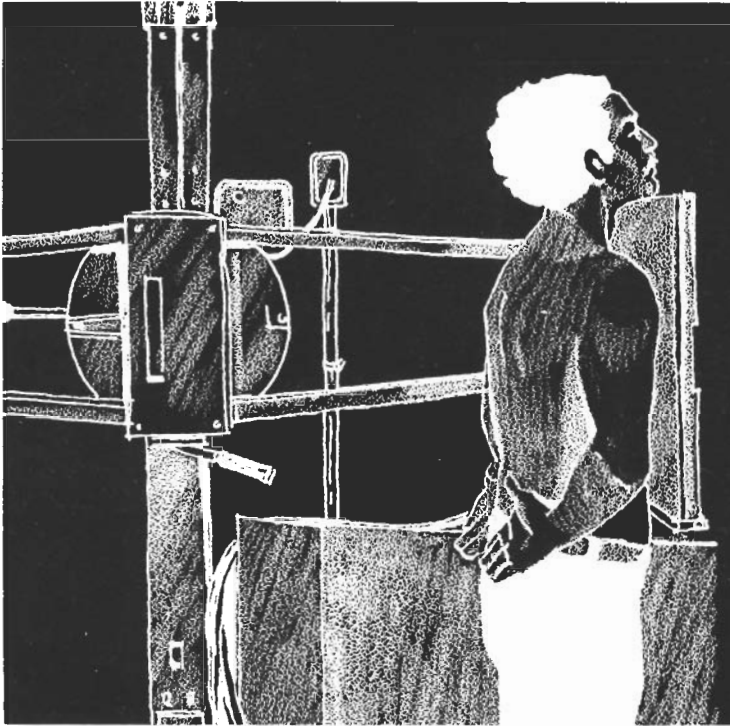


# RADIOLOGY AND PRIMARY CARE

P.E.S. Palmer



PAN AMERICAN HEALTH ORGANIZATION  
Pan American Sanitary Bureau, Regional Office of the  
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## INTRODUCTION

This manual was written in the conviction that simple diagnostic X-ray installations have a very valuable part to play in the medical care of rural and other underserved populations. It is intended to show that installation need not be costly in terms of building or investment, that equipment can be chosen that is simple to use, and that prolonged training is not required. Moreover, the cost may be more than balanced by the speed and efficiency with which patients are treated and returned home or to work, and by the prevention of further spread of infectious diseases first recognized on a chest X-ray.

Are there any figures to support this contention? It has been estimated that only one-third of the world's population has access to diagnostic radiology; this is probably correct. For example, a survey conducted in the late 1960's by the World Health Organization in the Middle East showed that in 10 countries with a total population of 50 million there was one diagnostic unit for every 70,000 people. A similar 1973 survey of 180 million persons in 20 Latin American countries, gave an average of one X-ray unit for every 13,000 people. Such figures can be compared with those of the United States where there is one radiodiagnostic unit for every 1,800 people. But even these figures are misleading because they do not demonstrate that the majority of X-ray units are concentrated in the larger cities, and that in many countries, even where there are units in rural areas, as many as 30 per cent are out of order at any one time. About half the population of many countries live in rural areas (e.g., Latin America, the Caribbean), and in these countries about half the rural hospitals do not have X-ray services.

The physician who has practical experience in primary care hospitals in rural areas knows the value of an X-ray machine, and knows how often such machines are ill chosen and unsatisfactory for many reasons. Yet in rural practice the majority of patients are suffering from trauma, chest disease, and, to a lesser extent, acute abdominal conditions. Eighty per cent or more of the patients could be treated more satisfactorily if radiological examination were available. Modern technology can produce X-ray units and techniques that make it possible for auxiliary personnel to obtain adequate radiographs of consistently acceptable quality and, equally important, for such equipment to be maintained and kept functioning.

This guide provides in simple terms all the information needed to establish X-ray facilities at a rural or isolated hospital or clinic. Alternatives are noted so that choices can be made with regard to local conditions. Simple rules for radiation safety are given. Everything is made as basic, simple, and economical as possible, and local labor and skills can be utilized for almost everything except the actual X-ray unit and the film processing unit. A way in which local staff can be trained is suggested. Guidance on the choice of the X-ray equipment is included.

This manual is only intended to provide guidance for the installation of one X-ray machine to serve one hospital or clinic. As the work increases and with it the complexity of the examinations, a different approach will be necessary, but by then 80 per cent or more of the simple diagnostic problems will be solved and the major part of the population should be receiving the care which humanity deserves, not as a privilege but as a right.

It is hoped that *Radiology and Primary Care* will become a standard guide for public health administrators and planners engaged in the design of small hospitals, now being planned or built, to ensure comprehensive health care to communities not yet covered, in both rural and urban areas.

Subsequent similar manuals on radiographic techniques, and basic radiology are in preparation to complete the series.

## **PRIMARY CARE RADIOLOGY: NEED, LOCATION, COST, PLANNING**

### *The primary care radiological facility*

A primary care radiological facility is a complete X-ray system that will provide radiography at rural or isolated health clinics and hospitals.

### *Why do rural populations need radiology?*

The majority of the health problems of rural populations are due to trauma and infectious diseases. Treatment for the majority of ills is possible at a local hospital or clinic, provided the correct diagnosis can be made. It is cheaper and more efficient to treat the patient closer to home than to make the wrong diagnosis or refer the patient to a major hospital for a relatively simple condition. For example, a fracture that is immediately diagnosed by radiography can be accurately realigned and treated: progress can be checked and the patient can get back to work more rapidly and efficiently with a minimum of disability. Only fractures that are not progressing well or are really difficult need be sent to a larger center.

Also, the diagnosis and treatment of chest diseases when guided by radi-

ography is much more accurate than with a stethoscope alone. Chest infections, such as pneumonia and tuberculosis, are common causes of acute and chronic ill health and recurrent illness. Tuberculosis in particular is a common community disease with public health and economic significance. Radiography permits the distinction between simple pneumonia and tuberculosis, and the accurate treatment of either condition. Such care reduces spread of disease and improves the general health of the population.

Money invested in X-ray installations will be returned over the years by rapid diagnosis, more efficient treatment, public health progress, and community health improvement.

#### *Diseases that can be diagnosed in a primary care radiological facility*

In rural practice the majority of patients who consult the primary care physician are suffering from trauma, chest disease, or acute abdominal conditions—limb trauma and chest disease predominate. Treatment of 80 per cent of these would be facilitated by radiological examination.

A brief and incomplete list of some conditions that can be usefully examined by primary care radiology follows:

#### *Trauma*

All limb fractures: hands, arms, shoulders, hips, legs, and feet.

Injuries to the spine.

Injuries to the skull: depressed and compound skull fractures.

Fractures of the facial bones and mandible.

Fractured ribs.

#### *Chest*

Pneumonia and all acute lung infections.

Tuberculosis and all chronic lung infections, especially histoplasmosis, fungus, and mycosis.

Pneumothorax, traumatic or spontaneous.

Pleural effusions: acute, tuberculous, amebic. Empyema.

Effusions due to cardiac failure.

Lung abscess: pyogenic, amebic, tuberculous, or fungal.

Asthma and emphysema.

Cardiac failure: specific valvular diseases, myocarditis.

Tuberculous pericarditis.

Aortic aneurysms and aortic diseases.

Mediastinal lymphadenopathy: lymphoma, Hodgkin's disease.

Carcinoma of the lung.



### *Abdomen*

Acute obstruction of the bowel. Differentiation between small and large bowel obstruction.  
Renal or bladder calculi.  
Cholelithiasis.  
Liver abscess and liver enlargement.  
Splenic abscess.  
Calcified bladder (schistosomiasis).  
Chronic pancreatitis with calcification.  
Calcified soft tissue parasites.

### *Miscellaneous*

Sinusitis.  
Osteomyelitis, acute or chronic.  
Arthritis: pyogenic, tuberculous, rheumatoid, etc.  
Gas gangrene.  
Congenital abnormalities and endocrine diseases.  
Dietary deficiencies.  
Scurvy, rickets.

This list is not complete. There are many other conditions in which primary radiography would help the physician and his patient.

### *Diseases primary care radiology CANNOT diagnose*

- Alimentary tract diseases: dysentery of any sort.
  - Peptic ulceration.
  - Colitis.
  - Malignant diseases in the alimentary tract.
  - Cirrhosis.
  - Worms or parasites in the bowel.
- The Brain. Cerebral hemorrhage.
  - Subarachnoid hemorrhage.
  - Brain tumor.
- Vascular and lymphatic diseases.
  - Peripheral emboli.
  - Venous thrombosis.
  - Filariasis.
  - Peripheral aneurysms (unless calcified).

This list is not complete; more sophisticated X-ray equipment is required for these conditions.

#### *Location of a primary care radiological facility*

It is not possible to give absolute guidelines because local conditions will dictate variations and there are many possibly significant factors. But in general:

A. There must be a doctor or skilled health practitioner who is either based in the same hospital or clinic or who visits regularly several times a week.

B. The facility should be easily accessible to patients who will need it at locations of large populations. Ideally:

1. No one should travel more than 50 km to reach the unit; if distances are longer patients will not come. Maximum travel time should not exceed 3-4 hours.

2. The population served should be 10,000 or more.

3. Access should be possible year round.

4. Communication with the area center both by telephone and transport should be satisfactory.

C. One unit (one X-ray machine, one operator, one darkroom), can serve populations from 10,000 to 100,000. It is practical if it provides only four examinations per day but can make 25 examinations per day. With an additional operator the same X-ray machine and rooms can make many more examinations per day.

#### *Will primary care radiological equipment require specially and expensively trained doctors and staff?*

All physicians should and will be able to interpret the majority of radiographs produced by a primary care radiological facility (see page 54). These units will be of the most help with the diagnosis of common diseases, not of rare and obscure ones. Operators will have to be trained, but it is not difficult and it does not take long to instruct those who already have some basic medical knowledge, such as nurses and aids (see page 53). Step-by-step operating manuals can be developed, and a suitable teaching file is being developed.

#### *Cost of a primary care radiological facility*

The exact cost will depend on local conditions, the number of units purchased at any time, and other variables, but it will not be as expensive as might be expected:

A. The buildings and the plumbing required are simple and can be of local construction (pages 7-13).

B. The electrical supply can be that of the existing hospital or clinic; there are several alternatives. Additional wiring may be minimal (page 13).

C. The X-ray equipment will cost between \$20,000 and \$25,000 (1977).

D. The darkroom equipment will cost between \$5,000 and \$10,000 (1977).

#### *How long will this equipment last*

With an average patient load of about 10 examinations per day, or 3,000 per year, the equipment will last at least 10 years and probably 15 years. The cost of maintenance and replacement parts should not be excessive during that time.

#### *Necessary planning considerations for a primary care radiological facility*

Existing or proposed health centers, clinics, or hospitals may be ideal situations for a primary care radiological facility, but changes in population density since they were constructed may require another location; future population growth should be considered. The availability of a doctor or skilled health practitioner is essential. A primary care radiological installation will be wasted if a physician or good diagnostician is not available most of the time. A good radiograph of a fracture or of active tuberculosis of the lung is not much help to the patient if there is no one to make the diagnosis or treat the disease.

#### *Choosing a location*

A. Look at the map of the country and the territory concerned.

B. Identify population densities and groups.

C. Circle populations of 10,000 or more within a 50 km radius.

D. Relate the population to existing health care facilities.

E. Relate the population to roads, transportation (buses, trains, boats, etc.). Identify any major obstruction such as rivers without bridges.

F. Relate proposed primary care sites to central hospital and supply depots and the main regional centers; determine ease of communication with these centers for both persons and supplies.

G. Identify the rural population who do NOT have access to alternative centers, regardless of density. How many will NOT benefit?

H. Locate the population densities in excess of 100,000; two units may be required or two centers each with one unit.

Population groupings may be:

1. Several small towns not widely separated; total population 100,000. Locate primary care in the largest town or market center with the best road or bus service. Maximum distance traveled 30 km.

2. Villages and small towns combined; population 75,000. Primary care located in densest population area. Maximum distance traveled 40 km.

3. Average rural population of farms, hamlets, and small villages; total population 50,000. Primary care located in best center of communications (not necessarily the central village). Probably in the largest village or between two large villages. Maximum distance traveled 50 km.

4. Scattered rural population, total 10,000. No access to alternative primary care because of mountains, rivers, or bad roads. Primary care located at best all-weather center. Maximum distance traveled 50 km.

### **X-RAY ROOMS, DARKROOMS, OFFICES: DESIGN, BUILDING MATERIALS, ELECTRICAL SUPPLY**

#### *The primary care radiological facility in relation to an existing or new hospital complex*

The location should be chosen primarily for ease of access for all patients. Radiological protection is not a major factor.

Patients come for radiography from every part of the hospital and associated clinics. In the average small rural hospital ( $\pm 50$  beds) the majority of patients for radiography are ambulatory or outpatients; others come in wheelchairs and occasionally on a trolley or bed. The X-ray room must therefore be accessible both from the hospital and the outpatient clinic; there must be no steps or other obstacle that would impede trolleys or wheelchairs. Access from the operating suite is an added advantage.

It is important that all the rooms for radiology (basically three: the X-ray room, the darkroom, and the office/storeroom) should adjoin. A cold water supply is desirable and hot water if it is available. If mains electricity is available, the X-ray room should not be too far from the main supply transformer.

#### *Rooms required in a primary care radiological facility*

Three rooms are required: a) the X-ray room; b) the darkroom; and, c) the office/storeroom. The X-ray room should be used for no other purpose.

If space is at a premium, the combined office and storeroom is the least essential of the three rooms, but alternative storage for both used and unused X-ray films, chemicals, etc., will have to be provided somewhere in the hospital complex. All construction must comply with local regulations or building codes.

#### *Size of the various rooms*

The X-ray room should be at least  $18 \text{ m}^2$  as a minimum. If all dimensions can be increased 1-2 m it will be a much better room.

The darkroom should be 5 m<sup>2</sup>. If all the dimensions can be increased 1 m or more it will be more convenient.

The office/storage room should be at least 8 m<sup>2</sup>. If each dimension can be increased 1-2 m, it will be a more practical room.

The smaller the size of the X-ray room the more radiation protection that will be necessary: in many rural hospitals it is less expensive to build a larger room than to increase the thickness of the walls or to use different materials. The limiting factors in the shape of the X-ray room are the size of the equipment and the amount of radiation protection. For these reasons it cannot be smaller than 18 m<sup>2</sup>.

The limiting factors in the design of the darkroom are the size of the processing equipment and the need to work in almost total darkness. There must be space to separate dry working areas from wet processing chemicals, and films that are drying.

The limiting factor in the size of the combined office and storage space is the shelving required to store records, chemicals, and unused films. The number of films that must be kept will continually grow: most large hospitals store their films for about five years from the last time the patient visited the hospital. Primary care clinics, which serve a stable population, may prefer to keep films somewhat longer. They are an essential part of the patient's record, and it is almost impossible to have too much storage space.

