MANUAL ON RADIATION PROTECTION
IN HOSPITALS AND GENERAL PRACTICE
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ON RADIATION PROTECTION
IN HOSPITALS
AND GENERAL PRACTICE

Volume 4
Radiation Protection in Dentistry

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Much technical material has been published at the national and international levels on radiation protection in the nuclear power industry, nuclear research, and conventional industries. On the other hand, the subject of radiation protection in hospitals and general practice, where a large proportion of public and occupational radiation exposure occurs, has not yet received much attention in the international literature.

The International Labour Organisation, the International Atomic Energy Agency, and the World Health Organization all have a long-standing interest in these problems from various points of view. They therefore decided to collaborate in the preparation of a Manual on Radiation Protection in Hospitals and General Practice in several volumes, with each agency taking special responsibility for the volumes that concern it most. However, to simplify distribution and to make it easier for readers to purchase the various volumes, the entire work is being published by WHO.

The manual as a whole deals with the radiation protection of patients, occupationally exposed persons, and the public and is written for the reader having a basic general knowledge of radiation and biology. It is hoped that it will be found helpful not only to those who are directly engaged in radiation protection in hospitals and general practice but also to national authorities, hospital administrators, supervisors, hospital workers, teachers in training centres, and all those who have some responsibility in the subject.

The present volume, the fourth in the series, deals with radiation protection in dentistry. Dental radiology has developed as a subspecialty of radiology in several countries and is applied most frequently by dentists rather than radiologists. The aim of the work, taken together with Volume 1, is to provide the dentist with all the technical information he needs to perform appropriate dental radiology safely and efficiently without bothering him with problems of general radiology with which he is not directly concerned.

The preparation of the volume was undertaken by Dr Kristian Koren and Professor Arthur H. Wuehrmann. Originally planned as a separate book, the text was modified by Dr Koren in collaboration with Dr W. Seelentag to harmonize with the other volumes of the manual.

The draft was reviewed by the experts listed on page 7, some of whom are the authors of other volumes in the series. The observations received were taken into account in the preparation of the final text, and the contributions are gratefully acknowledged.
1. The Need for Radiation Protection

The use of ionizing radiation in dentistry, like that in general medicine, was initiated soon after the discovery of X-rays by Roentgen in 1895. A rapid growth in the application of this new tool by dentists can be dated from 1913, the year of Coolidge's invention of the hot-cathode X-ray tube. By the decade following 1930, X-rays had come into general use in dentistry. Today, particularly in the more highly developed countries of the world, a complete radiographic survey of the mouth is considered an essential adjunct to diagnosis, and indeed, failure to examine a dental structure radiographically prior to diagnosis and treatment has in certain places been considered an act of malpractice. This vast increase in the use of X-rays by the dental profession calls for the development of guidelines, the purpose of which is to protect the dentist and the public by offering suggestions for minimizing exposure of the individual and the population as a whole.

The ionizing radiation used by the dental profession is mainly limited to X-rays, and this book deals only with that subject. The reader's attention is also directed to the radiation protection recommendations published by the International Commission on Radiological Protection and by the International Dental Federation.

Three kinds of biological consequences of radiation exposure of man are usually considered for radiation protection: (1) evident somatic effects, e.g., erythema of the skin up to destruction and necrosis of tissues, and retardation of growth when epiphyseal regions in children are irradiated; (2) somatic stochastic effects, sometimes called "late" effects, e.g., leukaemia, cancer, and life shortening; and (3) genetic effects occurring in the descendents of the irradiated persons. These effects are described in detail in Volume I of this manual, pages 19–26.

The unit of exposure to X-rays used in this book is the roentgen (R) or the milliroentgen (mR). The new SI unit for this quantity recommended by the Conférence générale des Poids et Mesures is the coulomb per kilogram (C/kg), which it is intended should replace the roentgen by 1985. To enable readers to become familiar with the new unit, values expressed in roentgens are also given in coulombs per kilogram (in parenthesis). The conversion factor is 1 R = 2.58 × 10⁻⁴ C/kg. For definitions of the quantities

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and units used in dosimetry the reader is referred to Volume 1 of this manual, page 16.

In dental radiology, the genetic effects are particularly important owing to the great number of persons undergoing dental examinations and the high radiation dose that can be delivered to the gonads if radiation protection measures are not properly applied. It has been demonstrated that the dose to the male gonads, due to a full mouth series of films, can vary from 0.01 mR (2.5 \times 10^{-9} \, \text{C/kg}) when appropriate techniques are used (including the application of a lead rubber apron to the patient) to over 200 mR (5 \times 10^{-5} \, \text{C/kg}) when little care is taken. The resulting factor of more than 20 000 between the two extreme techniques means that one full mouth exposure with a careless technique has the same genetic impact on the population as 20 000 such examinations performed on patients of the same age and sex with a careful technique!

Somatic stochastic effects are of less importance in dental radiology because of the limited extent of the irradiated volume. However, a careless technique and unnecessary repetition of examinations can provide considerable radiation doses to the mucosa of the mouth, the eye, and the thyroid. Irradiation of the thyroid can increase the frequency of thyroid tumours, particularly in children.

Evident somatic effects must not occur after dental radiology, and are to be considered as a technical failure. When using obsolete equipment or applying careless techniques, however, such effects are still possible. One of the most common effects is chronic radiation dermatitis of the fingers of the dentist or his technician caused by holding the films in the mouth of the patient and so exposing the fingers to primary radiation. Following the rules in this manual will prevent all such occurrences.

It has been demonstrated that the X-radiation exposure at the cone end from a complete mouth radiographic survey varies with practitioners from less than 5 R (13 \times 10^{-4} \, \text{C/kg}) to more than 200 R (5 \times 10^{-2} \, \text{C/kg}). This fact puts into perspective at least one aspect of the total problem and demonstrates how radiographic exposure can be reduced when maximum radiological care is exercised by the practitioner and the radiographic equipment is fully satisfactory.

It is also important to remember that the number and variety of radiation sources contributing to the total exposure of the public is continuously increasing. No user or group of users of ionizing radiation has the right to defend its position on the basis that, in comparison with other users, it is producing only a small population exposure and is therefore immune to

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1 Equipment not conforming to the recommendations given in the following publications:

criticism. All users of radiation must take every practicable step to minimize the exposures for which they are individually responsible, even if the resulting reduction from any one step is small compared to the total radiation burden to which the patient or the population is subjected.

In years past, when less was known about radiation effects, the dentist-patient relationship with regard to the use of X-rays was strictly a personal one. This is no longer the situation. It is now realized that the exposure of a patient may have a genetic effect, even though only a small one, involving the future population as a whole. Radiation exposure has the potential effect of influencing the genetic cells in the irradiated individual and ultimately of contributing to genetic alterations in ensuing generations.

An aspect of medical and dental radiology that is often overlooked is that most of the measures taken in the interest of radiation protection also contribute to the quality of the radiographic image produced and hence to the quality of the diagnostic service that can be rendered by the practitioner. *Almost without exception, the recommendations made in this manual, designed to reduce unnecessary radiation exposure of the patient, will result in the production of superior radiographs and assist in eliminating unnecessary exposure of the operator himself.*

In the past, the service rendered by the professional individual was generally not checked by a third party or agency competent to render judgment on the quality of the service. As standards of living increase and greater attention is given to the health needs of those who in the past were economically excluded from medical and allied services, some measure of quality control will be introduced. This development should not disturb any except those whose professional practice may be below desirable standards.
2. Delegation of Responsibility

Practitioner judgement

The responsibility for the conduct of a dental practice has traditionally been that of the licensed practitioner. While auxiliary personnel working in the dental office may also perform certain duties, the dentist is responsible for the actions of his employees, whether or not they are separately licensed. In so far as radiation protection is concerned, the practitioner is responsible for determining the frequency with which single- or multiple-film radiographic examinations are to be made and for approving the quality of the resulting radiograph. Should the quality of the radiograph be inadequate, the practitioner is responsible for improving the technique of the individual who produced the faulty film. This responsibility brings into focus the concept of "yield."

