE THE EFFECTS OF IONIZING RADIATION?

Effect on the Cell

The human body, like all living material, is made of small building blocks called cells. Cells, with the exception of brain cells, can reproduce themselves exactly (cell division) to compensate for cells that die The life-span of human cells varies from a few hours to several years. Ionizing radiation has the potential to damage these cells in a number of ways. It can:

- cause early death of cells
- prevent or delay cell division
- permanently alter cell properties and pass these changes onto daughter cells

The probability of cell damage is small at typical occupational doses of ionizing radiation.

Several chemical and biological exposures can also produce cell damage. If normal biological processes do not repair the damage, a variety of [illegible] effects can result.

Health Effects

Our present knowledge of the health effects of ionizing radiation is based on the studies of disease and death rates among:

- the survivors of the atomic bomb explosion
- patients who received large doses of radiation in medical procedure
- occupationally exposed groups of radium dial painters, radiologists, workers in uranium and some other mines
- laboratory animals

Most of the above data relate to doses much higher than typical occupational doses. These data are used to estimate the risk (probability) of long-term health effects resulting from occupational dose.

The risk of radiation-induced diseases depends on accumulated radiation dose, which is equal to the average annual dose multiplied by the years of exposure.

7. HOW DOES IONIZING RADIATION AFFECT EXPOSED PERSONS?

Ionizing radiation causes two types of health effects among exposed people:

- Early effects, or acute radiation syndrome, occur from a few hours up to a few weeks after exposure.

- Late effects occur from 5 to 30 years or more after exposure.

Early Effects: Acute Radiation Syndrome

Early effects occur when the whole body or a particular organ receives a large radiation dose (1 Sv or more) in a short time. The symptoms are disorders of the skin, bone marrow, digestive system and neuromuscular system. The severity of the effects depends on the total radiation dose, how quickly the dose was delivered (dose rate), the type of radiation and the part of body exposed. Higher doses can cause death within 10 to 15 days after exposure. A very high dose to the central nervous system can cause death within hours.

Acute effects do not occur below a certain minimum dose called "threshold dose," which depends on the type of effect and the tissue. Occupational doses of radiation are very small compared to threshold doses for acute effects. There is virtually no risk of acute effects from occupational exposure except in the case of a severe accident.

Late Effects: Cancers

Late effects, which appear several years after the exposure, include increased risk of leukemia and cancer of various organs. The time between the exposure and the appearance of the cancer is known as the latent period. The latent period is two to four years for leukemia and bone cancer, and ten or more years for other cancers. Increased risk of leukemia and bone cancer continues for up to 25 to 30 years following exposure, while excess risk for most other cancers may persist for longer periods.

The late effects appear randomly. Therefore it is impossible to predict whether or not an exposed individual will develop cancer. Even though only a few people develop cancer, all those exposed are at risk.

Ionizing radiation is not the only cause of cancer. In the general population some people develop cancer from unknown causes. Cancer is the cause for about 20 percent of all deaths among exposed people. If an exposed individual develops cancer, it is impossible to determine whether or not radiation is the sole cause of that cancer. More cancers tend to occur in people exposed to radiation than in people not exposed.

The exact relation between the radiation dose and cancer occurrence is not established with any certainty, particularly at the low doses and low dose rates typical of occupational exposures. The International Commission on Radiological Protection has estimated that the risk of fatal cancers due to radiation dose is one in every 100 exposed persons per Sv dose. The allowed dose limit is 50 mSv. If a person received 50 mSv every year for 20 years, the accumulated dose would be 1 Sv.

It is generally assumed that the rate of cancer occurrence in a population increases linearly with radiation dose. For example, if a certain number of cancers occur due to a given dose, then the number of cancers will double if the dose is doubled. Also, it is generally assumed that there is no absolutely safe radiation dose (threshold dose) below which the risk of cancer is nonexistent. The absence of threshold implies that any dose, no matter how small, carries some risk. For example, a radiation dose of 0.1 mSv carries a risk of about one in a million.

Ionizing radiation can produce cancer of most body organs. The sensitivity of different organs varies.

Organs of High Sensitivity

- blood forming cells
- female breasts
- thyroid (especially in females)
- lungs
- digestive system

Organs of Uncertain Sensitivity

- larynx
- nasal sinuses
- ovaries
- connective tissues

<u>Organs of Moderate or Low Sensitivity</u>

- pharynx
- liver
- biliary tract
- pancreas
- lymph nodes
- kidneys
- bladder
- brain
- nervous system
- salivary glands
- bone and skin

There are no reports of radiation-induced cancers of the prostate, cervix, uterus, and testes. As new evidence accumulates, knowledge regarding the sensitivity of various organs may change.

