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Radiation hazards in routine x-ray diagnosis and methods of decreasing exposure and protecting the radiologic personnel

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RADIATION HAZARDS IN ROUTINE X-RAY DIAGNOSIS AND METHODS OF DECREASING EXPOSURE AND PROTECTING THE RADIOLOGIC PERSONNEL

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The purpose of this paper is to discuss the present concepts of radiation hazards in x-ray diagnosis, especially to the medical profession and to some extent to the patient. However, the genetic effect to the population as a whole will not be considered in this paper even though it is fully realized that this may be the most important facet of the problem in the future as more and more people receive more ionizing radiation from other sources as well as from more diagnosis. This paper is to deal with the immediate and long term effects on the individual.

In 1895 Wilhelm Conrad Röntgen discovered x-rays and their ability to penetrate living tissue. Barrett (1). It was soon recognized that severe skin reactions, and temporary and permanent baldness could occur from exposure to these radiations. By 1897 twenty-three cases of skin lesions due to over exposure was reported in the literature.

There was much misuse of these rays. One such instance is the case of a manufacturer of x-ray equipment who kept an x-ray tube in his office with which he warmed his hands on cool mornings. Wild (2).

This we now realize was a terrible mistake.

In 1898 the A. E. Dean & Co., Ltd. was advertising in their catalogue a hand held exploring lamp that could be used with a fluorescent screen to examine the various parts of the body. We know that this would give both the patient and the physician excessive doses of radiation. However, at that time the manufacturers were only concerned with the danger from electrical shock from the lamp.

By 1904 the Dean Company had designed a table with an x-ray tube so that the patient could lie down while the tube was moved back and forth over his body to screen the entire body if necessary. It was stated that a view in any position could be obtained with this couch.

Not until 1908 were some of the dangers of x-rays being mentioned. The Dean Company had designed an apparatus that had the tube surrounded by lead glass, except for an aperture for the useful beam. A variable diaphragm was fitted over the aperture that could be controlled with a handle from a short distance away. At this time they had also developed a cabinet for the controls that was lined with 1.5 mm. of lead and fitted with heavy lead glass windows. At this time the dangers that were being considered were the very obvious ones such as skin erythema and ulcerations.

Later after more experience with x-rays was gained, the radiologists and other physicians were becoming more careful with the use of x-rays. Still in 1926, too little was known. It was still felt that screening should be used whenever possible in the reduction of fractures. Stevenson & Leddy (3). It was suggested that two pair of ordinary gloves be worn and the fingers should be under the screen only when necessary. It was also suggested that an assistant should alternate in the exposure and the work be supervised by a radiologist.

In 1931 it had become generally accepted that the tolerance dose was 0.2 r. per day. Stone (4). This value followed the development of the roentgen as a reproducible physical measure of radiation.

By 1935 and 1936 it was recognized that mechanically rectified tubes, aluminum filters, lower kilovoltages, small fields and increased distances would increase the amount of permissible exposure.

Stevenson & Leddy (3). No specific values were stated, however, for the above precautions.

Cilley et al (5) in 1935 were trying to devise a mechanical apparatus that would permit the palpation of the stomach to change relief of it without exposing the radiologist's fingers to the primary beam. They felt that on compression of the stomach there was not the thickness of the barium filled stomach to attenuate the rays, so the operator's fingers would get too much exposure. These men studied the dose to the fingers in various maneuvers of the upper gastrointestinal examination and of the barium enema. They measured the dose to the operator in skin erythema doses which they considered as 400 r. In a period of about four years, one of the radiologists received 1.67 skin erythema doses to his hands or 668 r. At this time it was felt that no change in technic should be made and no definite danger was presented by this exposure.

The maximum permissible dose in 1936 had been reduced to 0.1 r. per day. There were two main reasons for this change; (1) more penetrating rays were now in use than were used when the original value was set up, and (2) the 0.1 r. measured in air used in the United States was about equal to the 0.2 r. measured on the skin used in Great Britain and Europe.

Some more protective measures suggested by 1937 were the use of lead rubber gloves with an equivalent of 0.5 mm. of lead and the dark adaption of the eyes for fluoroscopy. Stevenson & Leddy (3). They also suggested that the screening time be kept to the minimum.

The National Committee on Radiation Protection and the International Committee after surveying the result of animal experiments and observations of many people exposed to radiation decided on a new level in 1948. This level was set at 0.3 r. per week. This was now possible to measure with the newer film badges. This also was justified, because it was felt that 0.3 r. any time during the week was no worse than 0.05 r. per day for six days.

This value stood until 1956 at which time some changes in the long term exposure were made. Preuss (6). The 0.3 r. per week was retained, but a maximum accumulated dose per year of 5 r. was set. Along with this was a maximum of 50 r. by age of 30 years was suggested. They also provided a 25 r. per lifetime emergency dose in case of accidental exposure. They recommend no unnecessary irradiation before age of 18 years and minimization of dosage before age 30 years. A formula was devised as a guide for accumulated exposure, also. This is $D=(A-18)x5$ r. where D is total permissible dose, A is age at present and r. is roentgens. This makes possible a new concept of exposure bank. This is the actual exposure that a person has received in his lifetime subtracted from the maximum permissible exposure as calculated from the above formula. Thus theoretically at least, if a person can save up his exposure in his younger life, he can have more exposure in his later life.

The above data on maximum permissible doses are summarized in table I.

The effects of exposure to x-radiation can be divided into two groups, the immediate and the delayed. Meschan (7). The immediate effects are skin erythema, skin burns, epilation, and death. It has been found that 375-400 r. will cause skin erythema.

TABLE I
Maximum Permissible Doses In Roentgens from 1931 to 1956

	Time Period			
	1931-36	1936-48	1948-56	1956
Day	0.2 r	0.1 r	0.05 r	
6 Day Week	1.2 r	0.6 r	0.3 r	0.3 r
50 Week Year	60 r	30 r	15 r	5 r
Age 20-30	600 r	300 r	150 r	50 r
Decade	600 r	300 r	150 r	50 r
To Age 60	2400 r	1200 r	600 r	200 r

It takes a somewhat greater dose to cause actual burns of the skin and necrosis. Epilation will occur at a dose less than the erythema dose. However, this epilation is only temporary and hair will again return. There is a dose level, however, at which the epilation is permanent. This is above the skin erythema dose. These above doses are to local areas of the body and are not whole-body doses because it has been estimated that a whole-body dose of 400-450 r. is a lethal dose in 50% of the population. Even though these effects are considered as immediate effects, they do not show evidence for from three days to two weeks.