"Yield" may be defined in several ways. For present purposes, it may be thought of as the amount of diagnostic information made available per unit of exposure. Should the clinical findings, without radiographic films, be sufficiently definitive to authorize treatment, the radiation exposure of an individual would produce no yield and hence would not be justified. Should a diagnostic film be needed to support clinical observations, a technically inadequate film (from whatever cause) would render a less than maximum yield. The re-exposure of the patient because of technical inadequacies is inexcusable. A second film can be justified only on the ground of giving additional supporting evidence, and some deliberate alteration in technical procedure is usually required in order to gain the desired result. The inability of the practitioner adequately to interpret an otherwise satisfactory radiograph also minimizes or completely negates the anticipated yield. Thus, the practitioner is responsible for deciding need, for ensuring technical competence, and for developing within himself or those who interpret his films a high level of interpretative ability.

Frequency of radiographic examination

The frequency with which a complete mouth radiographic examination is made for an individual patient will vary with circumstances. This judgment must be left to the practitioner, but many dentists have voiced the opinion that it would seem unnecessary to re-examine the entire dentition more often than once every five years. Single films are often necessary in order to obtain information about questionable areas, and bite-wing films
used with the intention of instituting early treatment (or of following radiographically the results of treatment) must of necessity be taken at more frequent intervals. Bite-wing films for the detection of caries in children and young adults usually need not be taken more frequently than once every six months. Certain clinical procedures necessitate the use of multiple radiographs in the course of treatment.

Use of radiation in clinical dental research involving human exposure

Any use of ionizing radiation in research involving human beings should be meticulously controlled. For dental radiology the same principles must be applied as for other medical work (see Volume 1 of this manual, page 34).

Need for control by a public body

The public health service of every country is responsible for promoting and creating favourable conditions for improving the standard of health of the population. A significant part of this general responsibility, which has grown in importance in recent years, relates to the protection of the population from radiation. With the steadily increasing use of ionizing radiation in dentistry, competent authorities should stress the importance of adequate control to protect the public from excessive exposure.

A competent authority that supervises physical factors such as filtration, collimation, timer functioning, timer cord length, tube head leakage, and radiation barriers (see Chapter 8) exists in a number of countries and can be advocated for countries where it has not yet been established. There is also a need for the competent authority to supervise that part of the dentist's working technique that has a direct bearing on patient exposure—e.g., the speed of the films he uses, the exposure times he selects, and the efficiency of his darkroom processing. This aspect of control, however, should preferably be of a more advisory nature and should interfere as little as possible with the dentist's work and his relationship with his patients.

Some consideration should be given to the need for control in matters relating to radiographic interpretation. Failure to interpret a radiographic film properly or a tendency to misinterpret radiographic evidence is a serious and unacceptable shortcoming. Admittedly, control of radiographic interpretation is a delicate matter since it can be construed as questioning the dentist's ability to discharge his professional duties, but in the interest of the public's wellbeing decisions may have to be made that impinge on professional immunity.
3. Radiographic Equipment

The X-ray machine

Line voltage and frequency; proper grounding (earthing) of equipment

Electrical line voltage and the frequency of the alternating current will vary from country to country and, in some instances, between cities in a given country. Caution must be exercised to ensure that the X-ray machine employed is designed for the available line voltage and frequency. The X-ray machine should be suitably grounded (earthed) to prevent electrical shock, and a mains switch and fuses must be incorporated in the circuit. During installation, care must also be taken that the electricity supply is not subject to significant variation owing to the intermittent operation of other electrical machinery in the neighbourhood.

Tube housing, transformer, and X-ray tube; rectification of the supply

The tube housing should be of the diagnostic type, recommended by the International Commission on Radiological Protection, or of corresponding quality. The high-voltage transformer is usually included in the tube housing, thus ensuring that the wiring to the tube housing carries no more than 250 volts. The X-ray tube commonly used in dental machines is a self-rectifying tube that has a focal spot not more than $1.5 \times 1.5$ mm in size. Self-rectification is usual when the high-voltage transformer is confined within the tube head. The monitoring of radiological equipment for protection purposes is considered on pages 44-45 and in Volume 1 (Chapter 7) of this manual.

Filtration

The authors recommend a minimum total filtration for dental X-ray machines of 1.5 mm of aluminium for dental X-ray machines operating at up to 70 kV and 2.5 mm for machines operating at over 70 kV. Normally

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3 The International Commission on Radiological Protection recommends, for general diagnostic X-ray installations, 1.5 mm of aluminium for voltages up to and including 70 kV, 2.0 mm above 70 kV and up to 100 kV, and 2.5 mm above 100 kV. For dental machines, however, the Commission considers that a filtration of 2.0 mm of aluminium at 50-70 kV is adequate. These recommendations are given in the Commission’s publications 15 and 16.
the inherent filtration in the machines (represented by the radiation attenuation in the glass of the X-ray tube, the medium surrounding the tube, and the oil seal at the radiation exit window) will not meet the minimum recommendations, and additional external filters will probably be required. The location of parts contributing to inherent filtration is shown in Fig. 1.

**FIG. 1. X-RAY TUBE HEAD SHOWING FILTRATION OF THE BEAM**

![Diagram showing filtration of the X-ray beam](image)

**Timer**

The X-ray timer should preferably be of the electronic or synchronous motor type, both of which give the higher precision required since the advent of increased film speed for intraoral radiography. Regardless of the timer used, the accuracy and consistency of the timer can be verified by the “spinning-top” test.

The spinning-top is essentially a heavy metal disc containing a small hole (or in some cases several holes that can be opened or closed by movable metal plugs). The disc is rotated over the surface of a film sufficiently large to encompass the dimensions of the top. It is spun slowly (less than one revolution per exposure interval) and X-ray exposures are made using a
variety of time intervals. Owing to the pulsating nature of the power supply the X-rays occur in the form of “bursts”, and images of the hole will appear as black dots on the film (Plate 1). The number of such dots should be consistent on repeated exposures and in accordance with exposure time and the frequency of the electrical supply.

X-ray timers should be activated by an override switch that will terminate the exposure abruptly if the switch is released, even though the timer may not have completed the exposure.

Although it is generally advisable for dental X-ray machines to be equipped with electronic or synchronous motor-driven timers, mechanical timers can be employed with high-speed film provided one or more of the following steps leading to exposure prolongation are taken: the electric current may be reduced, the amount of filtration may be increased, and the source-to-film distance may be increased. In the first two instances, the quantity of radiation leaving the X-ray machine per unit of time is reduced. In the latter instance, the quantity of radiation reaching the film is reduced on the basis of the inverse-square law. A dental practitioner will normally leave such technical alterations to a service company.

Timer cord

In the absence of a protective barrier, the timer cord should be of sufficient length to permit the operator to stand at least 2 m from both the patient and the source of X-radiation, out of the primary beam. The position of the operator is more fully discussed on page 32.

Cones

Dental X-ray cones are generally of two types—the pointed plastic cone and the open-ended cone (which is often made from plastic also). The cones are used as pointing devices and for the purpose of maintaining a constant source-to-skin distance. Obviously, the pointed cone cannot be lined. Pointed plastic cones are contraindicated unless they are equipped with an effective beam collimator, because much of the scattered radiation from a dental X-ray machine originates in the filter and the plastic of the cone. The pointed plastic cone, when used, should be collimated by a metal diaphragm, and by an appropriate metal tubular device inside the cone. Open-ended cones, regardless of length, should be provided with a collimator of such dimensions that the X-ray beam at the end of the cone matches the diameter of the cone at that point. They should be made of metal or lined with lead. The purpose of the lining is to absorb radiation coming from outside the focus of the tube and scattered radiation coming from the filter and other parts of the assembly.
Safety signals

Each X-ray machine should be equipped with a warning device indicating that the machine is turned on. In addition, it should be equipped with a second but different type of signal that indicates when X-radiation is being generated. In the rare instance that more than one tube is used with the same generator, the warning device should indicate which of the tubes is going to be activated. It is realized that old machines often do not have such devices. It is essential in this case to make sure that the machine is not operated unintentionally, e.g., by timer defects or short-circuiting. It is recommended that the machine should be connected to the mains (by a separate mains switch or plug) via mains fuses. The supply should be switched on only when the machine is about to be used and should be switched off after use.