#### *Relationship of the three rooms to each other*

There are many alternatives (see figure 1) but it is essential that the X-ray room and the darkroom adjoin. It is preferable to have the office/storeroom next to the darkroom, but it can be opposite, or next to the X-ray room.

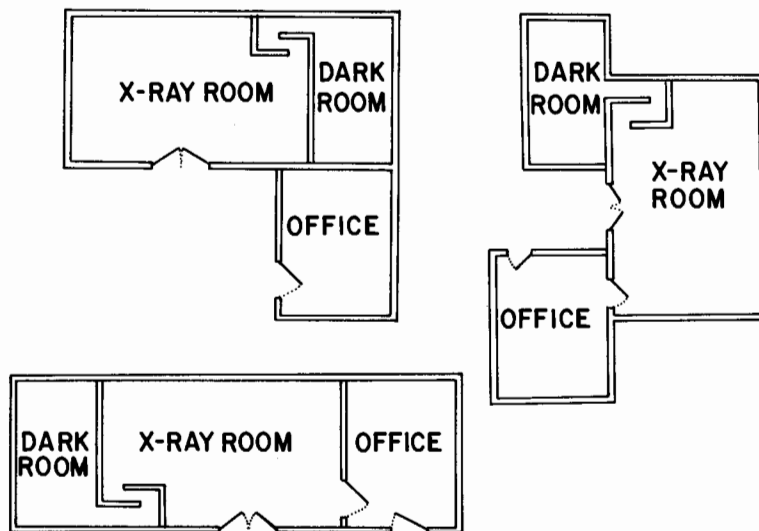
#### *Suitable building materials*

Almost any local material is suitable, providing it is:

- a) Waterproof and dustproof;
- b) Strong, especially the floor;
- c) Durable, and will last 20 years or longer.
- d) Useable in thicknesses appropriate for radiation protection.

Materials differ in their capacity to protect against radiation: wood is the least satisfactory; brick and concrete are ideal; thick mud walls are satisfactory; wood that is covered with plaster, preferably two or more layers, can be used but is less satisfactory than brick or concrete. Details of required wall thicknesses for radiation protection are provided on pages 15-18.

Figure 1



#### *The X-ray room floor*

The floor must be firm and capable of supporting the weight of the X-ray generator, the tube support, and either the X-ray table or patient's trolley. The weight of this equipment is 400 kg. The floor must be level overall so trolleys and equipment can be easily moved across it. It should be waterproof, washable, and free of dust. It can be constructed of concrete, wood, brick, tiles, or any suitable hard compound.

#### *The X-ray room walls*

The walls must be strong enough to carry the weight of the ceiling and the roof: they must be at least 2.5 m high, preferably 3 m. They must be completely waterproof and windproof. There should be one or more windows in two walls. They can be constructed of brick, concrete blocks, or thick plaster covering wood. (For exact thickness for radiation protection see pages 15-16).

#### *The X-ray room ceiling*

The ceiling must be a minimum of 2.5 m, and preferably 3 m, above the floor. An X-ray unit can be installed in any room even without a ceiling, but an inner covering to the roof is advisable for protection from dust, insects, bats, etc. The ceiling is not required to support any weight, except

to provide lateral stability with one pattern of tube support (figure 8, page 24). The room must have lighting, preferably from the hospital electricity supply. Three or four lights around the room are better than one single one. Four to six fluorescent tubes in pairs, each about 1.2 m in length will be satisfactory.

The ceiling can be constructed of plasterboard, wood, hardboard, or any suitable local material.

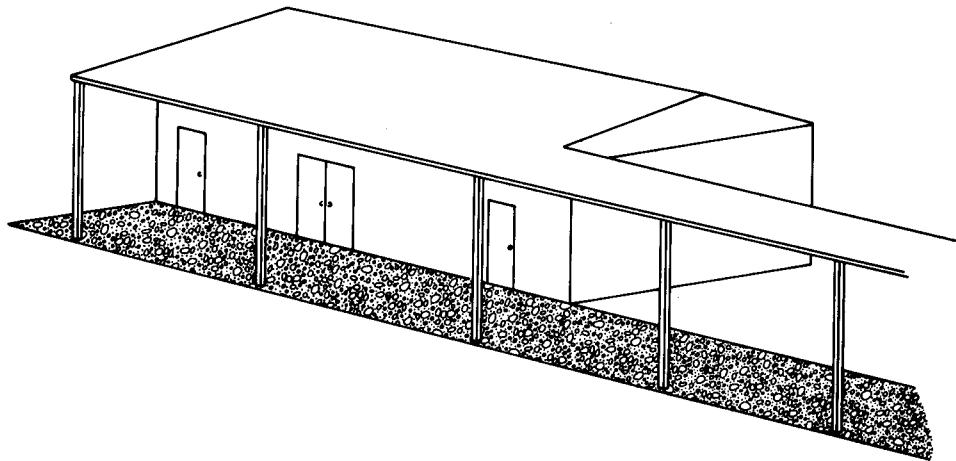
#### *The X-ray room roof*

The minimum internal height is 2.5 m thus, the height of the building must be 3-5 m. The roof must be well fitted and weatherproof, because moisture damages X-ray equipment beyond repair. Any suitable local material, such as wood, tile, slate, thick thatch, corrugated iron, corrugated iron with thatch, roofing felt, etc., is suitable. An inner ceiling of plaster or fiberboard is required, and is essential if the outer roof is thatched. There are no radiation protection requirements for the roof. Locale will dictate the width of the eaves, the availability of guttering, etc. The roof should extend over the doorways of the X-ray room and the darkroom, and preferably should connect with a covered way to the hospital and to the outpatient clinic (figure 2).

#### *Doors for the X-ray room and the darkroom*

A door into the X-ray room is very desirable. It should be made of wood and, provided it is correctly located relative to the X-ray equipment, it does not require additional thickness for radiation protection (page 51).

Figure 2



A door for the darkroom is essential and must be lightproof (page 12).

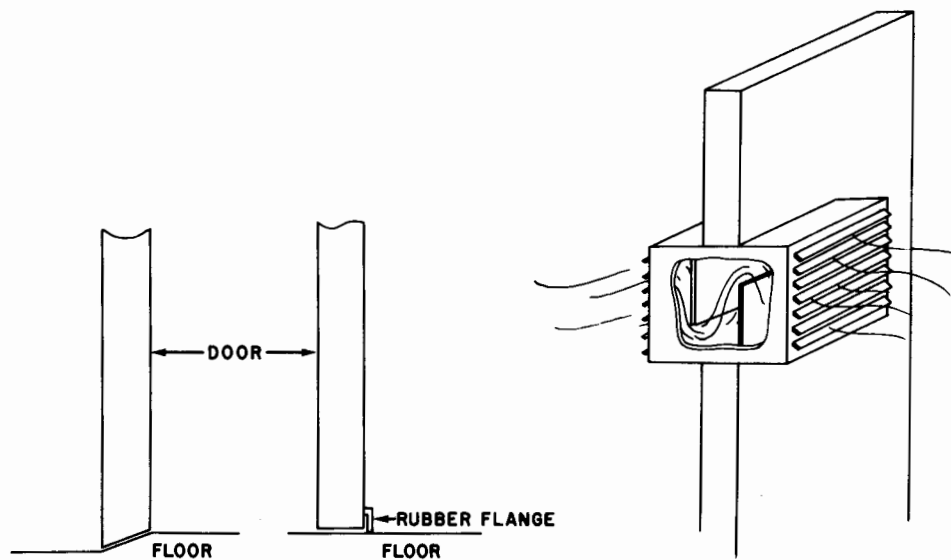
Neither the door to the X-ray room nor to the darkroom should have steps or obstruction. A minimum width of 1.4 m is desirable in the X-Ray room so that beds or trolleys can enter without difficulty. A 1 m door to the darkroom permits the easy installation of equipment.

#### *Construction of the darkroom*

The construction requirements for the darkroom are similar to those for the X-ray room described above. In particular, the wall between the X-ray room and the darkroom must provide adequate radiation protection (pages 16-17). Apart from this, the main requirement is that the room be waterproof; the darkroom must also be lightproof. One outside wall must be strong enough to support plumbing; all the walls will have to carry some minor weight such as ventilators, etc. The construction must include either a shielded ventilator or some other lightproof ventilation. A window is desirable but it too must be lightproof. The door should be constructed of wood but must be lightproof (figure 3). Where an adequate electrical supply is available an extract fan or air conditioner is desirable.

The darkroom floor should be waterproof, level, and, preferably, washable. A corner drain near the outside wall into which liquids can be swept is a useful addition. It can be under or close to the processing tank. When

Figure 3





floors are damp or uneven, removable platforms or wooden slats can be laid across them.

It is not essential, but very desirable, that the darkroom have a ceiling to keep out dust, insects, etc.

*Is a special darkroom entrance required?*

A lightproof door may be sufficient for a small primary care darkroom, but if space permits a "light-trap" entrance may be included: when the daily workload exceeds 10 patients such an entrance without doors is desirable because it increases efficiency and ventilation. The design is shown in figure 4.

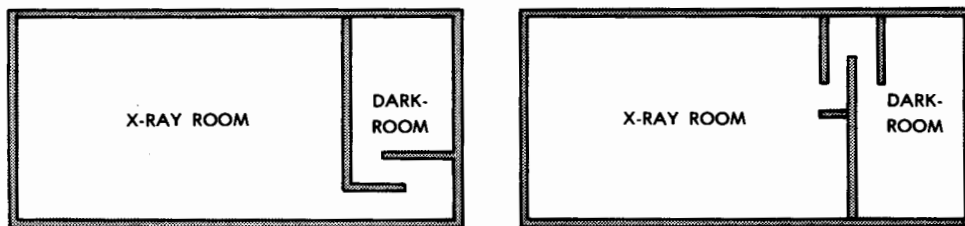
The entrance passage should average 1 m in width throughout. It should run parallel to the darkroom so that a cassette hatch (pages 46-48) between the darkroom and the X-ray room is still possible. To function efficiently, the inside of this light-trap must be painted matte black with an eye-level white line about 3 cm wide running the length of the passage on either wall. No lights are needed within the passage. The ceiling of the passage can be lowered to 2 m and the space above at either end utilized for storage.

An alternative design utilizing double doors into the darkroom with a small intervening space is unsatisfactory unless some interlocking mechanism is included to prevent both doors' opening at once. Such mechanisms tend to be complex and require maintenance to work satisfactorily. Curtains do not provide an adequate light barrier. These two alternatives will permit light to enter the darkroom when someone walks in unexpectedly. In the majority of primary care units a single lightproof door is sufficient.

*Walls of the office/storeroom*

This room can be built of any standard local material that will provide a floor strong enough to support the weight of the shelving to hold used and

Figure 4



unused X-ray films, chemicals, etc. An inner ceiling, windows, and a relatively weatherproof door are desirable but not essential.

*How thick must the wall be for adequate radiation protection?*

This is discussed in detail on page 15; standard bricks and concrete blocks are usually sufficient. Study pages 14-19 carefully.

*Electrical supply*

The electrical supply to the X-ray room will depend on the generator chosen. If it is a battery operated unit or a condensor discharge unit, a single wall outlet of about 15 amps is required to recharge the batteries or condensor. If a standard X-ray generator is used there must be a main electrical output and circuit breaker, and the power required depends on the load needed by the X-ray unit. The manufacturer's specifications will provide this information. Apart from this main supply it is wise to provide at least one additional 15 amp wall outlet on each of the two long walls of the X-ray room, if possible.

Artificial light is required for emergency cases at night. Three or four single lights in the X-ray room (or fluorescent tubes) are preferable to one large light.

The electricity supply in the darkroom is described on page 45. At least two safelights are needed and one 15 amp wall outlet is desirable, especially if the ambient temperatures fall below 19°C (65°F) and any form of water heater is anticipated.

The electrical supply in the office must provide standard room lighting sufficient to illuminate film files. A standard wall outlet for X-ray film illuminators is necessary.

The above are minimum requirements only.

*Color of exterior walls*

All three rooms will contain X-ray film, which can be damaged by heat: it is preferable to paint the outside of the buildings white or some heat-reflecting color. Apart from this there are no requirements.

*Color of interior walls*

All the rooms, including the darkroom should be light and cheerful in color.

The X-ray room should be white or cream. The finish should be glossy or semi-glossy so that the walls can be easily cleaned. The ceiling should be white or blue and a matte surface is preferable. The floors can be any suitable color, but should be easily cleaned and preferably waterproof.

The darkroom should be cream, white, or pale pink—a dark color is definitely not required. The finish should be glossy or semi-glossy to facilitate cleaning. The ceiling should be white with a glossy or semi-glossy finish. The floor can be any desired color but should be washable and moisture-proof.

The office/storage room can be any color.

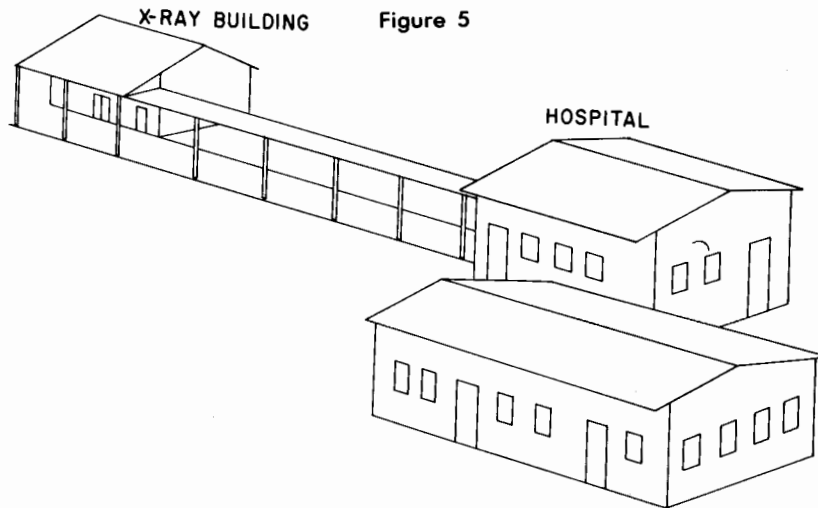
#### *Connection of the X-ray rooms and the hospital*

Patients come for X-ray examination from the hospital wards and from the outpatient clinic: a covered passage without steps, wide enough to permit movement of a bed, a trolley, or wheelchair is required. The floor should be concrete, brick, tile, or some equally firm material. The roof should be waterproof with wide eaves. The corridor may be completed by walls, or one wall on the windward side. If this corridor or covered way is continued alongside the X-ray room, darkroom, and office space it provides a waiting area protected from both sun and rain. Any local construction material such as thatch, corrugated iron, wood, etc., can be used (figure 5).

