SHOE-FITTING X-RAY FLUOROSCOPES

RADIATION MEASUREMENTS AND HAZARDS

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The question of radiation hazards is a topical one, and some newspaper publicity has recently been given to a type of x-ray equipment which may be seen in shoe-shops in this country—the x-ray fluoroscope for demonstrating the fit of shoes. As long ago as September 2, 1950, the *British Medical Journal*, under the title "Radiation in the Shoe-Shop," drew attention to the potential hazards of such machines. Since then, measurements have been made on typical British machines, both in shoe-shops and on a recent type of machine which was loaned to A.E.R.E., Harwell, for testing. Before giving the results obtained, it is appropriate to describe some features of these machines. The terminology follows that in the Recommendations of the International Commission on Radiological Protection (1954), so, for example, r=roentgen and mr=milliroentgen (1/1000 roentgen).

Description and Use of Fluoroscopes

All the machines examined were British-made, and they are known by the trade name "pedoscope." The company which manufactures these machines gave every facility to enable measurements to be made.

The x-ray equipment is contained in the wooden base of the machine. There is a high-tension transformer rated at 42 kV (R.M.S.), with the mid-point of the high-tension winding earthed. Both ends of the x-ray tube are thus at high potential; the tube acts as its own rectifier, and the voltage across it reaches 53 kV peak. These x-ray tubes are run well within their rating, which results in a long operating life, and in addition there is no need to limit the screening time because of tube anode overheating. The equipment is controlled by three push-buttons at the side of the machine; they are labelled "Man," "Woman," and "Child," and they control the mains input to the high-tension transformer (by series resistors), and so the x-ray output. With the "Man" button the x-ray tube runs at 53 kV peak, 5 mA; with the "Woman" button, 51.5 kV peak, 4 mA; and with the "Child" button, 50 kV peak, 3 mA.

To screen this x-ray equipment, the wooden box is lined with lead sheet 1.2 mm. (18 S.W.G.) thick, except for a rectangular area in the top. This area is "bakelite" 1.5 mm. thick, and in the newer machines there is additional 0.5 mm. thick aluminum underneath it to increase the filtration. The bakelite is about 24 cm. above the focal spot of the x-ray tube, and mounted above the bakelite (or useful beam area) is the fluorescent screen covered with lead glass of 1.17 mm. lead equivalent. The main x-ray beam illuminates almost the whole of the fluorescent screen, except for narrow margins at the edges.

The foot opening in the viewing-hood is an outlet for radiation scattered from the useful x-ray beam, and strips of lead rubber are hung over this opening to absorb some of this scattered radiation.

In the latest machines the fluorescent screen is fixed in place (instead of tilting as in the machines tested) and there is additional lead screening surrounding the foot area and the fluorescent screen.

To use a fluoroscope, the subject stands on the top step of the machine, of which the bakelite useful beam area

forms part. Above this is a viewing-hood, having three openings for viewing at the top. Only the front parts of the subject's feet project into this viewing-hood, and on the button being pressed a bright image is seen showing the bones of the anterior half of each foot, the shoe-nails, the outline of the shoes, and so on. Careful observation is required to make out the soft tissue of the feet, especially in the areas where corns and bunions occur.

In assessing the radiation hazards from these fluoroscopes it is necessary to estimate the time for which the x-ray equipment operates. The number of times a machine is used each day can vary between such wide limits that no generalization is possible; however, taking one x-ray viewing for each pair of shoes sold, the reader may speculate on the number of viewings each day or week at the local shoe-shop. Various observers have noted the duration of each separate viewing, and times between 5 and 20 seconds have been measured. The latest machines are fitted with a hand-set timer which limits each exposure to 10 seconds.

Radiation Measurements

Results of measurements on the recent type of machine are shown in the Diagram, in which the only measurement inside the machine is the 10.8 r/minute in the useful beam. Other results are given in Tables I and II.