The X-ray beam

Collimation, and further consideration of cones

The X-ray beam coming from the tube head should be of a size and shape adequate to cover the area under examination plus a small margin peripheral to the area in question. The peripheral allowance should be regarded as a margin allowing for small differences in focus–film distances and differences in alignment. Beam collimation is accomplished by means of a diaphragm, the internal shape and size of which are designed to provide the proper beam dimension. The diaphragm is placed at the top of the cone and must be of such size that it fits the diameter of the cone and the X-ray exit window. The beam shape is usually round, but there are advantages in a square or rectangular beam. For intraoral radiography, a beam diameter of 7 cm or less at the cone end is preferable. Beam diameters must be changed for extraoral projections by using suitable diaphragms or, preferably, special cones. Lead-lined open-ended cones or properly collimated pointed cones are used for directing the beam, for maintaining a consistent source-to-skin distance, and for eliminating primary and secondary radiation not parallel with the useful beam.

For extraoral panoramic exposures the X-ray beam is collimated to a very narrow line of radiation when it passes through a slit mounted on the tube head. The image is created by letting the tube and the film holder rotate around the patient’s head.

External (added) filtration and half value layer (HVL)

As mentioned earlier, the filtration for machines operated at 70 kV or less should be a minimum of 1.5 mm of aluminium. For machines operated
above 70 kV, the filtration should be a minimum of 2.5 mm of aluminium. Added filtration is needed if the inherent or "built in" filtration is inadequate. One can determine whether or not additional filtration is needed by sequentially adding 0.5 mm thicknesses of commercially pure aluminium at the tube housing exit window until, under constant and recommended processing and exposure times, there is evidence that the addition of the ultimate disc of aluminium materially reduces film density. This procedure requires a tissue or tissue equivalent absorber between the X-ray source and the film.

A more accurate procedure, but one requiring some type of radiation measuring device, is that which establishes the half-value layer of the beam. The object of the half-value layer is to serve as an indication of X-ray beam penetrability. It is defined as that thickness of a specified absorbing material which, when introduced into the path of a beam of radiation, reduces the exposure rate to one-half of its original value.¹ For X-rays having the penetrability of those commonly used in dental radiography, one must use aluminium for measurements of the half-value layer. For voltages of 70 kV or below, the half-value layer should not be less than 1.5 mm of aluminium; for voltages above 70 kV it should be at least 2.5 mm aluminium. Fig. 2 illustrates the effect of filtration.

FIG. 2. EFFECT OF FILTRATION ON BEAM QUALITY

Voltage

The difference in potential existing between the anode and the cathode of a dental X-ray tube is usually expressed in kilovolts or, more specifically,

Owing to the pulsating nature of the electricity supply (usually 50 or 60 Hz) an exposure appears as a number of dots. Counting the dots gives the true time of exposure, which may be compared with that at which the timer has been set. The first few dots of each exposure interval are lighter in intensity than the rest and represent the time taken for the filament to warm up. This phenomenon can be avoided on some X-ray machines by switching on the filament before making the exposure. If this is not possible, it is necessary to discount the first few hundredths of a second of each exposure.
PLATE 2

A. EXCLUSION OF PERIPHERAL LIGHT

Peripheral light surrounding the radiograph should be eliminated by masking. The visual effect of doing this is greater than would appear from the photographs because the white border is actually bright transmitted light.

PLATE 2

B. SPOT VIEWER

There are various kinds of spot viewer. The one illustrated here employs a constant light source and an adjustable iris diaphragm. Other devices are available in which the light source can be varied in intensity.
in peak kilovolts (kVp) when the tube is self-rectifying (Fig. 3). The peak voltage used in dental X-ray machines varies over the range 45–100 kVp and is permanently set at a fixed value in many machines—e.g., 50, 60, 65, 70, or 75 kVp. Voltage directly controls the quality or penetrability of the X-ray beam and therefore the contrast of the radiograph, the skin dose, integral patient dose, back-scatter, and film exposure. Generally speaking, the higher the voltage the more penetrating the X-ray beam. In addition, the voltage influences the radiation output.

**Current**

The reading on the milliammeter dial on the control panel of an X-ray machine (if fitted with such an instrument) gives an indication of the electric current flowing through the tube circuit. It is important to bear in mind that exposure rate is directly correlated with current, although the relationship is not always linear.

**Exposure time**

A direct linear relationship exists between exposure and irradiation time. The exposure time in radiology is an expression of the time an X-ray machine must be operated to produce a radiograph of suitable density. The exposure time will vary with the object under examination. The setting of the timer is not necessarily identical with the exposure time because the timer, in addition to closing the high-voltage circuit of the tube, also closes the filament circuit to permit heating of the tube filament. Depending on the
X-ray machine, there may be a noticeable delay before the filament reaches full heat.

**Auxiliary devices**

*Protective aprons and movable and permanent shields*

Protective aprons and shields are used to protect the patient and operator against stray radiation. This radiation has no function in image forming but increases the level of the dose. Operators can also protect themselves by proper positioning during exposure (see page 32) and by standing behind movable or permanent shields of some suitable material. Such shields become mandatory if the workload is high. Clinics where patients are being examined radiographically on a continuing basis should be equipped with permanent shields. Private dental offices where radiographs are made on a routine basis do not usually require permanent shielding, provided the operator and any auxiliary personnel position themselves correctly during exposure. Consideration must also be given to the protection of individuals located in rooms immediately adjoining the radiation area (see page 44).

Protective aprons for patients should have a lead equivalent of 0.25 mm or more, the thickness depending on whether an effort is being made to absorb only scattered radiation or primary leakage radiation as well. Since patient protection is basically related to genetic effects that may influence future generations, protective aprons should obviously cover the gonads of the patient. Unless large amounts of radiation are to be given or there is a prior history of heavy irradiation, the use of protective aprons with individuals beyond child-bearing age seems unnecessary.

In addition to aprons, other shielding devices are commercially available, e.g., neck-shields masking the body.

*Film holders and paralleling devices*

The patient usually holds intraoral dental films in place with his own fingers, but several different film holders and devices are commercially available that will eliminate unnecessary exposure of the patient's hand and produce even better radiographs. No single device is suitable for all cases, and it is recommended that the operator familiarize himself with all such devices and select those that appear to be most suitable to him. Under no circumstances must the operator hold the films in place for the patient.

*Extension cone alternatives*

Cones are used to standardize the source-to-skin distance. Several devices are available for attachment to the X-ray tube head and/or to the
short cone that project an arm forward beyond the cone and thus provide a standard source-to-skin distance greater than the length of the short cone. These devices do not, however, contribute to beam collimation or to the absorption of radiation other than that included in the useful beam. There is also an inherent shortcoming in the use of such extension arms that must be recognized and eliminated by the operator. Frequently, the extension arm is attached to the short cone without any change in the internal diameter of the collimator that is used to establish beam size. The beam diameter thus increases with the increase in distance, and a considerably larger area of skin will be irradiated each time an exposure is made. This can be avoided only by fitting a new collimator that has an internal diameter capable of producing the recommended beam diameter at the skin surface.
4. Radiographic Film

Intraoral film

Intraoral film has been standardized by the International Organization for Standardization according to size and speed groups.\(^1\) Sizes are defined in metric measurements, but some manufacturers continue to offer film in non-metric sizes, and these are included in the table below.

Film size

Three types of intraoral film are available: periapical, bite-wing, and occlusal film. The prefix or suffix “W” is used to indicate that the film has a bite-wing tab.

