Training for Non-Radiologists

To Perform

Radiographic Studies

SUNY Upstate Radiation Safety Office

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UNIT 1: PRINCIPLES OF EQUIPMENT FUNCTION

1.1 Radiological Terminology

ROENTGEN RAY. This term is synonymous with X-ray.

ROENTGENOLOGY. This study and use of radiation; synonym for radiology.

ROENTGENQGRAM. Synonym for radiograph which is the record of an image produced by the passage of X-rays through an object.

ATOM. The smallest particle of a substance that can exist and still retain the properties of that substance. It is composed of the following:

1) Nucleus. The positively charged center of an atom containing most of the mass in the form of protons and neutrons.
2) Proton. A positively charge particle having mass or weight.
3) Neutron. A neutrally charged particle also having mass or weight.
4) Electron. A negatively charge particle having very little mass orbiting the nucleus at various distances.

MOLECULE. A group of two or more identical or different atoms.

ION. A charge particle (either positive or negative) resulting from the ionization of atoms or molecules.

IONIZATION. The process of adding electrons to, or knocking electrons from, atoms or molecules, thereby creating ions.

1.2 Definition and Types of Radiation

Radiation may be defined as the process in which energy in the form of rays of light, heat, or X-rays, is sent out from atoms and molecules as they undergo internal change. Basically, there are two types of radiation, particulate and electromagnetic. Particulate radiations result from the splitting of atoms, such as alpha and beta particles given off by radium. Electromagnetic radiations are pure energy without mass or weight. X-rays, light, heat, radar, and radio waves are examples of electromagnetic radiations. Light or radiant energy travels as a wave motion and, therefore, wavelength is its one measurable characteristic. All forms of electromagnetic radiation are grouped according to their wavelengths in what is called the electromagnetic spectrum. In medical and dental radiography, X-rays have a wavelength of about one billionth of an inch. X-rays also act as if they consist of small, separated bundles of energy, and they can be understood if a beam of X-rays is considered as a shower of particles. This dual nature of X-rays, wave-like and particle-like, is inseparable.

1.3 Properties of X-rays

X-rays are invisible waves of electromagnetic energy that travel at the speed of light (about 186,000 miles per second or $3x10^8$ meters per second) and in straight lines in all directions. X-rays cannot be seen or felt, but they have properties, which make them valuable in diagnosis and treatment. X-rays, if not properly controlled can be harmful in stimulating and destroying living tissue. X-rays have the ability to penetrate opaque material, to affect the sensitive emulsion of photographic and radiographic film the same as light does, and to produce fluorescence in certain chemical compounds.

1.4 Production of X-rays

1.4.1 Electrical Terms

ELECTRIC CURRENT. A flow of electrons from one point to another.

ELECTRON. A negatively charged particle.

DIRECT CURRENT. A current of electricity which flows in one direction.

ALTERNATING CURRENT. A current of electricity which flows first in one direction and then reverses and flows in the opposite direction.

CYCLE. One forward and one reverse flow of an alternating current.

AMPERE. The unit of current flowing through a circuit.

MILLEAMPERE (mA). One-thousandth (1/1,000) of an ampere.

MILLIAMMETER. An instrument that measures milliamperage.

MILLIAMPERE-SECONDS (mAs). The number of milliamperes of electricity flowing around a circuit in one second.

VOLT. A unit of measurement of electrical pressure which forces a current through a circuit. A kilovolt equals 1,000 volts.

VOLTMETER. An instrument that measures voltage. In an X-ray unit, it measures the voltage of the current before that voltage is stepped up by the transformer.

WATT. A unit of measurement of electrical power. The voltage times the amperage equals the wattage. One volt times 1 ampere equals 1 watt.

OHM. A unit of measurement of electrical resistance. It requires 1 volt to force 1 ampere through 1 ohm of resistance.

1.42 X-ray Producing Equipment

An electric current is the flow of negatively charged particles called electrons. This flow normally occurs along wire conductors. If the voltage (pressure) is high enough, electrons will cross a gap between conductors. When electrons, which are rapidly moving across such a gap, are suddenly stopped by hitting a metal target, X-rays are produced. The following comparison may give a clearer understanding of X-ray production. If a handful of marbles is thrown at a drumhead, the marbles will lose their velocity when striking the drum but will cause the drumhead to vibrate. This vibration sends sound waves into the air. The marbles represent the electric current. The drumhead corresponds to the target of the electronic tube in which X-rays can be generated. The resulting sound waves in air correspond to the X-rays produced in the tube.

1.4.3 X-ray Beam Generation

X-rays are similar to visible light rays in that they radiate from the source in all directions unless they are stopped by an absorber. For this reason, the X-ray tube is inclosed in a metal housing that stops most of the radiation and permits a beam to leave the tube only through a "window" in the tube housing. The beam of useful radiation is composed of rays of different wavelengths and penetrating power.

In conventional X-ray generators a metal anode is bombarded by high kinetic energy electrons, as shown in Fig. 1-1. When electrons in a conventional generator strike the anode, roughly 99% of them experience nothing spectacular; they undergo sequential glancing collisions with particles of matter, lose their energy a little at a time and merely increase the average kinetic energy of the particles in the target; the target gets hot. Perhaps one percent of the incident electrons contribute a photon to the X-ray spectrum.

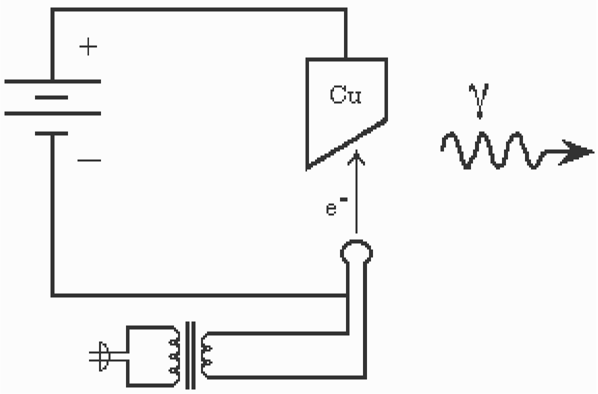

Figure 1-1: Schematic Diagram of an X-ray Generator. The heated filament boils off electrons, which then accelerate toward the positively charged Cu anode. The photons are

absorbed by shielding and collimators (not shown), except those headed along the main beam axis. (After Piccard and Carter, 1989.)

Two mechanisms produce X-ray photons: first, the sudden deceleration of the electrons produces photons with a wide distribution of energies, ranging from very tiny up to the kinetic energy of the incident electrons. These photons (known as "bremsstrahlung," German for "braking radiation") have a continuous spectrum with a broad peak of intensity for photons with roughly half the incident electron energy, and are more numerous in directions perpendicular to the electrons' acceleration vector.

Roughly as many X-rays are generated by the second mechanism, which begins when an incoming electron "chips off" an inner electron from an atom of the anode. Following such an ionization event, an outer electron drops down to fill the vacancy, emitting a photon of energy equal to the difference between the binding energies of the old and new states of this (orbital) electron. Photons of this sort have energies that are, of course, characteristic of the anode material, and are emitted from the atom with equal probability in all directions. We thus expect the spectrum of a conventional X-ray generator to show a combination of continuous and line features.

1.4.4 Types of Radiation Produced by a Radiographic Unit

Primary Radiation. Primary radiation includes all radiation that comes directly from the anode. Except for the useful beam, it is absorbed by the tube housing.

Stray or Leakage Radiation. Stray radiation is any radiation that does not serve a useful purpose. This category includes radiation coming from the tube head through a crack or joint in the tube housing.

Secondary Radiation. Secondary radiation is that radiation emitted by any substance through which X-rays are directed or by any irradiated material.

Scattered Radiation. Scattered radiation is that radiation that has been deviated in direction during its passage through a substance. It may also have been altered by an increase or decrease in wavelength.