One of the theories on the cause of these effects is advanced by Failla (8). He states that radiation of low specific ionization causes alteration of cellular chemical processes that may lead to cell death or altered chemical behavior. These rays of low specific ionization have the greatest effect on the skin. These effects of x-rays naturally were the first ones noted and the first ones that steps were taken to prevent. At the present standards these really are not a problem because they are well controlled. The means of control will be discussed later in this paper.

The second type of effect is the delayed effect. This is the one with which we are most concerned in present day radiology. Delayed effects are the formation of cataracts, impairment of fertility, alteration in hematopoetic tissue, induction of malignant tumors and shortening of life span. These effects are due to long term chronic exposure to small doses of ionizing radiation over periods of years.

The delayed effects of radiation may be due to other precipitating factors such as infections, trauma, etc. Dunlap (9). Dunlap believes that the radiation alters the cells so that the organism is more susceptable, but does not cause the delayed diseases per se. This suggests one approach to combating the effects of radiation and that is to remove or prevent the precipitating causes from reaching the irradiated person.

For some unknown reason, the lens of the eye is quite susceptable to radiation. The explanation stated previously about the alteration of chemical processes can partly, at least, explain this. The lens tends to develop cataracts much more rapidly when exposed to x-rays. This may also be in part due to the acceleration of the aging process. This aging process will be discussed later.

The second chronic effect of radiation is that of impaired fertility. This can be temporary or permanent dependent on the dose received. Hodges (10). In the testis the spermatogonia are destroyed by moderate doses. However, the mature sperm is quite resistant, thus spermatogenesis ceases because of the effect on the spermatogonia. Doses of 200-300 r. to the testis usually result only in temporary sterility because enough spermatogonia survive to repopulate the seminiferous tubules. However, doses of about 600 r. will destroy all the spermatogonia, leaving a person permanently sterile. The Sertoli cells are more resistant so at the lower doses libido and potency are retained, but if the dose is high enough, these, too, are destroyed and libido and potency are lost. At doses that produce sterility, some Sertoli cells remain, but the deficiency effects can be noted.

In the female the ova and the Graafian epithelium are the susceptable tissues. In contrast to the male, the more mature the ovum, the more susceptable it is to radiation damage. A dose at the ovary of less than 200 r. results in cessation of the menses and a dose of 300-600 r. to the ovaries can cause permanent sterility. The woman near menopause is more susceptable than the younger woman.

Another factor in the female that is very important is the fact that radiation in relatively small doses can cause death of the embryo and abortion. During the stage of organogenesis in the embryo mutation and malformation may occur also which does not lead to death of the embryo. Thus extreme care must be used to avoid radiation to the pelvis in the woman of child bearing age.

A fourth chronic effect is that of inducing malignancies. It was realized quite early that carcinoma of the skin could be induced by radiation. This was especially noted on the hands because the hands of the radiologist, physician or dentist were often in the primary beam. From 1919 to 1939 inclusive, some 39 physicians came to the Mayo Clinic with epitheliomas. Leddy (11). Most of these were physicians without special training in radiology; however, there were eight radiologists among them. One theory as to the carcinogenic action of radiation is based on the assumption that normal cells produce a substance that stops multiplication of cells when it reaches a certain concentration. Failla (8). An example is that of an incision in which there are normal cells on one side of the cells bordering the wound; however, on the other side of these cells there is the open wound. Thus only a partial concentration of this substance permits the cells in the wound to multiply. But when the normal cells meet in the healing process, the concentration of the substance reaches a critical level and growth and multiplication ceases. In the case of carcinogenesis, the x-rays damage the cell or cause mutation such that the substance is no longer formed. This may leave isolated cells without the substance in the midst of normal cells. In this case the substance is present in a high enough concentration to prevent multiplication, but if enough cells in a given area are mutated so that they have none of the substance or enough cells are killed by the x-ray or by other subsequent trauma, the concentration of the substance is not great enough to prevent multiplication. The multiplication takes place without limits and carcinoma is started. Since these cells produce none of the substance, there is no limit to their multiplication and the carcinoma spreads and grows.

The last chronic effect that is to be considered is the effect on life span. It has been shown that whole body x-radiation definitely shortens the life span in animals. Failla & McClement (12). Also, an extensive statistical evaluation of life span in physicians by Warren (13) has shown that exposure to x-rays have shortened the life span of physicians.

Miller (14) states that this aging process takes place during the time of the exposure and not at the end of life. Thus the natural aging process takes place more rapidly while the individual is exposed to radiation, but when the individual is no longer being exposed, he goes back to his normal aging rate.

The overall natural life span is under the control of the genetic make-up of an individual. Warren (13). This is then influenced by many environmental factors such as nutrition, infectious processes, traums, accumulation of metabolic products and ionizing radiation. When enough of these unfavorable stimuli are accumulated, the individual will die. When the cells are aggregated in a person, they show evidences of aging such as accumulation of useless metabolic products such as pigments, cytoplasmic atrophy and such. However, human cells in tissue culture appear to grow and reproduce asexually indefinitely as long as the environment remains suitable without the culture as a whole showing the appearance of age, whereas these same types of cells grouped into an individual will show evidence of aging with time.