TABLE I.—Film Results: Recent Model Fluoroscope

Film No.	Dose in r Recorded on Film	Dose Rate r/minute	Nearest Standardizing kV	Position of Film
1	1.00	12	83	5 seconds' exposure in useful beam, using "Man" button
2	1.10	13	83	
3	1.10	13	83	
4	0.35	4.2	83	5 seconds' exposure with $\frac{1}{4}$ in. (6 mm.) thick rubber sheet interposed in main beam to simulate a shoe sole. "Man" button
5	0.40	4.8	83	
6	0.37	4.4	83	

TABLE II.—Film Results: Shoe-shop Fluoroscope

Film No.	Dose in r Recorded on Film	Dose Rate r/minute	Nearest Standardizing kV	Position of Film
1	2.04	24	43	5 seconds' exposure in useful beam, using "Man" button
2	2.14	26	43	
3	1.88	23	43	
4	1.82	22	43	5 seconds' exposure inside child's new shoe, heel end. "Man" button
5	0.21	2.5	63	
6	0.71	8.5	63	5 seconds' exposure inside child's new shoe, sole end. "Man" button
7	0.72	8.6	63	
8	0.73	8.8	63	

The results shown in the Diagram were obtained from ionization measurements. A cylindrical ion chamber 20 cm. long and 8 cm. diameter and of about 1-litre volume was made, using x-ray film base, 0.007-in. (0.178-mm.) thick, graphited to make it conducting. Standard techniques were used for the insulation of this ion chamber, and for its voltage supply. The ion chamber was calibrated by comparison with a standardized Victoreen r meter; and, although it was convenient for measurements around fluoroscopes, it was too large to be completely irradiated by the useful beam when inserted through the foot opening of the machine. Other measurements were made, therefore, by using dental size x-ray films of the type used for personnel monitoring and special technique to allow for the low kilovoltage.

In using these fluoroscopes, feet are examined inside shoes, so some of the film measurements were made inside a shoe; and for the ion chamber measurements, a piece of $\frac{1}{4}$ -in. (6-mm.) thick rubber sheet was used as a substitute for a shoe sole. Further measurements were made using the alternative "Woman" and "Child" control buttons; taking the "Man" results as 100%, the "Woman" results were approximately 75%, and the "Child" results approximately 60%.

*When the measurements described in this article were made the author was in the Health Physics Division, A.E.R.E., Harwell.

The cone of scattered radiation which emerged from the foot opening of the machine spread out as would be expected from the geometrical arrangement of the useful beam area and the foot-opening area.

Some of the scattered radiation measurements were repeated with the addition of a demonstration pair of shoes, complete with wooden feet and legs, inserted into the machine as a dummy customer.

Minor radiation leaks were found around the wooden base of the machine where the top (which includes viewing-hood and foot platform) unscrews from the base when maintenance is required on the x-ray equipment.

American Radiation Measurements

In the *British Medical Journal* (1950) some American results are quoted and references given. The figures quoted in this paragraph are taken from these references. The American fluoroscopes described ran at about 50 kV, 3 to 8 mA tube current, and focus skin distance 7.5 to 20 cm. There is no mention of any added filtration. Many machines had a push-button timer, giving exposures of 5 to 45 seconds: about 20 seconds was the most popular time. Many measurements were quoted, made on 12 machines, by means of a Victoreen r meter in a shoe, and the range of dosage was from 30 to 350 r per minute. Values for the radiation

Test on recent model shoe-fitting fluoroscope. (Filter described as 0.5 mm. aluminium and 1.5 mm. bakelite.) Dosages, unless otherwise stated, were measured without shoes on platform, and were measured when "Man" button was pressed. "Woman" dose is approximately 75% of this, and "Child" dose approximately 60%. A $\frac{1}{4}$ -in. (6-mm.) sheet of rubber simulating shoe soles reduces dosage received by feet while on platform to one-third.

scattered out through the foot opening were nearly all above 100 mr per hour at 10 feet (3 metres) distance, and 15 mr per hour at 25 feet (7.6 metres) distance. Close to the machines, almost all the radiation dose rates quoted were higher than the corresponding results in the Diagram (which relate to a British-made machine).

