

DIAGNOSTIC IMAGING IN THE COMMUNITY

A Manual for Clinics and Small Hospitals

2011

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District 6440



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Table of Contents

Preface	3
Introduction	7
Chapter one: Diagnostic Imaging	9
Chapter two: Radiation Protection	20
Chapter three: Design, Building Materials, Electrical Supply for the X-ray Room, Darkroom, Office / Store	43
Chapter four: Power Supply, Choice of Equipment, Design, Specifications, and Accessories	59
Chapter five: Digital Imaging	109
Chapter six: Layout of Equipment and Accessories: Inside the X-ray Room	118
Chapter seven: The Darkroom: Cassettes, Screens, Film, Processing Equipment	125
Chapter eight: Training and Maintenance	171
Chapter nine: Ultrasound	183
About the Authors: Background and Credentials	192

PREFACE

Diagnostic Imaging (X-rays and ultrasound) is an essential part of medical care everywhere. Unfortunately, many people across the globe are unable to benefit from these basic diagnostic imaging services. The World Health Organization (WHO) estimates that more than half of the world's population does not have access to diagnostic imaging.

The choice, installation, and use of imaging equipment are complicated. Expert guidance is often needed; it helps to ensure the choice of the most suitable equipment for each hospital and that it will work successfully for a long time. For this reason, in 1978, the manual, *Radiology in Primary Care*, was written by Professor Philip Palmer, for the Pan American Health Organization (PAHO), Washington, D.C. It was published in Spanish (*La Radiología y la Atención Médica Primaria*) and English. In 1993, it was revised by Dr. Palmer, with Dr. Gerald Hanson and (the late) Dr. Thure Holm. By that time, all three had been very much involved for many years with the WHO and PAHO efforts to design equipment for small hospitals and make it widely available. With their presentation of this edition, Drs. Palmer and Hanson wish to acknowledge the many contributions of Thure Holm, MD; who was involved with this programme since the earliest days and who was Director of the WHO Collaborating Centre for General and Continuing Education at the Lund University Hospital, from 1980 until his death.

Since 1978, there has been much progress. WHO and the authors have gained a great deal of practical experience with imaging equipment in many small hospitals in different parts of the world. These efforts eventually lead to the specifications for the World Health Imaging System for Radiography (WHIS-RAD) which were published by WHO in 1995. The needs, buildings, and other requirements are very similar worldwide.

Currently, in 2011, the manual has been fully revised and updated by Dr. Palmer, and Dr. Hanson, who has confirmed all the information on radiation safety. A section on digital

imaging has been added, with the help of Michael Hoaglin and there is a new section on Ultrasound written by Dr. Palmer. The manual was edited by Dr. Janice Honeyman-Buck.

A vast amount of technical information is available on the Internet and in many excellent publications, but it is not always easy for the non-expert to find all the essential needs or even to understand the details. This revised and illustrated manual should provide straightforward answers to the many of the questions which will face anyone, physician or administrator, who is considering the imaging needs of one or more small hospitals or clinics. It has been written in sections which answer specific questions, such as room size, building materials, costs, and choice of equipment. There is sometimes duplication in the answers to prevent unnecessary cross references.

X-ray Equipment Options

There are many options for X-ray equipment. This manual emphasizes the WHIS-RAD; the World Health Organization System for Radiography. **What makes the WHIS-RAD different and better?**

The **WHIS-RAD** was developed specifically for underserved areas of the world because of the inadequacy of equipment not designed for these environments. The equipment must be reliable and safe to use, even where there is no fully trained radiographer/technician. It must be simple to operate and maintain and provide very high-quality images. Additionally, it has to operate where power is unreliable and unavailable for periods of time. The WHIS-RAD meets those requirements and has been successfully tested, installed and clinically proven in a wide variety of situations.

The alternatives to a **WHIS-RAD** are:

Used Equipment- Used equipment is frequently available from wealthier countries and is given to underserved areas. Such equipment has usually been heavily used, is often out-of-date and is sent to countries where service and spare parts are hard to find and expensive. This equipment usually is complex since it was designed to meet different clinical needs. Training and expertise to operate such X-ray systems are not available locally. In addition, power requirements are often heavy and there is no way to compensate for unreliable power supplies.

Inexpensive Equipment: Medical X-ray equipment can be purchased for as low as \$5,000. This equipment, however, usually is based on decades-old technology, has very limited application or versatility, is built cheaply and is unreliable. The company providing it has limited or no service or support capability. In addition, because of the compromises made in the design and application, the equipment can be dangerous for both patients and the operator. Training support is virtually non-existent.

New and/or advanced X-ray equipment: In most cases, newer, more advanced X-ray equipment is designed for the large markets of the industrialized countries. This equipment usually is more complex with features covering many applications. As a result, it requires special training, excellent service support, and experienced technologists and radiologists who understand where and how to use the technology most effectively. These X-ray units are expensive to acquire and are not designed to anticipate power failures.

While contributions based on these alternatives are well meaning, the gift can be of little or no value to the recipient.

The WHIS-RAD is the best way to supply X-ray services for up to 50,000 people where no such service now exists.

The authors are cognizant that a number of authoritative and unequivocal statements have been made in their effort to assist those responsible for providing diagnostic imaging in clinics and small hospitals make decisions. Consequently, information concerning the author's background and credentials has been provided at the end of the manual. See "About the authors" on page 192.

ACKNOWLEDGMENT

While fully responsible for the contents of this manual, the authors wish to acknowledge the continuous help and advice of John Vanden Brink and his colleagues in Rotary. Vanden Brink has long personal experience concerning many aspects of Digital Imaging but when, some years ago, he visited the Mater Dei Hospital in Bulawayo, Zimbabwe, he became convinced that it was essential to have an authoritative text with all the information needed when setting up a small diagnostic imaging department. With the Rotary Club of Park Ridge, Illinois, Vanden Brink has continuously supported us during the preparation of this manual. He has tirelessly coordinated the efforts of the authors, the editor, the Pan American Health Organization and Rotary, a role which has been vital to its completion.

The authors, 14 June 2011

INTRODUCTION

There are two parts to this manual:

The INTRODUCTION and CHAPTER 1 are written to help those who are trying to decide if their hospital or clinic should have diagnostic imaging. These sections describe the types of diagnostic imaging and the benefits that each provides. They tell administrators where equipment should be installed geographically, as well as what population size each unit can serve.

If you have already decided to install diagnostic imaging equipment and have the necessary funds, you may not need to read the Introduction and Chapter 1, but can start at Chapter 2.

CHAPTER 2 “RADIATION PROTECTION” should be read by all concerned with X-ray equipment. This subject affects every aspect of any imaging department.

CHAPTER 2 and the following chapters explain where the equipment should be installed in a hospital or clinic; radiation safety; what buildings, rooms, and staff are needed, and how to choose the most suitable equipment. All the essential information needed to set up an Imaging Department in a small, community hospital or clinic is given in a practical way in a series of questions and answers.

Imaging equipment can be simple to install, and easy to use. It can be cost effective, and the X-ray room need not be expensive. The initial outlay will yield dividends because of the speed and efficiency with which patients are treated and can return home or to work. Fewer patients will need transport to other hospitals so that the correct diagnosis can be made, which may prevent the further spread of infectious diseases. Doctors will be more

satisfied with their work and patients and their relatives will be happier to have X-rays and ultrasound available locally so that they can be treated by doctors and nurses they know.

There are many items involved when starting an imaging department, but the essentials are similar in a wide variety of clinics and hospitals: This manual lays down principles for the choice and installation of X-ray equipment for routine radiography as well as the choice and installation of equipment for general-purpose ultrasound

In most countries there are regulations and guidelines for all aspects of Diagnostic Imaging departments. There are also International guidelines which must be followed whenever possible. For example, the International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources have been approved or endorsed by all the member states of the co-sponsoring international organizations (the FAO, IAEA, ILO, OECD/NEA, PAHO and WHO)

CHAPTER 1 DIAGNOSTIC IMAGING

What is diagnostic imaging?

In small hospitals or clinics, diagnostic imaging means examining patients with X-rays (radiography) or with ultrasound (ultrasonography) to help doctors and other health-care professionals make the correct clinical diagnosis and use this critical information to decide on the appropriate treatment.

X-ray or ultrasound? Which should be chosen first?

X-ray equipment must be purchased first, even though ultrasound equipment costs less and is easier to install. This is because studies in many countries have shown that the majority of patients need medical care after injury or because they have a cough or other chest complaints. They then need an X-ray examination because ultrasound *cannot* image the lungs or diagnose fractures or any other bone disease (except early osteomyelitis in children and congenital hip disease in newborn babies, neither of which is very common).

Ultrasound cannot image the lungs or bones.
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An X-ray unit is the first and most essential imaging equipment. The only exception to the priority purchase of X-ray equipment will be in a dedicated maternity hospital, where ultrasound will be used very frequently and X-rays very seldom.

Excluding pregnancy, less than 20% of patients come to doctors because of abdominal complaints and many of these will benefit from routine radiography (plain X-ray imaging) or from X-ray examinations which include intravenous or oral contrast to show details of the urinary tract or the gall-bladder. Ultrasonography is a vital complement to radiography, but where financial priorities are important, it must come second to X-ray equipment.

Ultrasound examinations require a lot of the physician's time. Doctors must, in the majority

of cases, do ultrasound examinations themselves because it is not always easy to interpret ultrasound images (scans) which others have produced, even when taken by a highly trained ultrasonographer (ultrasound technician). Months of training are needed to become a competent ultrasonographer, so they are not usually available in small hospitals.

X-RAY equipment should be purchased first. ULTRASOUND should be the second imaging purchase. Ideally, have both.

Why is X-ray equipment needed at a small hospital or clinic?

Physicians learn during their training that "X-rays" are often an essential part of the clinical assessment of the patient and are frequently necessary to make the correct diagnosis before treatment can be started, and then to assess the patient's progress. Normal results are often as important as finding an abnormality. Doctors will not be satisfied to practice medicine without proper facilities, nor will their patients receive a good standard of care. If radiography is not available there can be many mistakes in diagnosis, leading to incorrect—and sometimes expensive and risky treatment.

Why install X-ray equipment in a small hospital if there is a larger hospital to which patients can be sent?

It may seem easy for patients in a suburb of a big city to go to a large central hospital. However, there is often difficulty in transport and ambulances are needed, both to take the patient for the examination and to bring them back to their own doctor and home. Equally important, if all patients from surrounding areas are referred to the main hospital, the imaging department will be busy making many simple, "routine" examinations. This often causes delays for the patients in the main hospital, and may prevent the highly skilled staff and the complex equipment at the major centre from performing the special and difficult examinations and patient care for which they are trained. This adds to the cost of health

care and wastes the time of doctors and staff, both in the community hospital and in the big central hospital. One of the advantages of a local X-ray department is that all the most common examinations can be done there. The patients and their relatives do not suffer unnecessary travel and waiting, and their doctors appreciate having the images quickly: apart from preventing possible pain; time and money are saved.

Why do patients in rural communities need an X-ray department locally?

Most patients, whether from town or country, come to their doctor as a result of an accident or complaining of a cough. The majority will sooner or later need to be radiographed so that the correct diagnosis can be made: treatment, and follow up is then usually possible locally.

Is it economically sensible to provide several small X-ray departments?

As work increases in an X-ray department, it may seem a good principle to add more rooms in an existing hospital so as to group imaging facilities together. Although the equipment and trained staff are expensive, expansion is not always the best solution. From populations of the same size, there will be about the same number of patients needing to be X-rayed every year. The larger the population, the more patients there will be who need imaging. It is then usually cheaper to add a small X-ray room to a small hospital rather than trying to expand a major X-ray department: the building costs are usually less, and the equipment will be less expensive. Patient transport will be much less. Highly trained staff using complex equipment at the large medical centre will not then have to perform many simple examinations.

It is always cheaper to treat a patient close to home for a relatively common condition than to refer them to a major hospital a long distance from the patient's community. For example, many fractures can be immediately confirmed by radiography, realigned, and treated without the need for a specialist's care. Progress can be checked, and the patient

can get back to work more quickly. Only the minority of fractures have complications or are so difficult to treat that they need to be sent to an orthopaedic centre. Similarly, chest infections, such as pneumonia and tuberculosis, are common and clinically can be very similar. The sputum smear may not always give positive information. A chest radiograph often allows the distinction between pneumonia and tuberculosis (TB), especially in children, so that accurate treatment of either condition can follow. Prompt care reduces the spread of disease and improves the general health of the population.

Money invested in imaging installations will be returned over the years by rapid diagnosis, efficient treatment, less transport and improved community health. The care of common diseases in community centres near the patient's home will relieve the congestion and delays which are so frequent when major hospitals have to provide primary care. It also makes the community doctor's work much more interesting and rewarding when he or she can treat the majority of patients; most patients and doctors will prefer this.

What are the most common diseases that can be diagnosed with the help of a small X-ray department?

The majority of patients who consult their primary care physician or come to a hospital are suffering from trauma, chest disease or acute abdominal conditions. Worldwide, limb trauma and chest diseases are the most common. Almost all will be better treated with the help of radiography to confirm, provide or exclude the clinical diagnosis.

How big a population can be served by one imaging department?

Experience shows that there should be at least one imaging department (X-rays and ultrasound) for approximately every 50,000 people. The departments should be evenly distributed, not clustered in big cities. All patients from any group of about 50,000 people should have easy (local) access to imaging, whether they live in a town, city suburb or rural area. Geographical factors, such as long distances to other hospitals, seasonally impassable

roads due to floods or, in some countries, snow, etc, will often dictate that smaller, more isolated populations (perhaps 30,000-20,000 or less) will need an imaging department locally.

What will influence where the imaging department should be located?

The important factors include;

- The total population to be served.
- The pattern of illness in the local populations, such as the average age, health, willingness to use the health facilities.
- The prevalence of infections such as respiratory illness, TB (with or without HIV-AIDS), local industrial work-related risks (for example, mining, logging), heavy road traffic.
- Geography, such as rivers, mountains, forests, impassable roads.

A basic imaging department has one-X-ray machine, one operator, one darkroom or digital processor and one ultrasound unit. This equipment can serve a population of 10,000-50,000 people. It becomes a practical investment if it provides four or more examinations per day, although such a department with one operator can make up to 15-20 examinations per day. With additional staff, the same equipment can make at least 40 examinations per day.

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. The best images are of no help unless there is a competent clinician to interpret them and then provide or refer the patient for treatment. A good radiograph of a fracture or a chest radiograph showing active tuberculosis of the lung is not much help to the patient if there is no one to make the correct diagnosis or, if the diagnosis is made by tele-consultation, when there is no one there able to treat the disease.

Unnecessary imaging is of no help to any patient. The incorrect choice of the examination or incorrect interpretation is also of no help and is often dangerous.

How do geographical factors affect the location of an imaging department?

When deciding where to put an imaging department, it is important to consider travel time, distances, ease of access and communications:

- Maximum patient travel time should not exceed 3-4 hours, and preferably should be much less.
- No one should travel more than 50 km (30 miles) to reach the department. If distances are longer, patients will not, or may not be able to come to the doctor, and if they do come, their illness may be worsened by travel.
- Access for sick people should be possible and reasonably easy throughout the whole year.
- Communication with the regional centre, by telephone, radio or e-mail, should be satisfactory and reliable even where tele-consultation is not available.

How can you find the best site for an imaging department?

- Look at the map of the country and region.
- Identify population densities and groups.
- Circle populations of 10,000-50,000 within a 50 km (30 miles) radius.
(Remember: one X-ray machine can serve 10,000-50,000 people).
- Relate the population density to existing health care facilities.
- Relate the population to roads, transportation (buses, trains, boats, etc.)
- Identify any major geographical obstruction, such as rivers without safe bridges, areas which flood, roads which may become impassable because of mud or, in the winter, by glaciers or snow.

- Determine the ease of communication and travel (for both people and supplies) from the proposed clinics or small hospitals to the main regional hospitals and supply depots.
- Identify the rural population which does NOT have easy access to alternative centres, regardless of population density. How many will get poor care if there is no local imaging department?
- Locate the population densities greater than 100,000 people. If the population is this large, then two X-ray units may be needed in one imaging department. Alternatively, two separate imaging departments may be better. Make this decision (one or two departments?) based on distances which must be traveled, not only on the number of people.

Are there any typical population groups in under-resourced areas?

There are many variations, but typical groups in currently under-resourced areas will be:

- **Several small towns and villages, not widely separated, with a total population of 50,000-100,000.** Locate the X-ray department in the largest town or market centre with the best road or bus service. For this size population, the maximum distance traveled by patients should not exceed 30 km (20 miles). Whether the imaging department should have one or more X-ray rooms will depend on the number of patients who visit the hospital each day and the number of doctors available. Install one department and design any new building to allow for expansion.
- **A smaller group of villages and small towns with a combined population of 20,000-50,000.** The imaging department should be located in the densest population area with good road and transport. Maximum distance traveled by patients may have to be up to 40 km (25 miles).

- **A rural population of farms, hamlets, and small scattered villages with a total population of 50,000, but may be less.** The imaging department should be located where it can be most easily reached by patients, not necessarily in the central village geographically. This may be in the largest village or between two large villages, depending on the current location of any hospital or clinic. Maximum distance traveled by patients may be 50 km (30 miles).
- **Scattered rural populations, with a total population of 10,000-20,000, without access to imaging facilities because of mountains, rivers, glaciers or bad roads.** The imaging department should be located at the best all-weather centre. Maximum distance traveled by patients may be 50 km (30 miles). This small centre can solve many problems by treating most patients locally who might otherwise need special transport to get imaging, even though they have a relatively straightforward illness, such as a fracture or pneumonia. The cost of such a small centre is often less than the cost of two-way transport by air or difficult roads for the first and follow-up visits.