<table>
<thead>
<tr>
<th>Size number</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mm</td>
</tr>
<tr>
<td>0</td>
<td>22.0 × 35.0</td>
</tr>
<tr>
<td>1</td>
<td>24.0 × 40.0</td>
</tr>
<tr>
<td>2</td>
<td>31.0 × 41.0</td>
</tr>
<tr>
<td>3</td>
<td>27.0 × 54.0</td>
</tr>
<tr>
<td>4</td>
<td>57.0 × 76.0</td>
</tr>
<tr>
<td>5</td>
<td>40.0 × 50.0</td>
</tr>
</tbody>
</table>

For purposes of clarification, film size 2 is the standard periapical film, size 1 being narrower and slightly shorter for use in the anterior part of the adult mouth in a vertical position. Film 0 is a small periapical film intended for children. In terms of yield, the dentist should give serious consideration to the elimination of films of this size from his stock. A film of size 1 can be inserted in a young child’s mouth in either the vertical (anterior) position or the horizontal (posterior) position.

Bite-wing films have the same dimensions as the periapical ones and differ only in having a bite-wing tab attached. The comment on the size 0 films applies also to these films. The size 1 anterior and posterior films are suitable for adult use and the size 1 posterior film is suitable for children.

The size 4 film is the conventional occlusal film.

\(^1\) INTERNATIONAL ORGANIZATION FOR STANDARDIZATION. *Photography - intra-oral dental radiographic film — specification.* Geneva, 1976 (ISO 3665-1976 (E)).
Film speed

The speed of a radiographic film emulsion is defined as the reciprocal of the number of roentgens necessary to produce a film density of unity under standard conditions of exposure and processing. In the system recommended by the International Organization for Standardization, the speed of a film is denoted by a letter of the alphabet. The slowest (least sensitive) film is labelled C, and the speed doubles for each succeeding letter, D, E and F. For instance, instead of using film type C and an exposure time of 0.6 second, one can use film type D and an exposure time of 0.3 second or film type E with an exposure of 0.15 second. The alphabetical designation of film speeds and the printing of such designations on film packages eliminates the misconceptions and ambiguities caused by the use of commercial designations, which may imply film speeds that actually do not exist (e.g., “high speed”, “ultra speed”).

<table>
<thead>
<tr>
<th>Speed group</th>
<th>Speed range (in reciprocal roentgens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>6.0–12.0</td>
</tr>
<tr>
<td>D</td>
<td>12.0–24.0</td>
</tr>
<tr>
<td>E</td>
<td>24.0–48.0</td>
</tr>
<tr>
<td>F</td>
<td>48.0–96.0</td>
</tr>
</tbody>
</table>

Extraoral film

The use of extraoral films is encouraged where there is a need to observe areas that are not readily detectable on intraoral film because of film size or lesion location. Extraoral film is generally of two types: (1) film sensitive to X-radiation and used without intensifying screens, and (2) film sensitive to light (and only minimally to X-radiation) and used with intensifying screens. Other factors being equal, exposure times are generally shorter by perhaps a factor of 10 when intensifying screens and light-sensitive films are used. However, films used without intensifying screens are generally superior in resolution and should be used as long as the exposure conditions are considered acceptable. The selection of film and film-screen combinations must rest with the operator.

Extraoral radiographs taken by means of conventional medical X-ray equipment will be of sizes normal in medical radiology. Extraoral radiographs taken by means of panoramic dental X-ray equipment will be about 30 cm long and 12.5–15.0 cm high.

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1 Slow films (group C) are prohibited in at least one country in the interests of minimizing the radiation exposure of patients.
Film storage

Failure to transport and store films properly, as well as excessively long storage, results in film fog. Film fog, in turn, obscures the image and impairs diagnostic quality. Unless they are used at a rapid rate, films should be purchased in small quantities and ordered frequently; this ensures that the film will be used before its expiry date. Films should be stored in a cool dry place away from radiation and chemicals. Sheet films should not be stored with additional material on top, because pressure can cause emulsion activation and fog.
5. Radiographic Techniques

Indications and contraindications for use of diagnostic films

Two-thirds of all teeth and all supporting structures of the teeth are invisible during clinical investigation. The contacting surfaces of tooth crowns and anatomical structures contiguous with bone supporting the dentition are also unobservable. For these reasons, radiographic examination is essential if an adequate oral diagnosis is to be made and a correct treatment plan developed.

Recognition of the essential character of the radiographic survey should not obscure the inadequacies of a radiographic film and should not contribute to hasty diagnosis based mainly on radiographic evidence and excluding important clinical findings. Judgement concerning the frequency of examinations and the need for more than one diagnostic radiographic film must rest with the dentist. There are no contraindications for the use of X-radiation for diagnostic purposes provided the practitioner is able to exercise judgment and justify the use of radiation.

Intraoral techniques

There are two intraoral radiographic techniques in common use. Although referred to in different ways by different people, they can best be named by describing the principles on which they function (Fig. 4). The "bisecting technique" is so called because the central ray in the cone of radiation emerging from the X-ray machine is directed through the tooth apex perpendicular to a line bisecting the angle formed by the long axis of the tooth and the X-ray film. The "paralleling" or "right-angle technique" is so called because the film and the teeth under examination are aligned in a parallel fashion, and the central ray passes through the midpoint of the tooth and at right angles to both the tooth and the film. The bisecting procedure is used by a majority of dentists because it is the technique they were first taught and because it is easier to use. The bisecting technique, as conventionally used, requires the patient to hold the film with a thumb or finger, irradiating a portion of the hand. The paralleling technique uses instruments for film holding and placement and has the advantage of casting an image of the structures in question onto the film with a minimum of distortion. The bisecting procedure distorts the image and necessitates film interpretation and knowledge of the distortion factor. Although the dif-
**FIG. 4. INTRAORAL RADIOGRAPHIC TECHNIQUES**

(a) Bisecting technique. The central ray (CR) is directed through the tooth apex perpendicular to an imaginary line (B) that bisects the angle formed by the long axis of the tooth (T) and the X-ray film (F).

(b) Paralleling technique. The central ray (CR) is directed at the midpoint of the tooth (T) and is perpendicular to both the tooth and the film (F).

The difference between the two procedures may not be great, skin exposure is slightly less with the paralleling technique because a longer cone is used, thereby increasing the source-to-skin distance.

While the paralleling technique is in certain respects preferable to the bisecting procedure, the most important consideration is that of producing high-quality diagnostic films, regardless of which technique is used. As a corollary, films of maximum quality must be fully interpreted. Undue attention need not be given to weighing the advantages and disadvantages of the two techniques. Emphasis should be placed on technical excellence and interpretative competence using the technique of choice.

**Extraoral techniques**

A variety of extraoral procedures can be used for both survey and specific purposes. Extraoral procedures are frequently needed in order to diagnose more adequately conditions that are not easily observable on intraoral films.
The dentist is encouraged to familiarize himself thoroughly with extraoral procedures and to use them when indicated, because failure to do so can result in diagnostic shortcomings. He should make use of the occlusal film,¹ the distal oblique film of the mandible and maxilla (so-called lateral jaw), and a posterior-anterior view of the mandible and maxilla. The latter will permit the dentist to appreciate alterations in osseous structures in a plane essentially at right angles to that observed when using the distal oblique projection.

Panoramic radiography is a relatively new advance in dentistry. It enables the facial structures to be shown on one flat radiograph. The structures of the maxilla and the mandible are normally pictured completely from condyle to condyle, giving the dentist overall information supplementary to that obtainable through conventional dental radiography.

The panoramic technique requires special X-ray equipment, which, although it varies from manufacturer to manufacturer, is based on the general idea that the image is created during relative movement of the X-ray source and the film (or of the patient and the film). The movement can be adapted to fit the curvature of the dental arch in order to optimize the quality (orthogonality) of the image.

Selection of X-ray beam criteria

Voltage

Voltages in the vicinity of 50–70 kVp are commonly used in dental radiography. When used with currently available film, such voltages produce an image of relatively high contrast. The films are pleasing to the eye and have a reasonable diagnostic quality. As the voltage is decreased, the film contrast increases (the films are more sharply black and white). As the voltage is increased, the resultant film appears greyer and is said to have a broader scale or range of contrast. Voltage selection, when there is a choice, must be based on the film quality desired by the operator for specific objectives. If a broad range of structural densities is to be seen on a single film, the purpose can be accomplished by using a high voltage. If the operator wishes to see sharp differences between structures and recognizes that some anatomical entities may be lost in the process, he should use a lower voltage. However, the full film density range from black to clear should exist regardless of whether high or low voltages are employed.