Possible Hazards from Shoe-fitting Fluoroscopes

In discussing the radiation dose rates described above, it is useful to consider the people at risk. Thus there is the customer in the shoe-shop who may have a brief look at his feet for a few seconds in the fluoroscope on the one or two occasions each year when he buys shoes. Alternatively, there is the customer who may peer at the screen picture for some time, with each of several pairs of shoes in one shop, and then go on to other shops and repeat the procedure. As well as irradiating his feet, the customer is subjected also to scattered radiation which reaches him through the foot opening of the machine and through the material of the viewing hood.

A special case of irradiation of the customer arises with children. The shoe-fitting fluoroscope does enable a parent to see an image of the child's feet in its shoes, and so form some idea of the fit of the shoes. However, from the point of view of radiation dosage, children are regular customers in the shoe-shop, and may have new shoes as often as every three months. Possible radiation effects to be considered include skin erythema, and there arises the general question of irradiating growing tissue, with the special case of irradiating the epiphyses of the foot. Cases are described in the literature in which the epiphyses round the knee were irradiated to slow down or stop growth of the leg (Spangler, 1941). Another case is described by Frantz (1950), in which a haemangioma of the leg and thigh of a baby was irradiated with 1,600 r of 135 kV x rays (4 mm. aluminium filter) during a period of six months; as the child grew there was gross shortening of the irradiated leg, as compared with the unirradiated one. Bisgard and Hunt (1936) describe experiments on the irradiation of femurs in young rabbits 3-5 weeks old. Subsequent microscopical examination showed cell damage in the epiphyses after 300 r or 200 r doses, but not after 100 r doses.

Besides irradiating customers, scattered radiation from these fluoroscopes irradiates the shop assistants. In a busy shop, with several assistants, a machine may be used many times a day, so that the dose accumulated by assistants over a period of time should be considered. There is the possibility also of irradiating the "people next door" (including above and below), but this is unlikely because the fluoroscope radiation is at low kV and so is readily absorbed in building materials such as brick and concrete. Along with the shop assistants one may include the customers in the shop; however (apart from actually using a fluoroscope), they will receive much less radiation than the shop assistants.

In addition to radiation hazards from fluoroscopes there is also the possibility of electrical hazards. In effect, one stands on a wooden box containing a generator giving several mA at about 50 kV. A substantial, well-earthed, and preferably x-ray-proof housing for this equipment is obviously desirable.

Radiation Hazards—Discussion

Comment here is confined to the measurements made on British machines, and the American results quoted above are not considered beyond noting that most of these American results are much higher than the corresponding British ones.

In considering the irradiation of the customers' feet by the useful beam, a standard of comparison is required. In the Recommendations of the International Commission on Radiological Protection* (1954), it is recommended that

maximum permissible levels of radiation dose, for large populations, be kept below one-tenth of those recommended for radiation workers. In the particular case of irradiation to extremities such as the feet, this large-population maximum permissible dose is 0.15 r per week. Assuming that averaging of weekly dosage over a three-monthly period is permissible, this is equivalent to about 2 r per three months. The recent type of British machine (with its additional 0.5 mm. aluminium filter) gave a dose rate in shoes of about 4 r per minute. Thus the permissible 2 r per quarter year would allow, for example, three exposures of 10 seconds each, or two exposures of 15 seconds, and so on, in each three-monthly period. The dose rates measured in the shoe-shop machine were twice those of the recent type machine, which suggests either using shorter exposures or reducing the useful beam intensity, to keep doses within the permissible limit.