When locating an imaging equipment, consider both the number of patients AND the number of doctors and how they can get together. Both are needed if it is to be worthwhile.

Having chosen the location, where is the X-ray department actually installed?

Existing (or proposed) health centres, clinics or hospitals are usually the best place to add a small imaging department, but do not install it in an existing hospital without reviewing the alternatives, such as a planned additional hospital. Sometimes, recent changes in population or communications may make it necessary to reassess the location of the hospital or clinic. An imaging department will probably increase the number of patients who come to the doctor.

Will specially trained doctors and technical staff be needed?

Ideally, all radiographs should be interpreted by specialist radiologists. However, in many countries this is not possible. Eventually, digital imaging and tele-consultation may help to solve this. However, general physicians should be able to interpret most of the standard images produced by general radiographic equipment. There are WHO diagnostic interpretation manuals specially written to help these doctors. Any images which are difficult to interpret can be sent for a specialist's opinion more easily than patients can be transported.

Ideally, all diagnostic radiography should be done by fully trained radiographers: it requires two or three years to become fully trained, and such trained staff are not always available in small hospitals or clinics. To work with standard X-ray equipment, assistant radiographers need several months of full-time, concentrated training before they can work alone.

Operators who work with WHO-designed radiographic equipment (the WHIS-RAD) will need less training. The WHIS-RAD training is not difficult and does not take a long time, particularly for those who already have some medical knowledge such as nurses, nursing assistants or nursing orderlies. Their training and routine work is made easier by the step-by-step radiographic technique manuals and darkroom manuals where films are used. These manuals have been published by WHO and are available through any United Nations office, any regional or country office of WHO or from the bookshop at WHO Headquarters: 1211 Geneva 27, Switzerland. The Manual of Radiographic Technique is available on line or through booksellers such as Amazon.com.

What is the initial cost of a small imaging department?

The exact cost of creating a small imaging department will depend on local conditions and what type of equipment is purchased. But it need not be as expensive as might be expected.

- **The buildings and plumbing** required are simple and can be built by a local builder.
- **The electrical supply** depends on the chosen equipment, but it can be that of the existing hospital or clinic, and additional wiring should be minimal.
- One standard 110/220V -15 Amp, outlet for the WHIS-RAD,
- About 50 Amps for standard (not-WHIS-RAD) equipment.
- **If the correct equipment and layout** are chosen, additional radiation shielding may not be needed. If it is required, it is usually minimal in a new building. Adapting an existing room does not necessarily require lead on the walls.

The cost of **NOT** having an X-ray unit in any particular locality will include the cost of providing two-way transport and the costs to the relatives staying with or visiting the patient. Also included must be the risk of making the wrong diagnosis without imaging, and then providing the incorrect treatment, the wrong drugs, longer hospital stays and the chance of infectious diseases spreading.

How long will X-ray equipment last?

With an average of about 10-15 examinations per day or 2,500-5,000 per year, the equipment is likely to last at least 10 to 15 years or more. The cost of maintenance and replacement parts should not be excessive during that time. If a battery-powered X-ray unit, such as the WHIS-RAD, is chosen, the battery life should exceed five years. The life of the X-ray tube is unpredictable, but one replacement is likely to be needed in 5-10 years or after 20,000-30,000 exposures. X-ray tubes are usually under warranty.

CHAPTER 2: RADIATION PROTECTION

Please read this chapter carefully (even if you are a radiologist or fully trained radiographer/ radiological-technologist)

There are three basic principles of Radiation Protection

- Justification: The examination must benefit the patient.
- Optimization: The best technique must be used.
- The exposure must use the lowest amount of radiation to obtain the best result.

In addition:

- Patients, staff, relatives and friends must not be exposed to unnecessary radiation.
- Dose Limits for individuals set by the competent authority must not be exceeded.
- Staff and members of the public must not be exposed to radiation in excess of those established limits.

PROPER RADIATION PROTECTION IS AS IMPORTANT AS IS CAREFUL STERILE TECHNIQUE FOR ALL SURGICAL PROCEDURES.

LIKE A SCALPEL, X-RAY EQUIPMENT IS SAFE IF USED PROPERLY.

IF THE RISKS ARE NOT UNDERSTOOD AND CORRECT PROCEDURES ARE NOT FOLLOWED, HOSPITAL STAFF AND PATIENTS MAY BE HARMED.

X-RADIATION CANNOT BE SEEN OR RECOGNISED WITHOUT SPECIAL MONITORING EQUIPMENT UNTIL IT IS TOO LATE.

All who use X-ray equipment must be taught how to prevent unnecessary exposure to X-radiation. Only those who have been properly instructed should EVER be allowed to use X-

ray equipment, even occasionally. While proper design of the X-ray department can reduce hazards, instruction about radiation risks will always be required, and working techniques must be rechecked regularly.

What are the radiation risks in a small imaging department?

If the imaging department has been properly designed, and proper working methods are used, then there should be **NO** significant radiation hazard for patients or staff.

If the X-ray department has NOT been properly designed, then radiation during an exposure can be dangerous for anyone in the X-ray room, as well as for those who are sitting outside or in a room that is next to the X-ray room, especially if working there for several hours. **All sources of hazardous radiation can be controlled so that the X-ray department will be safe.** High single doses in any diagnostic X-ray department are unlikely to occur; much more important, especially for staff, is the health risk of repeated small exposures over several years.

For patients, the possible harm from radiation following repeated X-ray examinations must be considered against the risk of not correctly treating their illness. Repeat examinations need consideration and should never be 'routine', especially for children with long illnesses. Although a patient would have to have many diagnostic examinations before there is any significant risk from the radiation, there must be always be a good clinical reason for every X-ray taken.

Every X-ray examination will give a patient a dose of radiation.

There should be a very good clinical reason for ALL X-ray examinations, especially for follow-up examinations and for children of any age.

Radiation exposure for examination of the abdomen or pelvis of any woman who is or might be pregnant should be avoided unless there are strong clinical reasons.

Only the patient and operator should be in the X-ray room when the exposure is made.

Anyone else, staff or relative or friend who is in the X-ray room during any exposure MUST be wearing lead protective clothing or be completely behind the safety screen which protects the operator at the control panel.

How does the danger of radiation occur in an X-ray department?

When an X-ray exposure is made to examine any part of a patient, there are two important but different sources of X-radiation which may reach anyone in the room: the direct (**primary**) beam and stray (**scattered**) radiation. A third type, **leakage** radiation, is very rare and seldom significant. All types of radiation can be hazardous, but all can be controlled so that X-ray departments are without any significant risk.

What is the primary beam? When is it dangerous?

The **primary (direct) beam** is the X-ray beam which comes straight from the X-ray tube. It goes directly towards the part of the patient which is being examined. This beam of X-rays travels through the patient and then goes through the cassette to the radiographic film or digital receptor. It is a cone-or-pyramid shaped beam. With the narrow apex at the X-ray tube, it continues onwards, getting wider and weaker until it is absorbed completely by some object. The primary beam of a WHIS-RAD never causes a radiation hazard.

Most X-ray examinations are made with the patient either lying down (Vertical beam) or standing/sitting erect (Horizontal beam).

Vertical beam:

When the patient is lying down, the X-ray tube is usually above the patient, and the primary beam goes downwards towards the floor. This is a **vertical primary beam**.

NOTE: There is no radiation risk from the primary beam in the vertical position, *unless* there is an occupied room under the X-ray room. There might then be some radiation hazard if there were people working all day in this room directly under the X-ray table. Even then, they will be quite safe if the floor is made of concrete (of the required thickness) or if a lead or steel plate is added under the X-ray table. This radiation risk will not be common in small hospitals because the X-ray room should be on the ground floor.

In large departments, the X-ray-tube may occasionally be under the patient, with the primary beam pointing upwards. The radiation risk may then be to anyone above the equipment if they are in the room all day. This type of equipment is practically never found in small hospitals, and the radiation will be reduced by the distance to the ceiling and the floor above it. It is not a major hazard.

For some examinations, the X-ray tube may be angled upwards or downwards 5° - 30° so that the primary beam is pointed at the top of the wall or corner of the ceiling or floor. This will not cause any hazard.

Horizontal beam:

The other common position for imaging is with the patient standing or sitting erect during an X-ray examination or lying down for the less frequent cross-table view. **This is a horizontal primary beam**, parallel to the floor. After going through the patient and the film cassette or receptor, it might continue on through the wall behind the patient being examined. If there is a room on the other side of the wall in which people work all day, or sit and wait close to the intervening wall for any length of time, it may be necessary to thicken or "protect" either the back of the cassette holder or the wall behind it.

Is there the same radiation risk from the primary beam with all types of equipment?

As a source of radiation hazard, all primary X-ray beams are essentially the same. However, the penetration and the quality of the beam itself varies with the exposure used and the wave-form. The extent of the radiation hazard depends very much on the type of equipment chosen. There are three different designs of X-ray equipment which are used in small hospitals (all can be used with films or digital imaging) which affect the risks from the primary beam.

- **Exceedingly low or insignificant:** The WHIS-RAD has a fixed tube column, a mobile patient table, and no separate chest stand.
- **Moderate risk:** The standard unit has an examination table on a fixed base, a moveable tube column and a separate stand for chest X-rays.
- **High risk:** The mobile unit designed for use in hospital wards; this has no patient table, an infinitely mobile tube column and a separate chest-stand.

What are the risks of the primary beam from the different designs?

The WHIS-RAD is the safest design. Its primary beam is never any hazard because in this WHO design, the primary beam is always centered on the patient and confined to a field size of no greater than 43 x 43 cm at a distance of 140 cm from the focal spot. The back of the cassette holder / receptor absorbs the X-rays which remain after going through the patient, the cassette, and the film or receptor. Whatever the position of the patient and the X-ray tube, the primary beam of the WHIS-RAD unit is, for all practical purposes, blocked by the radiation-proof shielding in the back of the cassette holder. No significant part of the direct beam will ever continue beyond it or escape alongside it, even if the operator's technique is not correct.

Standard X-ray equipment is less safe. The designs of standard X-ray equipment allow for safety hazards, especially when the equipment is used by someone who is not a fully

qualified radiographer. Even if the tube is centered on to the patient and cassette, the X-ray beam collimator can allow a beam wider than the cassette holder and the tube can be angled freely. Some of the primary beam may then pass around the patient and continue on beyond the X-ray cassette. This is particularly common when using the horizontal beam for chest examinations. Equally important, even when the beam edges are correctly restricted by the collimator, not all cassettes / receptors and their holders are designed to absorb all the significant radiation which goes through the patient.

Mobile X-ray units are the least safe. This is because mobile X-rays are on wheels, allowing the tube direction and the distance between the tube and patient to be freely varied. The beam can be pointed anywhere. The primary beam then becomes a significant radiation hazard, unless used by a very experienced and well trained and careful radiographer.

What is the risk from the primary beam for those outside the department?

This depends on the type of equipment and the wall thickness. If the X-ray unit is properly located in the X-ray room, or is the WHIS-RAD design, no significant radiation will reach the intervening wall.

Correctly locating the non-WHIS-RAD equipment means that the X-ray tube and cassette holder must be aligned so that, when chest radiographs are taken, the primary beam (after it has passed through the patient and the cassette or receptor) will not go on through a wall behind which there are people. With the correct X-ray room layout, there will be no significant radiation risk from the primary beam, no matter what material is used to build the walls.

However, if the primary beam can sometimes point at a wall with people behind it, any significant radiation risk outside the X-ray room must be reduced by increasing the thickness of the walls.

To ensure safety, the layout of the equipment in the X-ray room is very important. Apart from radiation risks, the correct choice and positioning of the equipment may save considerable expense and improves working efficiency.

What is scattered radiation? Why is it dangerous?

Scattered radiation is generated during every X-ray examination. When the primary X-ray beam passes through the patient, some of the radiation is scattered, like light in a fog. It can spread outward in every direction. This radiation is of a different wavelength, is weaker, and does not travel as far as the primary beam.

All X-rays, of any wavelength, decrease in intensity inversely as the square of the distance from the source. For example, if anyone who is standing close to the patient moves 3.05 m (10 ft) away, the intensity of the scattered radiation will be reduced by more than 97% percent. Practically no radiation will reach them and it will always be a very small risk at that distance in a diagnostic X-ray room.

Does scattered radiation affect people outside an X-ray room?

This depends on the position of the X-ray equipment and the type of intervening wall. Scattered radiation is not a significant problem outside any X-ray room, provided there is a normal brick, concrete or thick adobe wall. A thin plaster or wood-board wall may not offer enough protection. Then the risk of scattered radiation will depend on the distance of the scattering source, (normally the patient) from that wall. If this distance is 3½m (10ft) and for the workloads expected in a small hospital or clinic (3,000 to 6,000 examinations per year) there is no significant hazard from scattered radiation for anyone outside of any wall. [Note: Primary beam distances need to be longer, unless the WHIS-RAD is used.]

What is leakage radiation?

When we look at an X-ray tube, we are looking at the thick metal outer casing. This is the “tube housing” which will reduce the leakage radiation to internationally accepted limits at any kV used. Inside the tube housing there is the actual glass X-ray tube, usually called an “Insert.” **Leakage radiation** is radiation which in very small amounts may, penetrate the tube housing. It can escape in all directions outside of the primary beam. This radiation matches the quality (intensity) of the primary beam. This is not clinically important because independent tests have shown that new, complete X-ray tubes from the major manufacturers invariably meet the international safety requirements for protection against leakage radiation.

Significant leakage radiation levels have, in a few rare instances, occurred when a "burned out" tube has not been replaced correctly. This is why checking for leakage should be done by the supplier when an X-ray tube housing is opened and the insert has been replaced.

There is no need to be concerned about new, complete X-ray tubes (the housing and the insert) when pre-assembled and supplied together by a reputable manufacturer. They will be both radiation and electrically safe. Tube inserts should ONLY be replaced by the manufacturer. After replacement of a tube insert or when a new tube has been fitted, the alignment of the collimator and the beam limits must be checked.

What are the risks of radiation during fluoroscopy?

Fluoroscopy equipment is not included in the specifications for X-ray facilities for small hospitals and clinics because it is of very limited clinical usefulness. There are very few clinical indications for fluoroscopy. WHO does not recommend fluoroscopy unless there is a trained radiologist available, because of the considerably increased radiation hazard to all personnel (and to patients) and because it is not very helpful.

Why have a large X-ray room?

A large X-ray room is always safer than a small one. Even a 1m (3 ft) increase in overall room length makes a significant difference: scattered radiation striking a wall which is 1 m (3 ft) away from the patient is usually absorbed almost completely, except by thin wood or fibre board. When construction with local materials is cheap, it may be less expensive to build a larger room than to add extra wall thickness.

The room sizes recommended (the minimum is at least 16sq.m, 172sq ft) will usually not need any additional wall thickness, unless there are more than 50 examinations every day (about 250 examinations every week). Then additional protection may be needed, depending on

1. The pattern of the examinations, (the average daily number of exposures for chest, limbs or other examinations).
2. Whether an adjoining area is occupied during the working hours of the X-ray department.
3. If the X-ray equipment is incorrectly installed.

What is the required wall thickness?

This depends on the relationship of the X-ray room to other rooms and buildings. If an X-ray room is isolated and built so that no one can come within 2m (6ft) of its outside walls, no additional protection is needed. If the building has to be made from wood, it may be cheaper to fence off an area around it to stop people from being within 2m (6ft) of the outside wall rather than use heavier wall construction materials. If the X-ray room is part of another building, there are specific rules which must be followed. Much will depend on the X-ray equipment which is chosen.

How expensive is the required radiation protection?

The amount of radiation in a small radiology department is so little that radiation protection is usually a minor problem, particularly if the X-ray equipment complies with the WHIS-RAD specifications. If the room is of sufficient size (16sq.m-172sq.ft or larger) and the WHIS-RAD is in the correct position, almost any construction material will provide sufficient protection because the primary beam is never a problem.

With non-WHIS-RAD X-ray equipment, the correct thickness of construction material must be used, but even then major additional costs are unlikely unless:

- The X-ray room is very busy.
- The equipment has not been correctly aligned when installed.
- The room has thin wooden / plaster walls or is less than 16sq.m (172sq.ft) and all of the surrounding rooms are occupied most of the day.

What does "lead-equivalent" mean?

Simply, it means the thickness of any material which will absorb the same amount of radiation as a specific thickness of lead. For example, "1 mm lead equivalent" could mean a standard poured concrete wall of about 8cm (3in) thickness. If cinder block or clay brick is used, a thickness of about 12cm (5in) would be required to equal 1 mm of lead, depending on the density of the material. Many concrete blocks have central air spaces, and many bricks are quite cellular: the recommended thickness refers to the amount of actual concrete or brick and not the overall dimensions of the blocks. Specific recommendations follow on the next page.

The following advice applies only to X-ray equipment which does NOT meet WHIS-RAD design specifications. This will include all mobile X-ray units and most other X-ray units.

What about windows in the X-ray room?

Windows are not usually a radiation problem, unless there is a commonly used waiting area immediately outside. If so, it is better to have the bottom of the windows about 2.1m (7ft) above the floor of the X-ray room. When building a new X-ray room, the windows should always be at this height (2.1m/7ft) unless the building is isolated. If it is necessary to use an existing small room with low windows which is next to a high occupancy area (**and the X-ray unit is not a WHIS-RAD**), then the windows must be covered with high lead-equivalent material, such as bricks or concrete blocks. Wood will not be enough. If it is a WHIS-RAD, windows are not a problem unless the unit is very close to the window and people wait outside it.

What actual wall thickness will be required?

