RADIATION SAFETY IN X-RAY DIAGNOSTIC INSTALLATIONS

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Introduction

It is well documented that the major contribution to population dose from all man-made sources of ionising radiation is from the medical uses of radiations (Fig. 1). The medical exposures are of particular interest not only since they contribute the highest man-made per caput doses in the population, but also are given with instantaneous dose rates and cause the highest individual organ doses short of accidental exposures. From radiation protection point of view, they also offer the largest possibilities of dose reduction.

As can be seen from the above figure among the various medical uses of ionising radiation, viz. diagnostics, therapeutics (both with beam and discrete sources) and nuclear medicine, the dose contribution to the population is in that same order with diagnostic radiology giving the maximum. Further, the number of persons irradiated is maximum in diagnostic radiology. Whereas generally only the older group is irradiated in radiotherapy, persons of all age groups undergo medical radiological examinations. Table 1 gives the countrywide distribution of the number of persons undergoing radiological examinations annually per 1000 people. It can be seen that for the present, this number is very low in India compared to many technologically developed countries. However, in a developing country like ours, as better facilities, awareness to modern medicine etc. are on the increase, the annual rate of increase in the number of examinations is more than that in developed countries. From the sale of films, we can approximately put this around 10% compared to 2-3% in the developed countries. At present, the genetically significant dose is quite low in India. This is because of the fewer number of examinations for such a large population. But one has to consider the dose received by the individuals - the patient and the occupational worker - which is not so small compared to the work load per unit.

Even if the protection efficiency is unchanged, expanding practices will either increase the individual doses through a greater work load per individual or the number of individuals exposed. The increased collective dose will add to the total radiation burden of the population and it is important to keep this increase under review and control. This means that the radiation protection programmes has to be intensified to effect better work practices, use of better facilities with inbuilt safety etc., to offset the envisaged increase and keep the population dose to the present lower values.

What are the levels of exposures at present? A vast amount of information is available on medical exposures. Nevertheless, the variation in practice and performance is large not only among different states, but also among different hospitals. Probably this variation depends more upon the individual radiologist. Hence the exposures for the various examinations will be covering a wide range of values. In Table 2 the exposures to skin during certain types of examinations are listed.

For angiography of abdomen, skin exposures as high as 263 R are reported. Exposures up to 150 R to the skin are reported for pace-maker insertion procedures in routine practice; the exposures are likely to be repeated. In extreme cases, exposures up to 3200 R to the skin have also been reported.

Organ Doses

Lung: In normal procedures, dorsal spine examinations give the highest dose - 300 mR to lungs. It can be as high as 800 mR as reported in certain cases. During special procedures such as cardiac catheterisation the lung doses will be mugh higher.

A large number of the population is exposed to radiation due to mass chest surveys. Mortality from TB has enormously reduced. The majority of the population subjected to compulsory mass chest survey does not even belong to a high risk group for developing TB. For them the risk of dying from cancer induced by a chest X-ray examination may be greater than the risk of dying from pulmonary TB. (Dissendrof 1975).

Breast: Direct radiogfaphy of breast gives 10-35 rads to breast. Use of very sensitive films, high efficiency intensifying screens, vacuum packing etc. have enabled to bring down the dose to 100 mrad. The risks from mass surveys must be weighed against the number of breast-cancer cases detected in such surveys. It is generally felt that the chances of late occurence of cancer is more for irradiated breasts. Hence radiological examination may be done only on clinical indications. Special examinations such as X-ray Xero radiography result in an exposure of 2-5 rad/examination to the breast.

Cornea: Neurological examinations give 20-50 rads to the cornea, increasing the risk of radiation induced cataract. Scanning techniques such as computerised axial tomograms reduce this dose. Dental radiography also contributes significantly to corneal dose.

Foetal Dose: Children, who were irradiated before birth in the course of abdominal or pelvic X-ray examinations of their mothers, have about 50% more chance of dying from leukaemia or other forms of cancer than children who were not irradiated before birth.

