X-Ray Protection Techniques

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Oregon's radiation law, effective July 1, 1957, authorized a 2-year study of radiation exposure before promulgation of regulations and standards, discussed in a previous paper (PUBLIC HEALTH REPORTS, *April 1960, pp. 331–336*). *The first phase was a survey of diagnostic X-ray units, which not only provided information on conditions in the State but also afforded an opportunity to offer suggestions for improvement in equipment and techniques. On the basis of inspections of several hundred units, supplemented by appropriate literature references, this paper discusses technical aspects of the survey, emphasizing methods for reducing exposure of personnel and patients. The results and their interpretation will be reported in a later paper.*

THE chief of a radiological health program is continually called on to interpret the "real" biological hazard of a given exposure, the probabilities of delayed effects after certain radiation doses, reasonableness of a particular procedure from the radiological viewpoint, or significance of a given shortcoming in a specific X-ray unit. He must be able also to interpret various aspects of radiological safety practice based on, but not fully covered by, recognized standards. Good concise background material on these questions has been published (*1–3*).

Meeting such demands requires extensive training in the entire field of radiological health. Preferably, the chief should have a degree in medicine plus perhaps 1 year of residency in radiology or a postgraduate year in radiological health. However, with sufficient personal effort, individuals with other backgrounds may be able to assume the responsibilities.

Suitable short-course and long-term training is offered by the Division of Radiological Health of the Public Health Service. The Atomic Energy Commission also offers courses in radiological health, but so far these have dealt primarily with the control of the potential hazards of radioisotopes.

With a well-trained chief, the other personnel in an X-ray radiation safety program can have variable backgrounds and training. Particularly valuable is prior experience as an X-ray technician. In general, however, anyone with the approximate equivalent of a bachelor of science degree can be trained to survey X-ray units. Experience in reading instruments is helpful, as is some acquaintance with medical terminology.

The program chief may train his own personnel, regardless of background, so that the proper standards are applied in fieldwork. An orientation period of about 2 to 6 months is not unusual, with frequent group training in the field on X-ray units. The staff should be supplied also with suitable reading materials, such as glossaries of medical-radiological terms, manuals of radiographic techniques (*4*), and the materials of the National Committee on Radiation Protection (which are published as National Bureau of Standards handbooks, available from the U.S. Government Printing Office).

Inspection Forms

Making complex value judgments concerning X-ray units in the field may be somewhat easier by the use of standard recording and recom-

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mendation forms. Ideally, these should be based on practical experience of several months duration. They should be concise and allow "checkoff" whenever feasible. Coding for future tabulation should be included. Suitable forms have been developed by the Division of Radiological Health, Public Health Service.

Oregon finds it practical to use such forms for on-the-spot reports of the inspections. They can be filled out in carbon duplicate, with a ballpoint pen or typewriter, the original given to the practitioner and the carbon copy retained for the office file. Although it might be charged that such reports are not written by experts, we believe that the advantages outweigh this disadvantage. First, they permit suggestions and recommendations to be given immediately to the practitioner. Second, the radiation expert back in the office usually does not have time to go over the field reports in sufficient detail to insure that his judgment of the situation will be better than that of the person on the spot. Third, writing of reports in the office cuts down efficiency of the fieldwork. Sound training in radiation principles for the fieldworkers and the use of standard forms with checkoff items prepared by an expert are key factors in this process.

The use of checkoff forms not only saves much time but also permits more detailed and uniform recommendations. Writing complete recommendations on any given X-ray unit could be an extensive undertaking. Merely putting down that "adequate coning should be provided," for instance, is almost worthless from the practical viewpoint. Details are needed on how to choose cones, the possible use of an adjustable cone, and so on. The use of a checkoff recommendation sheet does not, of course, replace individual verbal explanations on each important item during the office visit. Also, space may be used on the form for items not covered in the printed schedule. A face sheet summarizing the major inadequacies noted, degree of cooperation, and need for a revisit is useful.

The Approach

Before fieldwork is begun, letters to X-ray machine owners describing the program and, preferably, expressing the endorsement of the appropriate professional society are useful. This step was taken in Oregon, and each user, not his secretary or nurse, was also called on the telephone and asked for a specific appointment. Time was taken to explain concisely the goals of the program, always with the attitude that the practitioner is a professional person who wishes to fulfill his responsibility in regard to radiation hazards. Our experience demonstrated that, when approached in this manner, the vast majority of practitioners will agree to a review of their X-ray units.

Endorsement of the program by the medical leaders in the community is important in obtaining active cooperation of the practitioners. The policy in Oregon has been to visit first the radiologists and larger hospitals. Grapevine information about the X-ray surveys is always widespread and can be helpful or harmful.

If possible, appointments for visits should be scheduled several days in advance to allow flexibility in regard to crowded practice hours, afternoons off, or prior commitments. A field staff of four needs perhaps half a day in a community for, say, 12 to 16 surveys. Using forms, we have found it possible to complete an inspection and report in an hour.

The typical medical or dental practitioner or veterinarian has had little formal training in taking and processing X-rays. Usually he has acquired his knowledge through experience, based perhaps on instructions supplied by X-ray distributors. Such instructions may or may not consider protection from radiation. X-ray technicians vary greatly in training and experience. Registered technicians usually have had hospital radiology department training and understand their work quite well, but even they should not be expected to know, for example, the implications of underdevelopment of films or increased kilovoltage in relation to exposure. The usual technician is office-trained by the physician and X-ray distributor, and many of them rely on prepared charts of exposure without understanding basic principles.