In most X-ray rooms of minimum size, a wall which has a shielding thickness equivalent to 0.5 mm of lead (see table below) is probably sufficient. For example from the table below, it can be seen that 44mm (4.4cm) of concrete, or 70 mm of solid brick (7cm) are equivalent to 0.5 mm of lead for shielding purposes. This thickness provides a large safety factor and will be satisfactory until more than 50 general X-ray examinations per day are made in a room which meets only the minimum dimensions given in chapter 3. Any larger room is certainly safe.

Thicknesses of different wall materials providing the same radiation protection at 100 kV

Thickness of Material (mm)		Material	g/cm ³
0.5	1.0	Lead	11.3
3.2	6.4	Iron	7.9
44	80	Concrete	2.2
70	120	Solid brick	1.8
110	200	Gypsum	0.84
135	270	Porous concrete	0.64

When considering wall thickness, it is the number of examinations per day that ultimately matters, not the number of patients. This is because any patient may have more than one examination.

However, some acceptable methods, such as one of those given in NCRP Report Number 147, use the number of patients and the average workload per patient as determined from nationwide surveys in their shielding calculations.

However, if the number of daily examinations increases above 50 per day in a 16sq.m (172 sq ft) X-ray room, or when the room is smaller than this, it may be necessary to make detailed calculations or actual radiation measurements to decide whether any additional protection is required.

To summarize wall thickness; there will be some variation in the thickness needed, depending on the type of equipment and the workload distribution in the radiographic room. In many departments, 0.5mm of lead equivalent (for example 4.4cm of concrete) will continue to be sufficient even with increased work, or it may only be necessary to add extra thickness to one wall. With most multi-pulse frequency-converter generators such as used in the WHIS-RAD and other modern equipment, about 50 X-ray examinations will have to be made every day before there is likely to be any significant risk.

When using equipment which does NOT meet the WHIS-RAD specifications, does any part of an X-ray room need special radiation protection?

Two specific areas of the X-ray room will need careful assessment to avoid radiation hazards in neighboring rooms or spaces:

- The wall behind a separate chest stand (where patients have their chests radiographed with a horizontal beam).
- The wall between the darkroom and the X-ray room.

If the equipment is NOT a WHIS-RAD design, the direct primary X-ray beam should never be pointed at the unprotected wall of a darkroom or occupied room.

The wall between the X-ray room and the darkroom, or any other room where unexposed film-loaded cassettes, or digital CR-cassettes are stored, must absorb any primary or scattered radiation because radiation penetrating the wall may fog (spoil) unexposed films or digital CR-cassettes.

A wall thickness of 4cm (1.6 in) of concrete or 6cm (3in) of solid brick is usually sufficient for this wall. If **the chest stand is free-standing**, and the primary beam is pointed at it, then the thickness of the **entire wall usually** must be doubled. Similarly, if during some exposures the tube may be pointing towards any wall behind which there may be people sitting, lying or standing, then the thickness of that wall will also have to be doubled. It is not necessary to add lead if the walls are of these thicknesses.

If the chest cassette holder is fastened on to the wall (not free-standing), it may then only be necessary to protect an area 2m high and 2m wide (6ft x 6ft) centered immediately behind the chest stand, using the equivalent of a double thickness of brick or concrete in this area only.

If the X-ray unit is properly positioned, and the primary X-ray beam is pointed away from the darkroom, storage room, or occupied room, then the wall will not need special radiation protection for the human occupants. However, if any radiation (primary or secondary) can strike a wall which does not have additional wall shielding, and behind which there are unused film, film in loaded cassettes, or CR cassettes, then a special storage bin, hopper, or shelf with about 1mm of lead lining will be required. This is because the requirements for protection of these items against fogging are very stringent, even more so than for the protection of humans.

It must be re-emphasized that these calculations provide a far greater margin of safety than is likely to be necessary in a small radiological department (optimization). It is cheap and simple to incorporate the right amount of shielding at the time of construction, because it allows the number of X-ray examinations to increase without further building alterations. Almost any building material, other than thin wood or plaster, will usually be satisfactory,

except perhaps behind the chest stand where additional radiation protection (for example, an extra thickness of bricks or concrete) may be required (see above).

Alternatively, choose the WHIS-RAD design because the primary beam of radiation is never a danger to anyone. If the WHIS-RAD design is chosen, there is no significant radiation hazard from the primary beam behind the cassette holder during chest examinations or anywhere else during any other examination.

How can personnel safety be ensured? What are personnel monitoring badges?

Everyone who works in an X-ray department must understand the hazards of exposure to X-rays and must know the radiation safety rules and requirements.

Personnel monitoring: If there is a country-wide personnel radiation monitoring system, everybody working with X-rays must be given a small personal badge (monitor) to be worn all the time while working. This will record any radiation which reaches it. A central system is necessary, because, although it can be done, it is difficult to provide an accurate service in any individual small hospital. Radiation monitoring badges can be sent by mail, by surface transport or by air. They should be changed regularly (usually once a month or once every three months, depending on the patient load, the local heat, and humidity). These badges must be worn all the time by anyone, usually clipped in front on the shirt/blouse collar while they are working in the X-ray department or with any X-ray equipment anywhere in any hospital or clinic.

Keeping an accurate record of any stray radiation which reaches hospital staff is a very good way to ensure that they are all being careful (for their own good!) and that applicable dose limits are not being exceeded.

What are personnel radiation monitoring badges?

The badges are small plastic holders, like name badges, which can be clipped or pinned onto the clothing of anyone who works in an X-ray department or anywhere near radiation (such as radiologists, radiographers, X-ray operators, darkroom assistants and, in big hospitals, some surgical operating room / theatre staff.) They must be worn in front, near the shirt or coat collar, all of the time while at work **but not under a lead apron**. There are two basic types, both of which will record the radiation dose accurately:

- Film badges.
- Thermoluminescent dosimeters (TLD).

Both must be evaluated at special centres equipped to interpret the results.

Where possible, records of the amount of radiation received by anyone working with radiation should be kept as part of their health records during their lifetime. This is important, to make sure that their total radiation dose is kept below the internationally recommended dose limits. It is not necessary to give all the details, but in general terms, for anyone working in an X-ray department, the radiation dose to the entire body must not exceed an average of 20millisieverts (mSv) per year. This information will be important in case they develop cancer or some blood disease. Apart from the importance for their health, they might then claim that their cancer is due to excess radiation received while working in the hospital or clinic.

What are the reasons for increased radiation exposure?

It is very uncommon for excess exposure to be the result of faulty X-ray equipment. Experience shows that when any personnel monitoring badge records an excessive dose of radiation, it is almost always due to human error / unsafe technique.

Common errors include wearing the badge in the wrong place or incorrect working technique such as holding a patient or not being behind the screen during an exposure. Sometimes, often in the morning when putting on a clean working coat, operators forget to wear their badge and leave it in the X-ray room. When trying to discover the cause of a high radiation exposure on a monitoring badge, it is almost always necessary for the radiation supervisor (radiologist or chief radiographer or physicist) to personally visit the radiology department. Written or telephone inquiries seldom solve the problem, because X-ray operators or even radiographers may perpetuate some error and not be aware of what is happening. They themselves may not know what they are doing wrong or the source of their radiation exposure. **Direct investigation in the department with on site explanation will help to prevent the recurrence of the majority of these problems.**

The amount of radiation in the average small department is minimal, because relatively few patients are examined, and the types of examinations do not produce excessive radiation. Modern X-ray equipment very seldom has significant radiation leakage.

Are there simple rules for staff safety?

The most important rule is that **no X-ray exposure should be made unless the operator and any other person in the X-ray room (other than the patient) are behind the protective shielding around the X-ray control panel.** If it is necessary for the patient to be held (e.g. a child or sick adult), then leaded protective clothing must be worn.

How is the X-ray control panel protected? What is a protective screen?

- **Position-** The control area must be at least 2m (6-7ft) from the patient..
- **Protection** - The area behind the control panel must be protected from radiation by a shield at least 175cm (70in) wide across the front of the control panel. The console or panel of the control unit must be in the centre, at least 0.5m(20 in) from either

end. The shield should be 2.1m (7ft) in height and have a window of lead acrylic, (the most convenient, because it can be ordered in specified lead-equivalent thickness) or thick plate glass (30cm by 30cm, 12in x 12in, or larger) with at least 0.5 mm lead equivalence. This window should be positioned in the central section, just above the control panel, so that tall or short operators can clearly see the patient and the entire X-ray unit. **There must be no need to look around the edges of the screen to watch the patient while making the exposure.**

The whole shield and window must be at least 0.5mm lead equivalence, and can either be supplied as part of the equipment or built locally of bricks or concrete [6cm (2½ in) of brick] or [4 cm (1¼ in) of concrete]. The lead acrylic or plate-glass can be purchased or supplied with the unit (ordered to size and lead-equivalent thickness). When installed, the edges of the window must all overlap the opening in the screen by a margin of at least 1cm (½ in) so that there is no gap or joint through which radiation can pass.

The X-ray equipment must be installed so that the direct beam from the X-ray tube NEVER points at or near the control panel. Additionally, the protective shield and the control console or panel must be secured in place so that they cannot be moved.

WHEN THE EXPOSURE IS MADE, THE OPERATOR MUST BE COMPLETELY BEHIND THE SCREEN.

The X-ray exposure switch must be an integral part of the control unit so that the exposure can only be made from behind the protective screen. The exposure switch must never be a long connecting cord

Mobile units do not always meet this rule. If there is a connecting cord, it must be shortened to 15cm (6in) or, preferably, the switch must be permanently fixed to the top of the control panel. Using a mobile unit, the operator must always wear a lead-apron. (See below)

What happens when a patient must be supported for an X-ray examination?

Every X-ray department should have two double-sided radiation protective aprons and two pairs of gloves made of lead-rubber (lead equivalent 0.25-0.50 mm) These must be worn by everyone who holds a patient during an exposure, even a member of the staff, a relative or friend of the patient. No-one who is, or might be, pregnant should be allowed to do this and the radiographer or operator must always ask about possible pregnancy before allowing anyone to help. This is particularly important when the only person who can hold the patient is a nurse, a nursing aide or any other member of the hospital staff.

Under NO circumstances should any X-ray operator or assistant ever hold a patient during an X-ray examination, NOR should the same nurse or aide hold patients every day, even when wearing a lead protective apron and gloves.

Where are the aprons kept and can they be damaged?

The lead rubber aprons and gloves should be kept in the X-ray room, the aprons hanging over a strong rail and not folded. The gloves should be on strong angle-brackets or Y-supports and not folded. All brackets must have smooth rounded edges. Unless properly

cared for, the leaded material is easy to damage. They can be wiped clean with a damp cloth. Every three months they must all be checked for cracks or other damage. Cracks or other damage to the safety-layer are not always visible on the surface of the aprons or gloves and it is easy to forget regular checks. To ensure safety, a record of the date of every check must be kept on the wall near where they are hung, and initialed after each check. How to make these checks must be included in the instructions for the radiographer or X-ray operator: it is very simple (see below) but very important.

How are lead aprons and gloves checked for damage?

Every three months, the aprons and gloves should be wiped clean with a damp cloth and inspected visually for any cracks or other damage, such as loose stitching. When there is any evidence of damage, or at least once a year (if used heavily, every 6 months) a large X-ray cassette or receptor should be put on the X-ray table and **the lead-apron** put on top of it so that a single layer of the apron is lying flat between the X-ray tube and the cassette or receptor. An exposure should be made, using the same exposure factors as used for examining the adult abdomen. After processing, any crack will show as a dark line on the image. Even the largest cassette / receptor will not be large enough to record the whole apron, so this examination must be repeated until the whole of the front of the apron has been examined. If the apron has separate panels for the front and the back of the wearer, the apron should then be turned around, so that the back section is checked in the same way. There is no need to turn the aprons inside out, only be sure that the complete front and complete back are X-rayed separately, including the shoulders sections. Make sure that only one layer of the apron is tested at each exposure. There should never be a double layer on the cassette/receptor.

The lead gloves must be X-rayed in the same way. They must be spread wide open on the cassette or receptor, and coins or keys should be put inside the glove. If the gloves are intact, the metal objects will not be seen on the processed image. The gloves should be

turned over, and the exposure repeated. These results should then be entered in a record-book. It is a good idea to label and date the images and store them.

TO KEEP EVERYONE SAFE, KEEP THE X-RAY ROOM EMPTY EXCEPT FOR THE OPERATOR, DURING ANY X-RAY EXPOSURE.

EVERYONE IN THE ROOM – STAFF, RELATIVES OR OTHER PATIENTS – MUST BE SHIELDED BY A RADIATION-PROTECTIVE SCREEN OR LEAD-APRON. If they MUST be in the room to watch the patient, THEY MUST STAND MORE THAN 2½ METERS (8ft) AWAY FROM THE X-RAY TUBE DURING THE X-RAY EXPOSURE.

ANYONE HOLDING / SUPPORTING A PATIENT DURING AN EXAMINATION MUST WEAR A LEAD APRON AND LEAD GLOVES.

Are there other ways to reduce the radiation exposures to staff and others?

Time must be spent in planning before the installation of the equipment in the X-ray room.

X-ray engineers who are used to installing equipment in large departments where there are trained staff do not always appreciate the different needs of a small department.

What is the best position in the X-ray room for each item of X-ray equipment?

When installing X-ray equipment, there are two very important details; the direction of the primary X-ray beam and the position of the chest cassette holder. These rules do not apply to the WHIS-RAD.

Which way should the primary beam point when horizontal?

When the patient is sitting or standing erect, as for chest X-rays, the primary beam will always be horizontal. It will occasionally also be horizontal for cross-table projections. **The primary beam should ALWAYS point toward an outside wall or a thickened wall or a wall with no one behind it.**

Which way should the primary beam NOT point?

The primary X-ray beam should **NOT** be pointed at:

- The darkroom.
- The control panel, even if shielded.
- The door of the X-ray room.
- The wall of a room or space where patients wait or staff work.
- The wall of any room in which unused X-ray films, or loaded and ready-to-use film or digital CR cassettes are stored.

Where should the chest cassette holder / receptor be installed?

The chest cassette holder / receptor should always be against an outside wall or, if that is not possible, a well protected wall or the wall of a space where there is never anyone working or waiting.

Where should the chest cassette holder / receptor NOT be installed?

The chest cassette holder / receptor should NOT be:

- On or near the wall of the darkroom.
- On the wall of a room or space in which people wait or work.
- Anywhere near the control panel.
- Near the door of the X-ray room.
- On the wall of any unprotected room which contains unused X-ray films, or where loaded and ready-to-use films or CR cassettes are stored.

IF ANYONE OF THESE TEN REQUIREMENTS IS NOT POSSIBLE, THEN CAREFULLY FOLLOW THE WALL THICKNESSES RECOMMENDATIONS FOR SHIELDING.

Will there be any radiation risks in any of the rooms near the X-ray room?

There will be exceedingly low or, insignificant risk in any nearby room or space PROVIDED the given construction rules have been followed, and the equipment is properly positioned in the X-ray room.

But if the layout of the X-ray equipment is not correct, or if the walls are not as specified, a significant amount of radiation may penetrate through the walls of the X-ray room and may affect staff or patients in the waiting room. It may also fog (spoil) unused X-ray film stored in any of the rooms, especially when kept loaded in cassettes. CR cassettes may also be fogged.

THERE ARE NO SHORT-CUTS. RADIATION CANNOT BE SEEN OR FELT, BUT IT IS DANGEROUS UNLESS THE PROTECTION RULES ARE FOLLOWED. FORTUNATELY, WHEN THE RULES ARE FOLLOWED, ANY X-RAY DEPARTMENT WILL BE QUITE SAFE FOR ALL WHO WORK THERE OR ARE CLOSE BY EVERY DAY.

MANY COUNTRIES, STATES, PROVINCES, AND CITIES HAVE STRICT PROTECTION REGULATIONS. THE RULES IN THIS MANUAL ARE MEANT TO SUPPLEMENT, NOT REPLACE THEM.

CHAPTER 3: DESIGN, BUILDING MATERIALS, ELECTRICAL SUPPLY FOR THE X-RAY ROOM, DARKROOM, OFFICE / STORE

This part of the book provides the information needed to establish diagnostic imaging in any hospital or clinic, using fixed X-ray equipment (not a mobile unit) and ultrasound.

Alternatives are provided to allow for local conditions. All the recommendations are as basic, simple and as economical as possible: local labor and skills can be used for almost everything (except the imaging equipment!). There is advice on the choice of X-ray and ultrasound equipment, and how to train local staff. There is no compromise in the standards of imaging although there will only be a few patients each day in a small department. For more detailed information on radiation safety, please see chapter 2.

Where should the X-ray department be located; ground level or an upper floor? The X-ray room (and ultrasound room, if different) should be where it is most easily reached by all patients: it should always be on the ground floor unless a reliable lift (elevator) can be provided and there is always electrical power for the lift. Radiation protection is not a major factor in making the choice of location, convenient access is more important.

Patients will come for imaging from every part of the hospital and from all emergency and out-patient clinics. In the average small rural hospital (20-200 beds) the majority of patients for imaging can walk: some will be in wheel-chairs and a few will come on a trolley / gurney or in a bed. The X-ray room must be accessible both from the hospital and the outpatient clinic. The route to the X-ray room should preferably be protected from both the sun and the rain, even when it is windy. There must be no steps or other obstacles that would impede trolleys or wheelchairs. Easy access from the operating suite is an added advantage.

What rooms are required for a small imaging department?

It is important that all the rooms for the imaging department are close together. Electricity must be available, a cold water supply is desirable and, if possible, hot water also. The rooms must have windows or good ventilation.

Three rooms are preferred: a) the X-ray / imaging room, b) the darkroom (unnecessary if there is only a digital system), c) the office / storeroom.