Current

Dental X-ray machines are either of the fixed-current type or of the variable-current type with a range of 1–15 mA. The higher the current used,
the shorter the exposure time (all other factors remaining constant). Within the limits of capacity of the X-ray tube, the dentist is encouraged to use high current and short exposure time and thus decrease loss in film resolution through movement. It is, however, important that the operator be familiar with the cooling curve of the tube he is using in order not to overheat the tube and cause deterioration of the tube target. Tubes operated at high voltages and high currents must be given a sufficient cooling period between exposure series.

**Filtration**

The object of the filter is to stop the soft components of the radiation, which are unable to reach the film and form the image. Adequate filtration will thus reduce unnecessary irradiation of the tissue without unduly prolonging the exposure time. If the filtration is increased beyond the optimum, the exposure time must be prolonged unnecessarily.

**Collimation**

Collimation reduces the size of the skin area and underlying tissue volume exposed to X-radiation and so reduces the dose to most organs, the integral absorbed dose, the gonad dose, and the dose to the operator. By protecting the patient with optimum collimation there is a reduction in the amount of secondary radiation reaching the film from surrounding tissues. Secondary radiation causes film fog, and a reduction in secondary radiation thus has a beneficial effect on film quality.

**Selection of exposure time**

When the area being examined, the type of film being used, and the combination of voltage, current, and filtration employed have all been determined, the exposure time should be such that film processing under standard conditions of time and temperature, as advocated by the manufacturer, will produce a film of appropriate density. Overdevelopment to the extent of 50% should have a negligible effect on the resulting film density.

Having selected all other factors, the exposure time can be determined using various objects. A dried mandible embodied in tissue-equivalent wax of an appropriate thickness can be used as a phantom. It should be kept in mind that dried osseous structures have a strong tendency to produce films of high contrast and require exposures less than those needed for living tissue. An extracted tooth placed on a film and covered with a plastic bag filled with water to a thickness approximately equal to facial soft tissue can also be used as a phantom.
Exposures are made of the film of choice, starting with an exposure time known to be inadequate, i.e., known to produce too light an image. Subsequent films are subjected to exposures each 50% greater than that used for the preceding film. Exposures should be increased by proportions rather than by units of time. Starting with the inadequately exposed film, one should reach the level of overexposure using no more than six films. Using fresh processing solutions and a recommended time-temperature method, all films are processed simultaneously. After final washing, the films are examined and the film density of choice determined, which thus gives the optimum exposure time. It is entirely possible that the operator may select an exposure time between two of the experimental films. If humans are used for the purpose described, the area of the mandibular molar teeth is the location of choice for experimental purposes because it represents the middle of the exposure range between the mandibular anterior teeth and the maxillary posterior teeth. Percentages of increase and decrease will have to be made from this mid-range if voltages below 70 kVp are used. If high voltages are used (80–90 kVp), constant exposure times can be used throughout the jaws. If a phantom was used for the experimental approach, a trial intraoral film will still have to be made, but the number of exposures made for experimental purposes on the patient will be minimized.

It should be stressed that under no circumstances is the dentist justified in overexposing films in order to reduce time spent in film developing. The resultant film will not be of maximum quality, and the patient will have been subjected to unnecessary irradiation. If speed is essential from time to time in a dental practice, special high-speed developer should be at hand.

**Machine–chair position**

In cases where the X-ray machine is positioned near the dental chair, it is usually best positioned to the left of the dentist. It can be placed in front of or at the back of the chair, preferably slightly to the left of the centre of the chair base. For ease of operation, the machine should not be placed to the right of the chair unless the operator is left-handed. If a protection barrier for the operator is used, it should have a lead glass window for the purpose of viewing the patient during exposure. Under these circumstances, the chair should face the barrier. Beam direction is also a consideration in positioning the machine. Unless the room is lined with a primary X-ray beam absorber, every effort should be made to direct the beam toward an unoccupied area (windows, stairways, storage areas, etc). In many cases, however, it is preferable to have the dental X-ray machine separated from the dental chair and to place it in a corner or even in a separate room, together with a special chair for radiography.
Operator position during exposure

The dentist and any other person who uses X-ray equipment should, in the absence of a protective barrier, stand at least 2 m from the patient and the source of radiation during exposure. The recommended position is in an area between 90° and 135° from the direction of the primary beam.

FIG. 5. BEST POSITIONS FOR OPERATOR

When exposures are made of the anterior portion of the face, the operator may stand on either side of the patient in the position described. When views are made of the side of the face, the operator should stand behind rather than in front of the patient. Fig. 5 illustrates the proper positions in which the operator should stand.
Danger to operator of holding film, cone or tube housing

The holding of film, either intraoral or extraoral, by the operator or office personnel is contraindicated. To do so leads to the exposure of the hand and possibly other parts of the body to the primary beam. The proximity of the operator to the patient and the source of radiation will expose the whole of the operator's body to secondary radiation. As a matter of principle, films should be held in place by means of film holders. If such a solution to film retention seems impossible, films should be held by the patient himself, or, if the patient is incapacitated, by an individual not occupationally involved with X-radiation and beyond reproductive age.

Steadying of the tube housing or X-ray cone by hand is contraindicated for the same reasons. Mechanical imperfections that cause the tube housing to wander or the cone to drop should be corrected.

Dental fluoroscopy

Fluoroscopic devices, usually in the form of a mouth mirror, have been used in the past. It is, however, generally accepted by radiologists that fluoroscopy should be used only for clarifying organ functions and specific geometrical conditions. For the identification of structures, radiographs must be used. Dental fluoroscopy leads to excessive exposure of patient and operator and is to be strongly discouraged.

Cases needing more specialized radiographic examination should be referred to an adequately equipped medical facility.
6. Film Processing and Handling

The darkroom procedures should be recognized as the phase in the whole of the radiographic process that should be most highly standardized. Any departures from a rigid standard should be done deliberately and in a manner that can be repeated at will.

Film processing is badly neglected in dentistry, and considerable space is therefore devoted to it in this volume. Faulty film processing contributes to inferior radiographs, many of which must be retaken in order to obtain satisfactory diagnostic information; the patient dose is thereby at least doubled. "Yield", the amount of diagnostic information per unit of exposure, is reduced when film processing is inadequate.

**Darkroom illumination**

The darkroom should be light-tight and well ventilated. In order to observe extraneous light entering the darkroom from outside it is necessary to isolate oneself in the darkroom in the total absence of light for a period of at least 10 minutes, which is the amount of time necessary for adequate eye adaptation. Light leaks will then be easily observed and can be marked using coloured chalk. The areas of light leakage can subsequently be blocked and the room retested.

The amount of safelight illumination permissible in a darkroom will vary with the size of the darkroom, the location of the safelights, and the type of film employed. In the conventional, relatively small dental darkroom, the maximum illumination permissible is that given by a 15-watt light bulb encased in a suitable receptacle equipped with an appropriate filter (e.g., Wratten 6 B) and placed 1.5 m above the workbench. This arrangement is satisfactory for all types of film generally used in dentistry. The fixture containing the light bulb and the filter should be periodically examined for light leaks. Plastic receptacles tend to warp and filters tend to crack or become reticulated as a result of age and excess heat. Faulty fixtures and filters should be discarded.

Non-screen extraoral film and some brands of intraoral film are less sensitive to light than are films used with intensifying screens and other brands of intraoral film. The use of lighting beyond that advocated above but in accordance with the manufacturer's directions is satisfactory, provided one recognizes the need for changing light intensity and filter type whenever more sensitive emulsions are used. Caution must be exercised because there
is a tendency to forget the necessary light corrections. Use should never be made of ruby bulbs and other makeshift devices as a substitute for suitable darkroom filters.