Initial results of Alice Stewart (1958) at Oxford is followed by a series of reports. By 1970 the case group contained 7649 children who had died of cancer by the age of 10. Of these, 1141 had been irradiated in utero, whereas in the control it was only 774 (Stewart & Kneale, 1970). In a study at Harvard, MacMahon (1962) estimated 40% increase in the incidence of leukaemia in children irradiated before birth.

A single whole body dose equal to our own neutral background administered before birth would probably induce 60 childhood cancer deaths for every 1000 children exposed prior to birth. This statistics applies to the live born.

Ten-Day Rule: The 10-Day Rule pertains to the radiological examination of female patients of reproductive age. The implementation of this rule would reduce the risk of irradiation of a possible early pregnancy, when the foetus is highly susceptible to radiation damage and death from even very low doses of radiation. Any X-ray examination involving the abdomen or pelvis should, if practicable, be carried out within the 10 days following the first day of the menstrual cycle. Hence, it is the responsibility of the referring clinician to weigh the risk against the benefit to the patient and the foetus before initiating the examination. The clinician should ask the patient for the date of the last menstrual period (LMP) of the patient. If it is 10 days or more prior to the date of examination, the clinician should consider whether the patient could wait till the onset of the next menstrual period for the X-ray examination, in case the examination cannot be avoided altogether. If the clinical condition of the patient demands urgent X-ray examination, the 10-day rule can be waived.

The implementation of the 10-day rule can be facilitated by having a space marked "LMP" in the X-ray request form so that the referring clinician is constantly reminded of his duty and in the "LMP" space the date of LMP can be entered. The clinician should also state in the request form whether the 10-day rule is to be "observed" or "ignored" for the guidance of the X-ray department.

The X-ray examinations involving the exposure of the part of the body from diaphragm to knees to which the 10-day rule is applicable, are Barium enema, Barium meal, Intravenous urogram, Intravenous pyelogram, Cystogram, Cholecystogram, Lumber spine, Pelvis and hips and Abdominal angiography.

The 10-day rule may be ignored in the case of the following types of female patients:

(a) who deny recent sexual intercourse,

(b) who are menstruating at the time,

(c) who use contraceptive devices such as pills or I.U.C.D. and are satisfied about their effectiveness over a period of about 3 months and

(d) who have undergone any sterilizing procedure.

Gonadal Doses

The average gonadal doses received in typical surveys in India (Supe, et al. 1974) are given in Table 3. It can be seen that compared to chest examination, the examinations of lumber spine, pelvis and abdomen give very high gonadal doses.

The contribution to the population exposure is usually expressed as the Annual Genetically Significant Dose (A.G.S.D.) which is defined as the average of the individual gonad doses, each weighted for the expected number of children conceived subsequent to the exposure. In India this value of A.G.S.D. is quite small at present, because of (a) the very small number of X-ray examinations for the whole population (35 X-ray examination per 1,000 of population per year) and (b) the weightage of the A.G.S.D. on a very large population of about 600 million. However, if the trend of the individual higher gonad doses is allowed to continue, this would result in higher A.G.S.D. value as the Annual number of X-ray examinations increases.

Radiation Workers

So far we were dealing with the dose to the population and the patient from diagnostic procedures. However we cannot overlook the exposures to the radiation workers such as the radiologists, technicians, nurses, physicists etc. American radiologists used to have a substantially higher incidence both of leukaemia and other cancers than other medical specialists. Further, Selster and Sartwell (1965) have associated non-specific life shortening effect with chronic occupational exposures.

In India, at present the number of people who avail themselves of the personnel monitoring service conducted by the Division of Radiological Protection is around 16,000, out of which more than 50% ($\sim$ 8000) are in medical institutions. Of these 8000, nearly 80%, i.e. 6,400 are diagnostic personnel. Taking into consideration the numerous private radiologic clinics who do not avail of personnel monitoring service, the estimated number of diagnostic personnel would be around 25,000.

Thus it can be seen that in diagnostic radiology we have to consider the patient, the staff and the population when we discuss about radiation protection. The reduction in dose to all the above three categories will depend upon the proper choice of radiological equipment for the type of examination, the use of appropriate accessories, proper installation including the room lay-out, good work practices with correct procedures and the participation of appropriately qualified personnel.