Effect of Internal Exposure

Radioactive materials entering the body tend to predominantly accumulate in one particular organ. If the internally deposited radioactive material emits alpha particles, the entire radiation dose is concentrated in the organ that contains the alpha emitter. A gamma emitter taken inside the body affects a larger volume of tissues or organs.

The tissue (or organ) that absorbs radiation is called target tissue (or organ). The lung is the main target organ at risk for inhalation of insoluble alpha or beta emitters. Table 3 shows some other examples of radioactive substances and their target organs.

The organ that receives the maximum dose is generally at maximum risk. For example, underground uranium mine workers inhale radon daughters, which emit alpha particles in the lungs. As a result, lung cancer is the major radiation disease among underground miners.

Table 3 - Examples of target organs for some radioactive substances

Radioactive Substance	Target Organs
Plutonium	ovaries, testes, bone surface, lungs, liver, walis of large intestine
Uranium	kidneys, bone marrow, bone surface, walls of large intestine
Radium	ovaries, testes, bone marrow, lungs, walls of lower large intestine
Iodine	thyroid, lungs, stomach walls

Effect of Exposure During Pregnancy

Exposure of the developing fetus can occur by:

- external radiation that penetrates the maternal tissue
- radioactive material that reaches the fetus after maternal ingestion, inhalation or injection

Radiation exposure of the human embryo early in its development can result in death of the embryo or spontaneous abortion.

The fetus is highly sensitive to radiation. Malformations can occur, particularly if exposure to very high doses occurs during the period when basic organ structures are developing. This period extends from week 2 to week 9 for human pregnancies. Researchers believe that there is a threshold dose below which radiation does not affect the developing fetus. The exact value of this threshold dose is not known, but it is likely that a total dose of less than 0.01 Sv (1 rad) would not have widespread effects.

Radiation exposure of the fetus can result in several types of abnormalities in the newborn. They include reduced head growth, mental retardation, general growth retardation, deformation of various organs and genetic abnormalities. Such effects have been observed only at very high doses. Some of these defects may be apparent at birth while others may appear later in childhood.

Effect on Fertility

No data exist on radiation-induced infertility for long-term exposure to low doses. Infertility can occur if the reproductive organs of a person receive very high radiation dose (one hundred times the annual dose limit) over a very short time. The sterilizing dose in the male is probably much larger than 4 Gy (400 rads). In women, acute doses of 3 to 4 Gy (300 to 400 rads), given in two or three installments, may result in permanent sterility. But this effect depends, in part, on age. Occupational doses that are within the accepted dose limits are unlikely to cause infertility.

Effect on the Eye: Cataracts

Data from animal experiments suggest that people would require a minimum of 2 to 5 Gy (200 to 500 rads) to suffer significant visual damage, and higher dose when given in several installments. There is no evidence of cataracts resulting from long-term exposure of the human lens at low dose rates.

8. HOW DOES IONIZING RADIATION AFFECT FUTURE GENERATIONS OF EXPOSED PERSONS?

Genetic effects of ionizing radiation have not been observed in humans. Animal studies show that radiation exposure can cause genetic or hereditary effects. The frequency of genetic disorders depends on the radiation dose to the ovaries and testes and not on the total whole body dose. Genetic disorders that appear in the children of the exposed persons are called dominant. Genetic disorders that appear in subsequent generations of exposed persons are called recessive.

Humans pass their essential characteristics from one generation to the next through the chromosomes located in reproductive cells. Chromosomes carry the genetic information in the form of genes. The genes from mother and father unite at conception. Throughout life, each cell division almost always faithfully reproduces the chromosomes. A number of physical and chemical agents, including ionizing radiation, can cause changes or mutations in genes. Mutation damage can cause a wide variety of diseases and abnormalities, including extra fingers and toes, short-limbed dwarfism, mental retardation, several kinds of anemia, eye cancer, blindness and death in the first few years of life. Most of these diseases are rare.

Changes in human chromosomes can occur more frequently among people exposed to high doses of radiation. The most probable consequence of chromosome change is miscarriage; often so early that it cannot be detected. One of the most studied disorders that chromosome changes cause is Down's syndrome, also known as "mongolism." Epidemiologic studies of the link between radiation exposure and Down's syndrome have reported conflicting results.