### **RADIATION PROTECTION: ROOMS, PATIENTS, OPERATORS**

#### *Expense of required radiation protection*

In general, the amount of radiation in a small primary care radiological facility is so little that radiation protection is not a major problem. If the



room is correctly laid out (page 7) and if the construction material is carefully chosen (see below) there is no reason to anticipate any additional cost in this respect.

### *The wall thicknesses required for radiation protection*

The wall thickness will depend very much on the relation of the room to other buildings, and on its size. If the room is isolated and built so that persons cannot come within 1 m of its outside walls, no additional protection is likely to be needed; if the building has to be made of wood, it may be cheaper to fence off an area around it rather than to use heavier wall construction materials.

The recommendations which follow are based on a room with a minimum size of 6 m by 4 m. Average figures provided in various manuals (e.g. *Manual on Radiation Protection in Hospitals and General Practice*, Vol. 3, X-ray Diagnosis, WHO, Geneva, 1975) calculate the required thickness of material on the basis of a total radiation exposure of 150 mA-minutes per week at 100 kV. (The number of milliamps used for each exposure times the number of seconds provides the milliamps for each exposure. The milliamperes-minutes per day can be calculated by multiplying the number of exposures per day by the average exposure used.) The average primary care radiological facility examining about 10 patients per day, mainly for chest and extremities, uses less than 20 mA-minutes per day at 100 kV, or at the most 80 mA-minutes per week. This is less than half the figure used for the basis of standard calculations in busy X-ray departments. Even these standard calculations are conservative because they assume an average radiation of 100 mAs per patient, and a more realistic assessment is that the primary care radiological facility would use half that amount. Recent calculations (British Journal of Radiology)\* have shown that the actual radiation used when accurately measured is usually much less than the theoretical calculated dosage.

In primary care radiological facilities it is, therefore, permissible to utilize a design figure of 1 mm of lead equivalent. This incorporates a sizeable safety factor and will be satisfactory until at least 30 patients are examined daily—at that stage, tests should be made to determine whether additional protection is required. In many instances the 1 mm of lead equivalent will continue to be sufficient.

One mm of “lead equivalent” means that a standard poured concrete wall of about 8 cm thickness would be required as a proper equivalent. If cinder block or brick is used, a thickness of about 12 cm is required depending on the density of the material. Many concrete blocks have

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\*Gifford, D. A new design policy for protective barriers in departments of X-ray diagnosis. *Br J Radiol* 48:851-857, 1975.

central air spaces and the recommended thickness refers to the amount of actual concrete or brick and not to the overall dimensions of the block. Architects may wish to know that these recommendations are based on a standard poured concrete with a density of  $2.35 \text{ g/cm}^3$ . If a similar material of different density is used the required thickness can be estimated as follows:

$$\begin{aligned} & \text{(thickness of concrete)} \\ & \text{multiplied by } (2.35 \text{ g/cm}^3) = \text{(thickness of similar material) multi-} \\ & \text{plied by (density of similar material)} \end{aligned}$$

Detailed information is contained in: *Structural Shielding Design and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV*, National Council on Radiation Protection and Measurements (U.S.A.), Report No. 49, 1976, and *Handbook of Radiological Protection*, Her Majesty's Stationary Office, London, 1971.

#### *Areas at greatest risk to radiation*

Within the X-ray room there are two specific high-risk areas:

- The wall behind the chest stand.
- The wall of the darkroom and other radiographic film storage area.

Provided that the X-ray unit is properly positioned (page 51) the wall of the darkroom will need no special protection if it is constructed of at least 8 cm of brick or concrete. At no time should the main X-ray beam ever be pointed at the wall of the darkroom because the radiation may fog the stored films. If this is unavoidable for any reason, the wall must be doubled (approximately 16 cm). This must be the thickness of the entire wall between the darkroom or other film storage areas and the X-ray room.

The main X-ray beam must be located so that whenever erect chest X-rays are taken the beam points away from the darkroom to another wall. There will then be a radiation hazard on the far side of this wall. There are two ways to overcome this:

- a) Increased protection as part of the chest X-ray cassette stand.
- b) Increased protection on the wall itself behind the chest stand.

If the first method is chosen, the chest cassette holder (whether independent or an integral part of the unit) must have 2 mm of lead equivalent covering an area exactly that of the largest cassette that will be used. When the second alternative (reinforcing the absorption of the wall itself) is chosen, an area 2 m high and 1 m wide centered immediately behind the chest stand must have the same 2 mm of lead equivalent. This can be obtained by doubling the thickness of the brick or concrete (16 cm), or

utilizing 1 mm thickness of lead sheeting or 5 mm thickness of steel sheeting. (In some circumstances it is worth remembering that simple plate glass of 1 cm thickness is equivalent to 1 mm of lead and, below 100 k Vp, provides a very satisfactory radiation barrier: if other types of glass are used the lead equivalence should be determined.)

Such protection will make it quite safe for the workers in an adjoining room (if the X-ray department is part of an existing building) and it will permit persons to stand outside or lean against the wall of the X-ray room for an indefinite period while the unit is working at the normal load of a primary care unit.

It may be reemphasized that these calculations provide a far greater margin of safety than is likely to be necessary in a primary care radiological facility. It is cheap and simple to incorporate such details at the time of construction and it allows the amount of work to expand reasonably without further building difficulties. Almost any material will be satisfactory, except behind the chest stand where additional protection is required as described.

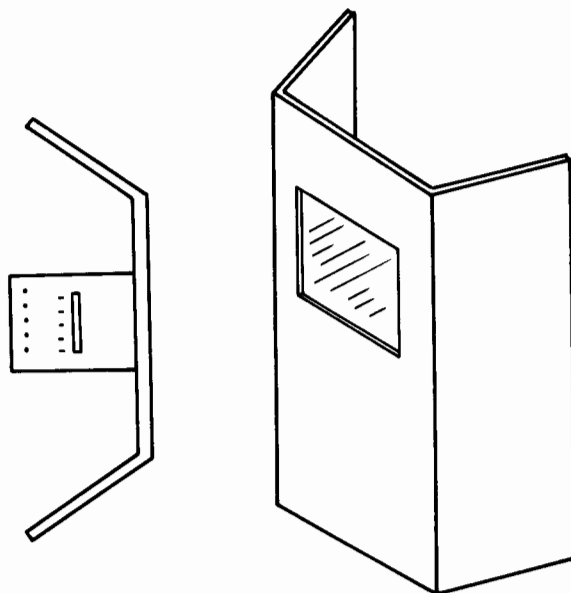
#### *Protection for X-ray operators*

No X-ray exposure should be made unless the operator and any other person in the room (other than the patient) are behind the control panel. If it is necessary for the patient to be held, then lead protective clothing must be worn (see page 19). The X-ray control must be designed so that the switch is an integral part of the unit; protection should be incorporated in the design of the control panel. This should be a shield of 1 mm lead equivalent at least 75 cm wide in front of the control panel and extending 50 cm on either side. It should be 2 m in height and should have a lead glass window with at least 1 mm lead equivalent (approximately 25 cm x 25 cm) situated in the central panel at eye level, so that the operator can see clearly through it without having to look around the edge of the screen while making the exposure. The equipment must be installed so that the X-ray beam never points at the control panel (see page 51). This control screen should be integral with the equipment and not a later addition: it should not be possible to separate it or move it apart from the control panel (figure 6).

#### *Windows in the X-ray room*

Standard glass windows do not provide much radiation protection, however, there is no radiation hazard if persons do not loiter within 1 m of the window of a standard size X-ray room. If patients wait outside the room, the window should be 2 m from the ground outside and at least 1 m above the ground inside. Windows are desirable for both ventilation and

Figure 6



light. The windows in the darkroom must be lightproof: shutters will probably be required, or the glass may be replaced with wood or hardboard.

*Increased distance for radiation protection*

In many rural areas it is cheaper to build larger rooms than the minimum size quoted (6 x 4 m) than it is to purchase lead sheeting. This will depend on local building material and the availability of both land and labor. Locally made bricks may be cheap and a double brick wall provides all the protection that can possibly be required even in such high risk areas as the darkroom and behind the chest stand. Increasing the distance is one of the best ways of providing radiation safety, because the dosage received from an X-ray unit decreases inversely to the square of the distance. For example, if the distance from the radiation source doubles, the radiation decreases to one-quarter (25 per cent) of its former intensity.

*Radiation safety monitoring*

Part of the instruction for the operators who will work in the X-ray department is safety rules and requirements. The purpose and the personal benefit provided by the film badges will be an essential part of the

training program. In addition a routine X-ray film badge service should be organized through the main X-ray department serving the whole area where there is a radiologist in charge. Badges can be sent by mail, by surface transport, or by air, and should be changed regularly.

Experience shows that when any film badge records an excessive dose, a visit to the primary care radiological facility by the supervisor is likely to be necessary. Written or telephone inquiries are seldom sufficient, because relatively inexperienced technicians may perpetuate some fault from ignorance and be quite unaware of the source of their radiation exposure. Direct investigation and example will help to prevent recurrence of the majority of these problems and must be included as part of the service commitment.

It is easy for an inexperienced technician to feel that any inquiry implies criticism rather than care for the person concerned: a personal visit usually dispels this idea and obtains more cooperation. However, it is stressed once again that the amount of radiation in the average primary care facility is small because relatively few patients are examined and the type of examination does not produce excessive radiation.

#### *Protection for nurses, aids, etc.*

Double-sided radiation protective aprons (lead equivalent 0.25 mm) and lead gloves (lead equivalent .3 mm) must be provided and must be worn when the patient has to be held by a nurse, aid, or other person who will be in the X-ray beam during the exposure. Such aprons and gloves must be readily available in the X-ray room.

### **POWER SUPPLY, CHOICE OF EQUIPMENT, DESIGN, SPECIFICATIONS, ACCESSORIES**

#### *Electrical power source*

The required electrical power for an X-ray generator can be obtained in four ways:

- a) Electrical mains.
- b) The hospital generator.
- c) A condensor discharge unit (capacitor).
- d) A selfcontained battery supply.

The last two methods (capacitor and batteries) require a basic small electrical supply, but do not increase the load during exposure.

a) Electrical mains can be utilized at 220 volts or 110 volts alternating current. It can be at 50 or 60 cycles. The available supply must be quoted in



the specifications when the equipment is ordered. Whatever the voltage or cycles, it must be steady and must not vary greatly when there is a heavy load, e.g., when the rest of the hospital is utilizing electricity for sterilizers, cooking, etc. There must be at least 50 amps at 220 volts (or the equivalent) in the X-ray room. The main transformer supplying the hospital must not be too far from the X-ray rooms unless an additional heavy cable can be provided. A 50 amp circuit breaker and fuse will be needed in the X-ray room, for direct connection to this type of X-ray generator. This will be a permanent connection; there should not be any other heavy electrical equipment on this circuit.

b) Many rural hospitals generate their own electricity with a diesel, gasoline, or kerosene generator. It must produce the same alternating current supply as described above. Problems arise because many small generators fluctuate beyond the acceptable limits, particularly under peak loads. Thus an X-ray exposure which is made at night, when the hospital lights are in use, may be beyond the capacity of the hospital power source and the resulting films will be unsatisfactory. There is often considerable voltage loss in the cable leading from a domestic generator to the hospital, because they are sited away from the buildings to avoid the noise and the odor. Before utilizing such a source as a power supply, a careful check of its output and load factors is essential. An X-ray unit will not function satisfactorily with a variable power input.

c) Where there is doubt about the main supply or the hospital generator supply, a condensor discharge (or capacitor) unit may solve the problem. Condensor discharge units store electricity which is released as a steady power for X-ray generation. They provide a powerful but short exposure. There is an upper limit to their output and they must be recharged immediately (i.e., the local generator must be running continuously while the X-ray unit is working with patients, or else the condensor cannot be recharged for the next exposure). The main power required for such X-ray unit is low and the results are good. Whichever type of installation is chosen, all electrical wiring must comply with local regulations.

d) Battery operated units have considerable power reserve (e.g., 1,000 chest X-rays between recharges) and can be recharged at any time, day or night, when the local power supply is available. The load required from the main supply for recharging is small but must be continuous. Provided the batteries are kept charged and in good condition they are always available and they are extremely flexible to use. They produce a very steady, constant power supply.

The batteries can be either lead acid or nickel cadmium: both have advantages and disadvantages. Both need constant care and maintenance and will probably need replacement every three or four years or less. Nickel cadmium batteries should last longer than lead acid, but mainte-

nance is more difficult. It will involve a visit from the central maintenance depot for recycling every three to six months, depending on the amount of usage. Whichever type of battery is chosen the specifications for the unit should be suitable for local climatic conditions, especially in tropical areas.

*Which is the best choice?*

If there is a good electrical mains supply it is the best choice. If the generator is large and can carry the load it is a good choice. If there are difficulties with the power supply, then a battery operated unit is preferable and will undoubtedly prove satisfactory.

*Basic equipment*

There is a wide choice of X-ray equipment: all units consist basically of five main parts and these must be considered separately. However, they should all be purchased from the same manufacturer and wherever possible equipment should be standardized throughout the area.

- a) The X-ray generator and its control.
- b) The tube and support.
- c) The patient support.
- d) Cassettes and screens.
- e) Processing tanks and darkroom equipment.

*Selection of generator and control*

Generators are specified in terms of milliamperage (mA) and the kilovoltage (kV) which they produce. The milliamperage provides the "brightness" or power for the X-ray exposure, and the kilovoltage alters the penetration of the rays through the patient.

To radiograph sick patients, whether they are adults or children, a relatively short exposure time is essential. This means that the generator must have sufficient power because all X-ray exposures are a combination of mA and time (seconds). The specification for the generator must therefore require a minimum output of 100 mA for not less than 0.1 seconds but must also specify 100 kV. It is an advantage to have a unit more powerful than this, but it will increase the cost of the unit and the electrical supply required.

Note carefully that it is essential that the generator produce both 100 mA and 100 kV simultaneously for not less than 0.1 second. There are many cheaper generators which will produce 100 mA at a lower kV (e.g., 100 mA at 60 kV) or produce 100 kV at a lower mA (e.g., 100 kV at 50 mA). These are not acceptable alternatives and the power capability must be 100 mA at 100 kV, specified as 11 kilowatts minimum.

### *Preferred type of generator and control*

These items may come as a single unit (as in a mobile X-ray machine) or in two separate units which can be installed in different parts of the room. When they are sold as one unit, the whole can be mobile or fixed; mobile units are not acceptable. If they are supplied in two units the generator (also known as the transformer) is likely to be fixed and the control may be supplied on wheels—it is recommended that the control become fixed also. Inability to move the equipment insures that the most satisfactory layout is maintained and reduces the radiation hazards.

If you have a choice, choose fixed equipment.

### *kV and mA control and kilovoltage settings*

The control of the kV and the mA must be separate and independent. Any link (other than to provide overload protection for the tube) is unacceptable. The specification should require a minimum of 3 kV settings with a variation between each of more than 22 per cent, for example, 110 kV, 75 kV, and 50 kV. Many controls provide additional kV settings at 5 or 10 kV steps and this is acceptable provided that making a change in the kV setting does not automatically alter the milliamperage available.