Unsuitable darkroom lighting, whether it be non-safe illumination or extraneous light, will cause film fogging. Darkroom testing for excessive light should be carried out with the most light-sensitive film used in the dental office.

The conventional darkroom safelight test is as follows. An unexposed film is stripped of all covering in total darkness. A thin opaque object, such as a coin, is placed on the film, and the darkroom safelight is switched on for as long as the film would be exposed to it during routine dental office procedures. (It should be recognized that it takes 4–5 minutes to strip and mount a complete mouth intraoral survey in preparation for processing.) The safelight is switched off, and the film is processed in the standard manner in total darkness. Any fogging caused by excessive light in the darkroom will make the image of the coin appear to be lighter than the surrounding area of the film. It should be emphasized that film fogging resulting from contaminated or improper use of processing solutions will not be revealed by this method.

**Essential equipment**

Equipment essential for standard procedures in a reasonably good darkroom includes the above-mentioned safe illumination, an interval timer, running water that can be temperature controlled (at least within the range 16–24°C or 60–75°F), a floating thermometer, a water jacket into which dishes or tanks for developing and fixing solutions can be inserted, adequate hangers on which to support films during processing, and a rack and drip pan suitable for film drying.

Most of the above-mentioned equipment needs no explanation. The outside jacket of the water bath can be made of any of a variety of materials provided they are nonporous and resistant to chemicals. Stainless steel, hard rubber, plastic, highly glazed porcelain, and wood surfaced by a hard chemically resistant plastic can all be used satisfactorily. There is some advantage in using materials that by nature are heat insulators because they will help maintain the temperature of the water in the jacket if it varies materially from atmospheric conditions.

The developer and fixer tanks should be removable for two reasons: removable tanks permit the circulation of water around the four sides and the bottom, which enhances solution temperature control, and they are obviously easier to clean. They should be made of a material that will permit temperature transfer through their walls. Hard rubber has been used but is now generally replaced by stainless steel. It is important that the stainless steel should be of an acid-resistant kind. All joints should
be welded using stainless welding materials and should be highly polished, particularly those that will be exposed to either fixer or developer. The effectiveness of stainless steel in resisting chemical change is only as good as the union of one piece of steel with another. The developer and fixer tanks should be equipped with covers to prevent oxidation of the solution when not in use. Developer and fixer tanks and their respective covers should never be interchanged. Separate chemically resistant nonporous stirrers should be provided for each tank and should not be interchanged since mere traces of fixing solution will adversely affect the developer.

Additional useful equipment

The availability of hot and cold running water is essential if the developer temperature is to be controlled within the advocated range. It may also be necessary to provide for water refrigeration.

The mixing of warm and cold water can be achieved by the manual adjustment of ordinary valves until the correct temperature is obtained in the water jacket. However, manual adjustment is time-consuming, and water temperature can readily fluctuate. An automatic water mixing valve set for the desired water temperature is useful as is a stem-type thermometer inserted in the water pipe between the mixing device and the water jacket.

A stop-bath tank between the developer and the fixer tanks may be considered important by some dental practitioners. The stop-bath consists of a dilute solution of acetic acid, and its purpose is to halt the action of the developer quickly and to allow the developed film to be placed in the fixer with a minimum of prior washing. A film drier, which combines a fan and a heating coil, accelerates film drying time as compared with the ordinary drip process. It may be desirable to have available in the vicinity of the drier or drying racks a tank containing a solution that reduces surface tension and allows water to run off the film rapidly.

Some type of film-viewing facility in the darkroom is extremely useful and may even be considered essential. Since it will be used with wet film it should be placed behind the fixing tank (never behind the developing tank) and should be equipped with a drip pan.

In order to prevent radiographs being interchanged, the patient’s name or number is normally written on the film hanger when the film is inserted into the developer. A film identifier to be used prior to processing is useful for sheet film, but has no application for intraoral film.

Solution preparation

Liquid concentrates for both developer and fixer solutions are available from a number of manufacturers. The use of powders for solution prepara-
tion is time-consuming and tends to give a less exact concentration. Powders are justified only when liquid concentrates are unavailable.

Great care must be used when preparing new processing solutions to clean the water jacket and the developer and fixer inserts and covers. After the old solution has been discarded and the water jacket emptied, the walls and bottom of the water jacket should be thoroughly cleaned with a bland soap and a soft brush or cloth. Under no circumstances should either the water jacket or the removable tanks or dishes be cleaned with an abrasive because scratches will encourage the subsequent adherence of chemical debris. After a thorough cleaning with soap, the water jacket should be washed with water to remove residual alkalinity, and it is then ready for refilling.

Similarly, the developer and fixer tanks and covers should be cleaned vigorously, inside and out, using a bland soap (but no abrasives) and well flushed with water. The fixer container and cover should then be further rinsed with dilute acetic acid in order to remove residual alkalinity and reflushed with water. The tanks and covers should never be interchanged. The need for thoroughness in the above procedures cannot be stressed too much. If either the water jacket or the tanks show signs of porosity (as may sometimes happen with hard rubber or porcelain) they should be discarded and replaced.

**Manual film processing**

The sequence of film processing is the same for all types of conventional radiographic film and for all developers. Time factors within the sequence will differ, depending on temperature, type of film (the principal variable being emulsion thickness), and the chemical composition of solutions.

The film is placed on a processing rack and inserted into the developer on the time-temperature basis recommended by the manufacturer. Strict adherence to the recommended time-temperature procedure is important; films should not be developed at temperatures above or below the recommended range. After development, films should be rinsed thoroughly in running water for a minimum of 30 seconds before being placed in the fixer. If a stop-bath is available, however, the film may be rinsed briefly in running water and then placed in the stop-bath for approximately 5 seconds before being transferred to the fixer. The purpose of both the wash water and the stop-bath is to neutralize as much of the alkaline developer as possible, thus stopping development and preventing contamination of the acid fixer with traces of alkaline developer. These procedures reduce or eliminate the chemical fogging of films.

The film is left in the fixer at least long enough for it to “clear” before it is viewed in a wet condition. A “clear” film is one that shows only the expected black, white, and intermediate greys and no sign of colour. About 2 minutes must be allowed for most fixers (when fresh) to clear the film.
After clearing, films should be rinsed, at least briefly, prior to their use in a wet condition. Complete fixing is essential if films are to be stored. This requires at least twice the length of time needed for the film to clear, and 8–10 minutes is usual in a fixer of ordinary strength. It must be remembered that the fixing process involves both the chemistry of fixing and an emulsion-hardening procedure. Over-use of fixing solution can result in varying degrees of film bleaching.

After fixing, the film is rinsed in running water for a minimum of 15 minutes and then dried. Drying may be accelerated by immersing the film (after washing) in a solution that reduces the surface tension of the water on the film surface. Inadequate fixing and washing procedures result in staining and fogging of films.

Apart from emulsion scratches and the discoloration and staining of films due to inadequate fixing and washing, films may be faulty through being either too dark or too light. Light films can be the result of either underexposure or underdevelopment. Dark films that have been processed according to recommended time-temperature procedures are caused by over-exposure and other irregularities that contribute to film fog. Properly exposed films cannot be grossly overdeveloped, but their density, in the form of fog, can be increased through excessive contact with developer. Other faults may be caused by excessively warm solutions which can cause the emulsion to run, and plunging a film from a warm into a cold solution, which results in emulsion cracks (reticulation). Spray from processing solutions will cause film faults.

The sequence of film processing discussed above should be preceded by a careful observation of solution surfaces, particularly if the solutions have not been used for several hours. Oxidation scum will often be observed on the surface of both the developer and fixer. This scum should be carefully removed by skimming the surface of the solution, otherwise the first film inserted tends to draw the scum on to its surface, where it interferes with the chemical reaction. Whether or not scum has been found on the surface (and after its removal if it has) solutions should be stirred with non-interchangeable, chemically resistant and nonporous paddles in order to make the solution uniform throughout. Solution level should be maintained with replenisher. Agitation of films during processing is recommended. Alternatively the solution itself should be agitated by the use of mechanical mixers or by the bubbling of nitrogen gas. The purpose of agitation is to maintain the uniformity of the solution and to ensure circulation equally over the film surface.