In the general population, roughly 10 percent of all children are born with some degree of hereditary defect. Ionizing radiation and some noxious chemicals may increase the frequency of occurrence of genetic defects. The International Commission on Radiological Protection has estimated the average risk factor for hereditary effects in the first two generations to be about 4 cases per thousand exposed persons per Sv dose.

In addition to the abnormalities and diseases, genetic alteration may predispose people to conditions such as diabetes, schizophrenia, cancer and mental retardation.

9. WHAT IS THE COMBINED EFFECT OF EXPOSURE TO IONIZING RADIATION AND OTHER PHYSICAL AND CHEMICAL AGENTS?

We can divide the combined action of ionizing radiation with other physical or chemical agents into three categories:

- Synergistic - the risk due to combined exposure is greater than the sum of individual risks.
- Non-interacting - the risk due to combined exposure is equal to the sum of individual risks.
- Antagonistic - the risk due to combined exposure is less than the sum of individual risks.

Studies of lung cancer deaths among uranium miners show that smokers are at higher risk of lung cancer compared to nonsmokers. The combined effect of smoking and radiation dose is higher than the sum of the individual risks from smoking and radiation dose.

A comprehensive review of the biological effects of ionizing radiation in combination with other physical, chemical and biological agents is given in UNSCEAR 82 (see Further Reading). Synergistic action may exist between ionizing radiation and microwaves in electronic and radio technical industry workers. Effects include nervous system disturbances and the feeling of discomfort.

Workers at metallurgical plants who were exposed to ionizing radiation and high temperature reported abnormally high numbers of nervous system disturbances. The evidence is insufficient to prove a synergistic action of high temperature and ionizing radiation.

The combined action of low temperatures and ionizing radiation has given inconclusive evidence in favour of both synergistic and antagonistic effects. We have found no studies that provide evidence of a synergistic action between radiation and any other physical agent such as high altitude, physical stress, mechanical damage, magnetic field or ultrasound.

The data on synergism between radiation and cancer-causing chemicals and dust are inconclusive.

10. HOW MUCH RISK DOES IONIZING RADIATION EXPOSURE POSE?

Risk means the probability of danger or injury. People exposed to radiation are at higher risk of cancer. If we divide the number of cancer deaths over a sufficiently long period (several years) into two large groups of people (several thousand)--one exposed to high level of ionizing radiation and the other non-exposed--we will find more cancer deaths in the exposed group compared to the non-exposed group. The number of excess cancers depends on the total accumulated dose of each exposed person and the number of exposed people as well on such factors as age, sex, length of follow-up and smoking habits. As it is difficult to precisely determine all these factors, the risk estimates of radiation-induced cancer vary from one study to another. For radiation protection purposes, the International Commission on Radiological Protection (ICRP26) has estimated that the mortality risk factor for radiation-induced cancers is about one case per 100 exposed people per Sv whole body dose. This means that if 1000 people receive 50 mSv whole-body dose each year for 20 years, ten excess cancer deaths are expected. In the general population, about 20 percent of all deaths are due to cancer.

In some situations, especially when radioactive material is deposited inside the body, one particular organ or tissue receives the highest radiation dose. The ICRP recommends a method to calculate a dose equivalent to the whole body from the single organ or tissue dose.

Dose equivalent to whole body = Tissue dose in Sv x Weighting Factor (W_T)

The weighting factors account for the risk of radiation-induced fatal cancers for different organs (see Table 4).

Table 4 - Weighting factors (W_T) and risk factors for tissues and organs at risk of radiation-induced cancer

Tissue	Risk,*Sv^{-1}	Comments	W_T
Ovaries, testes	4.0×10^{-3}	Genetic risk to first two generations	0.25
Breast	2.5×10^{-3}	Average for all ages and both sexes	0.15
Red bone marrow	2.0×10^{-3}	Leukemia	0.12
Lung	2.0×10^{-3}	Cancer	0.12
Thyroid gland	5.0×10^{-4}	Cancer	0.03
Bone surface	5.0×10^{-4}	Osteosarcoma	0.03
Remainder	5.0×10^{-3}	Cancer, assuming that no single tissue contributes more than 1/5 of this total	0.30
Total risk	1.65×10^{-2}	Total	1.00

* These risk factors are subject to change as new data accumulate.

For example, 1 Sv dose to the lungs is equivalent to 0.12 Sv dose to the whole body.