We have prepared a clearly written statement of the essentials of radiological protection which is left with each practitioner (in addition to the checked recommendation form), and explanations are provided while the standard form is being filled out. In addition, the X-ray safety program includes lectures at meetings of practitioners of various types. The practitioners are encouraged to read the available literature, such as the booklet on X-ray protection by the American College of Radiology (*5*).

Specific technical problems encountered in X-ray survey work are discussed in the remainder of the paper. References to the literature, of course, represent only a sampling of the many excellent articles of recent years. It should be noted, however, that a number of these articles were written by radiologists. Their standards are not always applicable, from a practical standpoint, to general medical or dental offices.

Film Badge Monitoring

The Oregon survey revealed few instances of gross overexposure for operating personnel. This finding is consistent with reports of other surveys (*6–8*). Positive documentation and recording of doses by means of film badges, however, were infrequent.

The Oregon State Board of Health recommends film badge monitoring for all radiation users, although for small caseloads monitoring need not be continuous. At an approximate cost of $1.50 per badge (for small quantities), the use of badges on two or three potentially exposed personnel for a month each year, for example, is not a major expense. Annual monitoring and special surveys whenever there is a significant change in equipment or caseload are recommended for the usual small X-ray installation.

The field personnel should be familiar with the so-called dental film monitoring method, which has been widely used, but certainly does not replace film badges. A paper clip is affixed to a plain dental film, which is carried in a pocket for a week or two and then developed. An outline of the paper clip, which appears at an estimated 25- to 40-mr exposure, is considered a positive result. Monitoring with dental films or film badges on walls, however, has little value for indicating exposure of personnel.

Pocket ionization chambers, encountered occasionally in hospitals, are useful as a supplement to film badge monitoring. They tend to read low because of the softness of scattered secondary X-rays, and recording of the doses must be systematic and evaluated with caution.

For definitive advice on personnel protection, the best resource is familiarity with the standards for occupational exposure formulated by the National Committee on Radiation Protection, and published in the National Bureau of Standards Handbook No. 69. The permissible radiation is different for various parts of the body—hands, neck, lenses of the eyes, and gonads—and for the whole body, to be applied as appropriate.

The recent revision of occupational exposure limits abolished a specific weekly whole-body or gonadal exposure limit in favor of 3-month, annual, and cumulative limits. For surveillance purposes, however, the weekly maximum is 100 mr for continuing occupational exposure. The quarterly limit is 3 r and the annual limit is 12 r, but cumulative exposure is not to exceed the number of roentgens arrived at by multiplying age, less 18, by 5. Even moderately good protection leads to weekly exposures much below these limits, on the order of 25 mr per week (*6,7*).

Since 3 months is the shortest period for which a limit is now given and since the cumulative limit has been lowered, some film badge processors offer a double film badge: one packet to be replaced every 2 weeks and the other to be worn for 3 months. Use of this badge, which minimizes the recording of "fog" as actual exposure to radiation, seems desirable when prior exposure records are accurate and close to limits. As an alternative, wearing a single film badge for a month instead of 2 weeks would seem reasonable in most instances.

The Oregon Board of Health has not undertaken to supply film badges as part of its survey because of the expense and also because of a feeling that badges would be used more consistently if paid for by the X-ray unit owners. Further, the practitioner will have to make contact with a film badge distributor sooner or later, and the occasion of a survey is a good opportunity.

Film badges appear to be much more reliable than survey instruments for most personnel monitoring, although instruments are useful in surveying fluoroscopes. The standard kit of instruments used by the Oregon Health Department, shown in figure 1, consists of a "cutie pie" ionization dose rate instrument and a condenser r meter. The instruments should be checked for accuracy in the energy region of soft X-rays before a final choice is made.

Personnel Protection Devices

In offices with small caseloads, special personnel protection devices may not be necessary, depending on attenuation by the tube head, design of the office, and work habits of the technician. Exposure should be documented in all instances, however. We usually suggest some sort of protective device to reassure the technician and provide legal protection for the owner, but on this question, as on others, judgment as to the hazards is a ruling factor. Rigid application of protection rules without consideration of the particular situation may lead to unnecessary difficulties.

In offices with a normal to heavy workload, a leaded barrier is recommended. It need not be expensive, since a lead sheet or lead-faced plywood can be purchased and installed by the owner (*9*). The field staff can easily learn where such materials are available locally, how much they cost, and how to install them. (This information should also be provided in the notes given each X-ray owner.)

Enclosed leaded cubicles are hardly ever mandatory in diagnostic work, although they are often found today in the larger hospitals. With adequate structural material in the walls, experience indicates that lead shielding in the walls of the radiographic room is needed only if there is an exceptionally heavy workload and permanent occupancy in adjacent rooms. However, lead is often needed behind the cassette holder used for chest and upright X-rays if the beam points into the waiting room or other occupied areas. Outside brick walls or distance often reduce the radiation exposure in the vicinity to small proportions. However, any possible exposure, including that in adjacent offices of the same building, should be documented.