Useful beam intensities are progressively reduced when the "Woman" and "Child" control buttons are used; the reduction is from 100% ("Man" button) to 60% ("Child" button). The I.C.R.P. recommendations refer to adults, and suggest also that lower limits are desirable for children. It may be desirable also to alter such limits for children of different ages. Although the reference quoted above shows that 100-200 r is required in a single dose to give detectable changes in epiphyses, children must be regarded as regular shoe-fitting fluoroscope viewers for periods of many years, so that it is the dose accumulated over a period of time which is the one to be considered, and this is the type of dosage considered by the I.C.R.P. in drawing up its recommendations on permissible weekly dose.

The "large population" figure of 0.15 r per week quoted above is suggested as an administrative level below which repeated radiation monitoring of the exposed personnel is not required. However, there is a further consideration, as, for example, the many papers at the International Conference, Geneva (1955), which discussed the genetic aspects of the total radiation dose accumulated by a population. A brief discussion of shoe-fitting fluoroscope doses and population dose is given in the next section.

It is interesting to compare shoe-fitting fluoroscope doses with those measured during x-ray diagnostic procedures. The I.C.R.P., for example, gives these figures for diagnostic fluoroscopy at 60 kV pulsating, 3 mA, and 35 cm. target-skin distance:

Equivalent filter	1.5 mm. Al	2 mm. Al	3 mm. Al
Average surface dose rate	7 r/minute	4.5 r/minute	3 r/minute

Other authors (Ardran and Crooks, 1952) also discuss fluoroscopy with additional aluminium filters up to 3 mm. thick. Comparing their results with 3-mm. filters with their results with no additional filter, they report reduced skin dosage with the 3-mm. filters, but no significant reduction in screen brilliance where the beam went through a patient; where there was no patient in the beam there was a reduction in screen brilliance. Applying these results to the shoe-fitting fluoroscope suggests that increased filtration would reduce dose to the customer while diminishing the screen brilliance only outside the outline of shoes; and a reduction of glare from the brightly lit periphery of the screen would assist observation of the foot image. In the present machines the tube runs at about 50 kV; a higher kilovoltage and more filtration may give as bright an image with less customer dosage.

From the results given in the Diagram, a calculation could be made of the dosage received by shop assistants standing in the area of scattered radiation; this would be compared with the value of 0.15 r per week used above. It is difficult to estimate how many times a machine is used in a week, how long the individual exposures are, and where the assistants stand; and so measurements were made by issuing film badges to some assistants, who wore them for a week. Only a minimal radiation dose (less than 10 mr) was

*Generally abbreviated to I.C.R.P.

measured on these films. The *British Medical Journal* (1950) quotes American results: 77 shoe salesmen carried film badges at work; two-thirds of these badges received no detectable amount of radiation, and of the rest only two received a dose around the maximum permissible level, and that at foot level (one of these film badges was carried in the trouser turn-up). It appears, therefore, that so long as the customer is adequately safeguarded shop assistants will receive little radiation dose.

Total Radiation Dose to the Population

Shoe-fitting fluoroscopes make some contribution to the total dose of radiation accumulated by the whole population of this country. Total dose is of interest because of its connexion with genetic effects in the population (International Conference, 1955), and the dose to be considered is that received by the gonads.

To compute the dose contributed by shoe-fitting fluoroscopes to the population of this country for a period of say a year, it is necessary to assume various typical figures about the machines used. The dose rates in question around a typical machine (see Diagram) are the 4 mr per hour figure against the viewing-hood for the customer examining his feet, and might be between 30 and 4 mr per hour for the nearest shop-assistants, and about 4 mr per hour for other customers sitting in the vicinity of the machine (these values are not the actual tissue dose rates used in the calculation). It might be estimated that, for the whole population, each person examines one pair of shoes a year with a fluoroscope, and also that each exposure lasts 10 seconds. Other average figures might be three assistants exposed to the radiation from each machine and about 30 pairs of shoes examined each working day in each machine. If these figures are used, and multiplied by the estimated number of machines in use in the country, a typical value for the gonad dose to the whole population in a year can be determined.