1.5 Penetrating Power of X-rays

X-rays vary considerably in the ability to penetrate matter. Those of relatively short wavelengths have greater penetrating power than those of longer wavelengths. The wavelength is determined by the positive voltage applied to the anode of the tube to attract the negative electrons emitted by the filament. The higher the voltage applied, the shorter the wavelength will be. Desired adjustments in penetrating power can be made by changing the anode voltage.

The degree to which X-rays penetrate a substance also depends upon the nature of the substance or density. Xrays will penetrate the soft tissue of the lips and cheeks very readily, but the bone and hard structure of the teeth are much more resistant. The greater the density of an object, the more radiation, it will absorb. Lead is one of the more dense substances and will absorb most radiation, a property which makes it useful in protection from radiation.

1.6 Production of a Radiographic Picture

1.6.1 General.

Because of the difference in the degree to which X-rays will penetrate different tissues and substances, the amount of radiation reaching any portions of the film will determine the degree to which that portion of the emulsion of the film is affected. Differences in these effects in different portions of the film produce a photographic record of whatever lies between the film and the source of the X-ray.

1.6.2 Radiolucency.

An object through which radiation passes freely is called radiolucent. The area on the film corresponding to a radiolucent area receives more radiation than the surrounding area; therefore, after processing, the area corresponding to a radiolucent object is considerably darker. All soft tissue is radiolucent.

1.6.3 Radiopacity.

The direct opposite of radiolucent is radiopaque. A radiopaque object or area is one which tends to absorb the radiation; therefore, the film is less exposed to radiation. These areas on a radiographic film appear light in contrast to the radiolucent areas. Bony structures are radiopaque areas. Due to the various densities in tooth structure, the radiographic film is exposed to varying degrees of radiation. The image is made of varying shades of light and dark areas corresponding to varying degrees of radiolucency and radiopacity.

1.6.4 Distance.

As the distance increases, the radiation intensity at the object decreases. This is a particularly important factor when cones of different lengths are used.

1.7 Dosage Measurements

The methods of measuring the energy, or quantity, of ionizing radiation involve the physical characteristics of the radiation. The photographic methods determine the quantity by the degree of darkening of a sensitive photographic emulsion. The personnel monitoring film badge is an example of that method. The fluorescent, chemical, and thermal properties are also used to determine the quantity of radiation, but the most important method of measurement utilizes the ability of radiation to ionize gases. The ions can be counted because of their electrical charge and resulting electrical current. The instrument used to determine the amount of ionization is called the standard free-air ionization chamber.

The radiation energy necessary to expose X-ray film is expressed as milliampere-seconds of electric current used to produce the X-rays. Milliampere-seconds can be converted to appropriate X-ray dosage at given distances from the X-ray tube target if the total filter equivalent, milliamperage, and voltage of the current, and the exposure time are known. Dosages at other distances vary inversely with the square of the distance. This means that doubling the distance from the X-ray tube target reduces the amount of X-ray reaching a given area of tissue to one-fourth of its value. The mAs is computed by multiplying the mA by the total number of seconds exposed.

1.8 Fluorescence and its Use in Radiography

The ability of X-rays to cause certain substances to fluoresce (glow) is the principle employed in fluoroscopy. Fluorescence is also used to intensify the exposure of X-ray film by means of visible light.

An intensifying screen is a device which augments the photographic effects of X-rays, decreasing the amount of radiation required. It consists of a thin, pliable material coated with a substance which fluoresces when exposed to X-rays. When used, the light emitted by the fluorescing surface intensifies the effect on the emulsion of the X-ray film so that less X-ray exposure is needed.

A fluoroscope is a device with a screen which fluoresces when exposed to X-rays, forming an image of the structure through which the rays pass. Use of a fluoroscope provides an immediate and direct means of examining tissues.

Radiologists recognized many years ago that the poor visibility of image detail was related to the dim image presented by a conventional fluoroscope. These persons emphasized the need for brighter fluoroscopic images and encouraged the development of the image intensifier. Image intensifiers increase the brightness of the fluoroscopic image and permit the observer to use photopic vision. Hence, dark adaptation is not required for fluoroscopy with image intensification.

UNIT 2: THE BIOLOGICAL EFFECTS AND SIGNIFICANCE OF X-RAY EXPOSURE

2.1 Introduction

The physical basis for the biological consequences of ionizing radiation exposure is the transfer of energy to the biological organism. The energy transferred to matter from ionizing radiation produces ionizations (electron missing from atom) of atoms and molecules. The deposited energy also produces excitations (electron vacancy in a shell) of atoms and molecules in the absorbing material. These ionizations and excitations can lead to permanent changes to the tissue, which may result in demonstrable biological injury.

The specific mechanisms involved in radiobiological injury are not completely understood; however, nucleic acids are probably involved in the more serious effects. Small modifications of DNA structure can have widespread consequences for the cell, because the structure of a DNA molecule constitutes the cell’s operational “program”. In addition, since DNA is replicated during mitosis, any point mutation may be perpetuated in the cell’s progeny. For example, a particular alteration could result in the synthesis of enzymes which differ from the normal in time of production, spatial distribution, or configuration. Depending upon the relative importance of the particular enzyme changes, their activity, and the frequency of their production, the effects upon the cell as a whole can range from insignificant metabolic alterations to severe interruption of normal function.

The severity of radiobiological injury is also clearly dependent upon the location of the initial radiation interaction. For example, small alterations in the protein synthetic mechanism occurring in the cytoplasm of the cell might cause localized damage but would be unlikely to generate large scale changes in cellular activity.

2.2 Cellular Amplification

Cellular damage at the point of the initial radiation interaction usually involves only a very small percentage of the total number of molecules in the cell. At this stage, therefore, any biological consequences of radiation-induced changes may be relatively insignificant. Subsequently, normal cellular metabolic processes may amplify this damage, causing the injury to develop from the molecular to the microscopic anatomical level, ultimately resulting in possible gross cellular malfunction.

2.3 Gross Cellular Effects of Radiation

One of the phenomena seen most frequently in growing tissue exposed to radiation is the cessation of cell division. This may be temporary or permanent, depending upon the magnitude of the absorbed dose of radiation. Other factors observed are chromosome breaks, clumping of chromatin, formation of giant cells or other abnormal mitoses, increased granularity of cytoplasm, nuclear disintegration, changes in motility or cytoplasmic activity, vacuolization, altered protoplasmic viscosity, and changes in membrane permeability.

2.4 Latent Period

Following the initial radiation event, and before the first clinically detectable effects occur, there is a time lag referred to as the latent period. The biological effects of radiation are arbitrarily divided into short-term and long-term effects on the basis of the latent period. Those effects which appear within a matter of minutes, days, or weeks are called short-term effects and those which appear years, decades, and sometimes generations later are called long-term effects.

2.5 The Dose-Effect Curve

For any biologically harmful agent, it is useful to graph the dosage administered against the probability of effect. With radiation an important question has been the nature and shape of the resulting graph or curve. Fig. 2-1 below shows three dose response relationships. Curve (1) represents a linear, nonthreshold dose-effect relationship in which the curve intersects the abscissa at the origin. According to the nonthreshold hypothesis, any dose, no matter how small, is considered to involve some degree of effect. There is some evidence that the genetic effects of radiation constitute a nonthreshold phenomenon. One of the underlying assumptions in the establishment of radiation protection guides has been to take the conservative approach and consider that any radiation absorbed will exhibit a nonthreshold effect. Under this assumption, some degree of risk is presumed to be present when large populations are exposed to even very small amounts of radiation. Curve (2) represents a nonlinear quadratic, nonthreshold dose-effect relationship. This model assumes that some fraction of radiation interactions will produce direct injury and that another fraction will produce subinjurious damage. The higher the dose the more likely that several subinjurious interactins will combine to porduce an injury and hence the superlinear increase in risk woth increasing dose. Curve (3) represents a “threshold dose-effect relationship. The point at which the curve intersects the abscissa is the threshold dose, i.e., the dose below which there is no immediately detectable effect.