The X-ray room can be used for ultrasonography if there are not too many patients, but cannot be used for anything unrelated to imaging. The darkroom cannot be shared or used for any other purpose. With a digital system, a dark room will only be necessary when there is back-up film processing. If there is not enough space for three rooms, the combined office and storeroom is the least essential of the three rooms. However, unless there is a digital system, storage for both used and unused X-ray films, chemicals, etc, will have to be provided somewhere in the hospital complex, and should be close to the X-ray room and darkroom.

How are the rooms inter-related?

There are many alternatives (see figure 1 on the next page), but in a non-digital department, if the X-ray room and the darkroom adjoin and if the X-ray unit is **not** a WHIS-RAD, see the sections on radiation protection and equipment layout in chapter 2. The office / storeroom must be close, preferably adjoining the other rooms, with easy access to the X-ray room.

What are the best sizes for the rooms in an X-ray department?

The X-ray department must not be too small but need not be excessively large. The dimensions given in the table below indicate both the **minimum** space required and the space which is preferred.

Best Sizes for the Rooms in the X-ray department.

	Minimum	Preferred
Total space	29 m² (312 sq ft)	50 m² (540 sq ft)
X-ray room	16 m ² (172 sq ft)	24 m ² (258 sq ft)
Darkroom	5 m ² (54 sq ft)	10 m ² (108 sq ft)
Office/store/film file	8 m ² (86 sq ft)	16 m ² (172 sq ft)

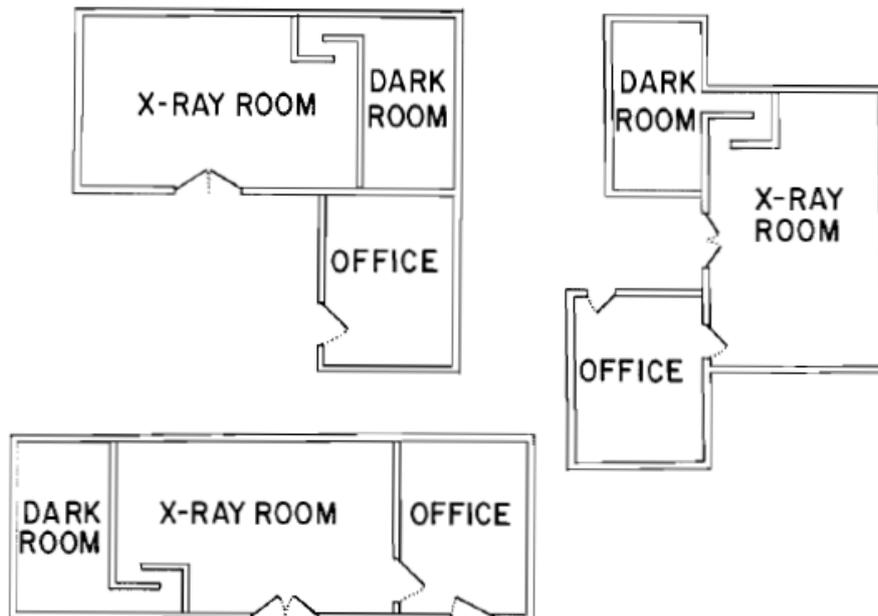


Figure 1: Alternative room layouts for a radiographic suite

What are the dimensions (length and width) of the X-ray room?

The ideal dimensions for the X-ray room are 4 x 6m (13 x 20ft). The absolute minimum size for an X-ray room is 16sq.m (172sq.ft). The size of the X-ray room depends on the size of the equipment and the space needed for patients. This is why 16sq.m (172 q ft) is the minimum recommended. It will not be possible to properly use a general purpose X-ray unit if less than 3.0 x 4.3m (10 x 14ft) is available for the X-ray stand and patient support.

When planning, this space, 3.0 x 4.3m (10 x 14ft) should be reserved for the X-ray table and tube-stand and 1.5 x 2m (5 x 6.7ft) for the generator and the control. Some X-ray units have the control and generator in a combined console: when separate, some overlapping is acceptable: for example, a small generator can be in a corner near the X-ray unit.

The minimum size given – 16sq.m (172sq.ft) - really is the ABSOLUTE MINIMUM. A larger room is very desirable and will be more efficient.

What are the dimensions of the Dark-room?

The minimum dimensions of the dark room should be 2m x 2½m (6½ft X 8ft).

The darkroom should never be large: Even if there are two X-ray rooms, 10sq.m, (108 sq ft) will be sufficient for the darkroom. The size of the darkroom depends on 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 the wet chemical processing tanks. If the darkroom is entered through a maze, the area of the maze (4 or 5sq.m/about 50 sq ft) must be added to the total area of the department.

Is a larger room needed if there are more than 20 examinations a day?

A busy department will function more efficiently with the larger room sizes and, unless only digital, the office / storage space will also need to be large enough to store an increasing number of patients' images. Choose the 'preferred' dimensions for all rooms

When planning, expect that the number of patients will grow every year.

If possible, start with the bigger room sizes, or even larger!

Are there specific reasons for these room sizes?

The smaller the size of the X-ray room, the more important extra shielding for radiation protection will become. In many rural hospitals, it is easier and less expensive to build a larger room than to increase the thickness of the walls or have to use special materials for shielding, such as lead or steel.

Room size will also depend very much on the type of X-ray unit chosen and the number of and type of examinations each day. There must be room to move wheel-chairs and trolleys / gurneys around the room. Many trauma patients will have splints and I-V fluid lines and some may need several nurses to move them into position for the X-ray examination.

Larger spaces make imaging easier and safer and quicker.

Where are (Non-digital) films and office records kept?

- **Less than 10 patients every day:** if there is no office, the office work can be completed in the X-ray room when patients are not being examined. A small table is needed. Daily records of patients must be kept manually unless there is a digital system. Patients' films may be stored in the X-ray room provided it is at least 24 m²

(258 sq ft), not including the darkroom. **UNUSED X-ray films can NEVER be stored in the X-ray room** unless properly protected in a designated radiation-safe area or box to prevent spoiling the films; it is much easier and cheaper to store films in the office or some other room. Films will also be safe in the darkroom if it is large enough: they should be kept off the floor and stored against the wall which is opposite the chemical tanks.

- **More than ten patients everyday:** the office work (and storage) cannot be done in the X-ray room, another room is necessary. This combined office and storage space in a non-digital department must be large enough to have adequate shelving 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 imaging department. Community clinics and small hospitals which serve a stable population may prefer to keep films much longer. Check to see if there are **government required record / film storage times**. For example, some governments require that films of children are kept until their 22nd birthday. **X-ray images and ultrasound scans are an essential part of the patient's records, and it is almost impossible to have too much dry storage space.** In a digital department, the same time-storage requirements will apply to the electronic storage system; although this will need less space, an office will still be very useful. See below

The office and storage space does not have to be enormous, but in the beginning it is better for it to seem too large than too small !

Is an office needed for a digital department?

It is very useful to have space adjoining the X-ray room, an office for the operator. There can be an extra monitor for doctors to review the images so that they do not need to go into the X-ray room. If there is a room available, use it. If no room, build it if you can.

What are the requirements for the Waiting area?

Patients waiting for imaging need to be sheltered, dry, and readily available for their examination. There must be enough space for relatives, often many relatives! Many small departments do not have a specific waiting room. Benches are provided in the corridor or on the patio outside the X-ray room. When the department is not busy, patients may undress in the X-ray room, and a screen is helpful. It can be opaque curtains across a corner but must not interfere with patient and staff movement around the X-ray unit. However, no-one should stay in this curtained changing-cubicle during the X-ray examination of another patient.

When is a designated waiting room needed?

When the number of patients, and thus the number of relatives who come with them, is increasing, a waiting area should be designated and at least one changing cubicle provided; the cubicle can be simply curtains (see above), but it is better to have a permanent cubicle leading from the waiting area with a door directly into the X-ray room. A pass-through dressing cubicle, or two if busy, will speed up the flow of patients.

What are the best building materials?

Building materials and wall thicknesses are very dependent on the room sizes and the type of X-ray equipment chosen. Radiation protection is as important as the weather!

Almost any local material is suitable, provided it is; (a) Waterproof and dust-proof,

(b) Strong, especially the floor, (c) Durable, lasting 20 years or longer, and (d) Useable in thicknesses appropriate for radiation protection where necessary. Thickness will be dictated by the type of X-ray equipment and the number of patients examined each day. Materials differ in their capacity to protect against radiation (page 29): wood is the least satisfactory, wood that is covered with plaster, preferably two or more layers thick, can be used but is much less satisfactory than brick or concrete. Brick is good, concrete is very good: really thick mud walls are satisfactory. Plaster which incorporates barium sulphate is not satisfactory. It cracks easily and needs special installation skills. **Lead paint on the walls is useless for radiation protection.** In earthquake prone areas it would be advisable to consider walls of reinforced concrete with a minimum thickness of 8cm. If additional shielding thickness is required, increasing the thickness of concrete would be preferable and cheaper than adding lead or steel.

If cost is not a limiting factor and when radiation is really significant, (this is rare in a well-planned department), added steel or lead sheets are very effective but not cheap.

Proper planning and equipment choice should make steel and lead unnecessary.

What are the best materials for the floor of the X-ray room?

The floor must be firm, level and able to support the weight of the X-ray generator, the tube support and the X-ray table and / or patient's trolley. The weight of this equipment may be 650 kg (1430 lbs.) or more. The tube and support alone may weigh 200-400kg (440-880 lbs). The power supply and control may weigh 100-250kg (220-550lbs). These weights will not be all in one area, but in different parts of the room. **Get the information from the supplier of the X-ray unit before building or altering an X-ray room.**

The floor must be level overall so that trolleys and medical equipment can be easily moved across it. It should be water-proof, washable and free of dust. It can be concrete, wood, brick, tiles or any suitable and hard compound. If wood, there must be strong underlying support under every part of the floor. Whatever the material, the part of the floor supporting the tube column (area about 1.0m x 1.0m, or 40in x 40in) may need to have an extra steel plate or a concrete insert. The tube column is quite heavy and it must be completely stable and firm while the tube arm is rotated for any examination and braked in a new position.

Long before the equipment arrives get all the individual weights of the equipment from the supplier before building the floor.

There are no radiation protection requirements for the floor unless there are people below.

What are the heights and the best materials for the walls of the X-ray room?

The walls must be strong enough to carry the weight of the roof and the ceiling, if there is one. They must be at least 2½m high (8ft), preferably 3m (9½ft). They can be constructed of brick, thick mud, concrete blocks or wood covered by thick plaster. The section of the side wall near the tube column may have to provide some extra support, depending on the design of the column. Check with the manufacturers and see also the floor instructions above. Sometimes a wall can be strengthened locally to provide extra stability for the tube-column by using wood boards (planks) inside and outside, bolted together through the wall.

Does the X-ray room need a ceiling?

It is not essential, but it is usually a good investment. The ceiling must be at least 2½m (8 ft), and preferably 3 m (9½ ft) above the floor. An X-ray unit can be installed in a room

without a ceiling, but an inner covering under the roof is advisable for protection from dust, insects, bats, snakes, etc, and to provide insulation. The ceiling is not required to support any weight other than the room lights. The ceiling can be constructed of plaster-board, wood, hardboard or any suitable local material. There are no radiation protection requirements for the ceiling, unless there are patients or other people in the room above. Even then, for the WHIS-RAD or for standard tube supports, no added ceiling protection will be necessary unless the X-ray tube will be used under the patient support, pointing up to the ceiling. This is unlikely in a small hospital or clinic.

What are the best materials for the roof of the X-ray room?

The minimum internal height of the room must be 2.½m (8ft) although 3.0m (9½ft) is better. The overall height of the building will be about 3-5m (10-16ft). The roof must be well fitted and weatherproof because moisture damages imaging equipment beyond repair and may cause electrical short-circuits. Any suitable local material, such as wood, tile, slate, thick thatch, corrugated iron, corrugated iron with thatch, roofing felt is suitable. An inner ceiling of plaster or fiberboard is desirable and is essential if the outer roof is thatched. There are no radiation protection requirements for the roof. Local design will dictate the width of the eaves and the need or gutters, down-spouts, water collection etc.

The roof should extend over the doorways of the X-ray room. darkroom and office. The roof preferably should connect with a covered way to the hospital and to the outpatient clinic.

Does an X-ray room need an entrance door?

The X-ray room must have a wide patient entrance which can be closed, preferably by a wooden door which can be locked. Provided the X-ray room is large enough and the doorway is not near the X-ray equipment, additional shielding for radiation protection is seldom needed. If there are many examinations each day, i.e. more than 100, the radiation level outside the door should be measured if anyone waits near it. The entrance to the X-ray

room should be at least 1.1m (44in) wide so that wheel-chairs, beds and trolleys can enter without difficulty. It can be closed by a single door or a door and a half-door. There should not be any steps or other obstruction on the floor.

Does an X-ray room need windows? Do windows allow radiation leakage?

The X-ray room should have windows to provide light and ventilation, but ordinary glass or plastic windows do not provide any radiation protection. However, there will be no radiation hazard if persons do not loiter within 2m (6½ft) of the window of a standard size X-ray room. If anyone must sit or wait directly outside the window of the X-ray room, the glass should be 2m (6½ft) from the ground outside, and the wall must be of solid brick; 12cm (5in) or concrete 8cm (3¼in). If it is possible to look through the window into the X-ray room, the glass should be 'frosted' or painted white inside the X-ray room to provide privacy. It should be possible to open the windows to provide ventilation when the room is not in use for X-ray examinations. The windows may stay open during an X-ray examination if the lower edge is 2m (6½ft) from the ground or if no person can be outside. There must be locks on the windows. Local needs will decide if there must be fly / mosquito-screens.

What are the best building materials for the dark-room walls?

The darkroom must be waterproof and lightproof. The construction of the darkroom is similar to the X-ray room, In some departments the wall between the X-ray room and the darkroom may need extra shielding for adequate radiation protection. One wall, usually the outside wall, must be strong enough to support plumbing and any of the walls may have to carry shelves, a shielded ventilator or other lightproof ventilation. A window or hatch (diagram) is desirable for ventilation in the darkroom but must be completely lightproof. Where an adequate electrical supply is available, a lightproof extract fan or air-conditioner is helpful in a hot climate.

The darkroom door may be wood but must be completely lightproof and, depending on the position of the X-ray equipment, it may also have to be radiation proof. Curtains are not a satisfactory way to exclude light or radiation.

Do not use curtains to keep the darkroom entrance lightproof.

What does the darkroom floor require?

The dark-room floor should be waterproof and washable, sloping slightly away from the door towards a floor drain, which should be under or close to the processing tank. When floors are damp or uneven, removable platforms of wooden slats should be laid across them, to keep the shoes of the staff dry.

Does the dark-room need a ceiling?

A ceiling is not essential, but very desirable, to keep out dust, insects, etc. and provide insulation. It will also help to keep the darkroom dark!

Does the darkroom need windows?

YES there should be windows in the darkroom, especially in hot climates.

All windows in a darkroom must be completely lightproof, fitted with solid internal shutters or a heavy, totally opaque, black blind running in an inside-frame of wood. This frame must be permanent, at least 8 cm (3½in) wide all around. It should allow the window to open: any retractable blind should run with the edges behind the frame, next to the window. **Black-out Curtains / Drapes** are not satisfactory unless very heavy; they tend to attract dust and do not last because of the chemicals. The **glass in a window** should be replaced with wood or hardboard, painted black on the inside. **Painting the inside of the glass with black paint is very unsatisfactory**, it does not last and will almost always allow light to come into the darkroom. Paint the **outside** of the windows **white** to reflect heat.

The windows should be able to open upwards or outwards, never inwards. They must be completely water proof and lightproof. Many window frames, particularly of metal, are not lightproof. An inner surrounding frame is needed.

Is a special darkroom entrance required?

If there is no maze, the entrance to the darkroom from the X-ray room will need a lightproof door. **Curtains are not satisfactory**, however thick. The darkroom door should be about 90 cm (36 in) wide. This door must be absolutely lightproof and will need wide overlapping panels around the entrance, to prevent light entering the darkroom when the door is shut.

The door must NOT have a key-hole.

In a small department, a good light-proof door is usually sufficient, but when the daily workload reaches or exceeds ten patients, a maze without doors is desirable, especially in hot climates. It increases efficiency and ventilation. Whether extra radiation protection is needed on the dark-room walls will depend on the layout of the equipment in the X-ray room.

Large equipment, such as processing tanks, will have to go in, and, occasionally, out of the darkroom and will not go through a standard door or maze. There must be another entrance, at least 2m x 1½m (6½ft x 4½ft) into the darkroom. This usually is a separate hole in the wall, kept sealed but easily opened when repairs have to be made.

It is not possible to move all the darkroom equipment through a correctly designed maze.

What are the best materials for the office/storeroom?

The combined office and storeroom can be built of any standard local materials. In a non-digital department the floor and walls must be strong enough to support the weight of the shelving needed to store exposed and unused X-ray films, chemicals, etc. Films and chemicals are heavy, and the shelves to support the films will have to be strong enough to hold 0.05 kg/cm^2 (0.7 lbs per sq in), corresponding to 500 kg/m^2 or 100 lbs/ft^2 on the floor. If the shelf were 40 cm deep, it would produce a load on the shelf of 200kg per meter of length. If the shelf were 16 inches deep, it would produce a load on the floor of 136 lbs per foot of length.

Does the office / store need an inner ceiling, weather proof walls and a door with a lock?

Yes, good walls, ceiling and a lockable door and windows are essential. If the office is next to the X-ray room, an extra thick intervening wall may be necessary, depending on the size of the X-ray room and the position of the X-ray equipment.

What is the construction of the connecting corridor to the rest of the hospital?

The **floor** of the corridor should be concrete, brick, tile or some equally smooth, firm material. It must be strong and wide enough to allow people, trolleys, and wheel chairs to move and pass easily, without any steps. The **roof** of the connection should be water-proof with wide eaves. Any local construction material such as thatch, corrugated iron, wood, etc, can be used. There should be **two 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.