Processing solutions should be changed whenever the quality of the finished films begins to deteriorate. This usually happens within 1–4 weeks. In no case should one try to compensate for the deterioration of the developer by increasing the exposure time. Conformity with manufacturer’s directions regarding solution disposal is generally advisable.
Automatic film processing

Automatic and semiautomatic film processing machines for intraoral dental films have recently been developed. The fully automatic machines are expensive and are normally installed only in major dental clinics. The semiautomatic machines do not include the film-drying stage; they are therefore cheaper and have found a more general acceptance by private practitioners. Considerable care must be taken to ensure optimum performance of the machine, and regular servicing is necessary.

Film viewers

The ability to extract useful diagnostic information from radiographs depends on the definition and contrast of the image, on the density of the film, and on the adequacy of the viewing conditions.

Film density is expressed as a figure usually ranging between 0.1 and 3.0, representing the logarithm of the ratio between the amount of light falling on the developed film negative and the amount transmitted through it. Normally film densities range from 0.5 to 2.0. Film densities of over 2.0 can be used provided special viewing facilities are available. Film densities of less than 0.5 can be made slightly more usable through the use of very lightly and uniformly exposed film overlays, which add to the total viewing density. It is, however, highly desirable to keep the film density within the normal range.

The average dental office is equipped with at least one film viewer. Such a viewer often does not adequately accommodate both intraoral film (in a variety of mounts) and extraoral sheet film, being either too small to accommodate a complete mouth survey mount or too large for a small number of intraoral films supported in an appropriate mount. The result is either an inadequate viewing surface or excess light peripheral to the mount. Only rarely does one observe a dentist eliminating extraneous light during film viewing or allowing time for the adaptation of the eyes prior to film viewing. A magnifying glass is used fairly frequently.

In order to increase the diagnostic yield from radiographic film, it is suggested that a viewer be available that is large enough to accommodate the largest dimension film or mount to be used in a given office. It is further suggested that the viewer be equipped with some means of shading peripheral light around the mount or film to be viewed (Plate 2A). In addition to the shading device designed to accommodate different mounts or film sizes, a light shielding device with an adjustable aperture should be available for the purpose of eliminating much of the light coming through an X-ray film. Such shielding permits the observer to concentrate on relatively small film areas (Plate 2B).
Extraneous ceiling and outside light should be reduced or eliminated when a film is being inspected, and the operator should permit a reasonable amount of time (5–10 minutes) prior to film viewing for eye adaptation. It is realized that the suggestions contained herein are foreign to most dental offices and that they place certain encumbrances on the practising dentist. However, such measures are necessary for optimum interpretative yield.
7. Patient Doses

X-radiation exposure of the skin and underlying tissues will depend on many factors, including film speed, voltage, and filtration. For example, a sensitive film requires less exposure than a slow film, and regular use of films of high sensitivity will lead to a reduction of tissue doses.

The importance of correct film handling following exposure must likewise be viewed in relation to tissue dose. Solution temperature and developing time must be coordinated according to instructions given for specific types of developer. The habit of overexposing and underdeveloping films in order to obtain radiographs quickly should be eliminated, because it increases the tissue dose unnecessarily. If the time of development must be shortened, fast developers are available. Such developers do, however, tend to deteriorate quickly.

X-radiation generated at relatively high voltages will more readily penetrate the object and expose the film than will lower-voltage radiations. Hence, choice of tube potential will have an influence on the tissue dose. A higher voltage setting will result in a reduction of skin dose but does not necessarily greatly alter the integral or total tissue dose.

If the beam of radiation is insufficiently filtered (i.e., if it is subjected to less filtration than that recommended on pages 16 and 19) it will contain a component of soft X-rays that will expose the skin but not be able to penetrate the tissues and contribute to the formation of the radiograph. Insertion of proper filtration will attenuate the soft non-productive photons and thus considerably reduce the skin dose. A possible slight prolongation of exposure time can be accepted in the process of adding suitable external filtration.

The size of the radiation beam will also have a bearing on the integral dose received by the patient. A beam wider than necessary will lead to irradiation of body sections not being examined, and this situation should be avoided. Unnecessary exposure of the eyes, the thyroid gland, the bone marrow, and (in children) the thymus must be regarded as highly undesirable.

The actual skin dose following one intraoral radiograph (after optimum dose reduction in accordance with steps described earlier) will ultimately also depend on the dimensions, particularly the thickness, of the object. For example, it is easier to penetrate the anterior teeth of a child than the maxillary molars of a fully grown man. All factors taken into consideration, the average skin exposure can be brought well below 1 R (2.5 \times 10^{-4} \text{ C/kg}) per radiograph. If adequate care is taken and if high voltage and/or more
than the recommended minimum filtration is used, the skin exposure can be as low as 0.25 R ($0.6 \times 10^{-4}$ C/kg) per film.

Dose to adults

Unintentional exposure of the bone marrow, the eyes, and the thyroid gland must be controlled. Good collimation will help reduce this unwanted exposure to a minimum. Direct radiation leakage from the tube head can sometimes occur and lead to heavy exposure. This is a production defect that should be detected before the practitioner uses the equipment in his practice. While the manufacturer should eliminate manufacturing defects, the responsibility for not putting X-ray equipment into operation before it is approved for use rests with the practitioner and, where they exist, with the radiation protection authorities.

Even with optimum collimation, all parts of the patient's body will be irradiated to a measurable extent during dental radiography. In men, typical gonad exposures are 0.1–1.0 mR ($0.25 \times 10^{-7}$ to $2.5 \times 10^{-7}$ C/kg) following one intraoral radiograph, depending primarily on the beam direction (lower and upper teeth respectively), when using optimum beam size and filtration. These figures can, however, be lowered appreciably to less than 0.01 mR simply by using a protective apron or neck shield. The use of a protective apron or neck shield is strongly recommended to make gonad doses negligible.

Dose to children

The various factors influencing the dose to adults also apply to children, but the doses to children are mostly higher owing to the shorter distances between the area irradiated and many organs.\(^1\) This is particularly true for the gonads. Exposure of the eyes, thyroid gland, and thymus should be carefully controlled. In general, it must be remembered that tissues in growing children are more radiosensitive than those in mature persons.

Dose to pregnant women and women of reproductive age

Radiation exposure of women during their reproductive years must be directly related to the possibility of a pregnancy. While it is undesirable to irradiate the fetus at any stage in its development, it is especially important not to expose the fetus during the first trimester of pregnancy. It is for this reason that authorities generally agree on the need for protecting the

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female patient of reproductive age. Frequently, the woman is not aware that she is pregnant until after the first trimester has passed, and it has therefore been recommended not to use radiation, particularly where the abdomen is involved, after the tenth day following the onset of menstruation.

In the case of dental radiography, however, it is easy to shield the abdomen against radiation by a protective apron and so keep the dose sufficiently low.
8. General Radiation Protection and Monitoring

The object of area monitoring around a dental X-ray installation is to evaluate the radiation safety of the patient, the staff, and the occupants of neighbouring rooms.

No maximum permissible doses are recommended for patients. When radiation monitoring of the X-ray installation shows that it meets the protection standards discussed in this manual, the dentist can be satisfied that he has taken the necessary precautions to minimize patient exposure (see Volume 1, Chapter 7, of this manual).

Maximum permissible doses are specified for occupationally exposed persons such as dental staff. When the X-ray machine meets the standards stated in this manual and is properly operated, staff exposure will be kept well below the maximum permissible level.

There is usually no significant radiation exposure in neighbouring rooms when the walls, floors and ceilings are of normal thickness, but in some circumstances (e.g., when the walls are not substantial or the workload is high) care may have to be exercised in this respect. No person having a fixed workplace should be located close to the X-ray machine behind a light partition wall. If the workload is heavy or if the timer is malfunctioning, the person behind the wall will not be aware of the hazard and there will be a risk of unnecessary exposure.