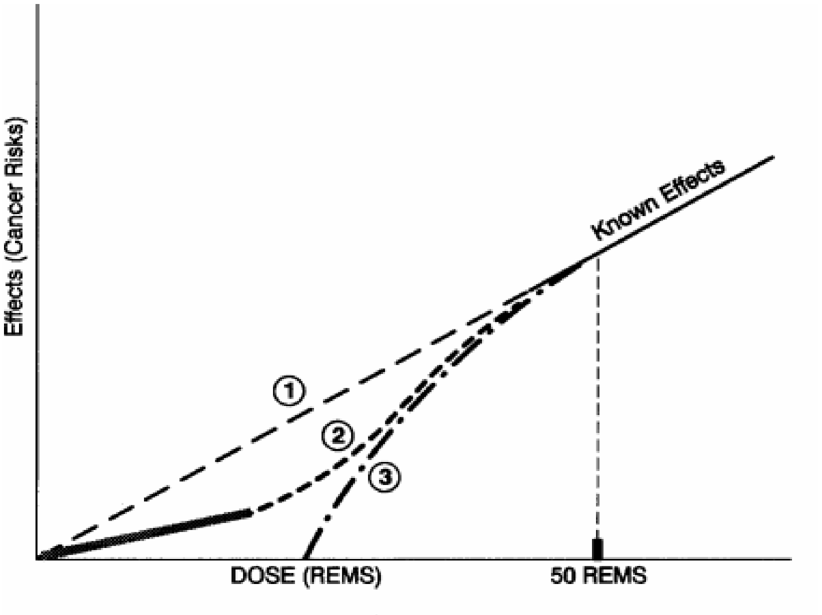

Figure 2-1. Dose Response Relationships

2.6 Area Exposed

The extent of the effect is measured by the total radiation received by the patient and primarily depends upon the total area exposed.

Of equal importance is the nature of the organs in the body area exposed. Even partial shielding of the radiosensitive blood-forming organs such as spleen and bone marrow can mitigate the total effect, especially in x-raying children.

2.7 Variations in Cell Sensitivity

There is wide variation among different types of cells in the amount of radiation required to produce radiation damage. For example, cells that are rapidly dividing, or have a potential for rapid division, are more sensitive than those which do not divide, and cells which are nondifferentiated (i.e., primitive or nonspecialized) are more sensitive than those which are highly specialized. The factors influencing the radiosensitivity of cells and tissues were recognized as early as 1906 by two French scientists. Their findings are expressed in the Law of Bergome and Tribondeau, which states:

> The radiosensitivity of a tissue is proportional to its reproductive capacity and inversely proportional to its degree of differentiation.

Therefore, immature cells, which are often primitive and rapidly dividing are more radiosensitive than older, mature cells which have specialized functions and have ceased to divide.

Based upon these factors, various kinds of cells may be grouped as follows, in order of diminishing sensitivity:

1. Lymphocytes
2. Erytbroblasts, granulocytes
3. Myeloblasts
4. Epithelial cells
    a. Basel cells of the testis
    b. Basel cells of intestinal crypts
    c. Basel cells of the ovary
    d. Basel cells of the skin
    e. Basel cells of secretory glands
    f. Alveolar cells of the lungs and bile ducts
5. Endothelial cells
6. Connective tissue cells
7. Tubular cells of the kidney
8. Bone cells
9. Nerve cells
10. Brain cells
11. Muscle cells

2.8 Short-Term Effects

2.8.1 Patients

In 1994 the Food and Drug Administration (FDA) Center for Devices and Radiological Health (CDRH) reported on reports of occasional, but sometimes severe, radiation-induced skin injuries to patients resulting from prolonged , fluoroscopically-guided , invasive procedures. They cautioned physicians performing such procedures to be aware that there is a potential for serious , radiation-induced skin injury caused by long periods of fluoroscopy during such procedures. They further stated that it was important that the onset of such injuries was usually delayed and the physician should be aware that they would not be able to discern any damage by observing the patient immediately after the treatment.

The absorbed dose in the skin required to cause skin injury depends on a number of factors and is presented in the table below.

Radiation-Induced Skin Injuries

Hours of Fluoroscopic “On Time” to Reach Threshold[+] at:			
Effect	Typical Threshold Absorbed Dose (Gy)[*]	Usual Fluoro. Dose Rate of 0.02 Gy/min	Time to Onset of Effect[++]
Early transient eryth.	2	1.7	hours
Temporary epilat.	3	2.5	3 wk
Main erythema	6	5.0	10 da
Permanent epilat.	7	5.8	3 wk
Dry desquamation	10	8.3	4 wk
Invasive fibrosis	10	8.3	
Dermal atrophy	11	9.2	>14 wk
Telangiectasis	12	10.0	>52 wk
Moist desquama.	15	12.5	4 wk
Late erythema	15	12.5	6-10 wk
Dermal necrosis	18	15.0	>10 wk
Secondary ulcerat.	20	16.7	>6 wk

- The unit for absorbed dose is the gray (Gy) in the International System of units. One Gy is equivalent to 100 rad in the traditional system of radiation units.

[+] Time required to deliver the typical threshold dose at the specified dose rate.

[++] Time after single irradiation to observation of effect.

(Table adapted from Ref. 6)

2.8.2 Occupational Worker

There is a very small probability of a person’s receiving an injurious acute dose from routine x-ray examinations. The dose range in diagnostic radiographic examinations usually varies from a few mrad to a few rad; however, in fluoroscopic examinations, the exposure rates seldom exceed 5 R per minute (as measured at the panel or table top), and the entire examination seldom delivers more than 30 rads. A special precaution should be noted on radiography of the fetus: absorbed doses of less than 50 rads could result in a spontaneous abortion.

Most of the data pertaining to the acute radiation syndrome come from animal experimentation, but there is human data which confirms the extrapolation of the animal data to human populations.

The specific effects of an acute dose are dependent upon the radiation dose rate and quality. In most mammals, there are categories of radiation death:

1. At very high doses, exceeding several thousand rads, death will occur with in hours after exposure and is apparently due to the breakdown of the neurological and cardiovascular systems; this is known as the central nervous system syndrome.

2. At lower doses, usually above 600 rads, death occurs within 15 to 30 days and is associated with destruction of the gastrointestinal system.

3. At even lower doses, but greater than 100 rads, both may occur due to radiation effects on blood-forming organs. This is known as the hemopoietic syndrome.

In general, at 50 rads or less, ordinary laboratory or clinical methods will show no indications of permanent injury.

Considering the extent of individual variation, it is difficult to assign a precise dose range to each of the syndromes discussed above. At 100 rads irradiation, most individuals will show no symptoms, although a small percentage may show mild blood changes. At 200 rads, most persons show definite signs of injury and some may even die. Approximately 600 rads marks the threshold of the gastrointestinal form of the acute radiation syndrome, with a very poor prognosis for all individuals involved; a fatal outcome may well be certain at 800 to 1,000 rads whole-body acute irradiation. It should be emphasized that these estimates of injury are based on doses delivered to the whole body in a single brief irradiation.

2.9 Long-Term Effects

Long term effects of radiation are those which may manifest themselves years after the original exposure. The latent period, then, is much longer than that associated with the acute radiation syndrome. Delayed radiation effects may result from previous acute, high-dose exposures or from chronic low-level exposures over a period of years. From the standpoint of public health significance, the possibility of long-term effects on many people receiving low chronic exposures is cause for greater concern than the short-term effects of a few individuals receiving a high dose. This is because of possible deleterious genetic effects.

There is no unique disease associated with the long-term effects of radiation; these effects manifest themselves in human populations as a statistical increase in the incidence of certain diseases or pathology.

Many epidemiological investigations on irradiated human beings have provided convincing evidence that ionizing radiation doses indeed result in an increased risk of certain diseases long after the initial irradiation. This evidence supplements and corroborates that gained from past and present animal experimentation which demonstrates these same effects. Among the long-term effects thus far observed, are genetic mutations, which may be expressed many generations after the original radiation damage, and somatic damage, which may result in increased incidence of cancer, embryological effects, cataracts, and life-span shortening.