Estimates of the risks of radiation-induced cancers are derived from studies of people exposed to high doses and a high dose rate. Therefore, the predicted disease rates among occupationally exposed low dose groups are only approximate.

11. HOW MUCH RADIATION DOSE IS ACCEPTABLE?

In Canada, the Atomic Energy Control Board (AECB) is responsible for setting dose limits for ionizing radiation from radioactive material and nuclear facilities. The provincial governments are responsible for setting dose limits for x rays that are produced by x-ray machines and other electrical sources. Tables 5 and 6 summarize the limits set by the AECB.

All doses of radiation are considered harmful and should be avoided if possible. The ICRP recommends keeping all exposures as low as reasonably achievable (ALARA) below the regulatory limit, taking economic and social factors into account.

Setting limits for the intake of radioactive substances is considerably more difficult. Physical, chemical and biological factors for each radioactive substance must be considered separately. The ICRP provides limits in its Publication 30, "Limits for Intake of Radionuclides by Workers."

Table 5 - Maximum permissible doses (in millisieverts)* for ionizing radiation in Canada[1-3]

Organ or Tissue	Atomic Radiation Workers[2] mSv per 1/4 of a year	Atomic Radiation Workers[2] mSv per year	Any Other Person mSv per year
Whole body, testes, ovaries, bone marrow	30[4]	50[4]	5
Bone, skin, thyroid	150	300	30[5]
Any tissue of hands, forearms, feet and ankles	380	750	75
Lungs (6) and other single organs or tissues	80	150	15

* 1 mSv = 0.1 rem

Table 6 - Maximum permissible exposures to radon daughters[1,2,6]

Atomic Radiation Workers WLM per quarter of a year	Atomic Radiation Workers WLM per year	Any Other Person WLM per year[7]
2	4	0.4

Notes to Tables 5 and 6

(1) The maximum permissible doses and exposures specified in table 5 do not apply to ionizing radiation:
   a) received by a patient in the course of medical diagnosis or treatment by a qualified medical practitioner
   b) received by a person carrying out emergency procedures undertaken to avert danger to human life

(2) The Atomic Energy Control Board may, under extraordinary circumstances, permit single or accumulated doses up to twice the annual maximum permissible doses or exposures for atomic radiation workers. Such variance will not be granted:
   a) if appropriate alternatives are available
   b) for irradiation of the whole body or abdomen of women of reproductive capacity
   c) for irradiation of the whole body, gonads or bone marrow if the average dose received from 18 years up to and including the current year exceeds 50 mSv per year

(3) In determining the dose, include the contribution from sources of ionizing radiation both inside and outside the body.

(4) The dose to the abdomen of a pregnant atomic radiation worker after the licensee is informed of the pregnancy of that worker shall not exceed a total of 10 mSv accumulated at a rate of not more than 0.6 mSv per two weeks.

(5) The dose to the thyroid of a person under the age of 16 years shall not exceed 15 mSv per year.

(6) For exposures to radon daughters, the maximum permissible exposures (in working level months) apply instead of the maximum permissible doses for the lungs (in mSv).

(7) The WLM unit is not appropriate for exposures in the home or in other non-occupational situations. In such situations, the maximum permissible annual average concentration of radon daughters attributable to the operation of a nuclear facility shall be 0.02 WL.

The Atomic Energy Control Regulations are presently under revision (see Further Reading). Tables 7 and 8 give the proposed dose limits. Annual dose limit (occupational) on exposure for radon daughters is proposed as 800 working level hours (about 4.7 WLM).

Table 7 - Proposed dose limits

Exposed Group	Exposed Duration	Dose Limit (in millisieverts)
Atomic radiation worker	1/4 of a dosimetry year	30
Atomic radiation worker	one dosimetry year	50
Person other than an atomic radiation worker	one dosimetry year	5

Table 8 - Proposed dose limits

Tissue or organ	Exposed Group	Exposure duration	Dose Limit (in millisieverts)
lens of an eye	atomic radiation worker	1/4 of a dosimetry year	80
lens of an eye	atomic radiation worker	one dosimetry year	150
any other organ or tissue	atomic radiation worker	1/4 of a dosimetry year	300
an other organ or tissue	atomic radiation worker	one dosimetry year	500
embryo or fetus	atomic radiation worker	semi-monthly period	0.6
embryo or fetus	atomic radiation worker	balance of pregnancy	10
any organ or tissue	person other than an atomic radiation worker	one dosimetry year	50

12. SUMMARY

Ionizing radiation is energy that travels through space as electromagnetic waves or a stream of fast moving particles. In the workplace, the sources of ionizing radiation are radioactive substances, nuclear power plants, x-ray machines and nuclear devices used in medicine, research and industry. Commonly encountered types of radiation are alpha particles, beta particles and gamma rays.