Warren (13) in an attempt to evaluate the effect of x-rays on humans has made a statistical study of the physicians dying from January 1, 1930 to December 31, 1954. He reviewed the J.A.M.A. obituaries during this time. He tabulated the ages at death, cause of death and type of practice where possible. For a control group with which to compare physicians, he used males over the age of 25 years in the United States in 1950. He used this group because most physicians in the United States are at least 25 years old. His findings are summarized and tabulated in table II. It can be seen from table II that those physicians who were chronically exposed to x-ray had a shorter life span than those not exposed to radiation. The average radiologist lived 5.2 years less than the physician not exposed to x-rays. This is a significant life shortening. These men we are

Table II
Average Age at Death of Various Groups of Males in U.S.
1930-1954

Type of Individual	Ave. age at death
Physician not having exposure to radiation	65.7 yr.
Radiologists	60.5 yr.
Specialists that have some exposure	63.7 yr.
Dermatologists	62.3 yr.
United States males over 25 yrs. in 1950	65.6 yr.

sure received much more radiation than the radiologist of today, if he is following the accepted standards of today. Warren feels that many of these radiologists received 1000 r. or more during their lifetime of practice. This is five times more exposure than the present accepted level of 200 r. The radiologists before 1930 received even much more radiation.

Another important finding in Warren's study was the fact that radiologists died at an earlier age from other diseases such as coronary disease, hypertension, cerebral hemorrhage, nephritis, infectious diseases as well as neoplasms. This difference in age was significant. For example, in cases of coronary heart disease, the non-radiologist died at 60.9 years and the radiologist at 58.6 years. This goes along with the general aging due to ionizing radiation. We thus have good evidence that chronic exposure of the human body to x-rays shortens the life span of a human.

Braestrup (15) in an attempt to estimate the amount of exposure the earlier radiologists received determined the radiation levels from the old non-protective installations of twenty-five years ago. He compared these with our present day equipment under similar working conditions. He concluded that these workers received about 100 r. per year whereas today they receive about one r. per year. On this basis he estimated that the radiologists in Warren's study received about 2000 r. in 40 years work. If this is true, then todays radiologist need not fear any significant decrease in life span.

In an attempt to establish a definite period of time that a life is shortened by 1 r. of radiation, Failla and McClement (12), with the aid of experiments in which mice were exposed to chronic low doses of x-rays made numerous calculations using the Gompertz function, applying it also to humans. After much calculation, they arrived at the conclusion that a human life is shortened one day per r. of accumulated exposure if the dose rate is less than 0.5 r. per day. The actual shortening might be somewhat more or less than this value, but from present evidence it is a good value to use as a basis for calculations. Thus we see by present standards of exposure, the life shortening is not significant, for a lifetime dose of 200 r. would shorten a life span by less than two-thirds of a year.

Now that the hazards of x-rays have been discussed, the next question is what can be done about them.

First let us consider the rooms in which the x-ray equipment is used. These need to be shielded so that there is none or at least minimum amount of x-rays getting outside of the room since the areas around the room in which the apparatus is installed is usually occupied by x-ray personnel and other personnel. The room must be adequate in size as there is back scatter from any object in the primary beam. Binks (16). When the x-rays pass through a patient there is a certain proportion of the x-rays that are deflected by the tissue of the patient. This then in turn is reflected in part from the walls of the room. Thus if personnel are working in the room, they are hit by this back scatter. The amount of this radiation that a person receives is inversely proportional to the square of the distance from the reflecting body. Thus if the wall is farther from the patient, less back scatter radiation will hit a given area of wall. However, the total amount of radiation hitting the wall will still be the same, but the personnel will be farther from the total area. Thus the dosage to personnel is reduced by distance. Binks feels that three to four feet between the equipment and any wall is the practical distance. Thus we see that the room should be of a size so that this can be obtained.

The x-ray room must also have adequate shielding to keep the radiation in the adjoining areas below the maximum permissible levels. Taylor (17). This requires primary and secondary shielding. The primary shielding is required in any part of the room that the useful beam may hit. The secondary protection is needed for all the rest of the room. The amount of primary shielding needed can be decreased by limiting the directions that the useful beam can be pointed. There must be enough freedom of movement, however, to take all views necessary for complete examination. In computing the amount of primary barrier, the length of time the useful beam will be pointed in that direction has to be taken into consideration. The National Bureau of Standards Handbook 60 (18) states that the workload should be assumed to be 1000 ma-min. per week at 100 kv., 400 ma-min.

per week at 125 kv., and 200 ma-min. per week at 150 kv. The workload is defined as "the working activity of a machine measured in milliampere-minutes per week". Handbook 60 states that the use factor should be considered as one for the floors and one-fourth for the walls. The use factor is defined as "the fraction of workload during which the useful beam is pointed in the direction under consideration". These values are quite high and probably much greater than would be encountered in actual practice, but this gives a good margin of safety. If we use the above values and consider that our equipment is five feet from the nearest occupied area, we need 1.5 mm. of lead for primary barrier for radiographic work. In the fluoroscopic room the fluoroscopic screen provides the primary barrier, therefore no primary barrier is needed. Assuming a workload of 4000 ma-min. per week for the fluoroscope and occupancy factors of one, one-fourth and one-sixteenth the secondary barrier needs to be 0.8 mm. lead at 100 Kvp., 1.1 mm. at 125 Kvp., and 1.3 Kvp. if the occupied area is three feet from the target. In the radiographic room the areas not covered by primary barrier needs a secondary barrier of 0.5 mm. lead if the previous radiographic load is carried and occupied area is three feet from the target. If the occupied areas are farther away, less lead is needed, but these values will insure adequate protection. Any moveable barriers used should not be depended upon for protection above 100 kv. If possible, there should be no windows in the room, but if there are, they should be protected with baffles. The useful beam should be prevented from hitting the doors and windows of the room if at all possible. A cubicle or barrier must be provided so that the operator of the radiographic equipment can be behind this barrier when the film is exposed, so that the operator receives practically no radiation. The booth must be arranged so that radiation has to be scattered at least twice or a door provided. The operator should be able to see the patient through a lead glass window sufficient to protect him.

Now that we have discussed the x-ray room, we will next discuss the diagnostic apparatus itself. First the equipment for radiography will be discussed. Handbook 60 states that "the tube housing shall be of diagnostic type". The diagnostic type housing must have 1.8 mm. lead or equivalent inherent protection. "Diaphragms or cones shall be used for collimating the useful beam and shall provide the same degree of protection as the tube housing. The total filter -- permanently in the useful beam -- shall be equal to at least 2.5 mm. aluminum. The aluminum equivalent of the table top shall not be more than 1 mm. at 100 kv. when a Bucky diaphragm is used under the table top. It is recommended that a timer or radiation exposure meter be provided to terminate the exposure after a preset time or exposure. A 'dead man type' of exposure switch shall be used or so arranged that it cannot be operated outside a shielded area."