2.10 Carcinogenic Effects

There is human evidence that radiation may contribute to the induction of various kinds of neoplastic disease. This evidence includes:

1. Radium dial painters, who ingested significant amounts of radioactive radium, have subsequently shown an increased incidence of bone malignancies.
2. Early radiologists and dentists have shown a significant increase in skin malignancies and leukemias as compared to physicians who did not use radiation.
3. Uranium miners have shown an increased incidence of lung cancer.
4. The Japanese survivors of Hiroshima and Nagasaki have an increased incidence of leukemia and possibly of other neoplasms.

2.11 Embryological Effects

Considering the fact that immature, undifferentiated, and rapidly dividing cells are highly sensitive to radiation, it is not surprising that embryonic and fetal tissues are readily damaged by even relatively low doses of radiation. It has been shown in animal experiments that deleterious effects may be produced with doses of only ten rads delivered to the embryo. There is no reason to believe that the human embryo is not equally susceptible to radiation.

The specific type of fetal radiation damage is related to the dose and to the stage of pregnancy during which irradiation takes place. In terms of embryonic death, the earliest stages of pregnancy perhaps a few weeks in human beings, are most radiosensitive. From the standpoint of practical radiation protection, this early sensitivity is of great significance, because pregnancy may well be unsuspected. Embryonic death because of irradiation is less likely during the period of organogenesis, the second through the sixth weeks of human gestation, than in the extremely early stage, but the production of morphological defects in the newborn is a major consideration.

During later stages of pregnancy, embryonic tissue is relatively resistant to damage by radiation. However, functional damage, particularly those involving the central nervous system, may result from such late exposure. They usually involve subtle alterations in such phenomena as learning patterns and development and may have a considerable latent period before they manifest themselves.

2.12 Cateractogenic Effects

The fibers which comprise the lens of the eye are specialized to transmit light. Damage to these, and particularly to the developing immature cells which give rise to them, can result in cataracts. Radiation in sufficiently high doses can induce the formation of cataracts; the required dose for humans is probably on the order of several hundred rads for x-rays in the diagnostic energy range for a single acute irradiation.

2.13 Life-Span Shortening

In a number of animal experiments, radiation has demonstrated a life-span shortening effect. The mechanisms involved in radiation life-span shortening are uncertain; however, irradiated animals appear to die from the same disease as the non-irradiated controls but at an earlier age. How much of the total effect is due to premature aging and how much to an increased incidence of radiation-induced damage is still unresolved.

2.14 Genetic Effect

The precursor cells of mature gametes or the mature gametes themselves are susceptible to nuclear damage (genetic mutations) form external influences such as radiation. When this occurs in those gametes which subsequently are utilized in conception, the altered genetic information is reproduced and passed on to all of the cells of the offspring.

Most geneticists agree that the greatest preponderance of genetic mutations are harmful. By virtue of their damaging effects, they can be gradually eliminated from the population through natural selection. The more severe the defect produced by a given mutation, the more rapidly it will be eliminated, and vice versa; mildly damaging mutations may require a great many generations before they disappear.

As a balance to this natural elimination of harmful mutations, fresh ones are constantly occurring. For man, it has been estimated that background radiation probably produces less than ten percent of these naturally occurring mutations. Man-made radiation, of course, if delivered to the gonads, can also produce mutations over and above those which occur spontaneously.

Animal experimentation remains our chief source of information concerning genetic effects of radiation. As a result of extensive experimentation, certain generalizations may be made. Among those of health significance are:

1. There is no indication of a threshold dose for the genetic effects of radiation, i.e., no dose below which genetic damage does not occur.
2. The degree of mutational damage which results from radiation exposure seems to be dose-rate dependent; i.e., a given dose is less effective in producing damage if it is protracted or fractionated over a long period of time, due to cell and tissue repair.

Radiation and other mutagenic factors have always been present on earth. It is reasonable to expect that all mutations have been expressed in the past so that man-made radiation would only add to the natural incidence of previously expressed mutations rather than create new ones. Since, in general, mutations tend to be deleterious, it is important to keep their incidence as low as possible. Therefore, the goal is clear; we should keep the radiation exposure of the gonads to a minimum.

UNIT 3: RADIATION EXPOSURE STANDARDS

3.1 Radiation Quantities and Units

The production of a radiographic image is dependent upon the absorption of radiation by the patient, or more precisely, the selective absorption of radiation throughout the irradiated tissue of the patient. It is the differential absorption of different structures that provides the desired information. Unfortunately, the absorption of energy from the X-ray beam can have deleterious effects on tissue. It is this dilemma that confronts every licensed operator: X-rays must be absorbed by the patient to produce an image, but the absorption of X-rays can produce undesirable effects, both somatic and genetic. The logical response to this dilemma is to try to maximize radiological information while minimizing radiation exposure to the patient.

A number of acute and long-term effects on humans have been related to the physical energy absorbed from various types of ionizing radiation. However, the relative effectiveness of each type of radiation per unit energy absorbed in tissue has been found to vary not only with the type of radiation and its quantum energy but also with the rate which the energy is delivered, type of tissue irradiated, the age of the patient, the biological effect under consideration, and other epidemiological variables.

In order for radiation dose measurements to be meaningful, they must be related to some biological effect of interest. We know that absorption of X-rays produces free electrical charges in air by ionizing air molecules. Such ionization requires the absorption of energy from the radiation. We now know that many deleterious biological effects can be related to absorbed energy in tissue.

The measurement of X-rays is important in any quantitative investigation of their properties. It is essential to distinguish, however, between a “quantity”, defined as the description of a physical concept or principle, and a “unit”, which is the measure of magnitude of the quantity.

For the purposes of radiation hazard evaluation, various units, of radiation exposure and dose have been introduced to account for the several methods of measuring and assessing the effects of different types of radiation.

In 1975, the scientific community within the United States agreed to adopt the “International System of Units or SI” for measuring and assessing the effects of the different types of radiation. Four of the most important quantities and corresponding conventional and approximate equal SI units are: Exposure - Roentgen (coulounb per kilogram); Absorbed Dose - Rad (Gray); Dose Equivalent - Rem (Sievert) and Activity - Curie (Becquerel). The conventional units are not directly equivalent to the SI system, therefore, arithmetic conversions are necessary in order to go from one system to the other.

3.1.1 The Roentgen:

The Roentgen (abbreviated R, and its corresponding one-thousandth, the milliroentgen, mR) is the unit of exposure and applies only to the interaction between X and gamma radiation and air. It is applicable only for photon energies not exceeding three million electron volts (MeV). Although historically the oldest and most widely used unit of X-ray measurement, it has no direct biological context and is used in the calibration of radiation-producing machines as a means of specifying their output intensity. Usually, if the exposure is known in roentgens, the dose in rads can be computed if the X-ray beam size, and other necessary factors are known. The QUANTITY of X-rays in a beam is frequently expressed as EXPOSURE RATE, i.e., Roentgens per minute (R/m) or milliroentgens per second (mR/s).

Roentgen is a "unit of exposure of X or gamma radiation. One roentgen is the exposure corresponding to ionization in air of one electrostatic unit of charge either sign in 0.001293 gram of air".

3.1.2 The Coulomb per Kilogram:

The Coulomb per Kilogram (abbreviated $C\ kg^{-1}$) is the quantity of x or gamma radiation that imparts a coulomb of energy to a kilogram of air producing ions (of either sign).

$1R = 2.5 \times 10^{-4}\ C\ kg^{-1}$

$3876R = 1\ C\ kg^{-1}$

3.1.3 The Rad:

The Rad, an acronym for Radiation Absorbed Dose, is the special unit of absorbed dose. The quantity significant in biological and medical work is not the amount of radiation passing through a point in air; rather, it is the amount of energy absorbed by the substance at the particular point, i.e., the absorbed dose. An absorbed dose of one rad corresponds to the absorption of 100 ergs of energy per gram of tissue or other material and is of primary importance in radiation dosimetry. (There is no abbreviation for rad or rem; initially a lower-case r was used for roentgen; an upper-case R is now used for roentgen, and hence there is no symbol for rad or rem).