### *Control of length of the exposure*

Timers can be electronic or mechanical: the electronic timer is more accurate; it should be solid state. The time switch must provide exposure settings from .02 seconds to about 5 seconds. There should be a 26 per cent interval change thereafter.

The milliamperage must be indicated either by a dial, a light system, or in some way so that the operator knows exactly what power is available at any given length of exposure. In some units the milliamperage and the time (the mA and the seconds, known as mA-seconds) are linked together so that altering the timer alters the mAs. Usually this means that the generator is set at one standard milliamperage and only the time is varied. It is acceptable to have alternate mA settings, such as 25 mA, 100 mA, controlled by a separate switch, but it does make it a little more difficult to operate.

If there is a choice, choose units with one mA setting and a variable time.

### *X-ray tube supports*

There are five basic designs for tube support:

- a) Integrated with the control unit and the transformer (such as a standard mobile unit);

- b) A column mounted on the floor rails alone;
- c) A column mounted on floor rails with a ceiling rail;
- d) A fixed column with a tube rotating on a central axis (a "C" or "U" arm);
- e) A column integral with the X-ray table;
- f) A carriage suspended from the ceiling on rails.

The last design (f), can be disregarded for primary care radiological facilities. It presupposes a strong ceiling capable of holding over 400 kg, adds complexity and cost to the installation, and increases the maintenance. It is desirable in larger hospitals but not in primary care units.

*Which is the best tube support?*

Eliminating the ceiling support, the others have advantages and disadvantages.

a) A mobile unit which is complete with an integrated generator, control, and tube support is simple and often chosen. The main disadvantages are that it must be moved from the table and repositioned to examine chests, it is less easy to center on the patient, and the operator is more likely to be exposed to scattered radiation. Because the tube can be off-centered from the cassette very easily and because the unit can be moved around the room, it is not so easy to control radiation hazards. It does have the advantage that it can be used elsewhere in the hospital, but under primary care conditions it is probably better to bring the patient to the X-ray department than vice versa. Of the available methods of tube support, this is not acceptable.

b) A single column can be mounted entirely on floor rails. It requires three wheels arranged in a triangular form (figure 7). If the column is to move freely the floor must be solid, level in each direction, and totally free from dust. The rails can be raised above floor level, or recessed into the floor. The latter is preferable because it allows easy movement of trolleys over any part of the X-ray room, but it is more difficult to keep clean and more difficult to install. A column of this type provides reasonably stable tube movement.

c) The single column can be mounted on a floor rail (which may be either recessed or above the floor) that bears all the weight while the top of the column is steadied by a single ceiling rail that stabilizes the significant lateral forces (figure 8). Both the ceiling and the floor rails must be entirely parallel throughout their length: any variation in height will render the support unstable. Such floor to ceiling tube supports are adjustable from 280 cm to 400 cm. Their installation requires care and expense, and derailment can occur with the possibility of injuring the patient and the operator, as well as the tube support and the column itself.

Figure 7

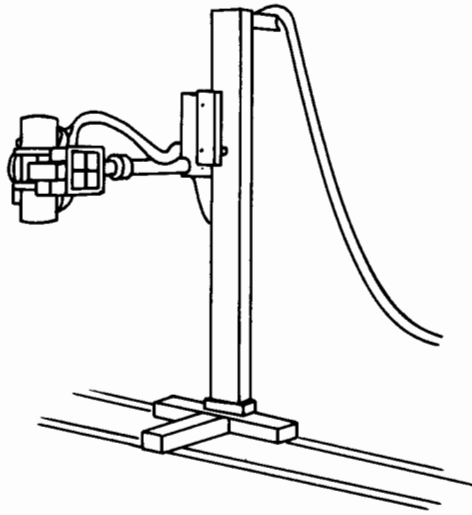
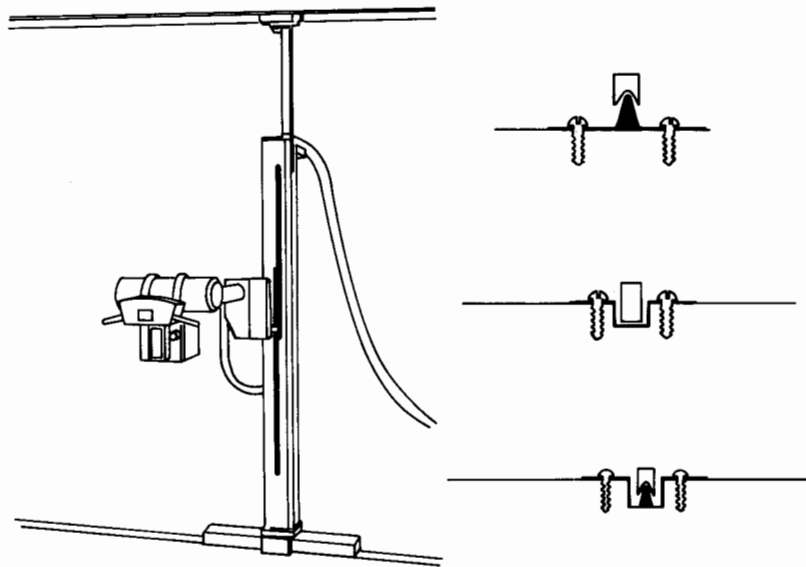


Figure 8



A good installation provides steady support, but needs very good local construction skills and materials.

d) The X-ray tube can be held on one end of a "C"- or "U"-shaped arm which is supported on a single column. Exactly opposite the tube on the

other end of the arm is the cassette holder. The supporting vertical column must be fixed to the floor and steadied against the wall or ceiling (figure 9). Fixation to the floor without ceiling or wall support is not sufficiently rigid. Usually the wall is satisfactory for this purpose.

This design of tube support has many advantages. It is rigid, it does not require a completely level floor beyond the base plate of the column, and it is easy to install without reference to ceiling timbers, etc. Patients can be examined either sitting, standing, or lying on a patient support with the beam in any direction. The centering of the tube to the film is accurate and fixed, thus eliminating technical error in either plane. The distance between the tube and the film can be similarly fixed. It is easy to manufacture and maintain and has a minimum number of movable parts. It is the best available design for primary care installations.

e) The tube support can be a column, which is an integral part of one side of the X-ray table, with movement along the length of the table. This requires that the table be fixed to the floor and be well constructed: the design is excellent, rigid, and simple (figure 10). The floor must be level and strong enough to support the combined weight. The film holder can be linked to the column thereby providing accurate centering in the vertical beam direction, but there can be no link between the tube and the chest stand when the patient is erect. It is easy to install and maintain and is second in preference to the "C" or "U" arm (design d).

It should be noted that designs a), b), c) and e) all require a separate chest cassette holder. Design d) does not require this.

Figure 9

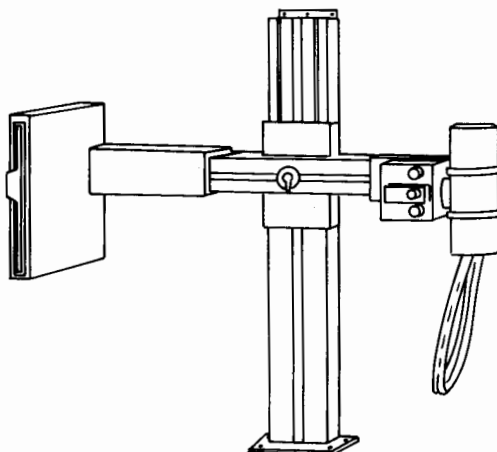
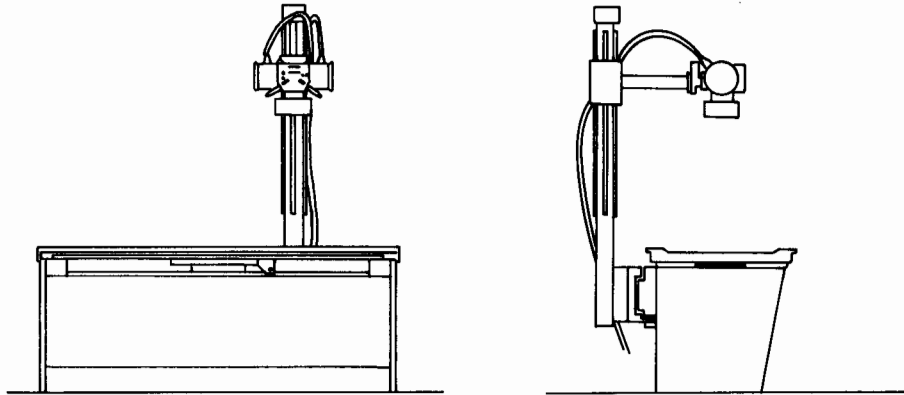


Figure 10



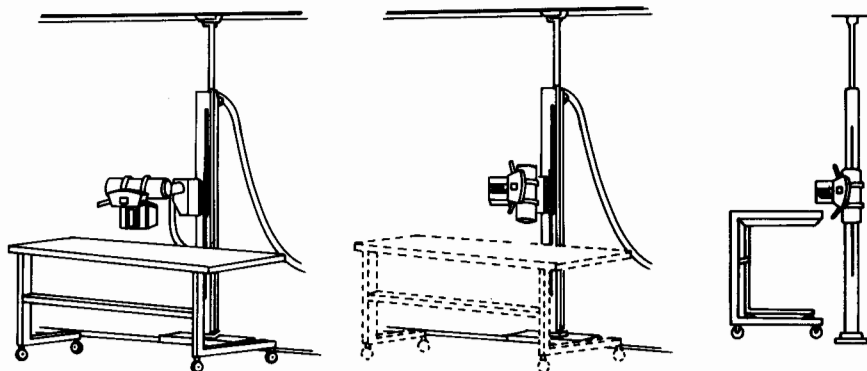
*Movements required of the tube*

The tube must be usable with patients in two positions: horizontal and vertical.

It must also be possible to examine patients on the X-ray table or a trolley when the patient is in a horizontal position and the beam is across the table in a transverse direction. There are therefore three basic beam directions. Vertical, horizontal, and horizontal transverse (figure 11).

It must be possible to lock the tube at any height: with a standard upright column, either on rails or attached to the patient support, the horizontal lateral beam requires a 90° rotation around the axis of the column and a 90° rotation around the axis of the tube. The "U" arm can provide these

Figure 11



views with only two movements but a mobile patient support is required to permit the horizontal lateral view (figure 12).

*Support for the weight of the tube*

All tube supports must be capable of vertical movement and because tubes are very heavy some sort of counterbalance is required. Two basic mechanisms are: a) counterweights and b) springs.

Counterweights are simple lead or steel weights attached to a cable that runs over a pulley at the top of the column. The pulley can be single or a variable ratio pulley series.

Springs can be of variable or fixed tension; they may be attached either at the base of the column connected to a cable running over a pulley, or they may be attached at the top of the column to provide direct suspension of the tube support (figure 13).

Of these alternatives the first (simple counterweights) is the most reliable and the balance is more easily altered if a different tube is later used in replacement. Springs attached to a cable function well but may become fatigued, and adjustment is less simple. Direct support with a spring is less satisfactory and less stable over a long period.

If the "C"- or "U"-arm tube support is chosen, the same counterbalancing alternatives apply, and simple weights on the cable with a single or differential pulley is preferred. It may be desirable with such units to have two cables and counterweights. In any of the designs the cables can be satisfactorily replaced by chains running over a toothed pulley (a cog).

Figure 12

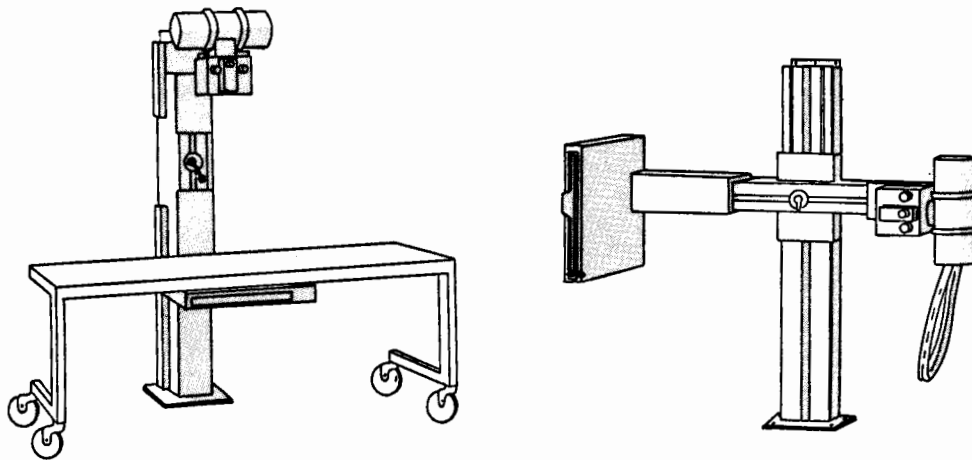
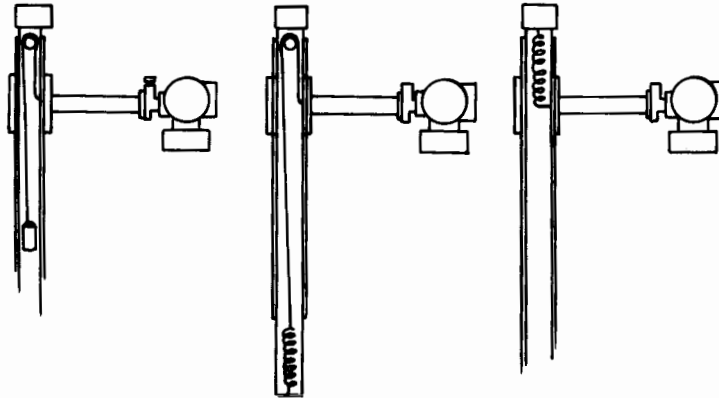




Figure 13



#### *Control of the movement of the tube*

Rotating and vertical movements of the tube support are controlled by two kinds of brakes: a) friction brakes locked by a simple screw or by an electronic mechanism, and b) a fixed position lock.

Friction brakes are best operated by simple screws, utilizing large contact surfaces with large levers or knobs to rotate the screw. Electromagnetic brakes add complexity and require additional maintenance and repair. They are usually less efficient, collect dirt and lint, and become unreliable. Moreover, they presuppose a constant electrical supply on an auxiliary circuit even when the generator is switched off. Without a generator electronic brakes do not function. They have no advantage over hand-operated screw brakes and because of their complexity are not suitable for primary care installations.

Fixed position lock points, e.g., at predetermined distances, utilize a bolt action to engage with a preset hole or catch. They provide good and accurate braking in the vertical position, but they are not satisfactory for X-ray patients in an erect position. Too many positions are required because patients vary considerably in their height.