What colours should be chosen for the exterior of the X-ray department?

All the rooms in the X-ray department will contain X-ray films, or digital equipment which can be damaged by heat. In a hot climate, it is preferable to paint the outside of the buildings white or some heat-reflecting colour. Apart from this, there are no special requirements. The roof should also be a light colour, unless it is thatched.

What colour is best inside the X-ray room?

All the rooms in the X-ray department should be light and cheerful in colour. 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 dark cream or pale blue, and a matte (non-glossy) surface is preferable for the ceiling. Patients may spend quite a long time looking up at the ceiling, and a bright white glare should be avoided. The floors can be any suitable colour, but should be easy to clean and preferably waterproof. Avoid black floors, they show a lot of dirt. There will be quite a lot of pedestrian and wheeled traffic across the floor.

What colour is best inside the darkroom?

The darkroom walls should be **cream or yellow**

Black or any dark colour is definitely NEVER needed on the dark-room walls or ceiling.

A dark colour may be a disadvantage in the darkroom because it leads to the use of stronger safe-light bulbs. The finish should be semi-gloss to avoid reflections and to simplify cleaning. The ceiling should be the same colour as the walls, with a semi-gloss finish. The floors can be any colour but must be washable and moisture-proof.

The top of the film bench should be dark red, dark brown or dark blue (**but not black or white**).

The "light-trap" (maze) entrance must be completely matte black inside, with a thin horizontal yellow line, width 2-3cm, (1in) situated 90-120cm (3-4ft) from the floor around both inside walls. If there is no maze and a darkroom door is used, the inside door frame and the edges of the door must be matte black.

What is the best colour inside the office/storage room?

The office / storage room can be any colour, preferably light, bright and cheerful and easy to keep clean. A matte or semi-matte finish is better than a glossy surface to avoid reflections on the monitors or viewing screens.

What electrical supply is needed, other than for the X-ray generator?

Apart from the mains supply for the generator, it is wise to provide at least two additional and independent wall outlets (10A-220V or 15A-110V), preferably on each of the two long walls of the X-ray room. There should be at least two more independent wall outlets in the office. The darkroom also needs a good independent electrical supply.

Are lights needed in the X-ray room?

Lights are needed to examine emergency patients at night. Three or four single lights or two or more fluorescent tubes on the ceiling of the X-ray room are preferable to one large light. There must be good lighting over the control unit and the X-ray stand and patient support. The light over the patient support must have a separate on / off switch if the X-ray unit is fitted with a light beam collimator.

The above are minimum requirements only. Other lighting will be an advantage.

CHAPTER 4: POWER SUPPLY, CHOICE OF EQUIPMENT, DESIGN, SPECIFICATIONS AND ACCESSORIES

A lot of money can be saved by taking time to choose the best imaging equipment, matched to the available electrical supply and then preplanning the layout of the department and accessories. Apart from money saved, there will be less frustration and better quality radiographs. This chapter, without trying to sell anything, will help in making the choices.

No X-ray unit will function satisfactorily with a variable power input, and very expensive damage may result if an X-ray generator is not protected from a fluctuating power supply.

Is it necessary to have a 'Mains' power supply?

Apart from a national or local public power supplier, a hospital generator, or a generator for the X-ray department may be satisfactory. Solar power is not satisfactory without a storage system, especially after sunset!

Whenever an X-ray exposure is made, power must be immediately available. The incoming voltage must not vary and the line resistance (impedance) must be low.

If the X-ray generator is not a WHIS-RAD and does not have a storage system, the direct load on the power supply may be up to 50A at 220V with a very brief surge requiring up to 150A.

What are the differences in power supplies?

Electricity is supplied in different voltages and frequencies, and is affected by the transformers and power lines which carry it. Single-phase electricity can be supplied either at 220-240volts (V) or 110-120V alternating current (AC), or it can be supplied as direct current (DC). DC cannot directly power the X-ray generator, it can only be used to recharge batteries or other storage devices. An AC 3-phase supply, 380-440V may be required for a large X-ray unit, but this is not usually needed in a small hospital or clinic.

What are "single-phase" and "3-phase" currents ?

A single-phase AC electrical supply provides a single alternating current. Because the power is in a wave, there will be alternate peaks and valleys at the rate of 50 or 60 cycles per second. This will require 3 insulated supply-wires. One will be "live", one will be "neutral", and the third will be to ground (earth). Single phase can be supplied at 110-120V or 220-240V.

A 3-phase AC supply at 380-440V means that 3 single currents are super-imposed so that the peak of each wave of the current quickly follows the preceding wave, smoothing and reinforcing the available peak power. A 3-phase supply requires 3 live wires as well as neutral and earth. Few hospital generators supply 3-phases. All the circuit breakers, fuses and switches for the electrical supply must match the voltage and either the single or 3-phase supply.

What is the "frequency" of an AC supply?

The frequency of an alternating current indicates the time-interval between the peak of each electrical wave. This is either 1/50sec. or 1/60 sec, designated 50 or 60 Hz (hertz or cycles per second). Because the frequency and voltage varies in different countries, it is important that this information be made available **BEFORE** the X-ray equipment is chosen.

Any supplier of X-ray (or ultrasound) equipment should be asked to confirm (in writing) that the X-ray unit they are offering will work properly at all times from the power source actually available in the specific X-ray room where it will be installed.

If a mistake is made, it can be very expensive to purchase a new main electrical transformer or rewire the supply to the X-ray room! Whatever the voltage or frequency, both must be steady under peak load.

The voltage must not vary by more than $\pm 10\%$ and the frequency must not vary by more than $\pm 2\%$ during any X-ray exposure.

Voltage must not alter when there is a heavy load of power being used elsewhere in the hospital, such for sterilizers or other electrical equipment. Some electrical supplies, especially from small hospital generators, will be steady when not in use, but fluctuate when a heavy load is turned on. This should be tested before ordering, even if it is a 'main' commercial power line.

Why is the power supply so important?

There can be many difficulties when (non-battery) X-ray units obtain their power from the local (commercial, national) electrical mains supply. There may be voltage fluctuation or the inability to maintain the correct level throughout the X-ray exposure, especially during a long exposure. Companies which sell X-ray equipment are seldom strict enough in stating the minimum power requirements of their units and often understate the needs of their equipment. It is a wise precaution to have the power supply in the X-ray room inspected by the prospective vendor before agreeing to purchase the X-ray equipment.

There should be a written guarantee that a vendor's equipment will function from the actual available power supply, not just occasionally but throughout the 24 hour period, seven days a week for the whole year, whatever is happening anywhere else in the hospital or surrounding district. The exact power requirements and permitted variation must be obtained from the potential vendor of the equipment before deciding which X-ray equipment to purchase.

If there is any doubt about the stability of the incoming electrical supply, a line-voltage regulator should be installed on the supply (input) side, controlling the electrical supply going to the X-ray generator to within acceptable limits set by the vendor. Alternatively, use equipment with a battery, such as the WHIS-RAD but even then, check the incoming line-voltage over a 24-hour period.

What is line impedance? Does it matter?

When electricity flows along a cable there is some resistance to the flow, like water flowing through a narrow pipe. Moving the electricity along the wire takes energy. The amount of energy which is used in this way will depend on the diameter and the length of the cable. The thinner and longer the wire, the greater the resistance (again, like water through a long narrow pipe). In simple terms, this resistance is called "the impedance". When an X-ray exposure is made, there is a sudden need for a lot of electric power instantaneously. If this power comes from a DC storage device located inside the X-ray generator, the internal connecting cables will be very short and the impedance will be negligible. However, if the power comes from a distant source, such as a mains transformer or hospital electrical-generator, through a long a cable, the impedance may be very high: at the end of the cable, where the power reaches the X-ray equipment, there may not be enough electrical power to make a satisfactory exposure. In extreme cases, the long cable may get very hot because, for example, the amount of current which may suddenly be required at 220V may exceed

150 Amperes (150 Amps or 150A). For comparison, an average family house will seldom have more than a 60A -AC-supply (at 110-220 V) for all its electrical equipment.

How is impedance measured? What values are required?

Impedance is measured in ohms (Ω). Low values, in the range of 0.1 - 0.2 Ω are desirable in the cable supplying the X-ray equipment. If the impedance is greater than 0.2 Ω , it may seriously affect the amount of power available during the exposure. Because most exposures should take less than 1 second, this means that a great deal of power will be required almost instantaneously.

What is the best power-supply if the line impedance is too high?

Line impedance is of much less importance when a storage system is used because very little current is needed to recharge the system.

A capacitor-system needs only a few amps (3A at 220-240V or 6A at 110-120V) and can be recharged in one or two minutes, compared with the 1 second or less of full power which is required for each X-ray exposure (see below). Capacitors can only make one or two exposures before recharging. (see page 67).

Batteries only require a very low current, usually about 3A at 220-240V or 6A at 110-120V. Battery packs have to be recharged over a longer time, maybe for several hours, but voltage and frequency variation are less important when recharging batteries: there will probably be enough power from a mains supply line even with very high impedance.

Both capacitors and batteries can be recharged from a small AC generator or solar power but this will take time. Batteries can make many exposures without recharging. (see below)

What are Power Storage systems?

Electrical Power can only be stored as Direct Current (DC) in a battery pack or a capacitor.

A battery-pack stores a large supply, enough for several hundred exposures, The batteries can be automatically recharged whenever there is AC-power available, even if it is only for a few hours a day or perhaps a few days a week.

A large capacitor, stores a limited amount of power, enough for one or two exposures, but the capacitor will exhaust its power after one heavy exposure (such as a lumbar spine) or a few small exposures (limbs). It then will need to be recharged from the AC supply before it can be used again. **Thus, for a capacitor generator, an electrical power supply must be available whenever more than one examination needs to be made.**

This makes the choice of generator very dependent on the quality (the availability and stability) of the electrical supply.

If power is not always available, or if the voltage is not uniform, or the frequency varies, choose an X-ray unit with a battery pack.

WITHOUT RECHARGING ...

A CAPACITOR CAN MAKE ONE OR TWO EXPOSURES.

A BATTERY-PACK CAN MAKE SEVERAL HUNDRED EXPOSURES.

Can a hospital generator be used to directly supply X-ray equipment?

Many rural-hospitals generate their own electricity with a diesel, gasoline (petrol) or kerosene generator. Some generators may not be satisfactory for use with X-ray equipment which does not have a storage system.

1. There must be a steady 110 / 220V alternating current, whatever the total load in the hospital. Many small generators fluctuate beyond acceptable limits, and many cannot produce enough power, particularly under peak loads. For example, an X-ray exposure made at night, when the hospital lights are all in use, may increase the total load beyond the capacity of the hospital generator. The resulting images will be unsatisfactory and other electrical equipment in the hospital may be damaged if most of the power suddenly goes to the X-ray unit. Some hospital generators may automatically shut down if overloaded.
2. There is often considerable voltage loss in the cable connecting an on-site electrical generator to the hospital and X-ray rooms. Generators are often situated away from the buildings to avoid the noise and the odour. If it is essential to use a hospital power supply, then the generator should have a DC power storage unit and a low-impedance supply cable.

Is a small AC-electrical generator or solar power a satisfactory power source?

A small AC-electrical generator or solar power is good only for recharging a storage unit. When mains supplied electricity is not available, a battery-powered or a capacitor discharge generator can be recharged from a small AC electrical generator or from solar power. If alternative power sources are available, then the choice becomes dependent on the power needed by the X-ray generator.

If the main electrical supply is reliable and constant, how much power is needed?

A standard (non-storage) generator will require at least a 50A-220V contact breaker with a slow fuse because the current may briefly be as high as 150 amps at the onset of the exposure.

All the electrical installation must comply with the local building codes and electrical regulations.

There is a poor power supply: which X-ray generator should be chosen?

If there is any doubt about the stability or reliability of the available power supply, the X-ray generator must have a back-up power source; a Direct Current (DC) power storage system. There are two alternative ways of storing power; batteries or capacitors. (see above). These must be supplied as an integral part of the X-ray generator, not purchased as accessories, even if that seems to save money.

What sort of batteries should be chosen?

The batteries can be either lead acid, nickel-cadmium (NiCad) or lithium but "maintenance free" lead-acid batteries are recommended. Ni-Cad batteries are more expensive and their maintenance is much more difficult. Maintenance for NiCad batteries requires a visit from the supplier or the central maintenance department for "recycling" every three to six months, depending on the amount of usage. When the Ni-Cad batteries fail, they are costly to replace. Lithium batteries are costly and offer little advantage compared with the widely available lead-acid packs.

The specifications for the batteries (and for the whole X-ray unit) must require that every part is suitable for the local climate, especially in tropical or very cold areas. Modern sealed lead acid batteries need no maintenance and should be guaranteed for at least five years. They may last longer. Experience with WHIS-RAD units worldwide suggests that sealed lead acid batteries are the best choice for this type of generator. No doubt other batteries will

be developed, but make sure that they do not require frequent service, are easily kept charged and provide sufficient power for multiple exposures under high load.

Most battery-powered generators will work with standard 12V car-batteries, but the manufacturer should be consulted if this is considered. One practical problem is that such 12V car-batteries are very liable to be stolen or 'borrowed' for use in a car or truck! Nevertheless, they provide an alternative if the original batteries fail and the unit can be kept working until replacements can be obtained. Make sure the batteries are in a closed, well-locked container! It will usually be necessary to use 9-10 of the 12V car batteries to provide the required 96-120V primary input for the X-ray unit, but no change in the number or type of battery should be contemplated without consulting the manufacturer.

If car-type batteries are being used, contact the supplier to be sure of the right number and wiring. They must be in a closed, locked box. Accidental contact with any part of a multi-battery-pack could be fatal.

What is a capacitor-discharge (condenser-discharge) generator?

Capacitor discharge generators use electricity which has been stored as Direct Current (DC) It is released as a strong power burst which provides a powerful but very short exposure. There is an upper limit to the total capacity of this type of generator and they usually must be recharged immediately before the next exposure. Thus, the local main electrical supply or the hospital generator must be available continuously any time that the X-ray department is working; otherwise the capacitor cannot be recharged for the next exposure. Alternatively, there must be a small AC-electrical generator, which must be started and kept running when patients are being X-rayed.

Do capacitor generators provide good X-ray images?

The power required for recharging a capacitor X-ray generator is low, and the output can be satisfactory for radiographs of chests and extremities, but even the best capacitor discharge units are not suitable for all abdominal, spinal, or other major X-ray examinations. While such a unit and the low price may seem attractive, there are many disadvantages, so that capacitor generators are not always the best choice. They are acceptable if they meet WHIS-RAD specifications and have a **constant kV and falling mA**. If this type of X-ray generator must be chosen and will be used for general X-ray examinations, the best results will be obtained by also using a fast digital system or a fast film-screen combination: good high-speed films may not be available in every country and may reduce image quality. These details are very important, and the wrong choice can be very expensive.

Are there different types of capacitor-discharge generators?

There are two types of capacitor-discharge X-ray generators. Only one design will meet the WHIS-RAD specifications.

The capacitor-discharge generator recommended by WHO uses multi-pulse frequency converter technology and provides a "**falling load**". The kV remains constant throughout the exposure but the mA decreases.

The alternative does not meet WHO specifications: it uses a **constant mA** but **decreasing kV** throughout the exposure. This will not be satisfactory for general radiography.

Technically, the WHO approved design has a large capacitor on the **primary side** of the high-tension transformer, whereas the unsatisfactory design has the capacitor on the **secondary side** of the high-tension transformer. This difference is VERY important.

What is the output of a capacitor- discharge generator?

Most capacitor discharge generators have a maximum output of 9 kiloWatt-seconds (kWs), although some of the largest models may deliver 12 kWs. For general radiography, including abdomen and spine, capacitor discharge generators cannot be used satisfactorily unless at least one of the following conditions is fulfilled:

1. The focus-film distance is not more than 100cm.
2. The body weight of the patient is less than 70kg (155lb).
3. The relative speed of the screen-film or digital system is 400 or more.

What questions should be asked about capacitor generators to get the right design?

1. Does the generator have a capacitor on the primary side of the high-transformer?
2. Does the generator use a multi-pulse frequency convertor?
3. Is the kV constant during the exposure?
4. Does the mA decrease during the exposure?

The answer to each of these four important questions should be "Yes". If there is no clear assurance or any less direct reply than 'yes', further information should be obtained or another company consulted.

Exactly what equipment is needed for an X-ray department?

There is a wide variety of equipment, but all installations have components which produce the image and ancillary equipment which record it. The components which produce the X-rays and align the tube with the patient are the same for both film and digital imaging systems

1. The X-ray generator and its control.
2. The X-ray tube and connecting cables.
3. The X-ray stand (tube-support) and table (the patient support).
4. For non-WHIS-RAD units, a chest-cassette stand.

The ancillary components which **record** the images are quite different for film and digital systems:

Film systems require:

1. Cassettes with screens.
2. Processing equipment with chemicals (e.g. manual processing tanks or an automatic processor).
3. Patient identification / film marker.
4. Film dryer if there is not an automatic processor.

Digital recording systems require:

1. Digital image receptor.
2. A digital plate reader.
3. A computer workstation to process the digital image and record patient data.
4. A monitor / screen to view the image.
5. A computer archive to store images and patient records.

What is meant by an X-ray generator and X-ray unit?

The term "**X-ray generator**" strictly means the high-tension generator and any rectification circuits. Any type of power storage (a large capacitor or a battery pack) is also included in the general term "X-ray generator".

An X-ray 'unit' always includes the generator, the controls and at least one X-ray tube and the connecting high-tension cables. Because the high-tension cables can affect the balance of the circuit, they must be ordered together from the same manufacturer. Trying to save money by ordering cables and tubes separately is likely to be an expensive error.