As a basis for comparison, we may consider the background radiation, which is the radiation everyone receives continuously from cosmic radiation and from the small amounts of natural radioactive material in our surroundings. If the population dose from shoe-fitting fluoroscopes is compared with that received by the population from background radiation it is found that the shoe-fitting fluoroscope dose rate is of the order of only 1/1000 of the natural background dose rate. Therefore the genetic aspect of shoe-fitting fluoroscope doses is negligible, and will still be so even if the various figures assumed above are increased considerably.

Possible Control Measures

Various control measures could be applied to shoe-fitting fluoroscopes; dosage to customers' feet could be limited by specifying a maximum dose rate in the useful beam, perhaps also with limits on the kilovoltage and current of the x-ray tube. The specification of some minimum filtration in the useful beam is very desirable, and some form of timing device may be necessary to limit the length of each individual exposure. If viewing could be done by a special shop assistant who kept partly dark-adapted (full dark adaptation is used in diagnostic fluoroscopy), a less bright fluorescent image could be used and the radiation doses would be reduced. To limit the dose to shop assistants, the minimum screening of the x-ray equipment and viewing-hood could be specified, or a maximum permissible dosage rate fixed, to be measured against the outside of the equipment. The effect of scattered radiation coming from the foot opening of a machine could be minimized by pointing the foot opening towards a wall and away from the centre of a shop. It may here be noted that the machines tested could be used for a limited number of short exposures before the radiation dose from them reached the limit recommended by the I.C.R.P.

The I.C.R.P. states clearly that the overall responsibility for the protection of personnel from radiation rests with the head of a radiological department; this will be the manager

in a shoe-shop. Manufacturers of machines could be asked to make sure that their instructions for the use of their machines describe these responsibilities. In the absence of a manager, responsibility would be delegated to another member of the shop staff who understands the hazards involved and the appropriate control measures. For the customer there could be warning notices, to draw his attention to the dangers of excessive exposure to x rays, and perhaps a reminder could be issued to the customer each time the machine is used.

New machines would be expected to conform to the specified requirements on installation, and some form of periodical checking would be desirable to ensure that these requirements continue to be met.

A Ministry of Health committee has already begun work on the drafting of proposals for control measures; these proposals will be submitted to the appropriate committees of the Medical Research Council for criticism; and they will be discussed with interested parties in the shoe trade.

Summary

The shoe-fitting fluoroscope is a familiar object in many shoe-shops. Results of measurements of radiation dose in and around British machines are presented. The hazards to adult and child customers from these doses of radiation are discussed. It is suggested that regulations are needed, in the public interest, to control doses of radiation given by these machines, and possible control measures are suggested. The machines tested could be used for a limited number of short exposures before the radiation doses from them reached the limit recommended by the International Commission on Radiological Protection. A Ministry of Health committee is considering proposals for control measures.

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Southern Europe, from Spain to Bulgaria, according to reports given at a recent W.H.O. conference in Athens on malaria, has achieved remarkable progress in reducing the incidence of the disease. Before the introduction of D.D.T.-spraying at the end of the last world war there were about four million cases of malaria a year in this area. The figure is now estimated to be less than 10,000. Progress was also claimed for the Eastern Mediterranean countries, a reservoir of malaria throughout the ages. In this region of some 170 million people there are said to be 100 million who live in areas where malaria is a threat. As late as 1949 about 40 million people regularly suffered attacks of malaria. Since malaria campaigns have been extended this figure has been reduced to about 14 million. The conference, attended by some 50 eminent malariologists, decided that it would be technically possible to eradicate malaria from the countries that surround the Mediterranean and the wider areas which constitute the European and Eastern Mediterranean regions of the World Health Organization. Dr. PAUL RUSSELL, of the Rockefeller Institute, said the solution of administrative and financial problems was the key to success in malaria education. Resistance to modern insecticides was also discussed, but, despite the hazard, an optimistic view was taken of the possibility of eliminating the disease. Professor GEORGE MACDONALD reported that experiments at the Ross Institute in London had shown that mosquitoes inherit resistance to insecticides according to Mendelian laws.