Exposure of the practitioner himself may pose special problems. There are still some

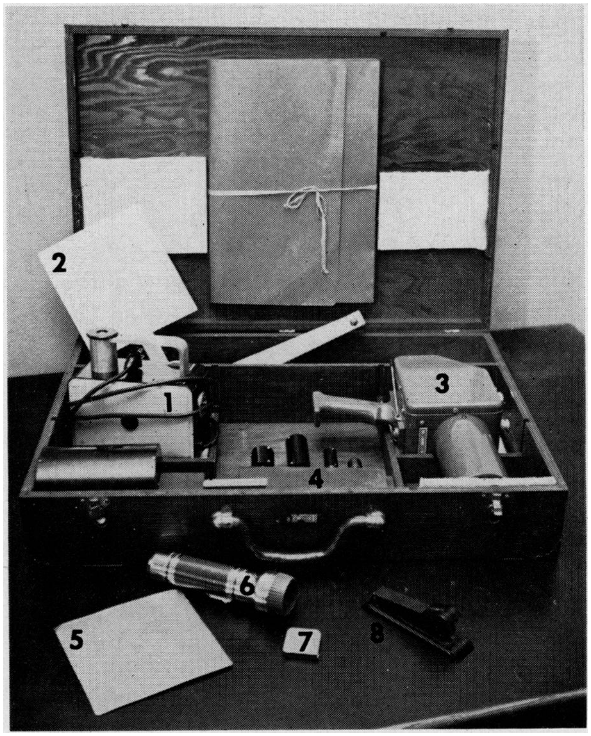

Figure 1. X-ray survey kit used by the Oregon Health Department

1. Charging and reading unit for air-equivalent wall ionization chambers.
2. Ruled fluorescent grid for determining dental X-ray beam size and symmetry.
3. Ionization dose rate instrument.
4. Air-equivalent wall chambers.
5. Aluminum sheet for half-value layer determinations.
6. Flashlight.
7. Tape measure.
8. Stapler.

physicians who do not wear lead aprons and gloves in fluoroscopy or who use excessively old or cracked aprons. Small cracks or holes in aprons are not usually important, but, of course, they should be avoided when feasible. A recent review by Hale (*10*) discusses other fluoroscope monitoring problems. X-ray work in operating rooms, especially in genitourinary surgery, may lead to exposure because the surgeon, normally in a sterile gown, is reluctant to go behind shielding, even if it is present. However, most such exposures are limited and the hazard is not large, provided the physician stays away from the primary X-ray beam. A film badge check of all operating room personnel is advised if such work is at all usual.

Since radiographic exposures occur in short pulses of comparatively high readings (in milliroentgens per hour), it is usually not practical to assess resulting hazards with a survey meter. We especially discourage any such time-consuming procedures as plotting isodose curves near a unit. Past experience allows one to judge protection with considerable accuracy, and, of course, film badges must provide the final proof. Since reports are written at once, we rely on past experience in making recommendations without waiting for the results of film badge surveys. If there is doubt as to what the film badges will show, we write several alternative recommendations with instructions on how to interpret the film badge results, and usually schedule a revisit.

During surveys of fluoroscopes, we record the dose rate through the leaded viewing screen and at waist height near the unit. Values in excess of about 20 mr per hour for the former and 1,000 mr per hour for the latter may require special attention if the workload in minutes of fluoroscopic viewing per week is sufficiently high. Most readings observed in Oregon, as well as those reported in the literature (*11*), have been below these values.

Dental X-ray units may pose some difficult problems in personnel protection. Because of space limitations and a desire to watch the patient during X-ray, many dentists consider protective shielding awkward. For small caseloads, not more than 10 to 20 dental X-rays a week, experience indicates that a long timer cord on the unit, allowing the technician to stand 7 to 10 feet away, may be adequate protection, provided there is a good tube head and careful use. A recent report shows that dental exposure rarely exceeds 300 mr per week even in offices with minimal or no protection (*8*). An adjacent thick plaster wall which usually provides an attenuation factor of 2 to 6, may serve as shielding. Much depends on the design of the X-ray unit.

For heavier workloads, we recommend installation of a shielding device. Special attention is given to making this convenient. A hinged, leaded plywood sheet may be attached to a wall, for example, or shielding may be built onto an existing partition. Few dentists today hold films in their hands during exposure, although cases of chronic radiodermatitis have been seen as the result of such practices in the past. For dental X-ray units, as for all others, the personnel exposure should be documented, and the suggestions made should take cognizance of individual needs.

Patient Exposure Reduction

Personnel exposure and patient exposure present quite different protective demands, and the distinction should be pointed out during surveys. Since one is often called on to discuss possible hazards of radiation exposure, all individuals conducting the survey should receive instruction on such subjects as genetic damage, leukemia, skin burns, and damage to embryos during pregnancy. Many moderate, carefully documented statements on these subjects are available (*3,5*). The information given to practitioners and technicians must be based on sound facts if confidence in the program is to be established.

Regardless of what specific conclusions are reached regarding the hazards mentioned above, and we feel the hazards should be put into the reasonable context of the numerous health hazards encountered in everyday living, one can state without equivocation that the changes the Oregon Board of Health recommends reduce patient exposures associated with needed X-rays by some 50 to 95 percent without sacrifice of X-ray quality. If this is understood, one need not argue about the possible deleterious effects of a given exposure or make the avoidance of X-rays a prime recommendation. Any substantial likelihood of harm justifies using the necessary protection techniques if they do not interfere with the advantageous use of X-ray. The Oregon program does, of course, try to discourage unnecessary or unusually hazardous procedures, such as spinograms, shoe-fitting X-ray, well-baby fluoroscopy, routine pelvimetry in pregnant women, and routine examinations that cause heavy gonadal exposure, such as pre-employment examinations of the lower back.

Present standards for total population exposure to radiation are based on genetic considerations. In other words, genetic damage is thought to be the major limiting factor to the use of radiation. Exposure of parts of the body other than the gonads may present some hazard in regard to leukemia, for example, but it is not thought at present to be a major consideration in ordinary diagnostic work. An exception is exposure of the fetus during pregnancy. There is some evidence that exposures of pregnant women to radiation may lead to an increased incidence of leukemia in the offspring and also that the mammalian embryonic nervous system is sensitive to radiation (*2*). It seems prudent to avoid radiography involving the abdomen of pregnant women that is not urgently needed. Some obstetricians estimate that not more than 5 percent of pregnant women need an abdominal radiograph.