Usually, the X-ray generator and its controls are supplied either as a single piece of equipment or as two separate units which can be installed in different parts of the room.

The tube is usually but not always separate from the generator. It is possible to connect several X-ray tubes to one X-ray generator, but this is not necessary in a small department and will add to the expense. Only the manufacturers or their agents should do this if an extra tube is deemed essential.

What are the problems if the high-tension generator and X-ray tube are combined?

Some manufacturers combine the high-tension transformer and the generator circuits with the X-ray tube, supplying them in the same tube-housing. Problems will arise when the X-ray tube becomes faulty and needs replacement. **There must be a written contract before purchasing this type of all-in-one equipment stating that the cost of replacing a faulty X-ray tube-insert will not include any additional charge for the high-tension generator components**, unless they are proven to be defective also (this is very unlikely). Although the filament, rotor or vacuum which make up the X-ray tube-insert may fail after heavy use, generators seldom need replacement. Failure to specify this limitation before purchase may be very costly.

Should the equipment be fixed or mobile?

"Mobile" refers to the X-ray equipment, not to a complete X-ray installation in a truck or van, visiting various hospitals.

Always specify FIXED equipment for the first (or only) X-ray unit for any hospital or clinic. If some patients will have to be radiographed in their beds, bring the beds to the X-ray department (or put the patient on a gurney/trolley) rather than taking the X-ray equipment to the patient. Apart from any other consideration, the resulting radiographs will always be of much better quality.

If a mobile X-ray generator is supplied to provide the power as part of a WHIS-RAD, the wheels should be removed and the generator/ control fixed in position so that the whole installation is in a permanent place.

Why is a mobile (ward) X-ray unit not a good choice?

A mobile X-ray unit with its own tube support (a ward X-ray unit, sometimes mistakenly called a 'portable unit') is a bad choice as an X-ray installation for general radiography in a small hospital or clinic. It is not radiation-safe and is difficult to use because of the variable tube-patient relationship; a mobile X-ray unit can only be satisfactorily and safely used by a very experienced radiographer. Even then, the image quality cannot be as good as a fixed unit.

What is the minimum acceptable X-ray generator?

A brief explanation is necessary, best made by simple comparison between the exposure factors for X-ray units and photographic cameras. Although either may have manual or automatic exposure settings, the basic principles are very similar. The X-ray film-screen combination or digital system (Fast, Medium, Slow) is the equivalent of the photographic film speed/quality (the ASA)

The X-ray exposure needed to obtain a radiograph is described by a combination of figures for the **tube current** in miliamperes (= mA,) **time** in seconds(=s or ms) and **kilovolts** (=kV). For example 100 mAs at 75kV.

All photographic exposures are described by the lens aperture (the *f* stop), length of the exposure time in seconds or fractions of a second (1s or 1/100s): for example, *f* 4.5 at 1/200th s

1. The X-ray tube-current (mA) is equivalent to the size of the lens aperture (*f*-stop) in regular photography.

2. Exposure time, usually measured in ms or fractions of s, has the same meaning in photography and radiography.
3. The combination of current and time, measured in milliampere-seconds (mAs) controls the total amount of X-radiation reaching and exposing the X-ray film or receptor and thus controlling the blackening of the film. In regular photography this is controlled by the aperture (f) and exposure time (ms).
4. The kilovoltage (kV) is equivalent to the quality of light in regular photography (sunny, hazy). In radiography: it controls the extent to which the radiation penetrates the body. The kilovoltage alters the contrast of the image and will affect the shades of grey on the film, making it 'flat' or 'contrasty'. In most digital systems, this can be done while viewing the image on the monitor.

An increase of either the mA-value or the kV-value, or both, increases the amount of radiation and will decrease the exposure time.

How is the output, the power, of a generator measured?

The amount of power which can be delivered by a generator is measured as the product of the mA-value and the kV-value. This product gives the power in watts (W). Because the resulting figure is always large, the unit "kilowatt" (kW) = 1000 Watts, is used. The exposure time is added, so the generator output is shown as kilowatt seconds, (kWs).

How is the output of a generator specified?

It is difficult to compare multi-pulse capacitor discharge generators with ordinary generators because they work in a very different way and produce beams with different quality radiation. However, provided the terminology is understood, it is possible to assess their relative capabilities very accurately.

A working explanation follows.

The power of a generator is often given in kilowatts, but using only the available kilowatts can be misleading; it is necessary to know not only the total power output, but also for how long (what length of exposure) that power is available because the power may change during an exposure. The most reliable and true indicator of the power of a generator is stated in kilowatt-seconds (kWs).

The maximum kilowatts is an inaccurate definition. The total milliamps and the highest kilovolts are not valid specifications.

ASK FOR THE GENERATOR RATING IN KILOWATT-SECONDS (KWS).

Are there any limitations on the generators?

Even if the kWs are sufficient, the maximum exposure may be limited by the heat capacity of the X-ray tube and not the power of the generator. If the generator is powered by a capacitor, the output seldom exceeds the tube capacity. The limitation will be on the amount of power which can be stored in the capacitor rather than the tube.

Is it necessary to know more about generators?

A more detailed explanation is not really necessary, but, it is important to:

- 1. Specify the generator output in kWs.**
- 2. Know what type of technology is used.**

How should a generator and control be selected?

Whatever the incoming power supply, X-ray generators will only work on alternating current, AC, which must be "smoothed" (rectified). There many different system of rectifiers (or, in very old terminology, "valves"), resulting in different patterns of wave-forms.

1. On a single-phase power supply there are "half wave" or "full wave" generators.

2. On a 3-phase power supply there are "6-pulse" or "12-pulse generators; these are more expensive, but give better smoothing.
3. On a single-phase power supply there are multi-pulse frequency convertor generators.

The most up-to-date and best design for X-ray generators is the "multi-pulse frequency convertor generator", originally and sometimes still called a "medium or high frequency multi-pulse generator".

ONLY A MULTI-PULSE HIGH FREQUENCY GENERATOR SHOULD BE PURCHASED. This design has many advantages over all other generators.

Why choose Multi-pulse frequency convertor generators?

All multi-pulse frequency convertor X-ray generators have much smaller transformers and other components when compared with ordinary 50/60 Hz X-ray generators. They take up much less room and weigh less. They use much less power, but the X-rays produced are of the same quality or better than the best (and most expensive) 3-phase generators. A multi-pulse frequency convertor generator of relatively small power (12kW minimum) can deliver as much radiation to the film or receptor (after passing through the patient) as an ordinary 20-25 kW single phase generator. The radiographs from small convertor generators are excellent. Independent clinical tests in Lund, Sweden, and London, UK, have confirmed the very high quality of the radiographs.

The best choice, a multi-pulse frequency convertor generator, will save space, weigh less, cost less, (including cost of installation and maintenance), and the patients will receive much less radiation than they would if examined with a single-phase X-ray generator. Staff will be safer and image quality better.

What are the correct specifications for small general purpose X-ray generators?

A small X-ray generator must be able to maintain at a minimum an output of at least 12kW for an exposure time of 0.1s. This describes the minimum peak output, not the total capability of the generator. Require clear specifications that the generator has a total output of at least 25kWs; within a maximum exposure time of 2.5s. This may be represented by an exposure of 100 mA at 100 kV for 2.5s or 250mAs at 100kV.

How is a capacitor-discharge generator defined?

When a capacitor-discharge X-ray generator delivers its stored energy, the result is either falling kV or falling mA during the exposure. Only generators with falling mA can be used to meet the WHIS-RAD requirements. A high output from a capacitor-discharge generator at the beginning of the exposure (often 20-30kW) is excellent for chest radiography, which needs total exposures of about 0.3kWs (2.5mAs at 120kV = 0.3kWs). This results in exposure times in the range of 10-15ms for a chest radiograph of an adult patient. But it is equally important to have sufficient power for heavier exposures, with exposures which are reproducible each time. Only the falling mA design meets these requirements.

Why such exact details in the specifications?

When a low power generator is used, the available output, measured in kW, is usually too small. To compensate, the exposure time will have to be long and patient movement during long exposures can be a problem, particularly with sick children and injured patients. Movement causes unsharpness, which blurs the image.

Similarly, when the total amount of energy (measured in kWs) available from the X-ray generator is low and a longer exposure is used, the exposure may be automatically cut-off to protect the generator before the image is correctly exposed, resulting in underexposure with insufficient blackening.

Is a less expensive generator a good alternative?

There are cheap generators which claim to provide both 100mA and 110kV, but in fact can only produce 100mA at a lower kV-value (e.g. 100mA at 60kV = 6kW).

Other generators may start the exposure at 110kV with 100mA but do not maintain this kV for at least 0.1s. It is very important not to confuse the figure for instantaneous output at 0.1s, measured in kW, and the figure for total output in kWs. It is common for manufacturer's representatives to claim that their generator is 15 or 20 kW, or even 30 kW. They must be asked to clarify exactly what they mean, kW or kWs, and exactly what kWs are available. The nominal output of generators must be stated at 0.1s. Nominal values of 15-20 kW are common for generators with a total output of only 8-10 kWs. which is below the minimum 12kWs required.

Low power generators are NOT acceptable alternatives. Make sure the supplier meets or exceeds the correct specifications.

It is worth emphasizing again that a battery-powered multi-pulse frequency convertor generator is independent of a fluctuating main supply; if it is rated at 12kWs or higher there will be no need for a fast film-screen combination or fast digital receptor. Such a generator will produce excellent radiographs for any type of examination, whereas any less powerful generator will not be satisfactory.

WARNING:

Advertisements for X-ray equipment, particularly mobile X-ray units, often claim that their generator is entirely suitable for all X-ray examinations of any part of the body.

Obviously, this is not always accurate and great care should be taken to obtain the exact details of the capability of the generator which is being offered, and to make sure that it meets the minimum power requirements: see above and in the WHO specification.

With less power the results will be less satisfactory.

Many diagnostic errors are the result of poor quality images.

Buying cheap equipment can be a dangerous economy.

SUMMARY OF SPECIFICATIONS

- The WHIS-RAD generator specifications are calculated for patients weighing up to 120kg (265lbs).
- A relative digital or screen-film speed of 200 is required.
- Only medium or high-frequency converter-generators are accepted.
- A focus-film distance of 140 cm is required.
- The X-ray generator must be able to deliver 25kW at 90-100kV within 2.5s.
- The voltage-drop during an exposure may not be more than 10%.
- The X-ray tube capacity should be 20-30kW at 0.1s.
- The focal spot must be 0.8-1.00mm or less. Anode-angle 12-14°.
- Two focal spots (double-focus tube) are not necessary, are an added complication without any advantage).

If the generator does not meet these WHIS-RAD specifications, the only other way is to: increase the relative speed of the receptor or the screen-film combination. This requires the **use of green emitting screens and green sensitive film**. In general terms, the faster the film-screen combination, the less the film quality.

Comparing combinations of intensifying screens and film when large patients are radiographed, the following X-ray generator outputs will be needed:

Speed of Screen-Film combination	200	400	600
Generator output at 90-100kV during the entire exposure	25kWs	12kWs	9kWs

Thus any generator with an output of less than 12kWs will not be satisfactory for radiography of the abdomen, spine or pelvis UNLESS fast green emitting screens and green-sensitive film or equivalent receptor speeds are used. These X-ray films require strict time/temperature controlled development without film-viewing during the process (Described in the WHO Manual of Darkroom Technique).

WHAT CONTROLS ARE REQUIRED?

What exposure controls are necessary?

At a minimum there must be an integrated exposure button, and It should be possible to alter the exposure time, the kV and mA or show combined anatomical settings.

How are the kilovolts (kV) controlled?

The quality of the radiation used during any exposure is dependent upon the kV. Some less expensive controls link the kV to other exposure factors but the various settings for the **kV must always be by a separate control and independent from the mA or mAs**. Any link

(other than to provide overload protection for the tube) is unacceptable. The specification should require **a minimum of four distinct kV settings** and a maximum of **six kV settings**, with a tolerance of $\pm 2\%$ (this tolerance means that **the actual kV delivered during an exposure must be within $\pm 2\%$ of that indicated by the control setting**).

These are the required combinations:

4kV settings	52	70	90	120		
5 kV settings	52	70	80	90	120	
6kV settings	45	52	70	80	90	120

More than six kV settings are not recommended or necessary. Control units must include a protective device so that the exposure setting will always be less than the maximum heat capacity of the X-ray tube. This type of overload protection is essential.

How is the mAs value controlled?

The amount of radiation for each exposure, the combination of mA and seconds (mAs), must be varied by only one control, which will automatically set the generator output to the highest available mA and the shortest possible time for each mAs setting. The X-ray tube current and the time; the mA and the seconds, (mA seconds or mAs) will be linked together so that **altering a single control alters both the mA and time, but never the kV**.

The total exposure will then be the product of tube current (mA) and time (s) and the exposure will be terminated automatically when the preset mAs-value is reached. It is this value which must be clearly indicated on the control panel. The circuit should be able to complete an exposure in as little as 2ms

Although it is possible to have a range of separate but fixed mA settings, such as 50 mA, 100 mA, and then set the exposure time with a different switch, this offers little advantage and makes it much more difficult for inexperienced personnel to make the correct choice.

1 control for combined mAs settings should be chosen.
--

What is the minimum range of mAs values?

The required range is 0.8-200mAs. The increments between the mAs steps should be 26%, with the magnitude of each step carefully chosen to give the correct minimum change in conventional "exposure steps". Larger or smaller intervening steps are not necessary and should not be accepted.

Can all combinations of mAs and kV be used?

All available mAs settings cannot be combined with all kV settings because this would damage the tube. The load characteristics of the X-ray tube should be programmed into the generator-control to prevent combinations which would overload the X-ray tube. The shortest possible exposure time for each kV setting should be chosen automatically and it is not necessary for the operator to know the actual time. It must be as brief as the system permits.

Conventional mechanical timers are not used in WHIS-RAD or similar generators. If a generator uses the technology known as "falling load" it is not even possible to calculate the exact exposure time, because most of the radiation is delivered in the beginning of the exposure and only a very small contribution is made after half a second. The "equivalent exposure time" (the time during which motion unsharpness may occur) is usually shorter than the real exposure time. When falling load technology is used, most exposure times are terminated within 1 second.

Any mAs setting which requires an exposure of more than 2.5 seconds should not be accepted. Apart from the likelihood of patient movement, prolonging the exposure is ineffective. It will not produce a better image.

Should there be a warning signal during an exposure?

There must be a warning when the X-ray exposure is actually being made so that the operator and patient know exactly when radiation is being produced. The best warning is **both a sound and a light on the control panel** or inside the operator shield.

What are "anatomical" controls and "thickness" controls?

Some X-ray units are supplied with preset exposures related to the anatomical part to be radiographed, e.g. skull, lumbar spine, etc. with an overriding control to vary the exposure for patients who are smaller or larger than average. In other units, the control settings are based on the thickness of the part to be radiographed, measured in centimetres

With all preset exposure settings, some flexibility is essential, especially when using films, because preset exposures will not be satisfactory in every department or with every population. To get good quality images, all preset exposure settings will need to be checked by a trained radiographer in the actual department, using the same films and screens or the same receptors before being used by a less experienced operator.

Another difficulty with ordinary generators (non-multipulse) is that they do not reliably deliver the same exposure each time. There is too much variation between each exposure, even when the control settings are the same.

No pre-set method of exposures will be satisfactory with a generator which is not a multi-pulse frequency convertor generator. With any generator, there must a simple way to adjust preset exposures.

What is automatic exposure control? Is it necessary?

X-ray equipment can be fitted with ionization chambers which automatically measure the amount of radiation which goes through the patient and will shut off the exposure when there is sufficient radiation for a good quality film. These are expensive additional items and are not always reliable. When the unit has an X-ray tube which is maintained at a fixed distance from the X-ray film, (a fixed focus-film distance), and a multi-pulse frequency convertor generator as in the WHIS-RAD, an automatic exposure control is not necessary. Ordinary generators also do not need automatic exposure controls in a small X-ray facility.

Automatic exposure controls are not recommended in small hospitals and clinics.

How are X-ray tubes supported?

There are seven basic designs for tube supports used in general radiography (specialized stands excluded):

- A. A movable column mounted on double floor rails, with a movable horizontal cross-arm for the X-ray tube. **This is a floor tube stand.**
- B. A movable column mounted on a single floor rail having a stabilizing ceiling rail and a movable horizontal cross-arm for the X-ray tube. **This is a floor-to-ceiling tube stand.**
- C. A ceiling-suspended telescopic tube support moving on ceiling rails. **This is a ceiling tube stand.**

D. A column integrated with a complete X-ray generator, mobile on wheels as a unit (designed for use with patients who cannot be moved to the X-ray department).

This is a mobile X-ray unit.