#### *X-ray table designs*

There are basically two varieties: a) fixed and b) mobile.

A fixed table has a flat X-ray-translucent top usually just less than 2 m and just over 60 cm wide. The unit must be able to support the weight of 120 kg patients without appreciable distortion. The table can be mounted on four legs, or on two with a cantilever arm. The design with four legs, providing support at each corner, is more rigid, less easy to distort, and can be fixed to the floor.

Mobile tables are available in the same basic design and dimensions. They can also be mounted on four legs with four wheels or on a double cantilever support, again with four wheels. The four-leg model is preferable because it is less likely to distort.

Each wheel must be equipped with a simple friction brake which can easily be foot operated. The wheels must be at least 5 cm in diameter and rubber treaded.

Neither the fixed nor the mobile version should have cross bars along the length of the table so that there is free access beneath the table. Either can be provided with a tray beneath the table top designed to support the X-ray cassettes. Above the trays there may be either a fixed or moving grid (figure 15 page 31).

Either design, fixed or mobile, is suitable for any variety of tube support. The "U" arm requires a movable patient support for maximum efficiency.

#### *Chest X-rays in the erect position. The chest stand*

With all designs of tube support, except the "U" arm, a separate vertical cassette holder is needed for chest radiography. Any design must satisfy four basic requirements:

- a) It must be strong enough to provide good support for the patients.
- b) It must be rigid and stable.
- c) It must hold a standard size cassette (for chests) and be adjustable in height.
- d) It must incorporate either a fixed or a movable grid and be able to carry the cassettes either in front or behind the grid.

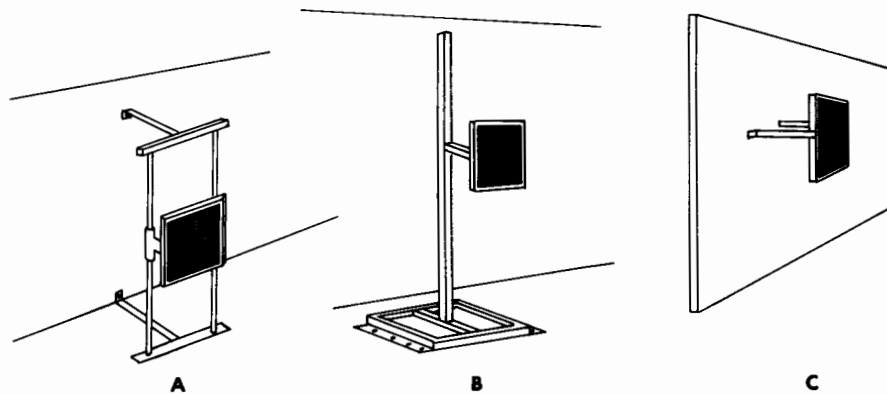
Figure 14 shows three designs:

- A. Fixed to the floor and the wall.
- B. Free standing.
- C. Wall mounted (adjustable in height).

They can be supported on the floor and steadied by a bracket to the wall. Many of the patients who have their chests X-rayed are sick and unsteady on their feet and they will lean on the cassette holder for support. It must be strong enough to support up to 50 kg without becoming unstable. Any unit that is fastened to the wall must be installed with the cassette holder far enough away from the wall to allow patients to wrap their arms around it for the support they require. This can be achieved by additional wooden blocks as spaces between the cassette holder and the wall; whatever method is used, fixation to the wall must be firm.

The "U"-arm tube support incorporates its own cassette holder in the horizontal position for chest examinations. No separate wall-stand is

Figure 14



required and it has the advantage that the tube is permanently centered in exactly the right position and at exactly the right height when the patient is in front of the chest cassette.

When choice is available, choose a cassette stand that is supported by the floor and fastened also to the wall (A). Those mounted on the wall itself are the second best choice (C); the free standing unit (B) should not be chosen.

Some of the chest cassette holders permit movement of the cassette from a vertical to a horizontal position. This added facility is not required in a primary care unit: it presupposes more technical knowledge than the average primary radiology operator will gain. Moreover, it can only be used with a tube support which runs either on a floor-to-ceiling or floor rail and can move across the X-ray room to the chest stand. It increases the complexity of the units and is not recommended for primary care installations.

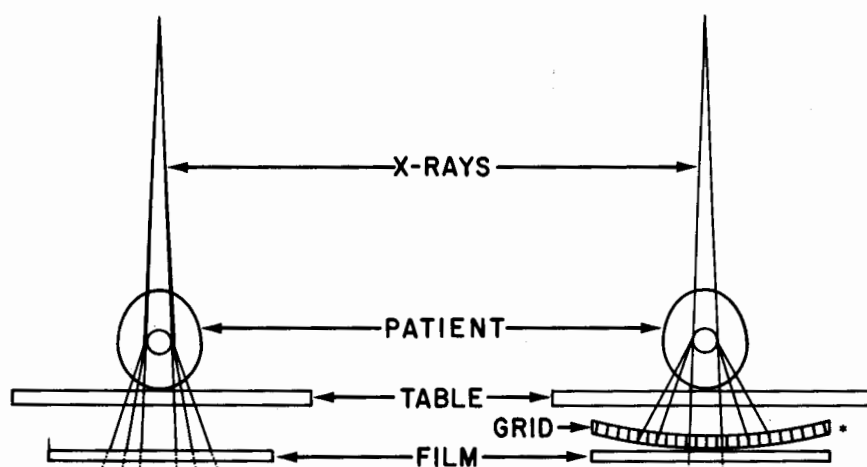
### *The grid*

When any X-ray beam passes through a patient, some of the X-rays are scattered in different directions and if these aberrant rays reach the film they distort and spoil the image. A grid is a metal screen that absorbs almost all of the scattered radiation. It is properly called a "secondary radiation grid."

Grids absorb scattered radiation so that only direct beams reach the film (figure 15).

They are made in various patterns depending on the number of grid slots per cm and the thickness of the grid. They may be either flat or focused (curved with a standard radius, such as 1 m, 1.8 m, etc.). They are always positioned below the patient and above the film. They can be used stationary or incorporated in a "Bucky" mechanism which allows them to

Figure 15



\*In practice the grid is flat.

move sideways and blurs out their image during the exposure. This movement can be effected mechanically or electrically.

A simple stationary grid is preferred in primary care units where the complex mechanism of a "Bucky" or moving grid is unnecessary.

#### *When is a grid used?*

A secondary radiation grid is necessary when examining the abdomen, the skull, the spine, the pelvis, the thighs, the large shoulders, or the knees. It can be used for chest X-rays, especially of large patients. Grids are never needed for the elbows, hands, or feet.

#### *What sort of grid should be purchased?*

It is recommended that the grid have 30-40 lines per cm, 8:1 ratio, and be focused at 140 cm. This is suitable for any examination at standard distances between 1 m and 1.8 m. If the "U"-arm tube support is chosen, a fixed anode-film distance can be utilized and the grid should be adjusted exactly to this distance. The grid must be the same size as the largest film, usually 35 x 43 cm.

All grids are delicate: if they are bent they become useless and if they are dropped they are easily damaged. They should be supplied either coated in plastic for protection, or as an integral part of a cassette. With proper care they will have a long life.

### *X-ray tubes*

There are two basic types of X-ray tubes: a) the stationary anode, and b) the rotating anode. Both are vacuum tubes.

The quality of the radiograph is influenced by the size of the focal spot of the X-ray tube and the speed with which the exposure is made. Both are inversely related to the ability of the tube to absorb and dissipate the energy which is produced by the X-ray generator and transmitted from the cathode to the anode. The higher the power (i.e., the higher the mAs and kV), the hotter the anode becomes, and the larger the size of the focal spot which is required to absorb the heat. A rotating anode is basically a spinning disc which utilizes only one rapidly changing segment of the periphery as its focus. It can absorb much more heat than a stationary anode tube.

A stationary anode tube is simple and rugged, but has a low heat capacity: it therefore requires a larger focal spot, usually 2 mm or more to permit exposures in the 100 mA, 100 kV range. A rotating anode is far more complex but is much more efficient and can have a smaller focal spot, in the range of 0.8 mm, which produces a significantly better radiography image. X-ray tubes can be supplied with a dual focus which may be of different or similar sizes. In a primary care unit there is little advantage in having a tube with a double focus.

### *Choice of X-ray tube*

Despite the increased cost and the complexity of a rotating anode tube, it is recommended. In practice a good modern rotating anode tube will exceed 50,000 exposures and will last many years under primary care conditions. The manufacturer should be asked to provide a guarantee for a minimum number of exposures (usually 20,000).

### *Special requirements for X-ray tubes*

Every tube supplied should meet the standards of the International Commission on Radiological Protection (ICRP) and the International Electrotechnical Commission (IEC).

### *Protecting the X-ray tube against accidental overload*

The combination of milliamperage and seconds which can be used at any time with a given X-ray tube is restricted by the capacity of that tube to

absorb heat. All generators and controls must therefore incorporate automatic tube protection. This must prevent overload, either mechanically or electronically. Such overload mechanism should not incorporate a fuse which needs replacement but an automatic circuit breaker which can easily be reset. The majority of control units have a simple mechanical system which does not require resetting but prevents excessive exposure. This can be adjusted in the factory or by the service engineer for the tube provided. More complex mechanisms to protect against too frequent exposures and resulting heat build-up are quite unnecessary in primary care radiological facilities.

### *The control panel*

There should be a clear indication on the control panel:

- a) That the machine is switched on.
- b) The time and mA settings.
- c) The kV setting.
- d) That X-rays are being generated.
- e) With a condenser or battery powered unit, there must be an indication that there is sufficient charge available or that recharge is necessary.
- f) With either a condenser or battery unit there must be an indication that recharging is taking place or has been completed.

All this information should be indicated by positive settings on a dial or by positive meters or lights. A light which shows as "off" when the unit is ready may be misleading because the bulb may be faulty. The light must be "on" to indicate positive information.

The button which controls the exposure of the X-ray unit must be an integral part of the control panel with no opportunity to expose from anywhere except behind the control area.

As already noted (page 17) a protective screen should be incorporated as part of the control unit.

### *Exposure requirement for rotating anode tubes*

An exposure must never be made unless the anode of a rotating anode tube is rotating satisfactorily, usually at 2,800 revolutions per minute. The control switch must therefore incorporate a protective mechanism which first starts the rotor of the anode and only permits exposure when the correct speed is reached. It is possible to incorporate an additional indicator light in the control panel showing that the tube is ready, but this is not essential: a switch which prevents premature exposure is more desirable.

### *Requirements for X-ray cables*

High tension cables connecting the X-ray tube to the generator should meet all IEC specifications and should be suitable for the local climate, especially in the tropics. They must be shock-proof and must not be of poor quality. The length required will depend on the layout of the equipment within the room, but the length must permit full movement of the X-ray tube. The supplier should be required to provide cables of the necessary length to insure this. All the cable connections at either end of the cables must be of standard design and interchangeable.

### *Cones and collimators*

Scattered radiation that has been reflected off or deviated from within the patient is a major source of hazard to staff and often to other patients. It also decreases the quality of the resulting radiograph. X-ray beams should therefore be limited and confined to the exact direction required. This may be done by circular or rectangular cones or by collimators, both of which are fastened to X-ray tubes.

Cones are metal devices (figure 16) designed so that the radiation exactly covers the standard cassette when the X-ray tube is the standard distance from the patient. Smaller cones can replace them for smaller cassette sizes. Unfortunately the ability to change the cone means that occasionally it is not replaced and films are taken without any beam limitation. One design allows the cone to stay in place; the diameter of the field is altered by changing a small diaphragm at the top. Neither method is as satisfactory as a collimator (figure 17) which can either be adjustable, or provide two or three alternative field sizes. It cannot be removed from the tube: the "U"-arm unit which utilizes a fixed distance allows the maximum protection, because the same field size is required in any position of the tube or

Figure 16

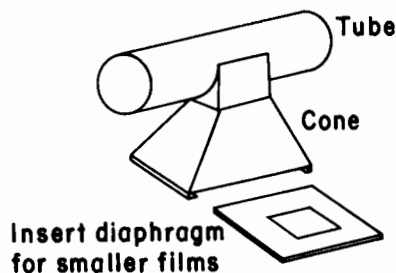
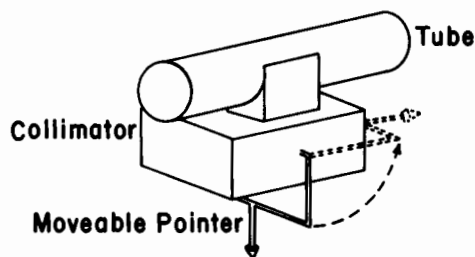


Figure 17



the patient, and the number of cassette sizes can be limited. Collimators in major X-ray departments incorporate multiple shutters and a light system coupled with mirrors which clearly defines the field size being used. These mechanisms are complex and can be inaccurate and troublesome, or the bulb may need to be replaced. They are not recommended for primary care units.

All tubes for primary care installations should be supplied either with a cone or collimators, preferably of a design that makes them irremovable except by maintenance personnel.

#### *Directing the X-ray tube at the correct part of the patient*

Tubes fitted with cones provide self-evident direction: positioning the cone over the patient (the average cone is about 30 cm long) indicates the exact area to be examined. Tubes fitted with a collimator should have a pointer that can swing out in front of the tube. Operators can easily be taught to "center".

Collimators fitted with a light beam have already been discussed and because of their complexity and maintenance problems are not recommended.

## **DARKROOM: CASSETTES, SCREENS, FILMS, EQUIPMENT PROCESSING**

### *Cassettes*

X-ray films are used in lightproof cassettes. Within the cassette are two fluorescent screens (page 36) between which the film lies. These screens fluoresce when irradiated and the film is exposed by the light from the screens. X-ray films therefore have emulsion on both sides.



Cassettes must be:

- a) Strong and rigid, without warp.
- b) Provide firm pressure and good contact between the film and both screens.
- c) Lightproof.
- d) Easily opened in the dark.
- e) Durable.

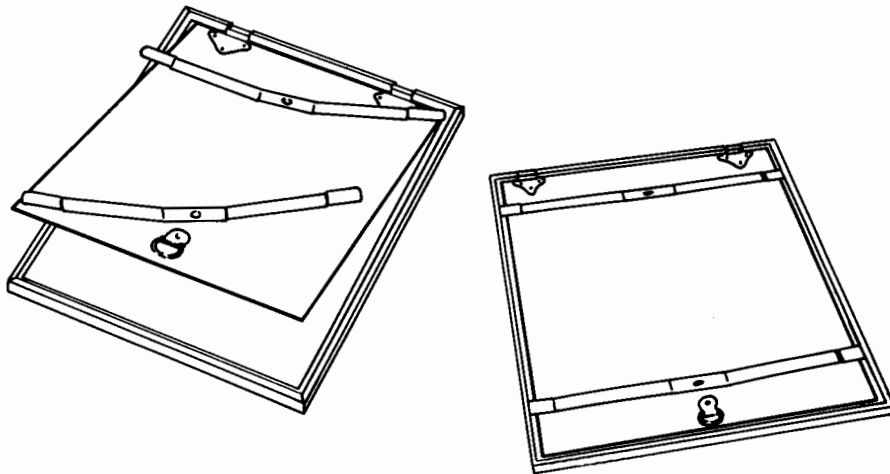
Metal cassettes are recommended for primary care units. They should last at least five to seven years. Plastic cassettes are excellent but have not been used long enough (1977), especially in tropical conditions, to be sure of their wearing qualities.