The above requirements have to be met in all new equipment. However, there are many pieces of older equipment which do not have these factors built into them. If the tube housings on these machines are not adequate, they should be replaced or remodeled so that they meet these standards. Also whether old or new, the x-ray tube and cone assembly should be checked periodically for radiation leaks, especially following any repair or change in equipment. Ardran (19). This can be done with a fluorescent screen in a dark room or with film between intensifying screens. These are placed adjacent to the tube. The radiographic exposure is made with the tube window closed with lead. Any gross leaks should be detected this way. If any are found they should be plugged with lead. The cone area should be checked in the same way, but with the window open. The area on the film that is blackened should be less in diameter than the appropriate sized film. Also the cone should be checked with the end closed with lead to see if there is lateral leakage. If these above tests and additions are done, even the older machine will be made much safer and no doubt will be within the recommended requirements.

To go along with this above idea, Stanford (20), states that cones or diaphragms should be used at all times to cut the beam area to a minimum. This decreases unnecessary direct radiation, often leaving the gonads outside the useful beam as well. This also decreases the risk of scatter radiation which is more penetrating than the useful beam. The reason that it decreases scatter is that there is more tissue of the patient around the useful beam to absorb the scatter. Stanford also agrees with Ardran in the use of aluminum filters. He says that at least 2 mm. Al should be used for units up to one-hundred kvp. and 3 mm. for unites up to 120 kvp. The purpose of the aluminum is to cut out the soft x-rays that have the greater effect on the skin, but add little to the diagnostic film.

At least one of the manufacturers today has taken into consideration this need of variable sized cones. Vahjen (21). They meet this need with their double diaphragm collimator. By setting a dial, any square or oblong field can be dialed up to 17X17 inches at a 36 inch T.F.D. In addition, they have provided a light source that outlines the exact area on the patient with cross hairs in the center of the field. Thus just the area needed can be exposed and the operator knows just what area will be taken. This will help eliminate retakes because of poor positioning of the tube.

Another important factor in decreasing radiation to the patient as well as the personnel is the newer faster films that have been developed. Ardran (22). Ardran states that film speed has been increased at least forty times the speed that it was in 1898. This makes possible a definite decrease in exposure to the patient and any time the dose to the patient is decreased, it in turn decreases exposure to the personnel. Thus faster films used in conjunction with more efficient intensifier screens further reduce the amount of exposure necessary to get a good film.

The use of higher kilovoltages aids in the decrease of scatter. Binks (16). It is stated that for fixed filtration the ratio of incident dose to exit dose decreases rapidly with increasing tube voltage. Thus there is less of the incident beam lost via scatter. If there is less of the useful beam scattered, there is less scatter to reach personnel.

There are also certain things that the personnel need to do themselves to decrease their exposure. The operator should at all times be in the control booth or behind an adequate barrier in a position so that scatter radiation has to be reflected at least twice during the time that the exposure is being made. No one should be in the radiographic room unless absolutely necessary during a radiograph. No person should be regularly employed to hold patients during radiography and no one from the radiographic department should hold a patient at any time during an exposure. Any person holding a patient during an exposure should have on a protective apron and protective gloves. Even with these protective devices, no part of the person assisting should ever be in the unattenuated beam.

Next the fluoroscopic equipment will be discussed. Handbook 60 states the following concerning fluoroscopic equipment. "The tube housing shall be of diagnostic type. The useful beam shall be limited by a cone and an adjustable diaphragm that, when open to its fullest extent, leaves a margin of at least one-quarter inch of unilluminated fluorescent screen regardless of screen position during use. The cone shall extend from the tube housing to a position as near the panel as possible. Its wall shall provide the same degree of protection as the tube housing. The total filter -- permanently in the useful beam --

shall be equal to at least 2½ mm. of aluminum. The target-to-table-panel distance should not be less than 18 inches and shall not be less than 12 inches. A manually reset cumulative timing-device should be used which will either indicate elapsed time or turn off the apparatus when the total exposure exceeds a certain previously determined limit given in one or in a series of exposures. If the device indicates elapsed time, it should have a maximum range of 5 minutes. The fluoroscopic screen shall be covered with a transparent protective material having a lead equivalent of at least 1.5 mm. for 100 kv., or 1.8 mm. for 130 kv. For a routine fluoroscopy the dose rate measured at the panel or table top shall be less than 10 r. per minute. An apron of 0.25 mm. lead-equivalent hanging between the patient and the fluoroscopist in horizontal fluoroscopy is recommended, but shall not substitute for the wearing of a protective apron."

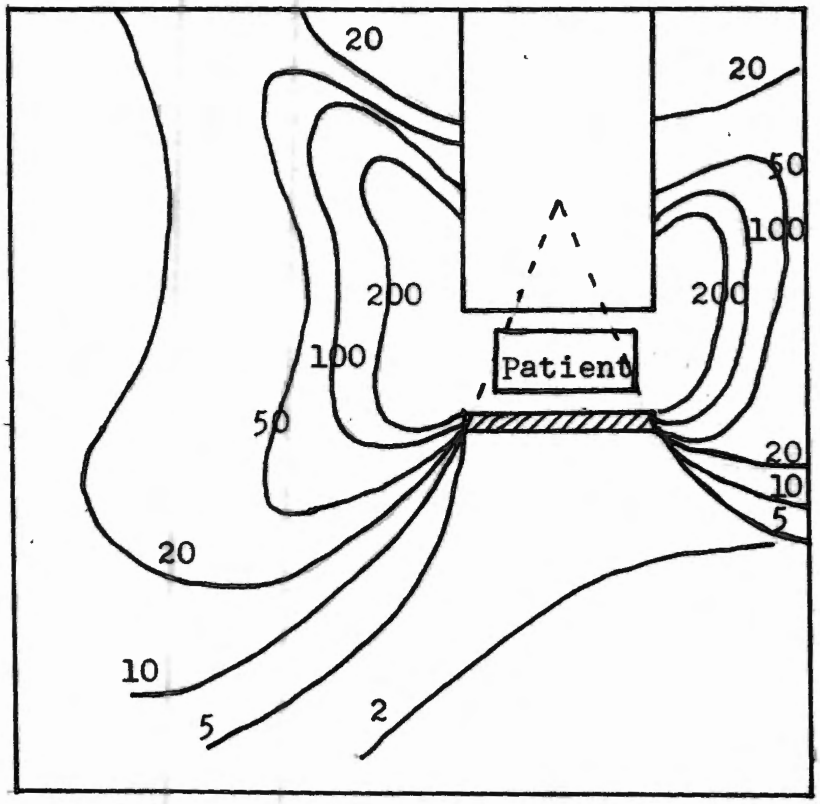
If the above recommendations are met in the fluoroscopic equipment and this equipment is used according to present standards, there should be no exposure over the maximum permissible levels. The newer equipment will meet these standards, but some of the older equipment may not. Such corrections as necessary should be made to these older pieces of equipment to make them meet these requirements.