3.1.4 The Gray:

The Gray (abbreviated Gy) is an absorbed radiation dose of one joule per kilogram in issue.

$1\ rad = 10^{-2}\ Gy$

$100\ rad = 1\ Gy$

3.1.5 The Rem:

Dose Equivalent: This unit (the rem) was devised to allow for the fact that the same absorbed dose in rads delivered by different kinds of radiation does not produce the same degree of biologic effect; some radiations are biologically more effective than others. For protection purposes, where a mixture of radiations may have to be considered, allowance is made for this by the quality factor which relates the effect of other radiations to that of gamma rays from cobalt-60. Some quality factors are listed below:

Quality Factor	
X-rays, gamma rays, and electrons (including beta rays)	1
Fast neutrons and protons of energies up to ten MeV	10
Alpha particles	20

The dose equivalent in rem is the absorbed dose in rads multiplied by the appropriate "quality factor." Permissible dose equivalent of radiation is specified in rem. The determination of dose equivalent is especially important when considering doses to critical organs. Occupational dose equivalent limits (maximum permissible dose, MPD) are all stated in terms of rem.

It is important to make a distinction between dose measured in rads, exposure measured in roentgens, and dose equivalent measured in rem; however, their biological impact is evaluated in rem.

"Rem" is an acronym for Roentgen Equivalent Man.

3.1.6 The Sievert:

The Sievert (abbreviated Sv) is the dose equivalent and is equal to the absorbed dose in grays multiplied by the appropriate "quality factor" and other factors.

1 rem = 10^{-2} Sv

100 rem = 1 Sv

3.1.7 The Curie (Ci):

The curie is used to specify the activity of a radionuclide, i/e., the rate at which its atoms disintegrate. One curie equals 3.70 x 10^{10} disintegrations per second.

3.1.8 The Becquerel:

The Becquerel (abbreviated Bq) is that quantity of radioactive material in which one atom is transformed per second.

$1\ \text{Ci} = 3.7 \times 10^{10}\ \text{Bq}$

$2.7 \times 10^{-11}\ \text{Ci} = 1\ \text{Bq}$

3.2 Maximum Permissible Exposure-MPD (Dose Equivalent)

In total, natural radiation in the United States results in an estimated average annual dose equivalent of about 300 mrem. It is unlikely to be less than 100 mrem for any individual and unlikely to be more than 400 mrem for any significant number of people.

The essential aim of radiation safety is to prevent injury from ionizing radiation. Three types of dose equivalent limits are:

1. Occupational dose equivalent limits for persons over 18 years of age.
2. Occupational dose equivalent limits for persons under 18 years of age.
3. Dose equivalent limits for general population.

However, the New York State Department of Health, Bureau of Environmental Radiation Protection in its Regulation on Ionizing Radiation, Chapter 1 – Part 16, dated April 2001, also refers to prenatal radiation exposure.

Before discussing the regulatory provisions regarding permissible dose equivalent limits, one should review definitions of occupational dose. Occupational dose is defined as the dose received by any individual in:

a. A controlled area (X-ray room), or[1/]

b. The course of employment, education, training, or other activities which involve exposure to radiation.

Exception: Radiation exposure received for the operator's own personal medical or dental diagnosis or medical therapy is not considered to be occupational exposure. If an operator is a patient, he/she must remove the personnel monitoring device before being X-rayed.

[1/] Controlled area means an X-ray room or any other area where radiation safety rules are enforced.

3.3 Occupational and General Population Dose Equivalent Limits

The basic provisions regarding the dose equivalent limits for occupationally exposed persons and the general public are given in the table below:

REM PER CALENDAR QUARTER[2/]

	Occupational Dose		
Body Area	**Over 18**	**Under 18**	**General Public**
Whole body	1.25	0.125	0.100 per year
Skin and any extremity	12.5	1.25	
Eyes	3.75	0.375	

3.4 Retrospective Annual Occupational Dose Equivalent

An occupationally exposed individual over 18 years of age may receive, on the average, a maximum whole-body dose equivalent of 5 rem per year.

3.5 Who Must Be Monitored

The question of who must be monitored and under what conditions persons must be monitored confronts every certified supervisor (registered user) whose employees run a risk of exposure to radiation. As is often the case with regulatory provisions, there are many implied provisions. To a very great extent, this is true with personnel monitoring requirements. We feel that the question you should ask yourself is: Would you, as a certified (registered user), want the responsibility of risking any person's safety by not monitoring that person?

The clearly stated personnel monitoring requirements are:

Each registered user must supply appropriate personnel monitoring equipment to, and shall require the use of such equipment by, any person who is likely to receive an accumulated dose equivalent in excess of 10 percent of the applicable annual radiation exposure standard specified by regulation, as listed in the table below:

[2/] "Calendar quarter" means not fewer than 12 consecutive weeks and not more than 14 consecutive weeks. Calendar quarters shall be so arranged that no day in any year is omitted from inclusion within a calendar. No user shall change the method omitted observed by him of determining calendar quarters except at the beginning of a calendar year.

REM FOR CALENDAR YEAR

Body Area	Over 18	Under 18
Whole body	5	0.5
Skin or extemities	50	5
Eyes	15	1.5

There are two additional personnel monitoring requirements: (1) for persons who enter high radiation areas, and (2) for persons who operate mobile X-ray equipment.[3/]

In addition, there are two broad provisions which deserve emphasis: (1) each user (certified supervisor) must take all precautions necessary to provide reasonably adequate protection to the life, health, and safety of all individuals subject to exposure to radiation, and (2) each certified supervisor is responsible for radiation safety in his X-ray department.

3.6 Occupationally Exposed Women of Procreative Age

A special situation arises with occupationally exposed declared pregnant women. NYSDOH Part 16 states that special precautions shall be taken to limit exposure to declared pregnant women, especially if they could be pregnant. Exposure to the abdomen of such workers to X-rays would involve exposure to the embryo or fetus.

You, as a certified supervisor, are responsible for instructing the employee of the following.

1. That the NYSDOH states that during the entire gestation period, the maximum permissible dose equivalent to the fetus from occupational exposure of the declared expectant mother does not exceed 0.5 rem, and that the working conditions be adjusted so as to avoid a monthly total effective dose equivalent of more than 0.05 rem to the embryo/fetus and

2. Provide the employee with reasons for the recommendation.

It is strongly suggested that the instruction be given both orally and in writing. Also, each individual should be given an opportunity to ask questions, and each individual should be asked to acknowledge in writing that the instruction has been received.

Some recent studies have shown that there is an increased risk of leukemia and other cancers in

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[3/] "Radiation area" means any area accessible to individuals, where a major portion of the body could receive a dose exceeding 5 millirem in any 1 hour or 100 millirem in any 5 consecutive days.

"High radiation" area means any area, accessible to individuals, in which there exists radiation at such levels that an individual could receive in any 1 hour dose to the whole body in excess of 100 millirem.

children if the expectant mother was exposed to a significant amount of radiation. The NYSDOH wants women employees to be aware of any possible risk so that the women can take steps they think appropriate to protect their offspring.

The following facts should be given to the woman employee:

1. The first three months of pregnancy are the most important, because the embryo or fetus is very sensitive to radiation.

2. In most cases of occupational exposure, the actual dose received by the embryo or fetus is less than the dose received by the mother, because some of the dose is absorbed by the mother's body.

3. At the present occupational dose equivalent limits, the risk to the unborn baby is considered to be small, but experts disagree on the exact amount of risk.

4. There is no need for women to be concerned about sterility or loss of ability to bear children.

5. The NCRP recommendation of 0.5rem dose equivalent limit applies to the full nine months of pregnancy.

UNIT 4: RADIATION PROTECTION

4.1 Terminology

DOSE-RESPONSE CURVES: The linear dose-response curve is characterized by an effect caused directly by a specific dose and no threshold. The sigmoid dose-response curve is characterized by a representation of nonstochastic effects or a non-dose effect relationship.