Alpha particles have very little penetrating power and pose a risk only when the radioactive substance is deposited inside the body. Beta particles are more penetrating than alpha particles and can penetrate the outer body tissues causing damage to the skin and the eyes. Gamma rays are highly penetrating and can cause radiation damage to the whole body. The probability of radiation induced disease depends on the accumulated amount of radiation dose.

The main health effects of ionizing radiation are cancers in exposed persons and genetic disorders in the children, grandchildren and subsequent generations of the exposed parents.

The fetus is highly sensitive to radiation-induced abnormalities. At high doses, radiation can cause cataracts in the eyes. There is no firm evidence that ionizing radiation causes premature aging. Radiation-induced sterility is highly unlikely for occupational doses. The data on the combined effect of ionizing radiation and other cancer-causing physical and chemical agents are inconclusive.

GLOSSARY

Absorption: The process by which the intensity of particles or gamma rays entering matter is reduced by interaction with the matter.

Alpha Particle: The positively charged nucleus of helium atom. Often referred to as alpha rays.

Atom: The smallest unit into which an element can be divided.

Background Radiation: The naturally occurring radiation in the environment.

Beta Particles: Electrons emitted from certain radioactive nuclei. Often referred to as beta rays.

Biological Half-Life: The time required for the body or an organ to eliminate half of a given substance.

Bone Marrow: A soft tissue which fills the centre of many bones. It plays a vital role in the production of blood corpuscles.

Chromosome: Rod-shaped structures of cell nuclei which contain genes.

Cosmic Rays: High-energy ionizing radiation which enters the earth's atmosphere from outer space.

Decay: A spontaneous process where radioactive atoms disintegrate by emitting alpha, beta or gamma rays.

Dose: A quantity (total or accumulated) of radiation energy per unit weight.

Dose Rate: The dose delivered per unit time.

Electron: A particle with a negative electrical charge and a mass of 1/1837 that of the hydrogen atom.

Gamma Ray (gamma radiation): High-energy electromagnetic radiation emitted by some radioactive substances. Gamma rays are very penetrating. Dense materials, such as lead, are suitable for stopping or shielding the gamma rays.

Genes: Sub-units of chromosomes which determine inherited characteristics.

Genetic Effects: Mutations or other changes produced by irradiation of the germ cells.

Gonads: The male (testes) and female (ovaries) reproductive organs.

Gray (Gy): Unit of radiation dose. 1 Gy is equivalent to one joule energy deposited per kilogram of body or organ weight.

Half-Life: The time required for one half of the radioactive atoms in a given sample to decay. This time depends on the element and is independent of the amount of radioactive material.

ICRP: The International Commission on Radiological Protection.

Ion: An atom that has too many or too few electrons, causing it to be electrically charged.

Ionization: The process that removes one or more electrons from a neutral atom

Ionizing Radiation: Any radiation capable of displacing electrons from atoms or molecules to produce ions. These include electromagnetic (x rays, gamma rays) and particulate (alpha, beta) radiation.

Latent Period: The elapsed time between exposure and the manifestation of radiation damage.

Leukemia: A blood disease distinguished by abnormal production of white blood cells

Mutation: A change that occurs to a gene as a result of radiation or other agents that alters the characteristics of the offspring.

Natural Radioactivity: The radioactivity associated with naturally occurring elements.

Neutron: A nuclear particle with no electrical charge and a mass similar to that of the hydrogen atom.

Quality Factor (QF): A multiplicative factor used to calculate the effective biological dose from the absorbed radiation energy dose. The quality factor equals 1 for gamma, beta and x rays; 10 for neutrons and 20 for alpha rays.

Rad: Abbreviation of radiation absorbed dose. It is the old unit of absorbed dose which is equal to 100 ergs of energy deposited per gram of tissue.

Rem: Roentgen equivalent man. It is the old unit of dose which is equal to the absorbed dose in rads multiplied by a quality factor.

Roentgen: The old unit of exposure defined by the amount of ionization produced under specified conditions.

SI: Systême International. Internationally agreed system of units.

Sievert: SI unit of dose equivalent equal to the absorbed dose in gray multiplied by a quality factor.

X Rays: Highly penetrating ionizing radiation emitted as electromagnetic waves.

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READER'S NOTES