Good screen contact is best obtained with the type of cassette that has two sprung steel straps across the width of the back that are fastened centrally onto the back plate of each cassette and clipped under two opposing edges under tension (figure 18).

This pattern is the best and most durable with the best pressure application. The backs of the cassettes should be steel and provide built in radiation protection. Each screen is mounted in the cassette on felt to absorb the pressure. Hinges should be of the long "piano hinge" design, running the full length of one side of the cassette. The alternative cassette with small hinges and clip fasteners may not be so durable.

The only part of a cassette (other than the screens) that requires replacement is the felt because it may become compressed or destroyed by a fungus or moths. It should last about three years.

Figure 18



### *Fluorescent screens*

Fluorescent screens are made of a backing, often a type of cardboard, coated with chemicals which fluoresce when X-rays fall upon them. There is a front (patient side) and a back screen in each pair. There are many different chemical combinations but they fall into three basic categories:

- a) Fast or high speed screens.
- b) Medium or standard screens.
- c) High definition screens, i.e., detail or slow screens.

Unfortunately manufacturers do not use the same terminology and a screen that is designated as "high speed" by one company may equal a "medium speed" from another manufacturer. Fast, or high speed screens require less radiation to provide a satisfactory exposure but give less detail because they have a coarser grain size. Medium screens provide good detail at moderate radiation levels. High definition or slow screens give excellent detail with very fine grain but require much more radiation per exposure.

There is no indication for high definition screens in a primary care unit nor will the generator be adequate for their use. A fast-medium speed screen should be required. All screens and all films, cassettes, etc. should be standardized.

"Rare earth" screens are currently (1977) more expensive but provide more speed with moderate but satisfactory definition. If they are not too expensive, such screens are an excellent compromise for primary care units but they are not, by any means, essential. The less expensive medium or fast screens are entirely satisfactory.

All screens within cassettes are damaged by dirt, chemicals, handling, scratching, etc. They must be cleaned every month with a soft cloth and a little soapy water, and allowed to dry thoroughly before reloading and closing the cassette. (Follow the manufacturer's instructions.) Under primary care conditions they should last three to four years, when they may need replacement; once a screen is damaged, a significant mark appears on the film which may be misinterpreted as a pathological finding or may obscure some abnormality in the patient.

### *Choice of films*

The majority of X-ray films are now polyester based and this is recommended. They come in various speed categories: a) fast; b) standard; and c) slow.

In general, the faster the film the less the definition: a standard or medium-fast film is recommended. Unfortunately, various manufacturers use different terminology to describe their products, but a middle speed

range should be requested. All these films are designed for use with screens. All films (and cassettes and screens) should be standardized for all primary care units.

It is possible to expose X-ray films without screens, by direct radiation. The use of "nonscreen film" requires that the films be supplied in light-proof containers. The results provide excellent detail, but they require a much longer exposure than do films with screens. Nonscreen techniques are of particular use for wrists, hands, and feet but for little else. Such film can be utilized in a primary care facility but its choice will depend on the skill of the operator, the amount, and the character of the work. Nonscreen films are by no means essential, they provide an additional technical complication, additional supply requirements, and may lead to the wrong exposure.

All X-ray films can be damaged by heat and moisture, and, of course, are fogged by light or external radiation.

#### *Storage of films*

The life of a film is dependent on storage conditions, particularly temperature and humidity. Until films have been tested in a specific primary care facility the life cannot be estimated. Even under tropical conditions, good films should last for six months without appreciable deterioration. In less extreme climates films may last a year. It is suggested that they be tested in the following way, before purchasing in bulk.

Several boxes of films of different sizes should be obtained from the supplier; a few films should be taken from each box and exposed in a standard cassette, using a known exposure combination. The boxes should then be resealed and left on the shelf in the local storage office at the primary care hospital; other films should be exposed after three months; and others after six months. Each time the same variables are used. Comparison with the original fresh films should then be made by the radiologist.

Manufacturers can provide films in "tropical packs" with special interleaving and wrapping materials suitable for the excessive heat and humidity. Smaller boxes containing 25 films are recommended although films of the large size (for chest) may be ordered in boxes of 50 sheets if the primary care unit makes a sufficient number of examinations per week to provide a rapid turnover of film. The delivery date and expiry date of the films should be stamped on every box. To avoid damage, unused films must be stored vertically (as books in a library) and must not be stacked on top of each other. Shelving must allow for this.

### *Sizes of films and cassettes*

There is a wide range of film sizes available but most are unnecessary in a primary care facility. Only two film sizes are necessary: a large size (35 x 43 cm) and a medium size (24 x 30 cm). Cassette sizes will match these film sizes: this will simplify both darkroom practice and X-ray examinations, and will be less expensive (figure 19). Other sizes may be added.

### *Multiple exposure on the same film*

If one part of the film is covered with a piece of lead rubber, 0.5 mm lead equivalent, then two exposures can be made of the same arm, hand, wrist, etc. on one film. Three or four pieces of lead rubber, each 12 x 30 cm should be in each department.

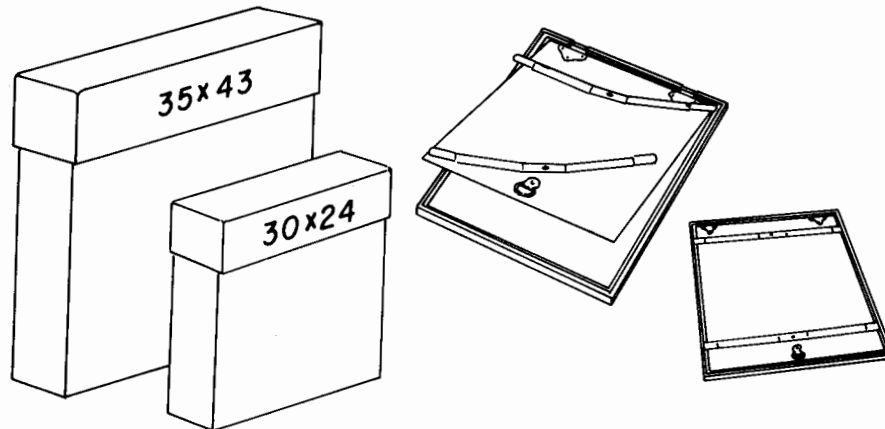
### *Darkroom equipment*

The darkroom will need a master processing tank fitted with two insert tanks for chemicals. There will be a "dry" workbench, safelights, film hangers, storage for films, a film marker, and if powdered chemicals are to be used, two auxiliary tanks or buckets for mixing, and mixing rods. Chemical mixing should not be performed *in* the darkroom.

### *Film processing*

There are basically two types of film processors: automatic and manual. It is unlikely that automatic processing will be needed in a primary care radiological facility: if the hospital clinic has two or three physicians

Figure 19



and is X-raying more than 20 or 30 patients per day, has a good water supply and electrical supply, then such equipment may be considered. Price is not the main limitation, but complexity and water and power needs are critical. It requires regular maintenance and is only economical if a large number of films are being processed every day. There are many different sizes, capacities, and brands. No unit will function satisfactorily if the ambient temperature of the water is wrong, if the water pressure is inadequate, or if there is much voltage fluctuation. Automatic processors do have the advantage of simplicity in operation and standardized results. They produce a complete, processed, dry film.

Hand processing is the traditional way, particularly in primary care facilities. The needs are less critical and it is more flexible. It is easy to teach and little maintenance is required. It produces a wet film which must be dried, and the process can give rise to film faults. When there are only 10 or 20 patients per day no other form of processing is justifiable.

#### *Processing tanks*

There are three alternatives for the master tank (figure 20):

- a) Locally made concrete.
- b) Stainless steel.
- c) Plastic.

The third alternative, plastic, should be disregarded. Currently plastic tanks are cheap but they are easily damaged and do not last long, they warp, especially in the heat, and they are difficult to handle when full.

Locally manufactured concrete or cement makes a satisfactory tank: the inside should be smooth and the edge and the operating long side should be tiled outside if possible. Tank sizes are quoted below.

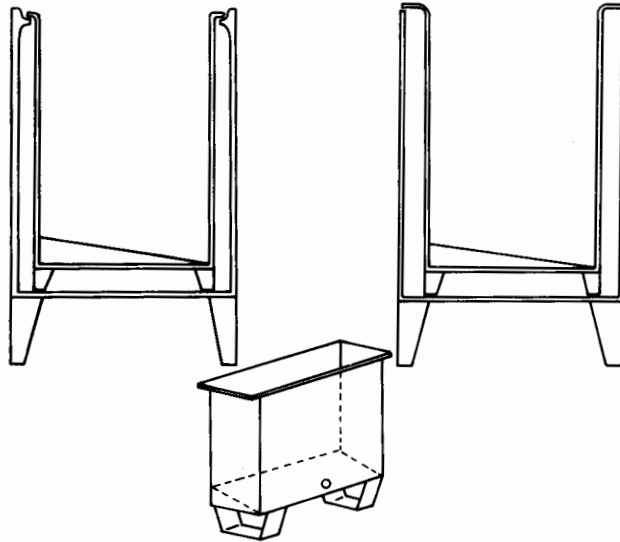
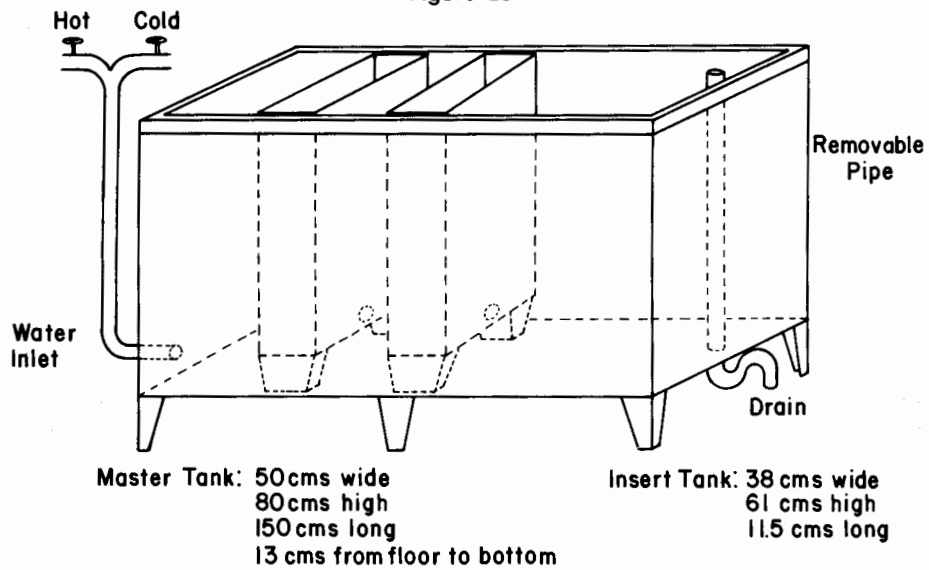
Commercially made stainless steel tanks are preferable: they must be manufactured of special 18 gauge chemically resistant steel. Any other stainless steel perforates in less than one year when used with X-ray chemicals. The correct steel is initially more expensive but lasts indefinitely (e.g. AISI\* type 316 or 317. These steels should be welded with electrodes of the same type number).

Figure 20 provides the dimensions whether made of concrete or steel. The water supply should come in at one end, preferably with the controlling faucet, just above the tank. If the local climate gets sufficiently cold and if a hot water supply is available this should be joined to the same inlet. The water should be allowed to run while the tank is in use, draining through an overflow pipe at the opposite end as shown in the diagram. The

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\*AISI: American Iron and Steel Institute, 1000 16th Street, N.W., Washington, D.C. 20036.

Figure 20



faucets or taps must be positioned so that when films are lifted out of the tank they do not get in the way.

The overflow drainage tube should be removable and the installation must be so designed that the water flows in from the end which contains the chemical insert tanks and leaves from the far end, the washing area.

#### *Chemical insert tanks*

Separate tanks are required within the master tank to hold developer and fixer. As in the case of the master tank (see above) stainless steel of the

highest quality for X-ray chemicals is the most economical material in the long run. If the master tank is made of concrete the insert tanks can be steel or plastic, but steel is preferable. The approximate size of the tanks is indicated on the diagram: they must fit firmly into the master tank. Each must have a sloping base, running towards the drain plug. Each should be supported on the floor of the master tank and kept securely in place by resting on the sides of the tank. They must be surrounded by water.

All insert tanks must be large enough to contain standard size film hangers suitable for holding the large film size, 35 x 43 cm. As shown in the diagram, the tanks will hold five or six films simultaneously: where the workload exceeds three or four cases per hour, an additional fixer tank is required. The films will be in the processing insert tank for 3-5 minutes at standard temperatures, whereas they will stay in the subsequent "fixer" tank twice as long. As the amount of work increases additional fixing space will be required and an additional insert tank should be purchased. The washing space as shown in the diagram will accommodate 30 or more films in hangers and usually allows a washing time of at least one hour.

#### *Wetting solution*

There is no indication for the use of a wetting solution in primary care facilities. It adds an additional complication, an extra tank, and serves no useful purpose.

#### *Control of water temperature*

It is seldom practical in a primary care facility to cool an incoming water supply by a refrigerator. Such a refrigerator requires a large electric power supply and is expensive to purchase, to use, and to maintain. It is better to use chemicals that react best in the average ambient water temperature. X-ray chemicals can be provided in two standard ranges, originally designed for the temperatures of hand or automatic processing. The temperature ranges are:

65-75°F	Standard chemicals	18-24°C
80-105°F	Automatic processor chemicals	27-40.5°C

Within each range there is an optimum temperature, e.g. 20°C for the first range, and this requires either 5 minutes developing or 3.5 minutes depending on the chemicals used. The temperature should be measured with a simple thermometer whenever processing starts and a simple chart can provide the correct developing time, measured by a darkroom timer. For example, if 5 minutes are required at 20°C, then 4 minutes may be required at 21° and 6 minutes may be required at 19°. A scale for such time-temperature development can be produced for each temperature

range, and technicians can be taught to develop strictly following these charts.

In some countries the winter and summer temperatures may be so different that different chemicals are required at different times of the year. The temperature may fall so low at night that the chemicals must be heated. In an emergency this can be done by placing very hot water in a suitable container, such as a large glass bottle or a hot-water bottle, and submerging it within the developer tank. The effect does not last but the procedure can be useful. Only if the master tank has to be heated by the addition of hot water for a large number of patients should a hot water supply or an immersion heater be considered.