Coning and Local Shielding

To prevent genetic defects produced by radiation, primary attention is given to protecting gonads from the direct beam whenever possible. Coning of the X-ray beam and gonadal shielding are the two main techniques for this purpose, and both present complex problems.

In principle, "coning" of the X-ray beam can provide good gonadal protection. Various devices are in use for confining the beam, the commonest being a metal cone attached to the tube head. Frequently, a cone of a single size is used for X-raying small fields, such as the gall bladder or sinuses, but no provision is made for limiting beam size when larger fields must be exposed. Another device in use is a lead diaphragm fitted into the tube housing. Sets of such diaphragms cut to required sizes for various fields are available in some localities. Cones and diaphragms, to be effective, have to be accurately tailored to the particular X-ray head and field sizes and used appropriately. A single cone or diaphragm cannot provide adequate protection. As a minimum, two different cones are needed for 14-inch by 17-inch films at 72 inches and 36 inches, and an additional narrow cone must be used for small fields. However, the narrow cone, known as a "sinus" cone, may also happen to suffice for 14-inch by 17-inch fields at 72 inches. The surveyor must have a clear mental picture of the geometry of X-rays and needs to know how to locate the position of the anode on the tube housing (usually indicated by a red spot). We usually carry a small slide rule to facilitate computations.

The following are examples of situations we have encountered in connection with beam collimation. Two or three cones are present but all are too large for the field sizes used. Cones are present, but the technician does not use them. The practitioner is willing to get one or two more cones, but the correct sizes are not commercially available. The practitioner is reluctant to spend some $20 apiece for new cones. There is little use of available diaphragms, although sets of four or more may be on hand, labeled according to field size and use.

A more fundamental problem is that properly chosen cones allow little margin, and poor centering of the machine leads to cutoffs on films, producing some annoyance and a need for retakes. Although many radiologists may not object to slightly cut corners, others are unwilling to accept them, with the result that the cones are not used.

A variable aperture collimator offers a way out of this difficulty. Essentially, a variable aperture collimator is a continuously adjustable round or rectangular lead diaphragm, which can be set conveniently for any given field size and distance combination. A centering light or light beam is provided to facilitate positioning. A small model sells for about $100, and better units up to $450. We have recommended purchase of variable aperture collimators when it appeared that the practitioner would be interested. However, even adjustable collimators pose some difficulties. They must be precisely attached to the tube housing in order to produce a symmetrically centered field. Put on carelessly, they can also cause cutoffs, which force the technician to set them at a somewhat larger field size than indicated, to that extent decreasing their protective functions. Also, some of these collimators have a built-in extra beam size margin of 1 to 2 inches in all directions, which is probably necessary if one alines with a central light spot. Several adjustable cones have been manufactured that project the entire field rather than one central spot. They should be very satisfactory, provided the light and X-ray beams are accurately centered with respect to each other.

The radiation-safety aspects of an ordinary P–A chest X-ray illustrates these problems further. One would hope to limit the beam sufficiently to protect the ovaries in the female. If a round metal cone is used, it must be checked first for proper size, using the diagonal measurement of the 14-inch by 17-inch film and about a 2-inch margin in each direction to give a final diameter of roughly 24 to 25 inches. In order to get an accurate field, the cone itself must be tailored to less than one-fourth inch in critical diameter. The necessary wide choice of cones is not usually available. If a circular field is used, its lowest portion will extend well down into the gonadal area of a woman, though the male gonads would be excluded. Rectangular cones (nonadjustable) are not widely available at present. If diaphragms are used (most machines are not equipped for them), the utmost precision is required in computing and cutting out the apertures. Because of lack of standardization on units of different ages and manufacturers, diaphragms must be practically tailor-made for the unit. If a variable aperture collimator is used, it must not allow excessive margins, and it must be accurately centered.

These complications are mentioned because it should be well understood by the field staff that the mere presence of one or even four cones does not assure good coning.

Accurate coning, of course, is more important in certain projections than others. For a film of the foot or ankle, almost any cone will protect the reproductive organs from the primary beam. In abdominal or lower back X-rays, it is difficult with cones alone to exclude the gonads from the beam.

Because of the practical difficulties in achieving adequate coning, we recommend gonadal shielding as a supplement to coning. Considerable overt resistance to local shielding has been encountered in the field. Some practitioners (and technicians) feel it will alarm patients. Local shielding may be a nuisance. For upright projections, as of the chest, rather cumbersome aprons or externally supported shields are sometimes necessary. A variety of gonadal shields are on the market, including leaded bivalved arrangements for the scrotum, but these involve hygienic and aesthetic considerations.

With radiography of the abdomen, the pelvis, the hips, or the lower spine, considerable care and ingenuity are needed if protection of the gonads is to be achieved by shielding. Variously shaped pieces of lead are needed, for example, for protection of the ovaries during abdominal work, shielding of the scrotum or ovaries in infants being checked for congenital dislocations of the hips, or protection of the ovaries and fetal gonads during pelvimetry. Shields made of leaded glass woven material can be used but are low in lead equivalence and are expensive. Descriptions of specialized shielding devices are found in the literature (*12–14*), and one's imagination is the only limitation for suggesting new arrangements. For routine chest X-rays externally supported shielding is probably necessary if large round cones are used. Few X-ray users surveyed in Oregon have taken the steps necessary to curtail gonadal exposure in examinations of the critical lower trunk area. A useful technique for local shielding is the mounting of lead sheet on a larger clear plastic sheet, which can be positioned over the patient accurately and easily.