Instruments and methods

All radiation monitoring should preferably be conducted by a radiation protection expert. If the dentist intends to carry out the necessary monitoring himself, he should make sure that the radiation measuring devices are of a suitable kind and properly calibrated for the radiation being used. The monitoring should include measurements of the primary beam, in which the exposure rate will be up to a few roentgens per second (about $10^{-3} \text{C/(kg.s)}$), and of scattered radiation, which may amount to only about one milli-roentgen per hour (about $10^{-10} \text{C/(kg.s)}$). The instruments employed should adequately cover this wide range of exposure rates.

Radiological equipment

The exposure rate from a standard dental X-ray machine measured in the primary beam at the end of the standard short cone should be no more
than about 1.5 R/s ($4 \times 10^{-4}$ C/(kg.s)). If the established figure is decisively higher, the equipment is probably not satisfactorily filtered and is therefore producing an excess of soft radiation. The adequacy of the filtration can be checked dosimetrically as explained in more detail on pages 19–20.

The adequacy of the collimation of the useful X-ray beam can be checked by exposing a film of sufficient size and measuring the diameter of the darkened area. If a fluorescent screen is used instead of a film, the glow will be seen in a normally illuminated room and will give immediate information on the beam size. The flash on the fluorescent screen will also give some useful information about the functioning of the X-ray timer. The timer can sometimes be seen to activate the equipment both before and after the intended exposure. Malfunctioning of the timer can under no circumstances be tolerated because it can lead to excessive exposures. A careful method of checking the timer is described on pages 17–18. Radiation leakage from the tube housing must not exceed 100 mR ($0.25 \times 10^{-4}$ C/kg) in any one hour at a distance of 1 metre when the tube is operated at its maximum rating.

Reduction of staff exposure

With proper collimation and filtration of the useful radiation beam, an operator who observes the safe distance requirements and keeps out of the path of the primary beam will normally show negligible exposure. The best position for the operator during exposure was discussed on page 32. Care should be taken that any assistant who may be present does not come into the path of the primary beam, even at a considerable distance. The exposure rate in the path of the unattenuated beam at 4 metres can easily be 400 mR per minute ($2 \times 10^{-6}$ C/(kg.s)). This means that within 10 minutes of exposure time at that point the maximum permissible monthly dose will be reached. Proper positioning of the assistant during exposure is similar to that of the operator.

Structural shielding

There is no need for heavy structural shielding around the average dental X-ray installation. Normally, a mean exposure of less than 0.5 mR ($10^{-7}$ C/kg) will be recorded on the inner wall of a dental treatment room of ordinary size for each radiograph taken.¹ Data for the calculation of shielding have been published by ICRP.²

If the workload of an X-ray machine is high, e.g., in a busy dental clinic, the installation of special structural shielding may be appropriate. The type of shielding to be used will depend on physical factors relating to the X-ray equipment and on the amount of radiation produced per unit time. The cheapest solution consists of a shielded enclosure, accommodating only the machine, a chair, and the patient. When the patient is watched through a lead glass window and the exposure released from outside, satisfactory radiographs can be obtained in safety.

Licensing of X-ray installations

Increasing knowledge and growing concern about radiation effects place greater responsibility on the professional man as he uses and supervises the use of ionizing radiation. The need for a licensing examination prior to use of X-ray machines on humans will become evident if the profession fails to accept the responsibilities described in this manual. In the last analysis, licensure must be related to the benefits that will accrue to the population as a whole. If the population can best be served by minimal legislation, it is obviously desirable to minimize restrictions. But if the population can best be served through restriction of radiation use and through the development of individuals and groups highly competent in radiation usage and interpretation, then legislation of a restrictive nature should be developed. In essence, the onus is on the dental profession.

Personnel monitoring

Personnel monitoring is suggested by various international and national recommendations for individuals who come into contact with ionizing radiation in the course of their work. According to Convention 115 (1960) of the International Labour Organisation ¹ concerning the protection of workers against ionizing radiations, appropriate monitoring of employees shall be carried out. The International Commission on Radiological Protection ² qualifies the extent of the need for monitoring by recommending that workers engaged in an operation where doses might exceed three-tenths of the annual maximum permissible dose should be subjected to personnel monitoring.

The reader is referred to Volume 1 of this manual for fuller information on maximum permissible doses (Chapter 2) and on personnel monitoring and health supervision (Chapter 8).

There is evidence that if the dental X-ray machine meets the suggested standards and if the operator has a normal workload and stands in the proper position at the indicated distance of 2 m, a personal dose of no more than three-tenths of the maximum permissible dose will be accumulated in the course of a year. Personnel monitoring should consequently not be strictly necessary in dentistry. However, the statistical chance of equipment failure (e.g., malfunctioning of the timer) has not yet been evaluated. Personnel monitoring of radiation exposure in dentistry may be regarded as superfluous only if the chances of failure prove to be sufficiently small.

The X-ray machines in dental radiography are mostly operated at voltages in the range 45–100 kVp. In this energy range a correct estimation of personnel doses may prove complicated because many radiation measuring instruments are designed for use at higher energies. For lower energies, instrument characteristics may give misleading readings—usually too low.

Dose-indicating instruments rely on various modes of operation such as the discharge of an ionization chamber, the blackening of a test film, and the luminescence released by heating irradiated crystals. Any of these principles can be used for personnel dosimetry in dentistry if the instruments are of satisfactory accuracy in the voltage range 45–100 kVp. The instruments should be worn for a sufficiently long observation time because the doses to be recorded will, in all likelihood, be small.
9. Educational Standards

Although dental educational standards vary from country to country, individuals responsible for the use of ionizing radiation in dental medicine should be thoroughly familiar with the problems encountered in dental radiology. Such individuals should be competent in the more commonly used techniques employed to produce dental radiographs, and they should be capable of rendering an adequate interpretation of the resulting films. Furthermore, if auxiliary personnel are to be employed in any procedures connected with the use of X-rays, the supervisor must be competent to instruct them in the delegated procedures and must assume full responsibility for the work performed.

In some countries every operator of a machine generating ionizing radiation must attend a prescribed course in radiation protection and be properly licensed to operate an ionizing radiation device. This includes operators of dental X-ray machines, and it is highly desirable that operators undergo such a course even where it is not legally required.

Predental education

Before starting his dental education, the student should be required to complete at least an introductory course in physics. Such instruction will give him an understanding of electricity, magnetism, and atomic and molecular structure, all of which are important to an understanding of radiation and its biological effects. Where such courses are given in conjunction with the dental curriculum during the first year of dental training, the same end is achieved.

Dental training

The undergraduate dental curriculum in all dental schools should include a course specifically designed to teach the theoretical, technical, and interpretative aspects of diagnostic dental radiology. Experience in some countries suggests that the minimum amount of desired knowledge cannot be satisfactorily communicated to students with less than 30–40 hours of theory combined with 80–100 hours of clinical, laboratory and seminar type instruction. Of particular importance are seminars providing group instruction in the broad field of radiological interpretation.
Postgraduate training

Students of dentistry should be generally knowledgeable about matters pertaining to dental radiology and particularly well informed about those aspects of dental radiology relevant to the specialty they may have chosen to study.

Graduate students who have chosen to specialize in dental radiology itself should be aware that this area of study interrelates with many clinical and basic science areas. In addition to a high degree of competence in dental radiology, the graduate student should have a reasonably thorough understanding of the peripheral clinical and basic science subjects most closely allied with the technical and interpretative phases of dental radiology. Additionally, it is highly desirable that the graduate in dental radiology should be familiar with research design and methodology and have participated at least to a limited degree, in research activity.

Training for practising dentists

It is recognized that many former dental graduates have had no formal training in the use of X-radiation. Both technical and interpretative skills have been acquired as a matter of necessity from any available source. Moreover, the courses in dental radiology in many dental schools have been weak and largely ineffectual. It is therefore incumbent on educational authorities to provide continuing education programmes for graduate dentists designed to establish among them a level of competence equal to that of the recent dental graduate.
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