Electric immersion heaters especially designed for X-ray chemicals are available. Only the specially designed type is satisfactory — X-ray chemicals destroy the casing of household immersion units very rapidly. Its use presupposes a satisfactory electrical supply.

In summary, the rule should be to choose the chemicals for the local climate and not to try to adjust the temperature of the solutions to the chemical.

#### *Chemicals: liquid or powder*

As far as results are concerned, there is little difference between liquid and powdered chemicals. Cost and local conditions will be the deciding factors.

Liquid chemicals have the advantage that they are easy to mix, clean, and efficient. They provide a standard solution with considerable accuracy and little possibility of error; they require a little more storage space than dry chemicals.

Powdered chemicals need thorough mixing and may require special buckets or plastic tanks and stirring rods. (The rods can be broom handles or other suitable sticks.) The process produces unpleasant odors and mixing should be done outside the darkroom. Powdered chemicals should be delivered in either plastic or metal containers. Paper bags deteriorate if stored for any length of time.

Whichever is chosen, chemicals should be delivered in packages so that each packet produces the correct amount of chemicals for the size of the insert tank being used, whether it be developer or fixer. Standardization prevents errors.

Finally, if costs permits, choose concentrated liquid chemicals.

#### *How often do processing chemicals have to be changed?*

There is no difference in the average life of chemicals supplied as liquid concentrates or as powders. With average use and five to 10 patients per day



the chemical tanks will need to be changed every month. In the interval they will need “topping up” with both developer and fixer, and a stock of both should be kept available.

No chemicals are satisfactory after six weeks, even if they have not been used at all. This should be the maximum interval between changes.

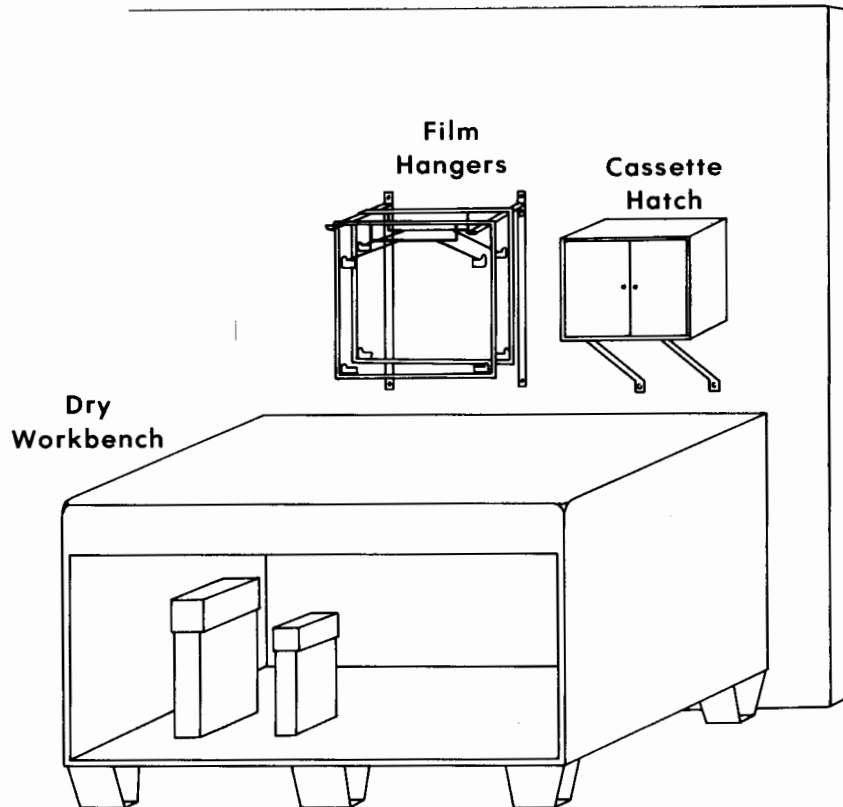
Many companies offer a “replenisher”, a solution which provides a proper balance as the chemicals are used—this is a luxury. Tanks in small primary care units can be kept filled by a simple replacement process, utilizing chemicals matching those in each tank. Supplying replenisher adds yet another type of chemical and increases possibility of errors.

As already noted, wetting solutions have no place in primary care radiological facilities (page 42).

*Dry bench*

The dry bench is a surface in the darkroom where films are inserted into and removed from cassettes. The dry workbench is best situated under the cassette hatch, against the X-ray room wall (figure 21).

Figure 21



The workbench should be 75 cm high, 130 cm long, and 50 cm deep. The top must be smooth, either polished wood, vinyl (such as vinyl tiles), standard procelain tiles, or formica. The color of the top should be deep red or deep blue (light colors can cause film fogging). Beneath the work surface there should be one shelf with enough space to store X-ray film boxes standing side by side. This requires a 40 cm shelf that is strong enough to support a considerable weight.

### *Lights needed in the darkroom*

Every darkroom needs one or two safelights with colored filters that will not fog X-ray films exposed to them for a short period of time. Standard darkroom filters are made of brown-red colored glass. The film manufacturer's requirements for the filters should be followed. In particular, the maximum recommended wattage of the bulb within the safelight should never be exceeded. It is a common fault to utilize too bright a bulb, which produces too much light, causing the film to fog, and overheats the safelight, frequently cracking the glass filter.

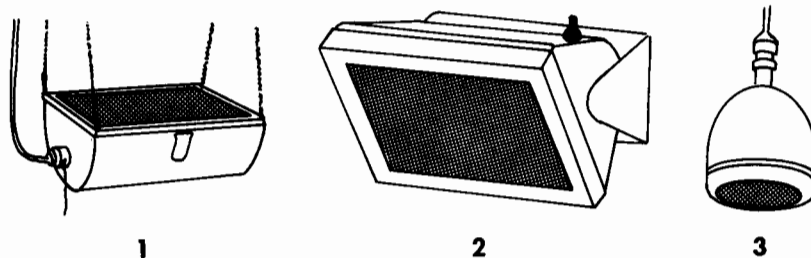
### *Safelights*

There are two basic patterns of safelights (figure 22):

- a) Suspended indirect beam (1)
- b) Suspended direct beam, fastening to the wall (2) or the ceiling (3).

Usually the direct beam (types 2 and 3) safelight is required directly above the dry bench and the central, indirect beam (type 1) is required hanging from the ceiling. If an additional light is required close to the processing unit, it should be positioned above the chemical tanks but not in such a way that films can be held in front of it (to prevent visual processing, which requires much experience to be successful). Also, in this position it will not be hit when films are lifted out of the tanks.

Figure 22



### *Suspending films in the chemicals*

After films have been exposed they are removed from the cassette in the darkroom and clipped into stainless steel hangers. There are basically two types: a) channel hangers and b) clip hangers.

The type with the channel supporting the film always causes marks around the edge of the film and does not provide such good support. Films can drop out of the hanger when in the chemicals or when drying.

The clip hanger type holds the films under tension. If it is made of high quality stainless steel it will last many years.

### *How many cassettes and film hangers should be supplied?*

A primary care radiological facility X-raying five to 10 patients a day needs two, or at the most three, large cassettes (35 x 43 cm) and three, or at the most four, medium size cassettes (24 x 30 cm).

One dozen hangers of each of the above sizes is recommended unless the clinic will have exceptionally busy days, as for example when there is a routine chest clinic once a week during which 10 or 15 patients will be X-rayed; then the number of hangers must be doubled to at least 24 of each size. Hangers are relatively cheap and it is better to have too many than too few.

### *Drying films*

Films can be dried in the darkroom or in electric dryers.

Electric dryers require considerable electrical supply, and are not required in a primary care unit. When the number of films per day increases to the point where an electric dryer could be justified, it may be better to buy an automatic processor.

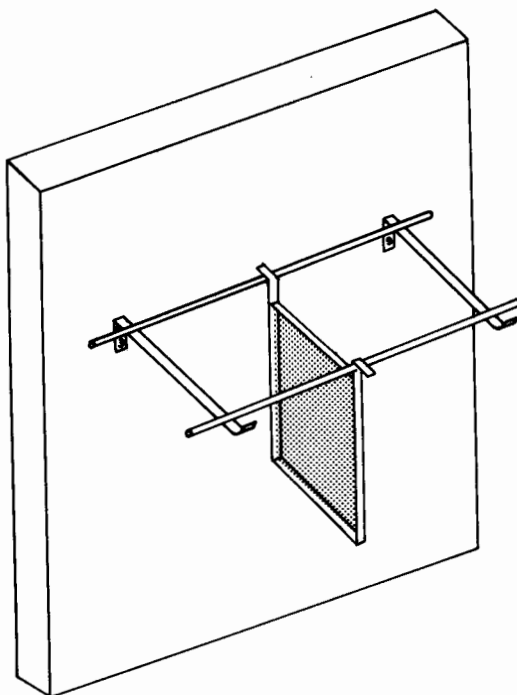
A standard drying rack can be easily constructed and should be placed on the wall opposite the dry workbench, next to the "wet" tanks (figure 23).

It should be made from two parallel rods, which may be of wood, bronze, or stainless steel. It must be at a height that will not cause an obstruction. Below it on the floor there should be an additional tank to catch the drips, or the floor beneath it should be easily drained and waterproof. Films will drip chemical residues even after washing and the surface or the tray should be capable of accepting chemical contamination. If the darkroom is too small to house the drying rack, it should be placed in a room which is not too dusty, or else films will be coated with dust and insects.

### *Transferring cassettes from the X-room to the darkroom*

The cassettes can be carried from the X-ray room to the darkroom—the two rooms should adjoin. However a simple "cassette hatch" is recom-

Figure 23

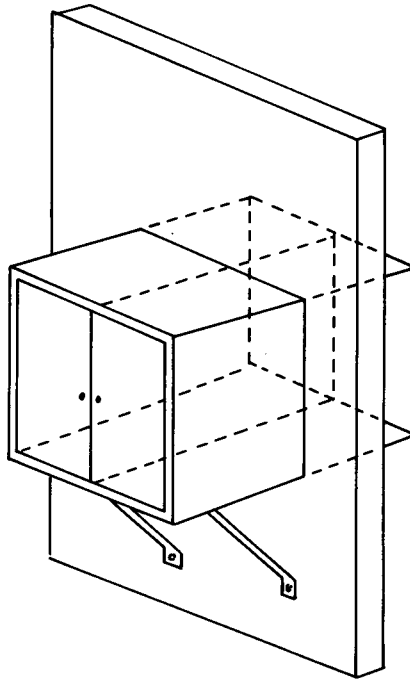


mended. It is an enclosed hole in the wall between the darkroom and the X-room of appropriate size and shape for the cassettes to be passed through it to the next room (figure 24). It serves as a safe storage for the cassettes and increases efficiency. The doors of the cassette hatch which face into the X-ray room will have to have additional lead or equivalent protection.

Commercial cassette hatches are made of metal, have double doors, and are divided internally into "in" and "out" compartments. The doors interlock so that only one pair of doors can be opened at any time and no light can reach the darkroom. These cassette hatches are generally well made, but they are heavy, particularly with cassettes inside, and additional support is required on either side of the average wall.

Alternatively a simple cassette hatch can be constructed locally. A divided box runs through the wall and at either end there is a counter-weighted single door moving vertically. Above the box and parallel to it is a tube through which a brass rod can slide. Its movement is restricted to 3-4 cm either way. When either door is let down the rod protrudes at one end over the top of the door but allows the other door to be vertically lifted and thus opened. With the door lifted, the rod cannot be pushed back and the other door must remain shut. Only when the first door is closed can the rod

Figure 24



be pushed through again and the other door opened. The doors must be wide enough to give good overlap of the divided box and must be lightproof. Counterweighting can be simple weights on pulleys. Additional protection on the X-ray side can be provided with 1-2 mm of lead rubber. The counterweighting will have to be adjusted to balance this (figure 25).

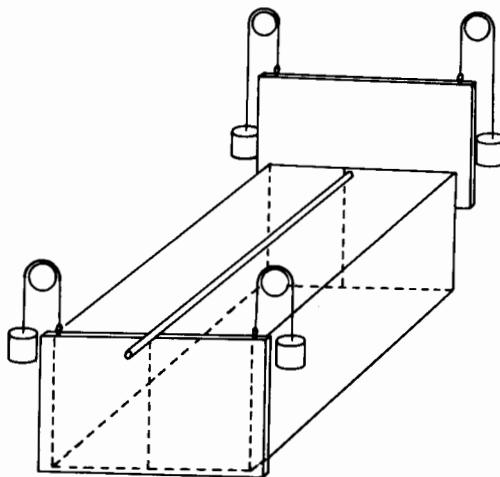
#### *Film identification*

Films can be marked with the name and if necessary the number of the patient by writing on them in pencil in the darkroom before they are processed. When they have been finished and dried the name can be re-written in white over the pencil.

A quicker and more reliable way is to mark the films photographically so that the name appears in the corner of the film. To use the commercial film markers available, the cassettes must be adapted by shielding one corner to prevent exposure. The name of the patient is put onto transparent paper in the darkroom (at the dry bench) and inserted under the film, above the small light which flashes to make the photographic image.

The equipment is cheap and the process simple: as soon as more than

Figure 25



four or five patients are being examined each day a film marker becomes a useful item.

#### *Storage and office room requirements*

The third room in the primary care radiological facility should be an office/storeroom which must be situated either next to or close to the X-ray room and the darkroom (page 8). Its size is optional but should be at least 8 m<sup>2</sup> and preferably 10 m<sup>2</sup> or more. It will serve the following functions:

- a) A room in which X-rays can be checked and examined.
- b) A room in which patients' X-ray records are kept.
- c) A storage room for X-ray films, both used and unused.
- d) A storage room for chemicals and film envelopes.
- e) A storage room for linen, gowns, etc.

The close proximity of this room to the main X-ray room and darkroom will allow doctors to examine their films other than in the darkroom or the X-ray room. A three or four panel fluorescent viewing box should be located above a table in the office, provided with a drip tray so that doctors may view both wet and dry films.

#### *X-ray department records*

Some type of record should be kept of every patient examined. A simple "daybook" utilizing one line per patient, recording the name, the dates, and the examination is essential. Where possible a hospital number should

be included. Radiographs should be kept for five years or longer if this is possible and are best filed under the hospital number or alternatively alphabetically under the patient's name. Records do not need to be complicated: they should be kept because they provide not only patient reference but information indicating the number and types of examinations made each year.

#### *Storage of patients' films*

Completed X-ray films should be kept in film envelopes (packets). The envelope size is about 1-2 cm larger than the film size. This will be approximately 38 x 45 cm. No other size is needed. Shelves with this space must be installed in the storage room, so that the films can be stored in a vertical position. Packets of X-ray films weigh a considerable amount and the shelves must be strong, with internal support and division every 25 cm. Shelving does not need to be solid: squared timber slats can be efficient. Strength is the deciding factor in the choice of material.