Installation

A well planned installation is essential for good work practices as well. Proper orientation of beam(s), position of control panel and other electrical accessories, location of dark room, thicknesses of shielding required for each wall etc. have to be well planned. During the past two decades the Division of Radiological Protection has been giving advice and guidance in the planning of new radiological installations in the country.

Radiological Equipment and Radiation Dose

Radiological examinations should be carried only with those machines which are intended to be used for such examination. For example, a mobile or portable X-ray unit with their lesser protection accessories should not be used for regular and routine radiography. Units with ordinary patient tables cannot be used for special examinations involving more personnel and complicated movements of the patient.

There are lots of obsolete units in operation in many district and state hospitals. Many of the X-ray tubes may be good for use, but the accessories do not offer any radiation safety either to the technician or to the radiologist. Let us now briefly see how the accessories help reduce the dose.

The dose to the patient, the staff and the public is contributed by the primary, the scatter and the leakage radiations. Primary radiation is the radiation coming out through the portal of the X-ray tube. The radiation which comes out of the X-ray tube through the tube housing is known as leakage radiation, radiation, incident on matter, interacts with it and part of it is either absorbed, transmitted or scattered. The scattered radiation is of lower energy than the incident and can easily be absorbed or stopped. Due to the scatter, a person not in the primary beam but standing in the vicinity can also get irradiated. The scatter dose at a distance will depend upon the total volume of matter irradiated (or the area of beam), the energy and intensity of the incident beam of X-rays and the duration of irradiation. The leakage radiation is limited to acceptable limits at the manufacturing stage itself which follows the safety standards. The primary and the scatter both can be reduced to the minimum by the proper use of filters and beam limiting diaphragms, by appropriate film screen combinations and processing procedures for radiography, by proper dark adaptation and use of image intensifier in fluoroscopy and by the selection of kV and mA appropriate to the investigation.

X-rays produced in an X-ray tube at a certain kV have a spectrum of energies commensurate with kV and inherent filtration. However, the lower energy components (called the softer components) when incident on a patient are mostly absorbed in or scattered from the tissue immediately below the skin and only the harder components penetrate and reach the film or the screen to give the diagnostic information. Hence these softer radiations which do not contribute to any diagnostic information are unnecessary components. Hence if we can cut off the softer components before they reach the patient, we can reduce significantly the dose to the patient and also the scatter from the patient. This is done by the use of thin aluminium filters interposed between the patient and the tube at the tube portal. The International Commission on Radiological Protection has suggested certain combinations of KV and filters for the various types of examinations (ICRP 1969) as shown in Table 4.

The beam of X-rays passing through the body and incident only on the area of the film or screen will give any useful information to the radiologist. Any part of the beam falling outside this area will only render a higher dose to patient and higher scatter. In case of abdominal examinations, there is a further hazard of irradiating the gonads of the patient with the use of larger fields. In chest radiography, because of the larger distance an unlimited beam will give a whole body exposure to the patient.

The beam can best be limited to the size of the cassette or the screen by the use of multivane beam limiting diaphragms with optical beam definition. For routine use, cones are cumbersome for quick changes from patient to patient and do not indicate the area that will be irradiated. Light beam diaphragms make it easy also to centre the beam. Hence all X-ray units should have the light beam diaphragms attached to them and should be used to limit the beam to the bare minimum.

Kilovoltage and Tube Current

Many a time a wrong selection of kV results in unacceptable radiographs leading to a re-take and increased patient exposure. Further the kV and mA indicated on the panel may be different from the actual kV applied to the tube, and the tube current. Hence periodical calibrations of kV and mA are essential.

Because of the higher skin dose and scatter with low kVs, the present trend is to use high kV techniques. So when buying new machines, those which have got a higher rating and operable up to about 200 kV should be preferred.