In photofluorographic (p.f.g.) work (in chest X-ray vans, for example) limitation of beam size is often more nearly satisfactory because precise diaphragms can be cut and permanently installed. We advise checking the actual field size projected with X-ray films or fluorescent materials. Usually the film-carrying hood assembly is coupled automatically to the X-ray head. Therefore, no centering problem arises, and small margins are possible, especially on the bottom edge. For photofluorographic work improved lens systems, fast screens, and fast film help to reduce the dose. The film used in p.f.g. units differs in size from ordinary X-ray film and is not necessarily available in the same range of speeds.

Limitation of beam size for dental X-ray units can be readily accomplished. Most dental units, however, have unnecessarily large beams although there is a plastic pointer on the outside, and a lead washer may even be installed inside it. Standards for dental radiography have been discussed in several articles (*15–18*). A 2¾-inch field diameter at the patient's jaw is advised. A 16-inch tube-to-skin distance is preferable to reduce parallax errors, but 8 inches is much more commonly used. Restriction of beam size is easily achieved by inserting a heavy lead "washer" inside the plastic pointer cone, of a size calculated to produce the recommended field diameter. Such washers, together with filters, are becoming widely available commercially, or they can be fabricated at minimal expense. We do not feel additional local shielding is indicated for general dental work.

Added Filtration

Another step that reduces patient exposure is the insertion of an aluminum filter into the X-ray beam (*19*). The filter cuts out the soft component of the X-ray beam, which otherwise would irradiate the soft tissues closer to the X-ray tube but would not contribute significantly to the actual X-ray image on the film. Current standards require a total filtration of 2.5 mm. of aluminum equivalent on radiographic units. Most X-ray tubes have an inherent filtration of about 0.5 mm., and therefore only 2 mm. of aluminum need be added. Some tubes have a substantially higher inherent filtration, up to 1.5 mm. We use a table listing inherent filtration for various machines, but when in doubt the assumption of 0.5 mm. is unlikely to cause difficulty. Provided a unit is used at kilovoltages higher than about 70, no change in exposure is required on insertion of 2 mm. of added filter, even where none was used before. At lower kilovoltages some small increase in milliamperage and time of exposure may be necessary. Many dental units operate at 55 to 65 kv. and with these the addition of 2 mm. of aluminum may cut down output to a level where exposure time becomes excessive. The current NCRP recommendations for dental machines call for total filtration equivalent to 1.5 mm. of aluminum. Most new units include the required permanent filters.

Film and Film Development

Film, film development, and film cassettes are comparatively simple components of radiological control. The usual X-ray film cassette contains two intensifying screens, one on each side of the X-ray film. Only when very fine detail is required (as in certain bones) should film be used without such screens. Therefore, the effective exposure speed depends both on the film emulsion and on the cassette screens.

In recent years films have been substantially improved and several excellent fast films are on the market. The price is perhaps 10 percent more than for standard-speed film, but this should not deter their use. The fastest films may show slightly less detail, and radiologists may not find them entirely satisfactory for critical work. However, they are adequate for many purposes and can be expected to decrease patient exposure by 30 to 40 percent.

Cassette screens have also been improved. A pair of 14-inch by 17-inch cassette screens cost about $30, in part because of the high standards of uniformity that are needed to prevent the production of spurious shadows on the films. Replacement of screens in all 6 to 10 cassettes used in an office is therefore expensive. Installation of fast screens in only one cassette is possible in a small office, but then two different exposure techniques have to be used. The reduction of patient exposure with newer screens is about 30 percent. An optimum combination of screen and film promises even greater reductions, and specifically matched sets will doubtless become available soon.

Experience in the Oregon survey has revealed that a majority of X-ray films are not properly processed. In order to utilize the full speed of the emulsion the film must be fully developed, which means 5 minutes at 68° F. Some film manufacturers offer charts giving times for "standard" development and "full" development. There appears little question that 5 minutes can and should be allocated to developing the film, even in an emergency. However, as with any photographic emulsion, the temperature of the developer is a critical factor in the chemical process. Full development may be obtained at 75° F. in less than 3 minutes, but with some increase in grain size and fogging. Most smaller offices have no thermostatic baths, and many technicians control developer temperature by trial and error, using surrounding sink water with fair results. Others do not watch the temperature at all and control density by inspection, which is not desirable. Small electrical bath thermostats are not expensive and ought to be recommended in practically all offices.

To produce a satisfactory film with a development time of only 2½ to 3 minutes at 68° F. requires approximately a 50 percent increase in exposure. If full development, fast film, and other innovations are used, exposure time and milliamperage used in the tube, or both of these, may be decreased. Usually a multiplication factor for the combined changes can be established by trial and error for some representative exposure and then applied "across the board." It is possible at times simply to decrease exposure while obtaining good results, because X-ray film has some considerable exposure latitude.

Increasing Kilovoltage

A number of articles have appeared on the advantages of high kilovoltage in X-ray work (*19–21*). Simply put, the kilovoltage determines the velocity of each electron while the tube current (in milliamperes) is proportional to the number of photons per unit time. The total exposure is therefore measured in milliampere-seconds (MAS); it is proportional to the total number of photons reaching the patient. A change in tube kilovoltage has a complex effect, since it both increases the number and energy of photons. In practice a rule of thumb is that the MAS should be halved for each increase of 10 kilovolts. The advantage of higher kilovoltage is that the resulting beam is more uniform and penetrating. This increases the ratio of useful negative image to patient exposure.