E. A column fixed on the side of an X-ray table (either the column or the table top or both can be moved). **This is an integrated tube column.**

F. A fixed column with a straight, balanced swiveling arm, movable up and down the column, carrying the X-ray tube and a cassette holder at opposite ends: or-

G. As above but with the swiveling arm shaped like an S or like a "prone question mark".

DIAGRAM. **These are versions of the WHIS-RAD stand shown in figure 2.**

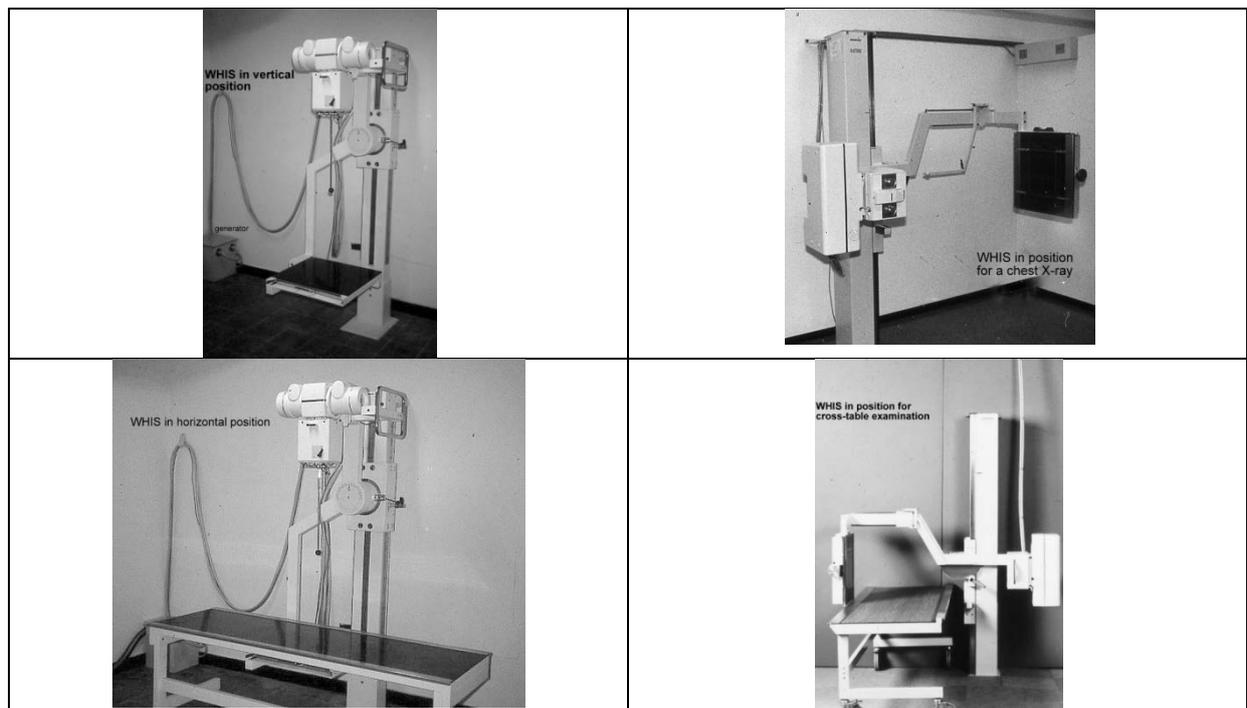


Figure 2: The WHIS-RAD stand in different configurations

Design C requires reinforced ceilings.

The mobile unit D is not acceptable.

To get good results, designs A-E are better with the skills of a qualified radiographer. Designs E and F are limited in use and several basic X-ray projections cannot be made. Design G can be used by almost anyone with short training.

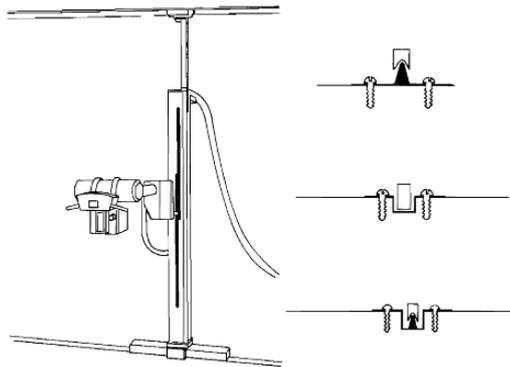


Figure 3: Tube support for design B.

Which is the best tube support?

The last design (G), described above, a fixed column with a tube on an angulated cross-arm (the "prone question mark" or "S" shaped) moving vertically and rotating on a central axis, is specified by WHO as being the best for small hospitals and clinics (see figure 2). The X-ray tube is held at one end of a long arm and the cassette/receptor holder is exactly opposite, on the other end of the arm. The supporting vertical column must be fixed to the floor and may be steadied by a bracket to the wall or up to the ceiling. A bracket attached to the wall is usually satisfactory. Standing the column only on the floor without lateral or ceiling support is usually not sufficiently rigid unless it has a very wide base (about 1sq.m or 1sq yard) which can be firmly fixed to the floor.

What tube supports are NOT satisfactory?

The most unsatisfactory equipment for a small hospital is mobile (on wheels), in which the tube column is mounted on the same base as the generator and the control unit: unfortunately it is often chosen because it is cheap and seems simple. The main

disadvantage is that it can be moved around freely in relation to the patient support (the X-ray table) and often needs to be repositioned, particularly to examine chests. It is difficult to centre directly onto the part of the patient to be radiographed and it is very easy, while moving it, to get the tube misaligned. It is almost impossible to routinely centre the X-ray beam correctly to the anti-scatter grid and it is also very difficult to maintain the proper focus-film distance.

Another disadvantage of a mobile unit is that the controls are on the same base as the tube column, so that the operator cannot stand very far away from the tube and the patient while making the exposure unless the control switch is on the end of a long cable. In daily use, the operator is more likely to be exposed to stray radiation because there is no protective screen. The risk of radiation exposure is variable and difficult to estimate because the tube can be very easily off-centered from the cassette, the angle and distance may be varied and the unit can be moved around the room.

In addition, not all of the X-ray generators supplied with this type of mobile equipment meet the multi-pulse frequency convertor, 12kWs specifications of WHO. Mobile units have only one real advantage: they can be used in another part of the hospital, but there are so many disadvantages that in small hospitals it is better to bring the patient to the X-ray department than take the X-ray equipment to the patient.

Although less expensive than most fixed units, a mobile X-ray generator should NOT be chosen for a small X-ray department and should not be used by anyone who is not a fully-qualified radiographer (X-ray technician).

What are the advantages or disadvantages of a single tube column on a rail?

A single column mounted on a rail or rails on the floor (see figures 3 and 4) (the rails may be recessed or above the floor level) with the top of the column steadied by a ceiling rail may be satisfactory, but there can be many difficulties. The ceiling may have to be reinforced and both the ceiling and the floor rails must be exactly parallel throughout their length: any variation in height will make the support unsafe. Floor-to-ceiling tube supports are usually adjustable from about 270 cm to 360cm (about 9-12ft): their installation requires care and expense, and derailment can occur if they are not properly maintained. This may cause injury to the patient or anyone else in the room, as well as to the tube support and the X-ray tube. Rails which are recessed into the floor become filled with dirt and must be cleaned regularly. When the rails are above the floor, they form a hazard and prevent the free movement of any wheelchair or trolley. Most importantly, all types of floor-rails require the floor to be exactly level, and this may not be easy to achieve.

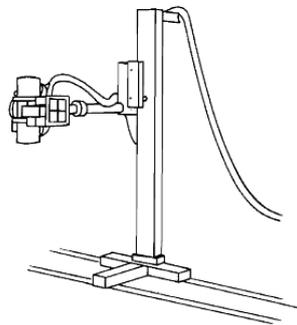


Figure 4: A floor rail mounted tube.

This type of tube column will need an additional and separate chest cassette holder, which is an extra expense, particularly if supplied with a moving anti-scatter grid (a Bucky). This combination was very popular in the past, but for small hospitals has been replaced by the more advanced design of the rotating arm used in the WHIS-RAD. Apart from being easier to use, the WHIS-RAD-design maintains fixed focus-film distance and centering.

What are the advantages or disadvantages of an integrated table and column ? (fig 5)

The integrated table and tube column is a satisfactory arrangement, but it will require a separate chest cassette holder which must be accurately aligned. Another problem is that most designs of integrated tables and columns cannot be used with the patient on a trolley or a bed unless the arm is able to rotate. To permit this movement, it will be necessary to have quite a large room so that the trolley (or, less easily, a bed) can lie at one end of the table with the tube above it.

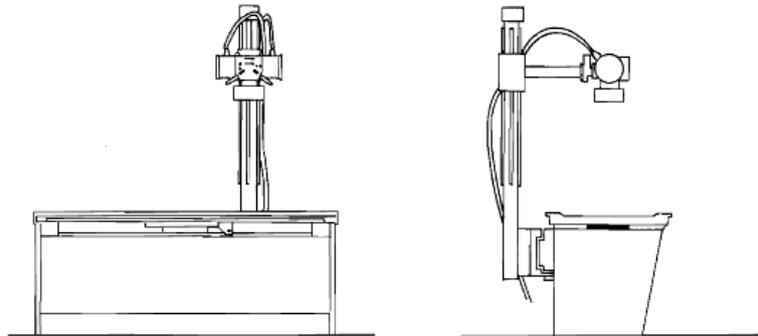


Figure 5: an integrated table and column

The integrated table and tube support are very rigid and satisfactory. If the majority of patients will be examined lying down, this is an excellent design, but in most small hospitals about half of all X-ray examinations are made with the patient standing or sitting, and this design is not very convenient.

What are the advantages of the WHIS-RAD design? (see figure 2)

This single column with a rotating "prone question mark" or "S"-arm does not require an exactly level floor beyond the base plate of the column. The base must be horizontal. The whole floor does not have to carry the weight of the equipment, so the part of the floor supporting the base can, if necessary, be strengthened locally. [The manufacturer's specifications should be checked before the unit arrives because there is a significant weight at the base of these columns.] **Installation** is easy and the ceiling is not involved. A single strong bracket is usually fastened to the wall to steady the top of the column. If the wall is

not very rigid, an extra supporting beam can easily be added. Installation can be completed in one day provided the floor has been checked and is strong enough to carry the weight. No other support is required for the tube column.

The patient support, a mobile trolley, will have to move freely across the floor, which, therefore, must be approximately flat. It must be firm, so that the wheels of the trolley move easily. It should be simple to clean and wash.

The radiation hazard is minimal with the WHIS-RAD design because the distance between the X-ray tube and the film holder is fixed and the centering of the tube to the cassette holder is accurate and cannot be varied. With the standard WHIS-RAD design, the primary radiation beam can never pass around the edges of the cassette holder. After passing through the patient and exposing the X-ray film/receptor the primary beam is absorbed in 0.8 mm lead in the back of the cassette holder, thus eliminating most of the risk of radiation from this source. The WHO specifications make these details clear.

It should be noted that there is a somewhat similar but **non-WHIS-RAD design** which allows independent angulation of the cassette holder and variation of the focus-film distance. It is very important to stress that these variations in geometry reduce the image quality considerably: when the focus film distance is altered, the exposure must change. Any variation of the geometry also upsets the focusing of the anti scatter grid relative to the X-ray tube and less radiation will reach the film. This affects the amount of scattered radiation, and the result may be an unsharp, underexposed and fogged image. The negative effects will be greater with increased change in the focus film distance, and especially when there is angulation from central alignment. **Angulation allows the additional risk of the primary beam passing beyond the cassette holder.**

Fixed imaging geometry simplifies and speeds up the use of the WHIS-RAD for general radiography: only a very small number of radiographic projections cannot be made with the standard WHIS-RAD. These few projections are only likely to be used in examining patients with severe trauma who cannot be moved.

The chest cassette holder is an integral part of a WHIS-RAD and extra radiation protection is not needed when radiographing chests. Other equipment designs may require extra radiation protection built into the wall behind a chest cassette holder.

What movements of the X-ray tube should be required?

For any type of tube support (including the WHIS-RAD) the specifications must require that:

The X-ray tube can be used with both horizontal and vertical beams and with angulations of +/- 30° from these directions.

- 1. It must be possible to examine recumbent patients on an X-ray table or a trolley with both vertical and horizontal beams, including the angulations mentioned above. Also included must be the transverse position with horizontal beam (e.g. the lateral decubitus view); this is an important projection which not all designs permit.**
- 2. It must be possible to examine patients standing or sitting erect with a horizontal beam, including +/- 30° of angulation.**
- 3. It must be possible to use a vertical X-ray beam to radiograph a sitting patient's ENTIRE arm (including shoulder) positioned on a small radiolucent support if necessary.**
- 4. It must be possible to lock the tube at any required height and in any given position.**

The WHIS-RAD design can meet all these specifications.

How is it possible to move a heavy X-ray tube to X-ray different sizes of patient?

The tube must move easily up and down if patients are going to be successfully radiographed. Because tubes and cables are very heavy, a counterbalance is required.

There are three basic balance mechanisms:

1. **Counter weights** supported by wires or chains that run over a pulley at the top of the column. **Simple counterweights are the most reliable.** The balance can be easily adjusted if a different (replacement) X-ray tube must be used later.
2. **Springs** can be of variable or fixed tension. They are usually combined with a cable running over a pulley with variable ratio. This combination functions very well, but may eventually become fatigued and adjustment is less simple. Direct support by a spring via a variable-ratio pulley is not acceptable. An automatic safety brake must be included in any of the designs using cables in order to provide protection if a cable should break.
3. **Electrically powered** movements in both vertical directions require a constant steady electrical supply and regular maintenance.

If the WHIS-RAD "prone question mark" or "S" arm support is chosen, the manufacturers use the same counterbalancing alternatives. Simple weights on a cable are preferred. It is better if there are two supporting counterweight cables because, as well as the X-ray tube, they must also hold the weight of the rotating arm, cables and the cassette holder. In any of the designs the cables can be satisfactorily replaced by chains running over a toothed pulley (a cog), but these will need more maintenance than a simple pulley.

Electric motors can work very well but are not recommended because they require electric power, more maintenance and are more expensive. If they fail, the whole unit will become unusable because the tube-arm falls and cannot be moved. When the electrical supply to the X-ray department is poor (or intermittent), a battery-powered generator can continue

to radiograph many patients but the batteries cannot be relied upon to supply sufficient electricity to the servo-motors which make the brakes work.

Columns with electric brakes and electric motors are certainly not necessary in any small hospital or clinic, and are a luxury even in larger departments. This design should not be chosen unless there is a reliable 24-hour power supply, a competent service engineer locally and a good supply of spare parts (see below).

<p>The WHIS-RAD does not use electrically powered movements or brakes.</p>

How are movements of the X-ray tube controlled?

All rotation and vertical movements of the arm supporting the tube must be controlled by brakes. There are two types:

1. **Friction brakes**, locked either by a simple lever or large knobs, or activated by an electronic (electro-magnetic) mechanism which applies the brakes when the power is off. Friction brakes are best. They should be operated by a simple hand-operated screw mechanism which will bring together large contact surfaces
2. **Locks with predetermined positions. These are not acceptable.**

Powered brakes add complexity and will require additional maintenance and repair. The brakes must be working all the time and cannot be used without an electrical supply.

Electric brakes will require an electrical supply to their auxiliary circuit. If there is no electricity the whole X-ray unit will be inoperable. If electromagnetic brakes are chosen, the switches should be positioned where they are convenient to use. These brakes are often less efficient, collect dirt and fluff and become unreliable. They have few advantages over hand operated brakes and, because of their complexity, are not suitable for small departments. They are almost always more expensive to purchase and maintain.

How are patients supported?

Many patients will have to lie or sit on an X-ray table to be examined. An X-ray table has a flat X-ray-translucent top, usually 2m (7ft) long and about 70cm (28ins) wide. This must be able to support at least a 120 kg (260 lb) patient without appreciable distortion. There are three varieties:

1. **Fixed:** this table is fixed to the floor, should be very rigid, and is usually mounted on four legs, but alternatively on a cantilever support. The cantilever design is usually not sufficiently rigid. This type of table is an old design but may be used with a floor-to-ceiling tube column. It can also be used with a mobile X-ray unit.
It cannot be used with a WHIS-RAD stand.
2. **Fixed, with a mobile floating top,** this type of floating- or sliding table-top may be mounted on four legs or on a cantilever support. The table top moves on ball bearings and can easily be pushed lengthways and transversally. The movements are usually controlled by electromagnetic brakes using hand or foot-operated switches, but mechanical brakes are available. This table may be used with any X-ray tube support except those with the tube and the cassette holder in a fixed combination (e.g, the WHIS-RAD). Moving top tables are very useful in a busy X-ray department but they add expense and complexity and require qualified maintenance. The electromagnetic brakes need a special power supply and should not be connected to an X-ray generator's battery-pack; **they are only suitable where there is a reliable and continuous power supply. They are not really worth the extra cost in a small hospital or clinic.**
3. **Mobile.** A mobile X-ray table is a trolley with an X-ray-translucent top supported on four legs with wheels, which should be on the corners of the table to make it more stable and less likely to distort. **There must be brakes on at least two wheels, one**

at each end of the trolley. The brakes should be mechanically simple and reliable friction brakes, which can easily be operated by a foot or by hand from a lever on the side of the table. The wheels must be at least 12cm (5ins) in diameter, with rubber treads/tires. Double wheels are an advantage. A mobile table must be without cross-bars which would prevent free access below the table, but must be able to support at least a 120kg (260lbs) patient without distortion. A mobile X-ray table is the only one which can be used with the WHIS-RAD.

Where are film-cassettes / receptors put under a patient?

Most stationary X-ray tables have a cassette holder which is always beneath the table top and is used in combination with a ceiling tube stand or an integrated tube column. It must be movable along the length of the table. Most of these cassette holders incorporate an anti-scatter grid, either stationary or in a Bucky mechanism.

The WHIS-RAD design includes a mobile X-ray table which does **not** have a cassette /receptor holder. The cassette/receptor and grid holder of a WHIS-RAD is an integral part of the tube support and can be used with or without the mobile patient trolley.

X-RAY FILMS AND CASSETTES CAN BE SUPPLIED IN CENTIMETRE OR INCH SIZES.

Secondary radiation grids are only available in metric sizes. The choice of metric or inch sizes must be decided before ordering any X-ray darkroom equipment.

(Metric sizes are more readily available worldwide and are NOT interchangeable with inch sizes)

CONSULT THE LOCAL X-RAY FILM SUPPLIER BEFORE SIGNING ANY CONTRACT FOR X-RAY EQUIPMENT.