BACKGROUND RADIATION: That radiation due to cosmic rays natural or environmental radioactivity, which is always present.

DOSE RATE: An important aspect of irradiation is the dose rate, which is the dose delivered per unit time. Dose rate is expressed in rem per hour, the absorbed dose in rad/h, and exposure in R/h.

HALF-VALUE LAYER (HVL): The QUALITY (average penetrating ability) of an X-ray beam is usually specified terms of half-value layer. The HVL is defined as the thickness or layer of a specified material which attenuates the X-ray beam to such an extent that the exposure rate is reduced to one half; e.g., 1 HVL reduces the exposure level by 1/2, 2 HVLs reduce the exposure level by 1/2 x 1/2 or 1/4, etc.

4.2 Conduct of the Examination

4.2.1 Introduction

The manner in which that examination is conducted will determine the patient's dose, one way to minimize the patients dose, dose to the operator**,** and at the same time improve image quality is to restrict the size of the exposure field by coning, collimation, and general patient shielding--particularly for such areas as the fetus, gonads, lens of the eye, and active blood-forming organs.

Only that part of the X-ray beam which has gone though the patient and reaches the image receptor (called remnant Xrays) can produce a radiograph with proper density, contrast, and detail and thus provide diagnostic information. Failure to limit the X-ray beam only to the area of clinical interest represents one of the most frequent causes of unnecessary patient radiation.

Most modern X-ray machines are equipped with adjustable collimating devices that can be used to restrict the size and shape of the X-ray beam. Most collimating devices are equipped also with a light localizer, which provides a visual indication of size and location of the X-ray beam at any distance.

All these devices have an important function to perform in addition to limiting patient dose -- they improve the contrast and detail of the radiographic image by reducing the amount of scattered radiation reaching the film and the operator. Therefore, it is vital that the operator properly employ these devices at all times.

4.3 Fluoroscopic Examinations

4.3.1 Introduction

Since Thomas A. Edison invented the fluoroscope in 1896, it has been a valuable tool in the practice of medicine. The primary function of the fluoroscope is to perform dynamic studies; that is, the fluoroscope is used to visualize the motion of internal structures and fluids. During fluoroscopy, the radiologist views a continuous image of the motion of internal structures while the x-ray tube is energized. X rays produced in the X-ray tube spread out (fan out) from the source and pass through the patient. The patient's anatomy filters the X rays. Some of the X rays completely penetrate the patient. When the X rays complete their passage through the patient, an image in the form of an X-ray field of spatially varying intensities is produced. This is the X-ray image. If something is observed that the radiologist would like to preserve for later study, a radiograph can be made with little interruption of the fluoroscopic examination. Such a radiograph is known as a spot film.

Fluoroscopic procedures may be performed by certified physicians properly trained in fluoroscopic techniques. The regulation specifies that only persons who have been adequately instructed in safe operating procedures and who are competent in the safe use of the equipment may operate it.

Fluoroscopy is actually a rather routine type of x-ray examination except for its application in the visualization of vessels, called angiography. The two main areas of angiography are neuroradiology and vascular radiology, and, as with all fluoroscopic procedures, spot film radiographs are obtained also. The recent introduction of computer technology into fluoroscopy and radiography is placing increasing demands on the training and performance of radiologic technologists.

Furthermore, fluoroscopic examinations should be performed only after careful consideration, because fluoroscopic examinations could expose the patient to much larger quantities of radiation than radiographic examinations. For example, an upper GI tract fluoroscopic study utilizing 120 seconds actual exposure time could deliver at the patient as much as 10 to 15 Roentgens, as compared to an AP abdominal film where the exposure range, according to the Nationwide Evaluation of X-Ray Trends (NEXT) data, is 100 to 750 milliroentgens at the patient.

Two facts should be kept in mind when operating a fluoroscope:

1. Operator exposure to scattered radiation is directly proportional to patient exposure.

2. Image brightness is directly proportional to the radiation exposure rate at the output phosphor.

The layout of a modern fluoroscopic system is shown in Fig. 4-2. The x-ray tube is usually hidden under the patient couch. Over the patient couch is the image intensifier and other image detection devices. The image intensifier (II) converts an radiologic image into a light image that is displayed on a television monitor. Modern fluoroscopic equipment allows the radiologist to select an image brightness level manually or maintained automatically by the machine varying the kVp or the mA, or sometimes both. Such a feature of the fluoroscope is called automatic rightness control (ABC), automatic brightness stabilization (ABS), automatic exposure control (AEC), or automatic gain control (AGC). Other fluoroscopes have the x-ray tube over the patient couch and the image receptors under the patient couch. Some fluoroscopes are operated remotely from outside the x-ray room.

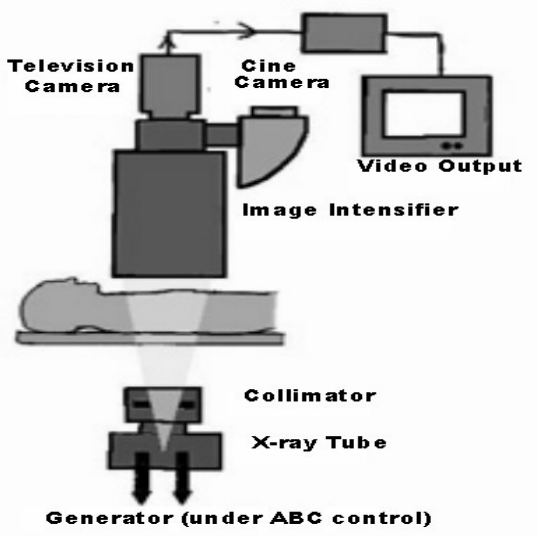

Figure 4-2. Fluoroscopic X-ray System

The radiation exposure rate at the output phosphor will increase with increased X-ray tube current in milliamperes. This will produce a brighter image on the screen (image receptor), but will also increase patient exposure, and hence operator exposure. Radiation exposure rate at the output phosphor is almost independent of the X-ray beam size. Consequently, the image will not be brighter with a larger X-ray beam size; however, the total volume of the patient that is exposed to radiation will increase, and with it, the amount of radiation scatter toward the operator. On the other hand, image quality is improved as the size of the X-ray beam is reduced, because there is a reduction in the amount of scattered radiation reaching the output phosphor.

It should be possible to reduce patient and operator exposure and still obtain a satisfactory fluoroscopic image for viewing purposes by fulfilling the following conditions:

1. Use the lowest milliamperage and optimum peak kilovoltage technique possible.
2. Restrict the X-ray beam to the smallest size practicable.
3. Keep the X-ray tube to patient distance to a maximum.
4. Restrict X-ray beam ‘ON” time to a minimum.

Factors which influence the exposure rate at the table top, and hence influence the dose to both the patient and the operator, are:

Milliamperage or tube current.

Collimation.

Patient Shielding

Exposure time.

X-ray tube to patient distance.

Light in the fluoro room.

Grid use.

4.3.2 Milliamperage

For a radiographic examination, the x-ray tube current is measured in hundreds of mA and the X-ray output is proportional to the mA used. If the mA setting is reduced from 5mA to 3mA, the exposure rate is correspondingly reduced to 40 percent of the initial exposure rate. During fluoroscopy, the x-ray tube is operated at less than 5 mA. When image intensification was first introduced, it was anticipated that tube current could be reduced by at least a factor of ten and that as a result patient dose would be reduced by a factor of ten. For a variety of reasons this tube-current reduction has not materialized. During image-intensified fluoroscopy, tube currents of 2 to 4 mA are normal. Consequently, the patient dose during fluoroscopy remains relatively high, considerably higher than doses resulting from radiographic examinations.

There are certain regulatory provisions which must be observed:

1. For routine fluoroscopy, the exposure rate measured at the panel or table top shall be as low as practicable and may not exceed 10 roentgen per minute.