The wave form of the output is also an important factor. Compared to a half wave rectification, a full wave rectification gives more energy in the higher kV region and hence even after cut off with a filter, still more energy (X-ray intensity) is available (for full wave rectification). If a constant potential tube is used, the percentage of high energy components will be higher even after a filter is interposed. This will help in reducing the skin dose and scatter.

Film-Screen Combination

The various types of intensifying screens used have specific light emission properties. Hence for each type of screen, there is a specific type of film which has maximum sensitivity for the particular emission spectrum. Hence, the film screen combination recommended by the manufacturers has to be followed to obtain better results. The exposure required depends upon the efficiency of the screen to convert X-rays into light photons. With high efficiency screen such as the new rare-earth screens, the exposure can be reduced by a factor of about 5 (Table 5).

Dark Room Techniques

The radiographic image contrast and henceethe image quality is reduced whenever films with high fog are used. Hence it is important that the fog is kept within reasonable limits. The factors responsible for high fogging of medical X-ray films are:

1. Improper storage of films: The films must be stored at the proper temperature and humidity as recommended by the manufacturers. The storage place should be a radiation free zone. This means it must be sufficiently away from the radiation sources such as X-ray machines and radioactive sources. Only the required number of films for a day should be taken to the dark room. It is necessary that the radiation levels in the dark room are negligibly small.

2. Suitable safe light, as recommended by the film manufacturers, should be installed in the dark room at a suitable distance from the work-table in the dark room. Any light leakages in the dark room should be prevented. The dark room should be a planned construction provided with light traps.

3. The film processing conditions such as the use of proper processing solutions maintained at proper temperature and concentration should be strictly followed. The durations of development and fixing should be strictly observed in accordance with the recommendations of the film manufacturers. It is usually recommended by the film manufacturers that the films should be processed for suitable timings in the solutions - developer, fixer and water maintained at 20°C (68°F). However, very few dark rooms in the country care to follow these recommendations. It is generally

found that the films are developed for shorter timings at higher temperatures. This underdevelopment of the film leads to overexposure of the patient. In most of the cases, the solutions are found to be at room temperatures which are much higher than 20°C. The films are intermittently taken out of the developer to inspect whether the film is sufficiently black. This means that the film development is adjusted to suit the exposure given to the film and hence to the patient exposed with the particular film. This practice is just the opposite of what is required, namely that the film-exposure should be adjusted to suit the standardised dark room techniques. Hence it is necessary that the dark room technicians are trained to practice standard dark room procedures. In this connection, it seems more appropriate to employ blind persons as dark room technicians so that they can follow blindly the instructions regarding the practice of standard dark room techniques. In a recent investigation involving a number of dark rooms in India, it has been found that the improper dark room practices lead to an excess patient exposure of about 200 to 300%. It is further observed that the image contrast is reduced. This is due to the specific nature of the particular emulsion and development at temperatures other than those recommended by the film manufacturers.

Fluoroscopy

Because of the proximity of the radiologist and others to the X-ray unit and the larger duration of operation of the tube, fluoroscopy is potentially very hazardous both to staff and patient. Unrestricted installation of cheapter units with practically no operational safety and the use of such units by unqualified medical personnel make conventional screening most hazardous.

The lack of proper room-darkening facilities, insufficient dark adaptation before screening, insufficient radiological training etc. contribute higher exposure to patient and staff. When the beam is not limited to the screen, the radiologist is in the primary beam and his forehead, gonads and extremities get high exposures. Units with cable-operated diaphragms tend to go out of order very often. Motorized controls are being put into operation in the new diaphragms. In many units the tube and screen have no proper beam or can be kept angulated, are quite unsafe for the radiologist. Such older units do not provide any shielding to the hands of the radiologist either. The use of fluoroscopic chair, lead aprons, red goggles etc. would enable reduction of dose to staff and patient.

One of the undesirable work practices in a radiology department is the use of screening unit by unqualified personnel without the supervision of a qualified radiologist. Use of an X-ray machine by unqualified personnel increases the radiation hazard. In one example the patient's skin dose for an abdominal examination by a radiologist was 600 mR while that by a nonspecialist gave an exposure of 1200 mR. To save the expenses of films and the associated equipment, many private practioners buy cheaper fluoroscopy units and do indiscrete screening. This is a very hazardous situation. Similarly, routine screening in X-ray department should be highly restricted as the exposure during screening is much more than in radiography.