Cederlund, Liden and Lindgren (24) devised a method to evaluate the scatter from their fluoroscopic equipment. They made two stands which had five horizontal bars set 0.05 m., 0.50 m., 1.10 m., 1.50 m., and 2.00 m. above the floor. These bars each had five English BD 11 type ionization chambers on them set 50 cm. apart. They placed these stands at various positions around their fluoroscopic equipment and measured the scatter when screening was done both in horizontal and vertical positions. They plotted isodose curves at these different levels above the floor. Thus they determined in what places personnel would receive excessive or high doses of scatter radiation. Figures 2, 3, and 4 give examples of these isodose curves at the levels that the doses were the highest.

These isodose values in figures 2, 3, and 4 were obtained using a tube potential of 80 kv. at 3 ma. with a tube wall equivalent of 1mm. aluminum with no extra filter. The half-value layer of the beam was

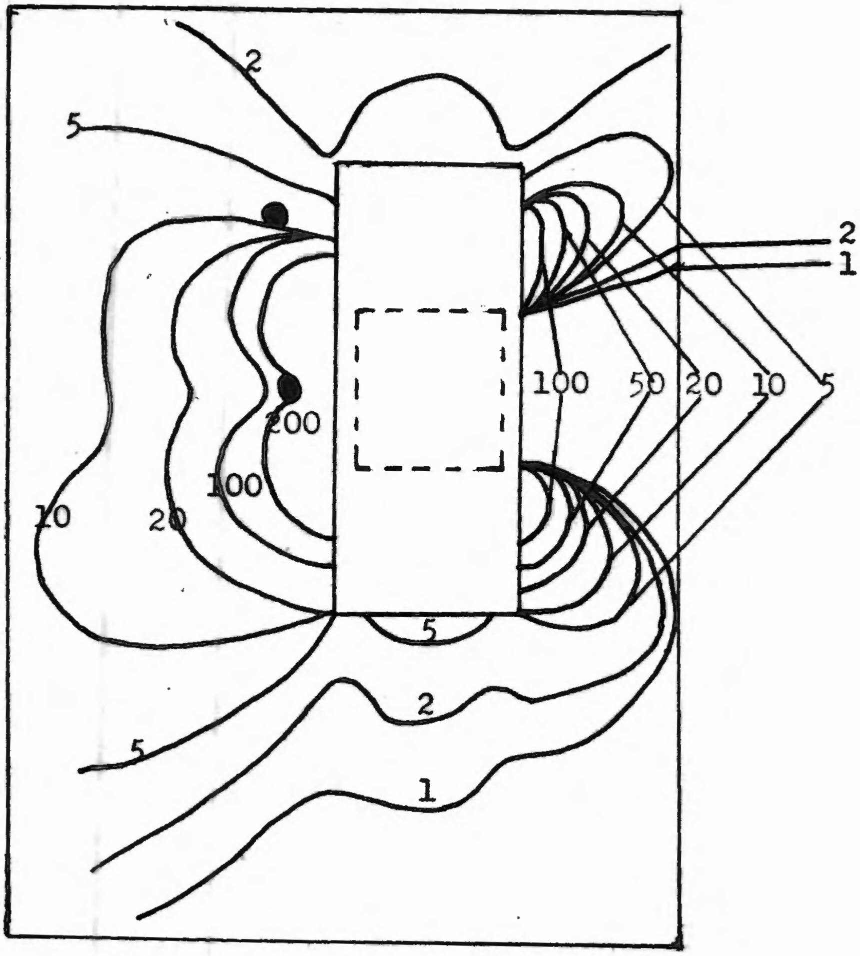
1.4 mm. of aluminum. The target-surface distance was 53 cm. with a field size of 30X40 cm. The phantom was 40X30X26 cm. of presdwood.