#### *Storage of chemicals and unused X-ray films*

Unused films are best stored in the darkroom if there is enough space, with excess films in the office/storage space. Wherever they are kept, the walls must be thick enough to prevent the films from being fogged by radiation. They must be stored vertically above the floor level, and in the coolest, darkest, driest area. Each box must be dated with its delivery date and the expiration date. Careful stock rotation is necessary to avoid keeping films too long and thus wasting them. A three months' supply of films is normally sufficient, provided there are regular deliveries available from a central supply depot.

A suitable (normally three months') supply of processing chemicals should be kept in the office/storage space, in plastic or metal containers. Paper chemical packets should be avoided. Chemicals may stand directly on the floor beneath the shelving, provided it is dry, but they must be kept away from the films, to avoid damage. The storage life of chemicals is excellent under good conditions.

## **LAYING OUT X-RAY ROOM, DARKROOM**

#### *Arrangement of X-ray equipment*

There are four basic principles in the layout of a diagnostic X-ray room:

- a) The X-ray tube should never point towards the control unit.

b) The X-ray tube should never point towards the darkroom.

c) The X-ray tube should never point towards any windows or doors.

Sometimes this is unavoidable, especially during a cross-table lateral view but no one should be allowed to stand next to a door or a window when these films are being taken.

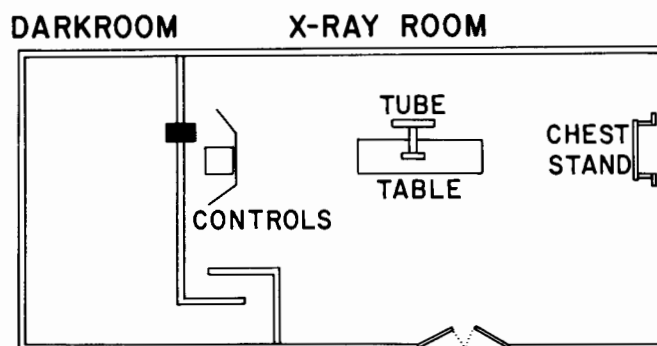
d) The controls should be as far away as practical from the X-ray table.

The main radiation danger in any X-ray room is scattered radiation, because with proper cones or collimators (page 35) the primary beam will be controlled. Radiation decreases inversely as the square of the distance, and distance is the most important single factor in radiation protection (figure 26).

The actual position of each item of equipment is dictated by the room size and the design of the equipment itself. The first item to be installed should be the chest cassette holder, which must be on the wall furthest from the darkroom. The patient support is then positioned in such a way that when the X-ray tube is immediately over the end of the table, it is exactly 1.6 m from the film in the chest stand. This locates the table, which must be parallel with the long wall of the room. A line drawn down the center of the table should be in exact alignment with a similar line drawn up the middle of the chest stand.

Normally there is a distance of about 60 cm between the tube support and the wall of the room. This is usually the wall opposite the entrance door. In a standard size room this provides ample space to maneuver trolleys or wheelchairs or even beds around the X-ray table and under the X-ray tube. If tube rails are utilized they must be on the far side of the table, between the wall and the table. The space on the door side should remain free of any obstruction on the floor.

Figure 26





If the "U"-arm design is chosen, it should be located with the tube in the horizontal position so that the cassette holder is close to the end wall of the X-ray room. This locates the whole unit; the column should be 60 cm from the wall behind it. A "U"-arm unit may use a little less space than this since the column can, in some cases, be supported by horizontal brackets from the wall, reducing the space to 40 cm.

The generator and control should be as far away from the table as possible. The generator may be against an outside wall if it is a separate item. The control should be situated as close to the darkroom wall as is practical.

Such layout satisfies our basic principles. The X-ray tube should always point away from the control area and the darkroom, and the distances should be as large as is practical. Only the occasional horizontal view across the table will allow the tube to point towards the door.

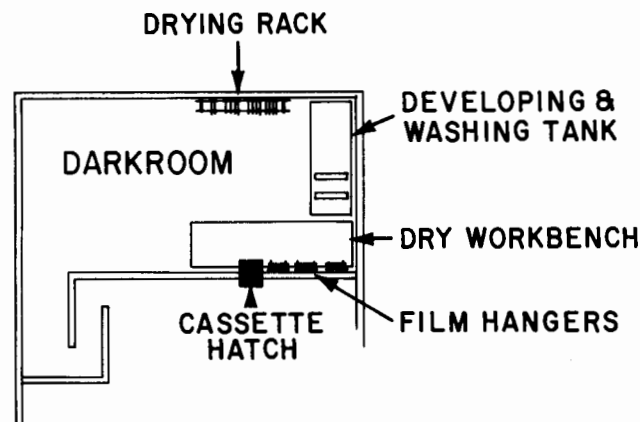
#### *Arrangement of darkroom equipment*

The layout of the darkroom is dictated by the position of the X-ray room and by the entrance door.

The dry workbench is best situated under the cassette hatch, against the X-ray room wall (figure 27).

To facilitate maintenance and installation of the plumbing, the processing unit should usually be on an outside wall, and the master tank should therefore stand a few centimeters away from the wall. Drainage from the master processing tank must be through porcelain or earthenware pipes or special quality plastic pipes. (The chemicals will cause standard metal pipes to leak after a few months.) The drying rack should be situated on the wall

Figure 27



opposite the dry workbench. Tile behind the workbench and the drying rack is helpful, if not too expensive.

A logical work sequence must be followed from the dry workbench, to the developer, to the intermediate rinse, to the fixing tank, to the wash, and finally to the drying rack.

The safelights in the darkroom will be situated so that one is over the dry workbench and the other is centrally located. They should be controlled by switches with pull strings because the darkroom technician or operator may have wet hands. All the switches for this room must be inside the room and not outside. If used, the film marker should be on the dry bench.

## **TRAINING AND MAINTENANCE**

### *Is a qualified medical radiation technologist required?*

A well qualified medical radiological technician is desirable in any X-ray department, when available. The standard and scope of work which can be performed with the equipment described will depend entirely on the skill of the user. However, even qualified medical radiological technicians may need reorientation to obtain the best results from such a system and must be prepared to accept the responsibilities inherent in working in a small department. These will include film processing and all photographic work, the clerical work, cleaning, care, and elementary maintenance of all the equipment.

### *Can anyone else be trained to operate the X-ray unit?*

Provided an advanced yet operationally simple X-ray unit is installed, there are two other categories of employees who can be trained to take X-ray films: those with previous medical, and therefore anatomical knowledge, and those without.

Those who already have some medical training and a knowledge of anatomy (nurses, orderlies, aids), can usually be trained in one to three months to produce good standard X-ray films with almost any simple equipment as described. Those who do not have previous training must be taught some anatomy and this may add an additional six to eight weeks. A basic knowledge of skeletal anatomy and patient care is essential.

### *Where to train*

To provide an adequate flow of work and supervision, training is best carried out at the central, and busy, X-ray department. However, it is

essential that training be with equipment that is identical to that which will be installed in the primary care radiological facility. Various limitations dictate that training be entirely practical, without attempting to convey complete comprehension of the systems involved. Emphasis should be placed on learning each procedure step by step, and on the importance of time-temperature processing and a methodical approach in their work. It is essential that uniform procedures be established and followed to the letter, with pre-ordered positioning and techniques.

After completion of basic training, an experienced teacher-technician must be sent to the specific primary care radiological facility to work with the trainee for two or three weeks, supervising every aspect of day-to-day work. Such a visit serves a double purpose of completing the training of the individual and checking the equipment in the installation for satisfactory operation. It also permits the instructor to become familiar with any local variations, and when subsequent difficulties arise and the inexperienced operator telephones or sends a written report asking for help, someone at the central department will know the problems of that local facility. This may save a lengthy journey for a relatively minor problem.

#### *How to maintain the standard of work*

Once training has been completed and the unit is working satisfactorily, it is still necessary that a specially trained supervisor visit each primary care facility at least every six months. This will encourage and maintain standards, check work and equipment, and continue the education and assessment of each individual. In the majority of such primary care units the person performing the radiography may have other duties which occupy rather more than half their time, e.g., a nurse or orderly. As the radiological workload increases this percentage may vary and a successful primary care technician may wish to progress. Such a career structure with promotion possibilities should be encouraged.

#### *Physician training*

Every physician who is to work in a primary care area should receive training, either when a medical student or after qualification, explaining the operation and the possibilities and limitations of the primary care X-ray equipment. He or she should know how it works, what it can and what it cannot do. Equally important, they should be trained to interpret and should become familiar with, the standard X-ray views that are taught to the technicians. Routine follow-up visits, preferably every six months, to each primary care radiological facility by the area specialist radiologist are most valuable. Ideally these visits should be at the same time as the super-

vising technician makes a visit, so that films can be reviewed for technique and at the same time the diagnosis can be discussed with the local practitioner. Continuing education and encouragement is a valuable investment. Isolation for either technician or physician encourages bad habits, quite involuntarily, and perpetuates errors. Regular contact stimulates interest and renews expertise.

#### *Maintenance requirements*

This depends very much on the equipment chosen, and whether it is battery operated or run from a main power source (page 19). The amount of work undertaken daily will also influence its maintenance problems. Many primary care installations need only a once yearly service visit. Apart from minor mechanical faults the main sources of breakdown are the tube and batteries. Timers, indicator lights, and occasionally meters may need attention or replacement. After some years of operation, contact breakers may become faulty, especially in tropical areas. However, properly made equipment should continue to produce X-ray films without much care or attention for many years. The primary care technician can be taught simple maintenance such as lubrication of pulley wheels and moving parts, tightening screws, etc. This can be checked at each six-monthly routine supervisory visit (see above).

#### *Organization of a maintenance service*

An equipment breakdown should lead to a telephone call to the area supervisor or central engineer. Often the fault can be identified over the phone. Inexperienced operators may make simple mistakes, such as forgetting to turn on the main switch. A central maintenance depot should be considered, and should carry a supply of spare parts including the following: replacement tubes, cables, timers, contactors, bulbs, switches, circuit breakers, batteries, and condensers.

The location of the service engineer and his stock will depend entirely on the local terrain and transport difficulties.

#### *The growth capacity of a primary care unit*

One complete X-ray facility (the X-ray room, darkroom, and office) can be used 12 or more hours daily: its output is limited more by staff than by equipment. Simple equipment can perform at least 80 per cent of all the radiographic procedures ever required in a primary care hospital (page 2). It does not provide fluoroscopy and therefore gastrointestinal and vascular examination are not possible. Utilizing appropriate contrast material, it

can provide adequate examinations of the kidney and the gallbladder. One such unit can therefore satisfy the radiological needs of three or four physicians, but extra technical help will be needed as the work increases. When the workload exceeds 20 patients per day an additional technician in the darkroom, or alternatively two X-ray technicians, will be necessary. The darkroom technician may also help with the clerical work.

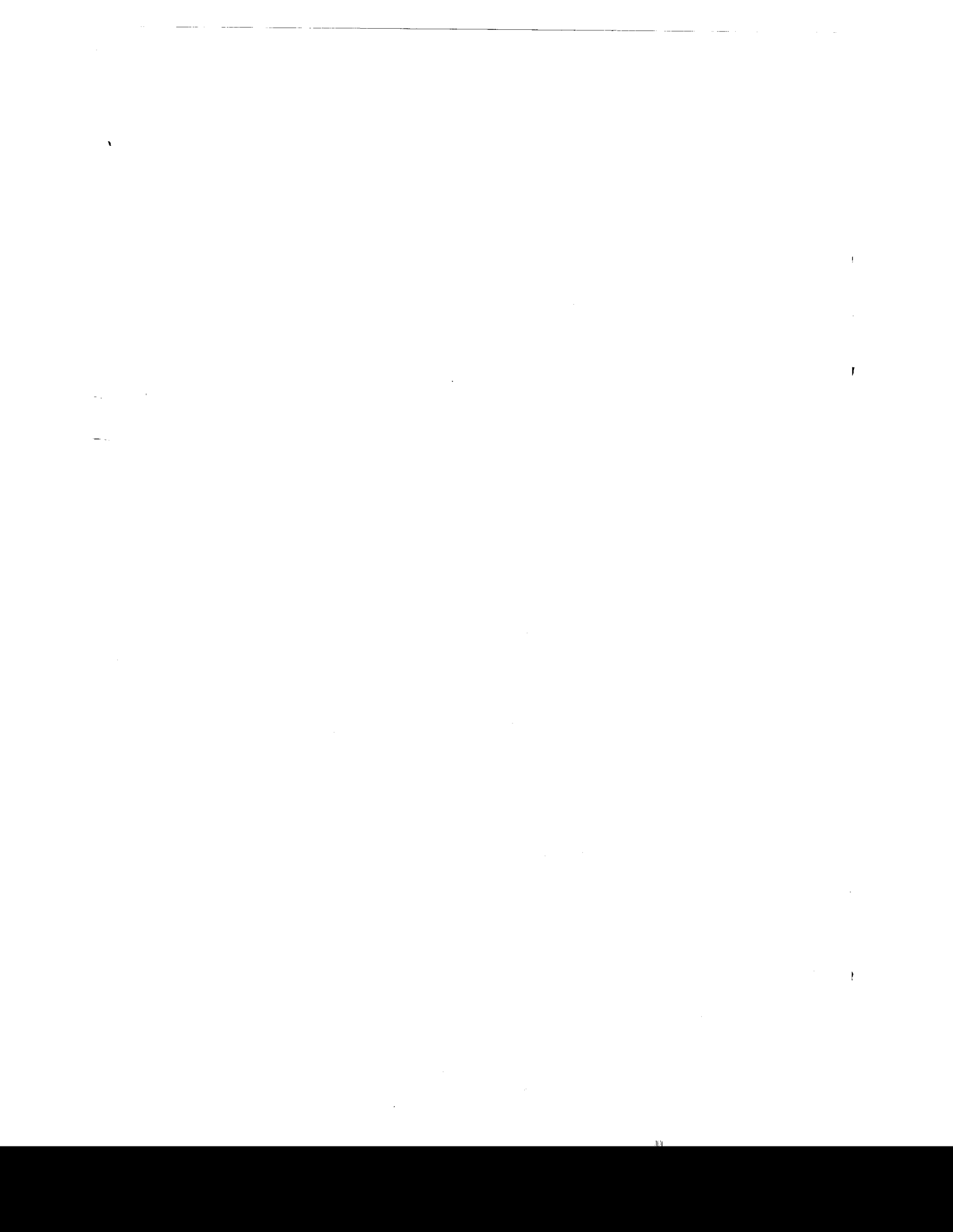
The growth of the hospital or the clinic does not necessarily mean new X-ray equipment but the radiation protection should be checked as work increases. The basic primary care radiological facility will provide a firm foundation on which the whole service of that hospital can expand.











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