The use of image intensifier can significantly reduce the exposures. However, it is seen that the examinations are extended for larger periods with the result that the intended reduction in exposure is not achieved.

A new device has recently been introduced to monitor and record the patient exposure in any X-ray examination. This procedure would help the radiologist in controlling the patient exposure. It consists of a flat ionisation chamber mounted between the adjustable diaphragms and the patient. The chamber is connected to a meter that continuously indicates during the X-ray examination the product of the exposure and the area of the beam on the patient's skin. At the end of the examination, the integrated product of exposure and area can be read from the meter and recorded in the patient's file. Such readings give an indirect indication of the patient's somatic and narrow doses. Such a device, if permanently incorporated in an X-ray unit, would greatly help the radiologist to follow good work practices and thereby reduce the patient dose. These are particularly useful in teaching.

Gonadal Shields

Use of gonadal shields can reduce the gonadal dose from the primary or scatter. However, the internal scatter, reaching the gonads from the patient's own body cannot be shielded externally. The thickness of the gonadal shields should be sufficient to cut off the primary from reaching the gonads in case the lower abdominal areas or pelvic regions are being radiographed.

Special Procedures

Special procedures such as cardiac catheterizations, pace-maker insertions, angiogram (cerebral, cardiac, abdomial etc.) should be done only with units intended for the specific purpose.

Cardiology Units

Conventional fluoroscopy should never be done for any cardioradiology study. Image intersifier coupled with TV moniters should be used. All studies should be done under the supervision of a qualified cardioradiologist.

Since many of these procedures normally may last for 40-45 min, it is important that the skin dose has to be kept as low as possible. There are instances in which the patients received very high skin exposures resulting in radiation damage. These will be reported in the session on "Accidents".

Paediatric & Mental Hospital Units

The use of beam limiting diaphragms in paediatric units has to be emphasised since the full primary beam can give a whole body exposure to the child. It is a general practice in handling mental patients and children, that the staff, particularly the ward boys in the X-ray department, hold the patient. It is advisable to ask the patient's relatives to hold the patient during exposure. However, they should be provided with lead aprons and gloves. Strapping the patient, if possible, can avoid exposure to other personnel.

Neuro-radiological Units

Generally this is quite hazardous for the neuro-radiologist and the other associated staff, if proper protection measures are not followed. Because of the proximity of the radiologist, staff nurse and the anaesthtist, beam has to be limited to the bare minimum. Normally series of two orthogonal views are radiographed. The horizontal beam, if not limited, will irradiate the person standing on the opposite side of the patient. The lead screen (which should be kept hanging from the ceiling) gives protection only from the scatter and not from the primary. The hands and forearms of the persons involved can be quite close to the area of irradiation. Hence beam limitation is most essential. Another item of potential hazard is the manual cassette changer. Many a time the technicion holds the top cassette for its quick removal and his hand will be in the primary beam. Further, he may be standing close to the patient's head resulting in enormous exposure.

Hence in all serial radiography procedures automatic cassette changers should be used. The use of automatic dye injector will further reduce the exposure to the staff.

Dental Radiography

The number of dental examinations is very much on the increase. Many dental units are without the proper converging cones. There is a very hazardous practice of using general purpose X-ray units for dental radiography, which cannot give the small fields required. The main hazard of dental radiography is the orientation of the beam. With the patient in the sitting position, the beam is directed downward and hence mostly the gonads are in the primary beam. The skin exposure is also quite high because of the short distance between skin and tube. Some typical exposure to various sites are given in Table 6. As can be seen, the use of rectangular collimator gives lesser exposure. Further, use of lap aprons by the patients should be made compulsory in all dental procedures.