2. Devices which indicate the X-ray tube potential and current must be provided, and should be located in such a manner that the operator may monitor the tube potential and current during fluoroscopy.

3. Periodic measurements of the exposure rate at the table top must be made.

4.3.3 Collimation

The restriction of the useful x-ray beam to reduce patient dose and improve image contrast is known as **collimation**. Collimators take many different forms. Blade-type, diaphragms, adjustable light-localizing collimators, and cones are the most frequently used colllimating devices. They also reduce scatter radiation and thus enhances image contrast. An X-ray beam should never be larger than the film size used; e.g., a 24 inch diameter circle exposes a body area of about 18 inches by 24 inches, or 432 square inches; a 36 inch diameter circle of radiation exposes a body area of approximately 18 inches by 36 inches, or by 648 square inches. A well-collimated X-ray beam covering 14 inches by 17 inches exposes only 238 square inches.

As may be readily ascertained, reduction in X-ray exposure is considerable where rectangular collimation is used. Even more striking reduction of exposure could occur during an AP lumbar spine X-ray examination if a well-collimated X-ray beam is used instead of a circular cone of 24 inch diameter. The 24 inch diameter circular cone covers approximately 432 square inches of body area, whereas a well-collimated X-ray beam of 7 inches by 14 inches covers only 98 square inches. Exposure field reduction and the reduction of skin exposure is considerable:

$$\frac{432-77}{432} = 77\%$$

Conversely

$$\frac{432-98}{98} = 340\%$$

excess skin exposure
if a 24 inch circular
cone is used.

Consequently, the importance of a rectangular collimating device and its correct use cannot be overemphasized. As a certified supervisor, it is your responsibility to enforce the regulatory provision which requires the radiographic field (X-ray beam) restriction to the area of clinical interest only. During fluoroscopy, you should restrict the X-ray beam to the smallest size practicable for the examination at hand. Doubling the exposure area also doubles patient exposure.

4.3.4 Gonad Shielding

Suitable protective devices, as stipulated in the U.S. Department of Health, Education, and Welfare publication, entitled “Gonad Shielding in Diagnostic Radiology,” must be provided to shield gonads in potentially procerative patients when gonads cannot be excluded from the X-ray beam and the shielding of the gonads does not interfere with the diagnosis. The gonadal shielding may not be less than 0.5mm lead equivalent.

The use of 0.5mm lead equivalent gonad shielding reduces gonad dose by approximately 97 percent, e.g., for a primary X-ray beam of l00kVp and 3mm aluminum filter, the transmission throughout the shield is 3 percent, assuming that the shielding material encloses the testes. The testes under a lead sheet gonad shield can receive internally scattered radiation up to about five percent of the incident primary X-ray beam. Therefore, total gonad dose reduction for a 0.5mm sheet of lead (or shadow field) is 97% - 5% = 92%.

The ovaries in female patients are situated in the abdomen at varying depths so that shielding would more frequently interfere with diagnosis. However, whenever possible gonad shielding appropriate for females should also be utilized.

4.3.5 Exposure Time

You should restrict the X-ray beam “ON” time to a minimum. Doubling the exposure time also doubles the exposure. Patient and operator exposure will increase with prolonged beam “ON” time. Usually, the X-ray beam need not be on continuously, and fluoroscopy can be accomplished with a series of short spurts of x-radiation. A cumulative manual-reset timer activated by the exposure switch that produces an audible signal or temporarily interrupts the X-ray beam when the fluoroscopy time has exceeded a predetermined time limit, not to exceed five minutes, must be provided. This device is designed to make sure that the fluoroscopist is aware of the relative beam “ON’ time during each procedure, and is primarily for the patient protection.

4.3.6 Magnification and X-ray Tube-to-Patient or Image Intensifier-to-Patient Distance

All images on the radiograph are larger than the objects they represent, a condition called magnification. (Distortion, however, is unequal magnification of different portions of the same object.) Therefore, use of an optimum field size is important for the efficiency and effectiveness of a procedure as well as minimizing the entrance skin exposure to the patient. Standard field sizes for some modes of operation are 4, 6, 9, or 12 inches. Some may only have one size and typically it is 9 inches in diameter. The smaller the field size, the more magnification appears on the TV monitor. The entrance skin exposure increases if the image is magnified and the effect may be different for different systems. A good rule of thumb is to use the smallest magnification consistent with the procedure with close collimation.

The x-ray tube-to-patient (tabletop) distance must be not less than 15 inches on stationary fluoroscopic units and not less than 12 inches on mobile fluoroscopic units. Increasing the distance between the fluoroscopic tube and the patient results in reduced patient dose because of the corresponding decrease in the difference between the entrance and exit dose to the patient.

4.3.7 Excessive Light

Provisions must be made to eliminate extraneous light that interferes with the fluoroscopic examination.

4.3.8 Grids

The grid is an extremely effective device for reducing the level of scatter radiation, it selectively shields the image intensifier from scattered X-ray. It can be either manually removed as on many C-arms or automatically removed from the beam as on many GI units. When manually removing it care should be taken to so as not to nick or dent the grid and ruin the effectiveness of the grid. It is a carefully fabricated series of sections of radiopaque material alternating with sections of radiolucent material. The grid is designed to transmit only those x-rays whose direction is on a straight line from the X-ray tube to the image receptor. Because it reduces the amount of scatter reaching the II it can improve the quality of the image, however, the patient's radiation dose can increase. It could increase the patient dose by a factor of 2 or more. This may be alright if image quality is a necessity. A grid may not be required for fluoroscopic procedures involving either pediatric patients or small adults particularly if the II can't be brought closer than 25 cm to the patient.

4.3.9 Bucky Slot Cover

During fluoroscopy, the Bucky tray is moved to the end of the examination table, leaving an opening in the side of the table approximately two inches wide at the gonadal level. This opening must be automatically covered with at least 0.25mm lead equivalent material.

4.3.10 Protective Curtain

A protective curtain (overlapping protective drapes) or hinged or sliding panel of at least 0.25mm lead equivalent should be positioned between the patient and the fluoroscopist or others who are required to remain in the room during exposure.

4.3.11 Operator Protection During Fluoroscopic Examinations

The following guidelines are provided:

1. Protective aprons of at least 0.25mm lead equivalent (preferably 0.5mm) must be worn in the fluoroscopy room by each person unless they stand behind a radiation barrier, except the patient. Usually, leaded eye protection or thyroid protection are not required, except for high dose rate techniques. It is most unlikely that the risk of induced cataracts should be a concern, as the threshold dose is so large for chronic exposure. However, patient shielding of gonadal area should be provided, if appropriate.

2. The operator shall monitor the X-ray tube current and potential at least once each day during the use to ascertain that they are in the normal range, and keep logs of all such daily monitored readings.

Personnel monitoring devices shall be worn by anyone routinely performing fluoroscopic procedures (IF only one monitoring device is worn, it should be located at the collar of the apron or on the outside of the thyroid shield.)

Bucky slot cover and protective curtain must be provided on conventional fluoroscopic units.

Physicians should never put their hands into the active beam.

4.3.12 C-Arm Fluoroscopy

In C-arm fluoroscopy there are no shielded drapes, no shielded table, and the examinations are usually performed in the room. In these configurations it is very important that the operator pay attention to radiation management practices specific to this type of unit.

With the C-arm oriented vertically, the X-ray tube should be located beneath the patient and the image intensifier above. In a lateral or oblique orientation, the X-ray tube should be positioned opposite the area where the operator and other personnel are located. The operator and the image intensifier should be located on the same side of the patient. The orientation of the X-ray system is essential because it takes advantage of the patient as a protective shield and it reduces the amount of radiation scattered from the patient. If additional personnel are required in the room during the procedure, they should be positioned on the X-ray tube side and should stand behind a mobile shield. Any person in the procedure room and who is not behind a shielded barrier must wear a lead apron and may need to have a radiation monitoring badge. Persons not directly involved in the procedure stand behind a protective barrier or step back from the X-ray field at least 6 feet or leave the room.