Radiologists have generally considered high kilovoltage to be above 100 kilovolts. An objection has been raised that at values of 100–120 kilovolts the films have lower contrasts and are harder to read. However, radiologists who take time to get used to the "greyer" high-kilovoltage films find them completely satisfactory and often superior in range of detail. Most units in use, however, are not designed to operate at high kilovoltage. Some units may show a scale up to 110–120 kilovolts, but are not necessarily intended for heavy usage above 100 kilovolts, unless of recent design. For instance, the conventional high-voltage cables found on most smaller units are said to fail rapidly at levels above 100 kilovolts. On the other hand, much work today is still done in the 60–75 range, which is less than satisfactory in producing a full range of detail. We recommend the use of the 75–90 kilovoltage range for the ordinary nonhospital installation, which affords a compromise between maximum reduction of patient exposure and practical demands.

When higher kilovoltage technique is adopted, the exposure charts must be extensively modified. Since modification is a complex undertaking, it is advisable to get a ready-made high-kilovoltage chart from an X-ray distributor. This can then be adapted to the given unit by a simple proportionality factor.

The radiological surveyor needs to know which distributors have charts and to study them himself so as to provide correct advice. Changing from 65 to 85 kilovolts results in substantial reductions in entrance skin exposures (by as much as 75 percent) with somewhat lesser reductions deep in the body.

Considerable time goes into explaining why higher kilovoltages are recommended since most technicians find this contrary to what they expect. Radiologists (and hospitals) commonly use medium-high kilovoltages and time and effort expended in encouraging them to go higher may be fruitful. Since radiologists are specialists in this field, some restraint is advisable in insisting that they alter their working technique. On the other hand, many of them have not given the high-kilovoltage technique a fair trial and may be encouraged to do so.

Since most dental units operate at a low, fixed kilovoltage in the order of 55–70 kilovolts, no major change in voltage is possible unless the unit is replaced. The newest dental units are adjustable and go up to 90 kilovolts.

The installations in use by chiropractors, osteopaths, veterinarians, and others are frequently, though not necessarily, old and of low maximum kilovoltage and current output. Replacement may often be advisable. However, it should be noted that kilovoltage is only one factor among many, such as filtration and film speed, and the vast majority of units in use can be put into acceptable condition though at lower than optimum kilovoltage.

We have encountered only a small number of really obsolete machines in Oregon, such as those with exposed wiring or bivalve tube shields without a full housing. These units are hazardous with respect to electrical shock alone. The surveyor should have a general idea of what new and good used X-ray machines cost and keep these figures in mind when discussing replacement. If replacement at a future date is decided upon, the practitioner nonetheless may still need to install protective items on his current equipment, since the purchase may be put off for years.

Dose Rate Measurements

A word may be said here about taking measurements of dose rate in the direct X-ray beam. We do not routinely measure dose rate in the X-ray beam except in fluoroscopic installations for the following reasons: many instruments do not read accurately with short pulses; making a full set of measurements with a condenser r meter is much too time consuming; and, most important, such measurements are really not needed to assure protection. The X-ray film itself serves as a final dosimeter for any exposure. Therefore, if a filter is present, if the kilovoltage is adequate, and if fast film is used and processed fully, the skin exposure for a given high-quality X-ray negative can be accurately predicted. While the output of machines at a given kilovoltage and milliamperage varies greatly when there is no filtration, much less unpredictability is found if the routine protective devices are present.

Many units in the field are of the convertible type, that is, the radiographic head swings under the table and is locked into position to produce a small fluoroscopic installation. For these, much information about the fluoroscopic output is already at hand after the standard inspection. Larger installations have separate fluoroscopes which require a separate survey. Frequently it is difficult to examine adequately the fluoroscopic tube head for filtration, and we therefore routinely obtain a half-value layer measurement as well as fluoroscopic dose rate in air. The half-value layer is that thickness of a given material which reduces the beam intensity by one-half. It is convenient

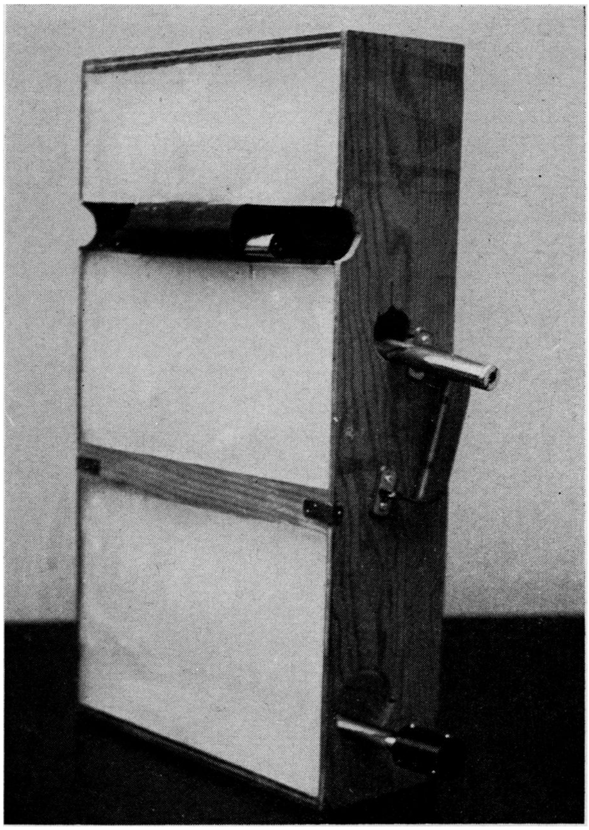

Figure 2. Paraffin phantom for measuring scatter radiation and depth dose

to use a 1 millimeter thickness of aluminum (pure, not alloyed) and take measurements with two suitable (5 and 10 r capacity) condenser r chambers simultaneously. Trout and associates (*19*) provide charts of the effective half-value layer equivalents of X-ray beams with a given kilovoltage and total filtration. Under ordinary conditions, 2.5 mm. of total tube filtration results in an X-ray beam that is further attenuated about 25 percent by an additional added millimeter of aluminum; that is, the measured dose in air and through the standard aluminum sheet (directly on the tabletop) should not differ by more than 25 percent. It is suggested that the proper values for a given instrument, filter standard, and so on, be checked empirically when a program is set up, using hospital units with a known total filtration. Somewhat more precise half-value layer measurements can be obtained with special metal caps over a condenser r chamber (*10*). Inaccuracies resulting from using the chambers directly on the table rather than in a scattering medium are not very important in routine fieldwork.