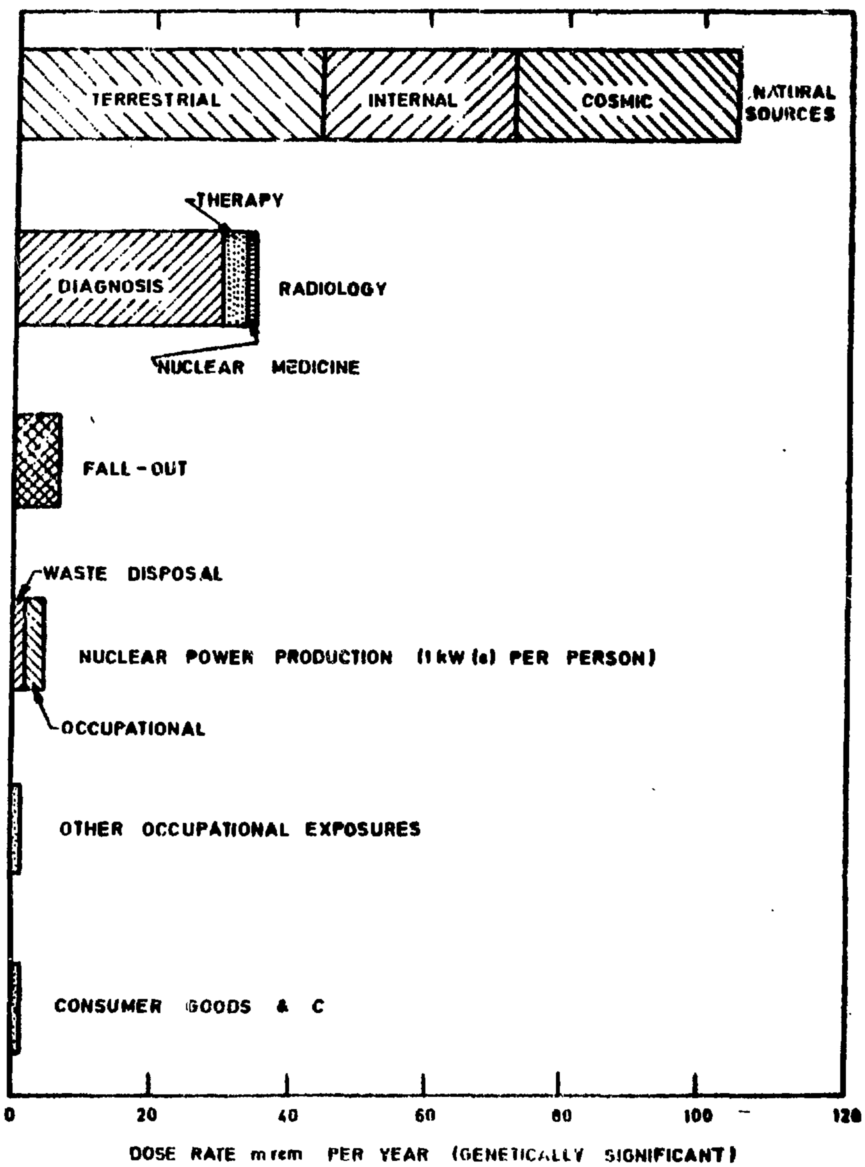

Fig.7. ANNUAL GENETICALLY SIGNIFICANT DOSE RATE AS AVERAGED THROUGH WHOLE POPULATION

TABLE 1

ANNUAL NUMBER OF RADIOLOGICAL EXAMINATIONS PER 1000 PERSONS PER YEAR (EXCLUDING DENTAL)

COUNTRY	NUMBER OF EXAMS	(YEAR)
INDIA	35	(1974)
TAIWAN	53	(1972)
IRAQ	238	(1972)
PUERTO RICO	598	(1973)
SWEDEN	650	(1974)
U.S.A.	669	(1970)
JAPAN	828	(1974)
ROMANIA	1012	(1970)
NETHERLANDS	1186	(1972)