Figure 2



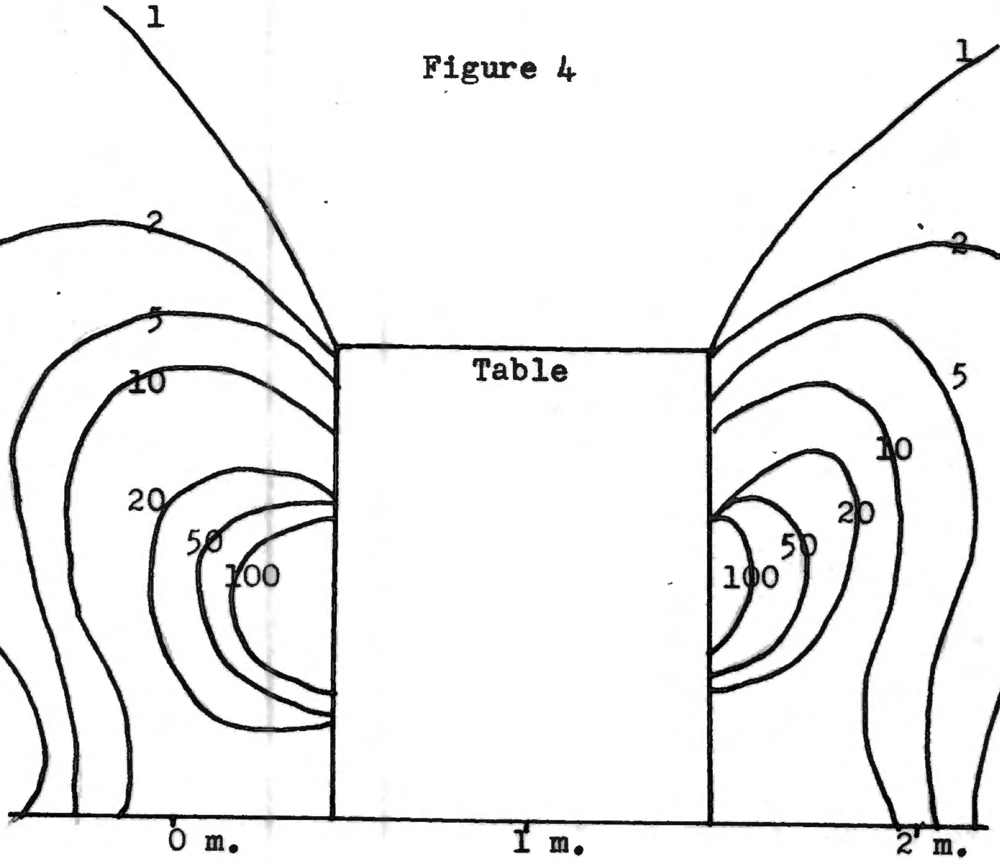
Isodose values 1.10 m. above the floor when doing vertical screening measured in mr. per ma-hr. Cederlund et al (24)

Figure 3



Isodose values 0.50 m. above the floor when doing horizontal screening measured in mr. per ma-hr. Cederlund et al (24)

Figure 4



Isodose values in a vertical section during horizontal screening in mr. per ma-hr. Cederlund et al (24)

They calculated from these data that the isodose curve for 2 mr. per ma-hr. is the boundary outside of which unprotected personnel can work without receiving a dose of more than 100 mr. per week when the working day is 10 ma-hr. or less. They concluded that the radiologist is quite well protected in any procedure as long as he is in the normal position behind the screen. In doing vertical fluoroscopy, however, any personnel just lateral to the patient can get quite high dosages. Thus assistants should stay away from this position if they are aiding the radiologist. Another means to decrease the scatter here would be to place a barrier on either side of the patient to cover up this area to prevent scatter from getting into the room. When the horizontal screening is done, again the radiologist is well protected but attendants on either side of him or on the opposite side of the table can receive considerable amounts of radiation. Thus any assistant or observer should wear a protective apron. A considerable amount of this scatter radiation comes through the slot in the table provided for the bucky. One of the manufacturers have provided a device which automatically closes this slot during fluoroscopic exposure. Vahjen (21). This provides a table that entirely encloses the tube with metal and thus decreases the scatter radiation.

Naturally these values shown on these figures pertain only to this piece of equipment, but similar isodose curves could be set up for any equipment.

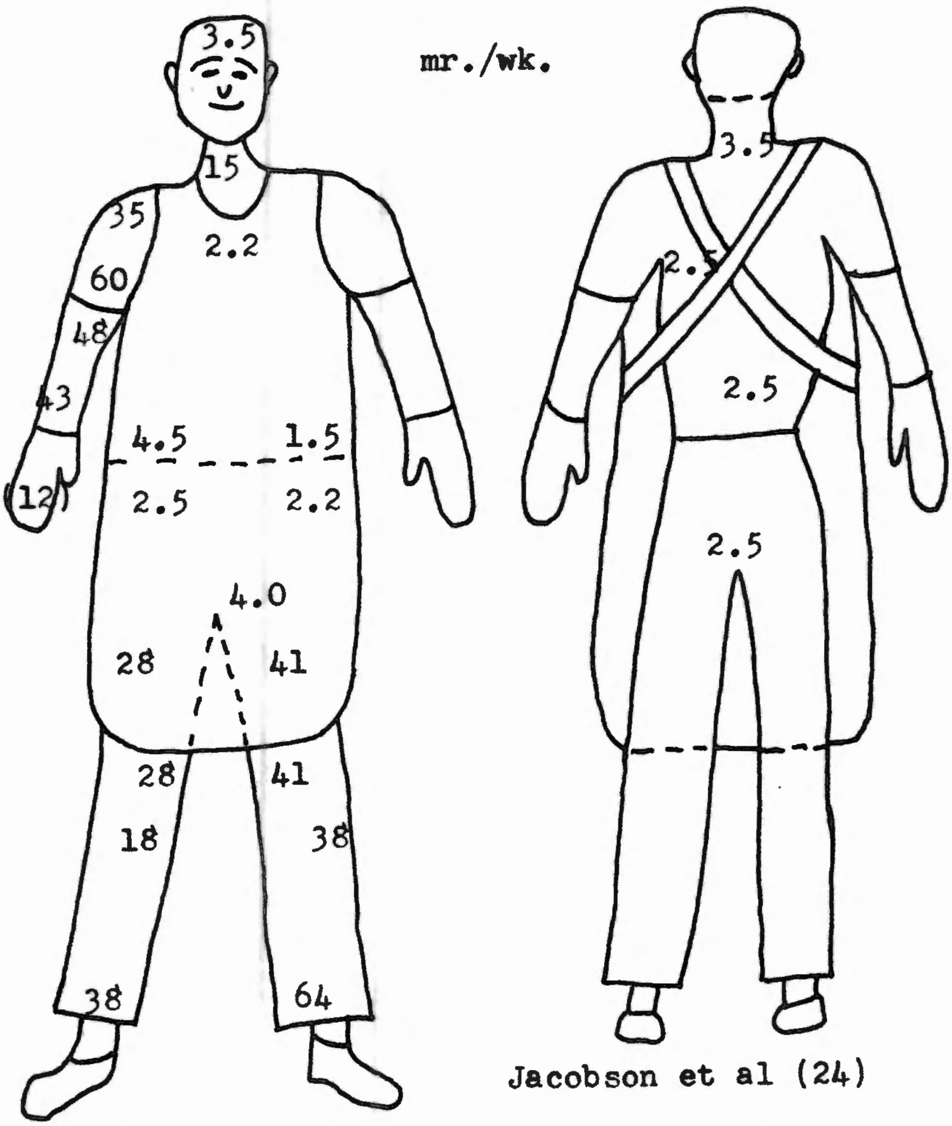
These curves do give an idea where to expect the highest doses of scatter radiation.