Measurements of secondary radiation, however, should preferably be made with a scattering medium in the X-ray beam. Lateral dose rate at a fluoroscopic table is at least doubled by a scattering mass as large as the human body. A block of paraffin or stack of masonite sheets will serve this purpose. Measurements of semiresearch quality can be obtained by a standard paraffin block with openings at the surface and deeper channels for measurements equivalent to various depth doses. Figure 2 illustrates such a block. Aluminum sheet for half-value layer determination can be built into the block. It is then possible to get three or four useful measurements from a single exposure quickly and efficiently. If such a "phantom" is used for radiographic as well as fluoroscopic studies, special care should be taken to avoid saturating the chambers with excessively short and intense pulses of radiation.

Another basic fact concerning measurements is that even though the X-ray beam may be sharply limited by a cone, the secondary electronic equilibrium built up in any scattering mass, including the human body, extends appreciably beyond the original limits of the beam (*22*). Scatter measurements in a paraffin block taken, for example, 4 inches beyond what is thought to be the actual edge of the beam will be much higher than more distant scatter measurements. This point is also of importance in connection with recommendations about local shielding. For instance, any attempt to shield the ovaries with a pair of 2-inch diameter lead sheets on a plastic sheet would probably result in only a small decrease in actual radiation exposure of the ovaries because of the electronic equilibrium conditions built up deep in the body.

Special Techniques for Fluoroscopes

The present NCRP limit on fluoroscopic dose rate at the tabletop or panel is 10 r per minute in air (*23*). Judging by comments from local radiologists 5 r per minute is adequate for observations, and not infrequently 1 to 3 r per minute may be practical. Milliampere settings to achieve these dose rates run on the order of 1.5 to 3.5; but milliamperage meters are often inaccurate and should not be relied on. To fluoroscope sucessfully below 5 r per minute, 15 to 20 minutes of dark adaptation is recommended; even 10 minutes improves vision materially. Unless the fluoroscopic room is completely dark, light leaks may interfere with viewing. Red goggles for dark adaptation are owned by many but used by far too few. Low-efficiency screens used with some older fluoroscopic units should be replaced.

When the fluoroscopic viewing screen is examined for shutter adequacy, a dark margin should be found on the screen with the shutters wide open. However, this specification depends on the distance from the tabletop at which the screen is used, and judgment is therefore exercised in placing the screen for this test. Twelve to fifteen inches seems realistic, but perhaps a greater distance is safer. The residual dose rate through the leaded-glass fluoroscopic screen under normal conditions is commonly 5–20 mr per hour. Rates above this require investigation (*10*).

High rates may sometimes be due to a failure to readjust kilovoltage to the usual fluoroscopic kilovoltage; this, of course, also increases the dose rate in air. Several scatter measurements can be made in the vicinity of the unit, preferably with a scattering block in place. Rates at the sides of the unit are often 250 to 1,000 mr per hour, rising to as high as 1,500 mr per hour at certain locations above the table but not in the direct beam. While these values are high, it should be noted that few units are used for as much as an hour a week, except in hospitals, and also that the user is expected to be wearing protective garments. Some also employ lead hangers at the fluoroscopic assembly and to cover the Bucky slot. The fluoroscopist's forearms may be exposed to more than 300 mr a week, but this is below exposure limits for the hands and wrists of 1.5 r a week. Normally the shutters are at least partly closed during actual use. Film badges should be the court of final appeal. They should be used inside the apron and possibly on the collar and coat sleeves.

An additional NCRP specification for fluoroscopes is a minimum distance of 12 inches and a preferred distance of 18 inches from tube target to panel or tabletop. We have found that most units fall somewhere between these measures. The reason for this specification is rather complex, involving differences in effective dose rate at varying depths in the body, as influenced by the inverse square law. Some recent actual measurements suggest, however, that the dose at minimal distances is not too great (*10*), and we believe considered judgment, with cognizance of measured dose rate, should govern suggestions for rebuilding a unit. It should be clearly understood that the point at issue here is not simply dose rate as a function of distance, but a much more involved physical phenomenon.

Among various specialized types of fluoroscopic installations, a common one is the upright unit used by internists for quick inspections of the heart and lungs. Since the fluoroscopic unit does not tilt to the horizontal position, it is practical to tape up the chambers and half-value layer filter with wide adhesive tape. The controls on such units often show transformer primary (line) voltage rather than secondary voltage actually impressed on the X-ray tube, and it is therefore often impossible to assess operating kilovoltage. However, this is immaterial as long as dose rate and half-value layer are known and adequate.

Fluoroscopic units in pediatric clinics require careful scrutiny. It is easily possible to deliver as much as 10 r to the gonads and much of the body of an infant in a single fluoroscopy examination if the exposed field is not well collimated. If every infant received such a dose, the gonadal limit of 10 r for the total population by age 30 would be exceeded (*1*). Many authorities have strongly urged decreased use of pediatric fluoroscopes, and we have found it possible to persuade many physicians to agree, although a few pediatricians wish to have the unit available for emergency work, to locate foreign bodies, for example. If the unit is used, it is clear that low milliamperage and adequate filtration and shutters should be present for protection. In some instances a lead sheet (2½ pounds per square foot) with a small rectangular cutout somewhat smaller than the usual infant chest is permanently mounted on the tabletop in place of shutters. Pediatric units unfortunately are frequently found to be converted X-ray units without shutters. The pediatricians always welcome information about the dose rate of a unit and a discussion of the current concepts of gonadal and other exposure limits.