TABLE 2

EXPOSURE(R) TO SKIN OF PATIENT FOR VARIOUS EXAMINATIONS

A. HIGH DOSE GROUP:			B. MEDIUM DOSE GROUP	
Ba. SWALLOW	F	8.5	HEAD, CERVICAL SPINE,	
Ba. MEAL	F	6 - 25	THORAX, CHOLECYSTOGRAPHY	
Ba. ENEMA	F	5 - 26	ABDOMEN, UROGRAPHY(BOTH),	
WHOLE CHEST	F	12	PLACENTOGRAPHY, PELVIS,	
MAMMOGRAPHY		15	CYSTOGRAPHY, CEREBRAL	
PELVIMETRY		8	ANGIOGRAPHY, MMR	1-3
LUMBAR SPINE		5	C. LOW DOSE GROUP:	
			CHEST RADIOGRAPHY	0.1-0.6

TABLE 3

TABLE 3 GONAD DOSE (MREM) IN DIAGNOSTIC RADIOLOGY

TYPE OF EXAM.	SEX	AVERAGE DOSE MAHARASHTRA	AVERAGE DOSE TAMIL NADU
SKULL	M	0.92	0.13
	F	0.25	0.15
LOWER ARM	M	1.79	2.02
	F	0.23	0.01
D. SPINE AP.	M	1.40	10.3
	F	1.55	52.5
L. SPINE	M	37.5	75.6
	F	89.4	64.6
PELVIS	M	732.0	335.0
	F	73.8	47.0
HIP JT	M	876.0	432.0
	F	49.9	111.0
ABDOMEN	M	79.6	56.8
	F	1020.0	244.0
I.V.P.	M	443.0	36.4
	F	267.0	196.0
CHEST PA	M	0.49	0.39
	F	1.62	8.96

TABLE 4

SUGGESTED COMBINATIONS OF KV_p AND FILTRATION

TYPE OF EXAMS.	KV_p RANGE	TOTAL FILTRATION RANGE
SOFT TISSUE STUDIES, SMALL BONE STUDIES (NON SCREEN)	50-70	2 TO 3 MM AL.
BONE STUDIES, IODINE CONTRAST STUDIES, LOW VOLTAGE LUNG TECHNIQUES	60-90	2 TO 4 MM AL.
OBSTETRIC RADIOGRAPHY	90-120	4 MM AL + 0.2 MM CU.
AIR OR BARIUM CONTRAST STUDIES, HIGH VOLTAGE LUNG TECHNIQUES	120-150	4 MM AL + 0.1 TO 0.2 MM CU.

TABLE 5

RELATIVE SPEEDS OF COMMON FILM-SCREEN COMBINATIONS

COMBARED WITH THE 3 M TRIMAX SYSTEM

INTENSIFYING SCREENS	FILM	RELATIVE CASSETTE EXPOSURE FOR A TOTAL DENSITY OF 1.0
TRIMAX ALPHA 8	TRIMAX XM	1.0
TRIMAX ALPHA 4	TRIMAX XM	2.2
TRIMAX ALPHA 8	TRIMAX XD	3.0
TRIMAX ALPHA 4	TRIMAX XD	5.4
TRIMAX ALPHA 8	KODAK BLUE BRAND BB 54	2.8
TRIMAX ALPHA 4	KODAK BLUE BRAND BB 54	6.4
ILFORD FAST TUNGSTATE	KODAK BLUE BRAND BB 54	2.7
ILFORD FAST TUNGSTATE	TRIMAX XM	2.7
ILFORD FAST TUNGSTATE	KODAK RP 54	4.0

TABLE 6

SKIN EXPOSURE AT VARIOUS SITES
DURING DENTAL RADIOGRAPHY

SITE	SKIN EXPOSURE (MR)		
	WITH UNSHIELDED CONES	WITH 3 MM SS. SHIELDED CONES	RECTANGULAR COLLIMATORS
PHILTRUM	1842	1695	846
FIRST MAXILLAR MOLAR	1068	1060	1012
EYE	672	731.8	246
PAROTID	88.8	53.3	30.9
THYROID	30.1	12.3	5.7
LAP	1.0	0.5	0.2
LAP UNDER APRON	0.05	0.03	0.03

REF; DIESENDROF- SEARCH VOL.6. AUG.1975.

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