Further studies of exposure to the radiologist have been made by Jacobson et al (24) in which pocket dosimeters were worn at different positions on the body and the accumulative doses measured. These values are presented in figure 5.

From figure 5 we see that even to the highest dosage areas which are the upper arm, the radiologist only receives 60 mr. per week which is well below the 300 mr. per week maximum permissible dose. This figure also gives an idea of the area that receive the most exposure. These values agree quite well with the value seen on the film badge carried by these radiologists which varied from 0-40 mr. per week. These badges were carried on the upper arm where the dosage is the highest, thus we can assume that a film badge carried on the upper arm will give the maximum exposure that the personnel is receiving so it will be useful in monitoring.

Another method of studying the scatter exposure to the personnel was done by Crooks et al (25). They monitored the areas where the personnel were likely

Figure 5



Average mr. per week for fluoroscopic personnel for 50 min. per week average fluoroscopic time.

to work in the x-ray room with a cassette with intensifying screens using screen films placed for one week at a site to be studies. From these studies it was found that no personnel should ordinarily receive more than 3.5 mr. per week. If any area was found that it appeared that excessive scatter radiation was reaching it, the source was sought out and the cause corrected if possible.

In their study they also used personnel badges for monitoring in which Ilford PM 1 film was used. They found that in a busy department that the weekly dose could be cut to 5 mr. per week in 1955 and to 2.5 mr. per week in 1956. Even when doing considerable therapy it was found that it was quite practical to keep the dose down to 50 mr. per month. From all their data the authors concluded that 30 mr. per week rather than the present 300 mr. per week could and should be used as the maximum permissible dose.

It is seen from the above how important it is to monitor all personnel with film badges and to keep accurate track of the amount of exposure each of the personnel is receiving. Whenever any one of the personnel receives a dose higher than the rest of the personnel or higher than he usually receives, his technique and his equipment should be thoroughly examined. If there is no fault in the equipment, then he should be observed in his technique to see if he is making some error in his technique. This procedure will often bring about lowering of exposure.

There are some general principles that should be conformed to in the fluoroscopic examination. First of all the radiologist and all personnel in the room should wear lead aprons and if they are using their hands close to the machine or patient, they should wear lead lined gloves. These aprons and gloves should be checked periodically for holes and other flaws. Osborn (26). This can be done by examining these pieces of equipment either with the fluoroscope or with radiography of the equipment. If there are defects, they must be repaired or discarded because these flaws can be a source of considerable exposure.

Another important measure is to keep the fluoroscopic field to the minimum. This helps protect the patient and the radiologist as has previously been stated. The duration of the examination should be kept to the absolute minimum time consistent with adequate diagnosis. One important factor in this is dark adaptation of the eyes before attempting an examination. The eyes should be given at least 20 minutes dark adaptation. This can be done by wearing red goggles that permit no white light to reach the eyes. The radiologist should be very familiar with the examination and have a definite technique so that he can do the examination in a short time. Ardran, Emrys and Kemp (27) studied the length of time it took various examiners to do the various procedures in their departments. This is summarized in table III. There were 633 examinations done by six consultants and five trainees. These times were measured with a time clock built into the fluoroscopic circuit. The measurements were recorded over a period of time starting three months after the timer was installed so that the radiologists would be less concious of the fact that they were being timed.

From table III we see that at two different radiological departments the time was comparable. Thus we see that if the dose at the table top was the recommended ten r. per minute, the patient would get up to 128 r. in an upper gastrointestinal series, but it would seem that most of the patients would receive about 50 r. in an examination except for chest and hysterosalpingograms which were less. This does not tell how much the personnel is receiving, but it does show that there is sufficient dosage being used that the radiologist must be careful.

Table III
Actual times that the patient was exposed to the x-rays during various procedures

Procedure	Maximum	Minimum	Average
Upper G. I.	12'48"	2'50"	3'48"
Barium enema	9'49"	4'35"	5'11"
Chest & Heart	5'54"	1'05"	2'35"
Hysterosalping-ogram	3'48"	1'43"	2'18"
Retrograde pyelogram	6'43"	1'13"	5'44"
Upper G. I. at Harwell	8'30"	1'45"	4'54"
Barium enema at Harwell			5'00"

Ardran, Emrys, and Kemp (27)

There have been studies made of the exposure to personnel in some of the special procedures such as myelography, angiography and cardiac catheterization. Osborn (26) found that in cardiac catherization that the surgeon received 0.05-0.09 r. per case to his hands and up to 0.09 r. to his trouser pocket per case. Thus if he were doing 4-5 cases per week, he would receive his maximum permissible dose or more. The nurse assisting the surgeon received up to 0.05 r. per case also, so if she helped on more than one case per week, she would get excessive doses. Osborn found in cerebral angiography that the operator received from 0.01 r. to 0.2 r. during a case of 14 exposures, dependant on whether he used a lead shield or not. Thus we see that the lead shield should be used at all times. During this same case the anesthetist received 7 r. to his hands as he had his hands in the primary beam for a period of the exposure. Also in one case of 12 exposures, the operator received 2.35 r. to his hands because he had them in the primary beam for part of the exposure. We see from this that it is very important that the personnel do not get their hands in the primary beam.

Weens and Tolan (28) in their study found that the neurosurgeon may receive 50 mr. during a single cerebral angiogram. They found that the urologist may receive thirty mr. during a pyelogram and that the operator in cardiac catheterization may receive a 30-70 mr. to the forearm and hands. We thus see from their data that, although the dose from a single case is less than the maximum permissible dose, if they do many cases per week, they will exceed the limit.