Most osteopaths and chiropractors in Oregon disclaim substantial use of fluoroscopy. However, their units, usually those of the convertible type, are checked for fluoroscopic output. Some hospitals have portable units and use is made of a hand-held fluoroscope. These devices are rapidly disappearing, as their use is condemned today.

If a unit owned by a chiropractor is used for spinograms, special collimating diaphragms with a slot-shaped aperture and the use of special gonadal shielding will at least reduce the dose. Most of the chiropractic units we have encountered have been older units of small output. Under these conditions the exposures required for penetration of the spine and pelvis run into many seconds; further reduction of output by filtration may extend this time. Since chiropractic work involves X-raying thick parts with potentially high gonadal exposures, the burden of justification is on the prescriber. As noted above, the State considers the dose unnecessary and actively discourages the use of spinograms.

Summary and Conclusions

Highly trained personnel are sought for inspection of diagnostic X-ray units. This work requires considerable specialized knowledge of X-ray technique, radiation measurements, personnel exposure standards, and radiobiological effects. The chief of such a program has to answer questions relating to radiological hazards, and it is advisable for him to have formal postgraduate training in radiobiology. The working team requires specific field instruction under the guidance of the program chief.

Occupational X-ray exposure appears to be fairly well under control; few gross overexposures are found. Film badges are suggested wherever personnel monitoring is required, but not necessarily for use continuously. Experience is often more reliable for judging personnel exposures than survey instruments.

Collimation of the X-ray beam is probably the most important single factor in reducing patient exposure. Adequate coning is difficult to attain in practice. Fairly good results can be obtained with some types of variable aperture collimators, particularly if they completely illuminate the field with visible light. Gonadal shielding is recommended for all examinations involving the lower trunk, however, as an additional precaution.

Additional protective techniques readily applicable to most units include added filtration, fast film, full-film processing, and correct exposures. To these may be added under some circumstances fast cassette screens and high-kilovoltage technique.

Fluoroscopic output can be reduced at the tabletop or panel to 5 r a minute or less without much difficulty. Personnel exposure in fluoroscopic examinations is not excessive if the usual protective garments are worn.

Pediatric fluoroscopes and chiropractic installations used for spinograms are discouraged.

For good results, persons in radiation safety programs dealing with diagnostic X-ray units need a detailed understanding of X-ray work, both from the theoretical and practical viewpoint. They must also be familiar with the complex current exposure standards and with diagnostic radiology. One cannot depend on simply recommending that "adequate coning be provided," for instance, if success is to be expected. Specific advice is demanded on all details of accomplishing the desired improvements. For this purpose, special instruction forms and explanatory materials for owners and operators are a useful supplement to counsel and surveillance.

Information concerning the Public Health Service inspection programs and training courses can be obtained by writing to the Division of Radiological Health, Public Health Service, Washington 25, D.C. Copies of inspection forms used in Oregon can be obtained by writing to the Oregon State Board of Health, Portland 1, Oreg.

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Occupational Health Notes

Carbon Tetrachloride Poisoning

In Tennessee a worker brushing a bonding agent on metal plates to hold a rubber mat developed acute nephrosis. Samples from the worker's breathing zone showed concentrations of carbon tetrachloride and xylene above the maximum allowable concentration.

Sawdust Trail

A dust explosion and fire recently destroyed the cyclone collector and sawdust bin of a hardwood flooring company at Everett, Pa. Apparently, the explosion and blaze resulted from overheated sawdust on rafters in the boilerroom adjacent to the dustbin and cyclone collector. Rafters which supported the boilerroom ran through the common wall and across the dustbin. There was no solid wall between the dustbin and boilerroom. Ignited dust on the rafters above the boiler burned in a slow trail to the dustbin where the explosion occurred.

It is customary for lumber plants to collect sawdust in a cyclone and dustbin, and to burn it in the boiler. For safety, it is recommended that a solid firewall separate dust collection units and boilerroom; that dust be prevented from accumulating on rafters above the boiler; and that firing the boiler with sawdust be done with care to prevent a backflash. It is also good practice to keep the firedoor between dustbin and boilerroom closed except to remove sawdust for burning and to keep flammable material away from the boiler and sawdust bin. Without such precautions, a dust collector and a boiler are potential dynamite.

—W. C. Mawhinney, *industrial hygienist, Pennsylvania Department of Health.*

Celery Workers' Rash

Pink rot, a fungal disease of celery, causes a skin rash among cutters who handle celery before it is washed in the packing sheds. Most frequently the cutters complain of blisters which break and develop into a depigmented type of lesion, but the disease can also cause hyperpigmentation. The hyper- or hypopigmentation may last for 9 months.

At the request of the Michigan Department of Health, the Occupational Health Branch, Bureau of State Services, Public Health Service, studied the dermatitis among workers on 15 farms in that State. Patch tests on celery workers and volunteers at the Occupational Health Field Headquarters indicate that the cause of the rash is photosensitization of pinkrot-diseased celery.

Exposure to Microwaves

Experience and research have not indicated a need to change the present standard, 10 milliwatts per square centimeter, of a safe working exposure to microwaves, it was reported at the Third Tri-Service Conference on the Biological Effects of Microwaves held at Berkeley, Calif., August 27–29, 1959.