Review of the components and their effect during a Fluoroscopic Exam

Component element	Radiation and Quality Effects		
	Image Quality	Dose to the Patient	Scatter Dose to the Staff
Size of Patient	Decrease	Increase	Increase
Increase Tube Current (mA)	Increase	Increase	Increase
Increase kVp	Decrease (reduced contrast)	Decreased if mA is appropriately decreased	Depends on the tube current
Increase Tube-to-Patient Distance	Increased Usually (depends on focal spot size)	Decrease	No Significant Change
Increase Image Intensifier-to-Patient Distance	Decrease Usually (depends on focal spot size)	Increase	No Significant Change
Increase Image Magnification	Increase	Increase Usually (depends on equipment design)	Not Much Change Usually (depends on equipment)
Grid Used	Increase if II is close to adult patient)	Increase	Increase
Increase Collimator Opening	Decrease	About the same dose, more tissue exposed	Increase
Increase Shielding of Room and Staff	No Effect	No Effect	Decrease
Increase Beam On-Time	No Effect	Increase	Increase

4.4 Time - Distance- Shielding

There are three basic principles, which can be used singly or in combination, to reduce dose to x-radiation. These are:

1. Time - keep the time of exposure as short as practicable.
2. Distance - keep the distance between the source of exposure (X-ray tube or any scattering medium such as a patient) and the exposed individual as large as practicable.

3. Shielding - insert shielding material between the source of radiation and the exposed person, as applicable.

4.4.1 Time

The exposure times in radiographic work usually are predetermined. During fluoroscopic examinations, the dose to the patient is directly related to the dose rate and the duration (time) of exposure. Also, the greatest operator exposure to scattered radiation is directly proportional to patient exposure. The cumulative manual-reset timer has been specifically designed to make the fluoroscopist aware of the relative X-ray beam "ON" time during each fluoroscopic procedure.

4.4.2 Distance

The intensity of radiation varies inversely as the square of the distance. It is obvious that the farther the person is from the X-ray source, the less radiation dose per unit of time they will receive. This is why in radiographic work the target-to-skin (usually the target-to-film) distances are relatively long (usually 40 inches). Also, the target-to-tabletop distances in fluoroscopy usually are as long as practicable (not less than 15 inches for stationary and not less than 12 inches for mobile units).

Inverse square law: At points distant from a common source of x-radiation, the intensities of radiation at these points vary as the square of their respective distances from the X-ray source. As one moves farther away from an X-ray source, the less radiation they receive, because the X-ray beam diverges as it moves away from its source. The inverse square law can be expressed as a simple mathematical relationship and as shown in Fig. 4.3:

$$\frac{E_1}{E_2} = \frac{(D_2)^2}{(D_1)^2} \qquad \text{or} \qquad E_1 \text{ x } (D_1)^2 = E_2 \text{ x } (D_2)^2$$

Where: E_1 - intensity at distance D_1
E_2 - intensity at distance D_2

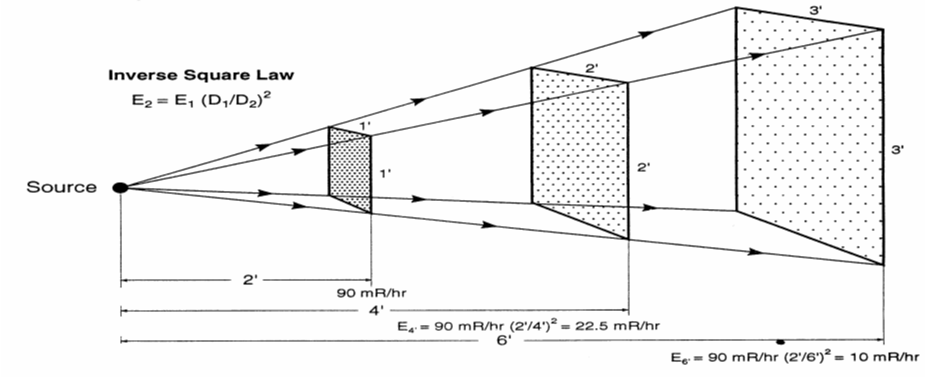

Figure 4.3. Inverse Square Law

It is easy to see that if the distance from an X-ray source is doubled, the radiation intensity is reduced to 1/4 of the intensity at the original distance. If the distance from the source is tripled, the intensity is reduced to 1/9. If the distance from source is quadrupled, the intensity is 1/16, etc.

Most radiation sources are point sources, the X-ray tube target, for example. However, the scattered radiation generated within the patient during an X-ray exposure comes from an extended area.

In radiography, the distance from the X-ray tube to the patient is generally fixed by the type of examination, and the technologist stands behind a protective barrier. During special procedures work or during fluoroscopy, the technologist may be required to remain in the X-ray room during the exposure. In such cases, it is wise to remember the configuration of isoexposure curves and stand where the radiation levels would be the lowest. As a rule of thumb, the technologist should remain as far from the examination table as practical.

During portable work, the technologist should stand as far away from the patient as practical. This is why the control switch cord must be at least six feet long.

4.4.3 Shielding

Shielding is one of the most important principles for radiation protection. Shielding refers to the different means used to stop radiation or to prevent exposure to it. To be able to apply shielding methods, one must have some understanding of the manner in which x-radiation is attenuated (absorbed) in an absorbing medium. Energy is lost by three methods. The three methods are: the photoelectric effect (a collision between a photon of x-radiation and an orbital electron of an atom where the electron is knocked out of its orbit and the photon loses all its energy); Compton scattering (interaction of a photon of x-radiation with an orbital electron of the absorber atom producing a recoil electron and a photon of energy which is less than that of the incident photon); and pair production (an incident photon is annihilated in the vicinity of the nucleus of the absorbing atom, with subsequent production of an electron and positron pair). The photoelectric effect is most important at low energies (up to 100k kVp), Compton scattering at intermediate energies and pair production at high energies (above 1,022 kilovolts).

As X.rays pass through an absorber, their decrease in number is governed by the energy of radiation, the specific medium, and the thickness of the absorber traversed. Mathematically, the absorption may be expressed by the equation:

$$I = I_0 e^{-ux}$$

where

I - intensity after absorption
I_0 - incident intensity
u - absorption coefficient
x - thickness of absorber traversed
e - natural logarithm base = 2.72

In discussing shielding, there are a few facts to keep in mind: (1) persons outside the shadow cast by the shield are not protected; (2) a wall or partition is not necessarily a safe shield for persons on the other side; and (3) radiation can bounce around corners; that is, it can be scattered.

The third fact is so important that it merits further clarification. Scattered radiation is present to some extent whenever an absorbing medium is in the path of radiation. The absorber (patient during irradiation) then acts as a new source of radiation. Frequently, room walls, the floor, and other solid objects are near enough to a source of radiation to make scatter appreciable.

Certain factors determine the quantity of scatter radiation. These are as follows: (1) kilovoltage, (2) part thickness, and (3) field size. Scatter radiation is maximum with high kVp techniques, large fields, and thick parts, and unfortunately, this is what we usually deal with in diagnostic radiology. We rarely have any control over part thickness and frequently must use large fields. The only variable we can control is kVp, but even here we have less control than we would like since patient doses go up sharply with low kVp techniques.

The Center for Devices and Radiological Health, an agency of the Food and Drug Administration, has the responsibility for conducting the regulatory program. Its authority is limited to regulating the manufacture and repair of equipment and is exercised through its promulgation of performance standards. Standards pertaining to ionizing radiation have been issued for diagnostic X-ray systems and their major components, television receivers, gas discharge tubes, and cabinet X-ray systems, including X-ray baggage systems. It performs surveys on the exposure of the population to medical radiation. It conducts an active educational program on the proper use of X-rays for medical purposes and has completed teaching aids for X-ray technicians, medical students, and residents in radiology. It has published recommendations for quality assurance programs at medical radiological facilities to minimize patient exposure. It has also issued standards pertaining to nonionizing radiation, such as microwaves and laser beams.

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