Jacobsen et al (24) in their study found that during myelography that the radiologist received about 24 mr. to his upper arm when the average myelographic study was eight and two-tenths minutes in duration, and the neurosurgeon received about 20 mr. to his arm during the same procedure. The rest of their bodies received considerably less exposure. During cerebral angiography they found that on the average the neurosurgeon received about 17 mr. to the left shoulder and on the average three mr. to the rest of his body. However, one surgeon had his hands in the primary beam part of the time so he received 2.8 r. Thus we see here again how important it is to keep the hands out of the primary beam. In cardiac catheterizations they found that the operator received from 150-200 mr. per hour to the hands and the anesthestist and nurse each received from 30-50 mr. per hour to their hands. For angiocardiography they found the exposure to the hands of the operator to be on the average of 20 mr. per series of exposures.

All these studies point up the fact that these special procedures that involve others than the trained radiologic staff do definitely get exposures that are significant. It is the radiologist's duty to instruct and suggest ways that these personnel can conduct their examinations with the least exposure to themselves and the other involved persons.

Emanuel and O'Conner (29) have described a means for decreasing exposure to the urologist during retrograde pyelography. They use a lead-rubber apron with hooks fastened to the apron so that it may be hung over an arm of the x-ray machine. This apron has a 1.5 inch hole cut in the center of it with a lead rubber flap attached to hang down over the hole. The apron is hung so that the patients thighs, buttocks and genitals are covered. The cystoscope and catheters can be passed through the opening. This cuts down the exposure of the urologist's hands to 10% of the exposure without the device. Thus we have an easy and good way to decrease the urologist's exposure.

A further step to be considered in decreasing exposure is to use the kilovoltage and milliamperes that give the least exposure with adequate visualization. Also when examining the patient, intermittent exposure is better than continuous exposures for decreasing the exposure. A foot switch leaves the hands free for moving the screen and permits the exposures to be decreased. There are also some things that should never be done -- setting fractures with the aid of the fluoroscope, removing foreign bodies with the aid of the fluoroscope and doing head fluoroscopy because they give grossly excess radiation doses.

There is one other means of decreasing exposure to the patient and personnel that is to be discussed in this paper. This is the image intensifier and cineradiography, Nemet and Ing (30). This is an apparatus that attaches to the fluoroscope that permits a gain in brightness of at least 1000 times. This permits a lower exposure to the patient and thus to the radiologist. Another factor is that the image intensifier permits cineradiography at radiation doses that are not overly hazardous as the previous methods of cine-radiography were. For example, older methods required an exposure of about 300 r. per minute for abdominal movies, and for heart it was 325 r. per minute. However, with the intensifier, the heart can be photographed with an exposure of 9 r. per minute and the abdomen with 6.4 r. per minute. These values are considerably less than previously. Also this method can permit a shortening of the duration of the fluoroscopic examinations at times because the full range of maneuvers and areas to be exposed in a set manner. Even if the radiologist is not satisfied that he has seen all that he wants to, he can review the movie of the examination rather than prolonging or repeating the examination to patient. This also permits a permanent record for future comparison. There are disadvantages, however, in that the apparatus is very expensive. Also the image is smaller and a certain amount of detail is lost due to the small size and the high magnification.

We have discussed many things that the radiologist can do to decrease his and his personnel's exposures. There are many other small details that he can do also to help to decrease their exposure. The important thing is to remember that all radiological personnel should be constantly alert to the hazards of their profession and do everything that they can do to keep their exposures to a minimum. They must remember that all radiation is detrimental no matter how slight and that it all is cummulative so that once they receive it there is no getting rid of the radiation.

SUMMARY

Shortly after the discovery of x-rays in 1895, it was learned that there are certain hazards to the use of x-rays. The hazards discovered early were those of skin reactions and baldness. Steps were

soon taken to decrease the exposure levels enough so that these superficial reactions were pretty well eliminated. It was about 13 years after the discovery before protective devices were being mentioned in the manufacturer's catalogues, however. It was not until 1931 that a definite dose level was set as a maximum permissible dose. This dose was 0.2 r. per day. From this time on more and more was learned about x-rays and how to decrease the dangers from them. Some of these means were better rectifiers, aluminum filters, lower voltages, smaller fields, shorter exposures and better shielding of the equipment and personnel.

A national and an international organization were established in the 1940's to study the effects of x-rays and make recommendations as to doses and equipment. They have continued to revise the standards and the maximum permissible doses downward until the present levels were established in 1956.

The two general types of effects of x-ray exposure, the immediate and the delayed, were discussed. The immediate effects are skin erythema, skin burns, skin necrosis, epilation and death. The delayed effects are formation of cataracts, impairment of fertility, alteration of hematopoetic tissue, induction of malignant tumors and shortening of life span.

There are many things that can be done to provide protection from exposure to x-rays. The x-ray room should be well shielded with lead to prevent scatter into adjacent areas. There also should be a shielded cubicle to protect the radiographer. The diagnostic equipment needs to be shielded so that there is little radiation getting into the room except that of the useful beam. The equipment should be checked carefully periodically for leaks and these repaired if they are found.

A number of methods of decreasing the exposure to the patient and thus to the personnel was discussed. This included protective garments for the personnel, certain things that the personnel should not do, such as placing any part of their body in the useful beam.

Various means of surveying the equipment for radiation leaks were discussed and various means for decreasing scatter and radiation leaks were discussed. Personnel monitoring with film badges was discussed.

Exposure of other specialists that use x-rays in special diagnostic procedures such as myelography, angiography and such were discussed. Some methods of decreasing their exposure during these procedures were discussed.

The use of the image intensifier was discussed. This can decrease exposure to radiation as well as provide a permanent record of fluoroscopic examinations.

CONCLUSIONS

1. If the present day standards are met, radiological diagnosis is safe for the patient and the radiologic personnel.

2. Exposure should be kept to a minimum at all times.

3. There are definite hazards in the use of x-rays, but with care they can be minimized.

4. The aid to diagnosis and the number of lives that can be improved or saved by the use of x-rays, warrants the use of x-rays when they are indicated.

5. The radiologist should monitor his department well and see that all his personnel conform to the regulations.

6. The radiologist should instruct all specialists in other fields who use x-rays in their diagnosis the proper precautions to use during the use of x-rays.

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