If the cassettes and films / receptors/grids do not fit into their holders, you cannot examine patients.

How can patients be X-rayed erect (standing or sitting)?

All designs of tube supports, except the WHIS-RAD pattern, need a separate vertical cassette/ receptor holder for chest and other erect radiography. A vertical cassette holder must satisfy five basic requirements:

1. It must be strong enough to allow the patient to hold on to it for support.
2. It must be rigid and stable in any position.
3. It must hold all necessary cassette / receptor sizes.
4. It must be adjustable in height.
5. It must incorporate an anti-scatter grid large enough to cover all cassette / receptor sizes positioned either vertically or horizontally and focused at the distance used for chest X-rays (140-200cm, 55-80in). If a less accurately focused grid is chosen to allow use at variable distances, the quality of chest radiographs will not be as good.

There are three designs of erect cassette holders

1. Fixed to the floor and the wall.
2. Free standing.
3. The WHIS-RAD design.

Why must the chest cassette/receptor holder be fixed?

Many patients who need to have their chests radiographed are ill and unsteady on their feet: they will lean against or hold on to the cassette holder for support. The cassette stand must be strong and firm enough to support at least 75kg (165lbs) without becoming unstable. Many of these holders stand on the floor and are also fastened to the wall; an excellent design. The back of any cassette holder that is fastened to the wall must be at least 30 cm (12in) away from the wall to eliminate back-scatter (secondary radiation) from the wall. This space will also allow patients to wrap their arms around the cassette holder for support. If necessary, space can be achieved by additional wooden blocks between the

cassette holder and the wall: whatever method is used, fixation to the wall must be very firm, with additional floor fixation where possible.

Free-standing cassette/receptor holders, however supported, are not a good design because of stability. If they must be chosen, perhaps because the wall is not strong enough, they must be rigid, easily adjustable in height, have a wide base and be fastened to the floor so that they are stable when used for support by a patient.

When either the wall fastened or freestanding holders are used, the exact position of the tube stand for erect chest radiography must be marked on the floor to provide 150-180cm (5-6ft) anode-film film/receptor distance, matched to the focal length of the grid when incorporated.

The WHIS-RAD tube support incorporates the cassette holder and can be used in the horizontal position for all chest and other examinations with the patient erect and the X-ray beam horizontal. **No separate wall-stand is required.** The tube is always centred in exactly the right position and at exactly the right distance and height for any patient who is in front of the cassette holder.

Which is the best "erect" (chest) cassette/receptor holder?

If not using a WHIS-RAD design, choose a cassette stand which stands on the floor and is fastened also to the wall. The free standing design should not be chosen: it is too unstable.

Some cassette holders allow angulation of the holder from a vertical to a horizontal position. These added movements are not required in a small department, they will seldom be needed, and can be used only with a ceiling tube support or a tube support which runs on a rail long enough to move right across the X-ray room to the cassette holder. These extra movements increase the complexity and cost and are not recommended for small installations.

What is an anti-scatter or secondary radiation grid?

When an X-ray beam passes through a patient, most of the X-rays are scattered in different directions. If these aberrant rays reach the film/ receptor, they 'fog' and thus spoil the image. A "grid" is a metal screen that absorbs most of the scattered radiation, but allows the primary beam to pass without affecting it. The correct names are " anti-scatter grid" or "secondary radiation grid".

Grids are made in various combinations depending on the number of grid slots per cm and the thickness of the grid. Very thin metal foils (bars) separated by a rigid radiolucent material form the grid and may be parallel or focused around a standard radius (such as 100 cm, 140 cm, 180 cm, etc.).

Grids are always positioned between the patient and the film / receptor.

They can be stationary or oscillate sideways (a moving grid is often called a "Bucky" or Potter-Bucky). The movement blurs out the image of the grid lines during the exposure. This grid movement can be started mechanically or electrically.

A focused stationary grid is preferred in any modern X-ray department provided there are at least 40 grid lines per centimetre. The complex and expensive mechanism of a "Bucky" moving grid is unnecessary. Modern stationary grids are so fine that the lines will seldom be visible on the image, unless used at the wrong angle or an incorrect focal distance. This can never happen with a WHIS-RAD provided the grid is correctly installed and is of the correct 140 cm focal length.

When is a "grid" used?

An anti-scatter grid is necessary when the part of the body to be radiographed has a large volume, for example when examining the abdomen, the skull, the spine, the pelvis, the thighs, large shoulders or thick knees. A grid should **always** be used for chest imaging, except

in small children. A grid is never needed for the elbows, hands or feet; where the irradiated volume is small.

Grids can be separate, not part of the X-ray table and not in a Bucky. They are placed in front of the cassette, below the patient. They are usually lower ratio grids.

Can grids be damaged?

Grids are expensive and delicate. They are not always interchangeable between manufacturers, particularly those incorporated in a Bucky. **Grids cannot be repaired.** Some grids are separate items, of different sizes and focal lengths. They are the least expensive but easily damaged in routine use.

There are grid-cassettes, which have a stationary grid firmly fastened on to the front. They last longer, because it is not so easy to bend or damage them, but they may become loose. If they are dropped they are easily damaged and once the grid is bent it becomes useless. With proper care, even separate grids can have a long life, but when they are damaged, it is not possible to straighten out or repair a grid. In the WHIS-RAD, the grid is built into the cassette holder and is well protected: it is rarely damaged and will hardly ever need to be replaced

What is the "grid-ratio"?

The ratio of the grid is the ratio between the height and the width of the narrow spaces between the thin metal strips through which the primary beam can pass. The higher the ratio, e.g. 10:1, the better the resulting image quality but the focus- film/receptor distance must be very accurate with a high ratio grid.

Ratio 6:1 This ratio is used at bedside examinations without a proper cassette holder, a wide variation in distance is acceptable;

Ratio 8:1 This is a common all-purpose ratio used in X-ray units with a variable focus-film distance or with the possibility to angulate the X-ray beam;

Ratio 10:1 or 12:1 These ratios give the best image quality but require exact imaging geometry. Variable distances and angulation are not acceptable.

In the WHIS-RAD, the 10:1 ratio is best for radiography of the chest and axial skeleton. The grid in a WHIS-RAD is exactly focused for the focus-film/receptor distance of 140cm (55in). With non-WHIS-RAD units, the grid ratio must be reduced to 8:1. This will allow the grid to be used at distances between 1m and 1.8m (40-70in). However, this is a compromise and the images will have less contrast (they will be "grey" or "flat") and measurements on chest images may be non-standard.

How is a grid specified?

The grid must be at least the same size as the largest film. Grid dimensions are usually specified in metric units only, therefore the grid will have to be 43 x 43cm.

For general purpose radiography, all stationary grids should have at least 40-50 lines per cm. The focal length required will vary with the anode-film/receptor distance most commonly used. When different distances are likely to be used, e.g. from 100-180cm (40-70in), the grid should be focused at 135cm.

If the holder (**non-WHIS-RAD**) is used mainly for chest examinations, the focal length of the grid should be at least 150cm. All examinations on that holder, even non-chest, will have to be made at 150 cm (or whatever focal length is chosen for the grid). The grid under a horizontal examination table (with a floor-to-ceiling or ceiling -suspended tube stand) should be focused at 100-115cm. At that distance, grids incorporated in moving "Bucky" holders will have only 35 lines per cm, not the preferred 40-50 lines.

The WHIS-RAD has a fixed anode-film distance of 140cm, but to allow the cassette or receptor to fit behind the grid, the correct / exact grid focal length is 138cm.

The usual variable focus general purpose grid will have:

40-50 lines per cm, 8:1 ratio and 135cm focal length.

Grids for use in a chest holder will have:

40-50 lines per cm, 10:1 or 12:1 ratio and 150cm focal length.

Grids for use under a horizontal examination table will have:

40-50 lines per cm, 10:1 ratio and 110-115cm focal length;

(If incorporated in a Bucky, they are usually only 35 lines per cm).

The WHIS-RAD specifications require the grid to have:

40-50 lines per cm, 10:1 ratio and 138cm focal length.

Sometimes these specifications may be changed by different manufacturers; however, film quality will be decreased if the correct grid (as described) is not supplied.

X-RAY TUBES

What are the advantages and disadvantages of the different types of X-ray tubes?

X rays are produced when electrons move at high speed across a vacuum and hit a target. The metal case of a diagnostic X-ray tube contains an inner glass vacuum tube (the 'Insert'). The electrons produced by the X-ray generator go across the vacuum from the cathode to the anode, and the anode becomes very hot. To obtain a good radiograph, a narrow beam of X-rays is needed so that the electrons are focused on to the focal spot; a small area of the anode. The higher the kilovoltage and the longer the exposure time, the hotter the anode becomes. To absorb so much energy, the anode is made as a rotating disc so that only a small rapidly changing segment of the periphery is the focal spot. This rotating anode can absorb a lot of heat and allows a short but very high-power exposure.

When the exposure switch is pressed to make an exposure, the anode starts to rotate but the electronic circuits prevent any exposure from being made until the anode has reached the correct operating speed. Then the exposure will occur. In some controls, there is a two-stage exposure switch. Depressing the switch half-way starts the anode rotating and then further pressure allows the exposure to be made; this is useful when a patient, especially a child, is restless, because there is no delay when the second stage is depressed; the exposure is immediate.

It may be possible to use a tube with a stationary anode, but its heat capacity will be too low for a modern generator. They are much less expensive but should not be purchased.

The smaller the size of the focal spot, the better the radiographic quality, but the lower the heat capacity. Thus the size of focal spot chosen will depend on the power of the X-ray generator. Rotating anode tubes can be supplied with a single or a double focal spot; the second spot being much larger, but the image quality is correspondingly less. Dual focus tubes are not necessary with the WHIS-RAD.

For the WHIS-RAD, or any multi-pulse frequency convertor generator, a single focal spot no larger than 1 mm is required, and 0.8 mm is preferred. The image quality from an 0.8 mm focal spot will be much better than from any focal spot larger than 1 mm.

For a single phase generator, a double focal spot is necessary, usually 1 mm and 2 mm, with resulting decrease in image quality.

How long should an X-ray tube last?

Rotating anode tubes have become standard items: a good modern rotating anode tube will often exceed 100,000 exposures and will last many years in a small X-ray department. The manufacturer should be asked to provide a written guarantee for a minimum number of

exposures (at least 20,000) and an inbuilt exposure counter. Multi-pulse frequency convertor generators give a more stable load on the tube and this should result in even longer tube life. While an X-ray tube may last 5-10 years, depending upon the workload, some tubes might only last a year or two. However, spare X-ray tubes should never be purchased to be kept in stock. All X-ray tubes deteriorate when not used.

Are there any 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). The manufacturer should certify this in writing.

What is the correct rating of the X-ray tube for each generator?

If the generator has a constant output (constant kV and constant mA) then the nominal maximum load of the X-ray tube should be twice the nominal output of the generator for 0.1s. Thus, for such an 11kW generator, the tube should have a rating (nominal peak load) of at least 22kW. However, if the generator uses the falling load technology (constant kV and falling mA) the tube rating can be the same as the output of the generator for 0.1s.

For a 30kW generator, the tube should have a 30kW rating.
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Is it possible to protect the X-ray tube against accidental overload?

The combination of the tube voltage (kV), tube current (mAs) and exposure time which can be used for an exposure with any X-ray tube is limited by the ability of that tube to absorb heat. All X-ray generator controls must incorporate automatic tube protection, either mechanically or electronically, which will prevent overload. The overload protection should **not** incorporate a fuse which needs replacement but an automatic circuit breaker which can easily be reset. In practice, the majority of control units have a simple system which prevents

overheating by turning off the power during a 30s cooling period. This is adjusted in the factory or by the service engineer to match the tube provided. The heat overload which results from too many exposures made too quickly, causing heat build-up, is unlikely to occur in small hospitals where there is no fluoroscopy, because it is not possible to make rapid repeated exposures. However, it is a wise precaution to avoid the maximum kilovoltage permitted by the X-ray tube (usually the same as the maximum which can be obtained from the generator).

Although reducing the exposure by 6% (e.g. from 125 kV to 120 kV) may increase the life of the tube, lowering the kV often spoils the image quality, making it necessary to repeat the examination. Use the recommended kV/mAs for every examination.

What should be indicated on the control panel?

The control panel should clearly show:

1. When the X-ray generator is **switched on** (Power on/off).
2. The **kV setting**.
3. The **mAs setting**.
4. When the unit is **ready** to deliver an exposure.(the anode is rotating at the correct speed). [
5. When the exposure is being made and X- rays are being generated.
6. When a battery-powered generator needs to be **recharged** and is re- charging its batteries.
7. When a capacitor-discharge generator is **fully discharged** (no power left) and is recharging its capacitor.

All this information should be indicated by **positive settings** on a dial or by positive meters or lights. A light on the control which goes "off" when the unit is "on" may be misleading because that bulb may be faulty.

The light or meter must be "on" to indicate positive information.

Where is the best place for the exposure switch?

The button or switch which starts generating X-rays (the exposure switch) must be an integral part of the control panel so that the exposures can only be made from behind the control area. The switch should not be on any cord / wire. A long connection may allow the operator to stand outside the protective screen and be exposed to radiation.

What are the requirements for X-ray cables?

The high-tension cables connecting the X-ray tube to the generator should meet all IEC specifications and should be suitable for the local climate: this is especially important in the tropics. They must be shock-proof, rodent proof and of high quality. The length required will depend on the layout of the equipment within the room, but must permit unrestricted movement of the X-ray tube. The supplier should be required to provide cables of the necessary length to ensure they are correct at the time of installation. **It is not permissible to shorten cables locally** because they are an integral part of the generator circuit. If the length of the cables is changed, the generator will have to be modified and this is a very complex and expensive process.

Arbitrarily altering the length of the high-tension cables could be dangerous.

All the connections at either end of the cables must be of standard design and interchangeable. It is wise to specify that the cables be rodent and damp proof.

Where do cables run in the X-ray room?

The cables must be carefully installed along the wall, above the floor so that they cannot be damaged or get wet. They may be covered in conduits or fitted to comply with local regulations. Some multi-pulse frequency convertor X-ray generators do not need external

high-tension cables because the high-tension generator is inside the tube housing. It is important to know this when ordering the equipment. In these generators there will be thick cables connected to the single high-tension tank which carry DC at 300-800 volts.

The alternative design, a combined generator and X-ray tube, is NOT recommended.

What are cones, collimators and diaphragms?

Scattered (secondary) radiation that has been reflected off or deviated from within the patient is a major source of hazard to staff and to others. It also reduces the quality of the radiograph. To limit this scattering, X-ray beam should be well defined and confined to the exact area to be radiographed. This may be done either by beam limiting devices such as circular or rectangular "cones" or by "collimators"; both are fastened to X-ray tubes, or in some models are interchangeable.

Square or circular cones are not common on modern equipment for general radiography. They are open ended metal cones, designed so that the beam of radiation is limited to a standard size, usually the size which exactly covers or is slightly smaller than the chosen film when the X-ray tube is at the correct distance from the patient. Unfortunately, because they can be detached, they are not always put back in place, exposures may be made without any beam limitation.

Any design using detachable cones and diaphragms should be avoided when specifying equipment.

What is a light beam collimator?

A collimator is a device which restricts the X-ray beam. It incorporates lead shutters which form diaphragms at two or more levels. Within the square 'box' of the collimator, one set of shutters is usually quite close to the X-ray tube, the others 20-30 cm from the tube focus.

Complex collimators such as those used in large X-ray departments incorporate multiple shutters and an internal light system, coupled with mirrors, providing a light which illuminates the exact area to be radiographed.

This type of light beam collimator is excellent but the mechanism is complex and can become inaccurate and troublesome: in some X-ray rooms the internal light may not be strong enough. Sometimes the light-beam becomes off-centered and does not match the position or coincide with the X-ray beam. Adjustment will usually have to be made by an X-ray engineer.

The bulb in all light-beam collimators will eventually need to be replaced. Light-beam collimators are helpful for many examinations but are not necessary or recommended for small hospitals unless there are service engineers readily available and the unit will be used by trained radiographers. They can be a continuous source of expenditure and maintenance.

The WHIS-RAD beam limiting device is designed so that should the operator forget to change the field size, the X-ray beam will always be within the area of the protective shielding behind the cassette holder. There can never be danger from the direct primary radiation beam of a WHIS-RAD, even if behind the cassette-holder. This design also limits scattered radiation.

When purchasing X-ray equipment, always choose a beam limiting device which is fixed in such a way that it cannot be removed from the X-ray tube, except by maintenance personnel. Never choose any design which allows radiography without beam limitation; preferably avoid detachable cones and inter-changeable diaphragms.

How can the operator be sure that the X-ray beam is directed at the correct part of the patient?

X-ray tubes fitted with a permanently attached collimator, which does not have a light inside, should have a pointer that can swing between the tube and the patient showing the exact centre of the X-ray beam. Using this, operators can easily be taught to "centre" the beam correctly. In the WHIS-RAD, the position of each size of film is marked on the front of the cassette holder and the part of the patient which has to be radiographed is positioned accurately within those limits. The pointer is an additional way to be sure that the most important part is in the center of the film/receptor. (The pointer is in position in the 1st picture of Fig.-2- page 84)

Collimators fitted with a light beam which illuminates the area to be examined are accurate as long as the light is working, but they are useless without a light. Because of their complexity, maintenance and the need for a continual electric supply, they are not recommended for small hospitals. When a light-beam collimator is not working properly, no patients should be examined.

The regulations of some countries require this type of collimator for all X-ray equipment: while this is not strictly necessary as far as radiation safety is concerned, the rules of each country must be obeyed. Moreover, the law will probably require that the exact alignment of the X-ray beam and the illuminated area is checked regularly. Light beam collimators are by no means fool-proof: they can be fitted to the WHIS-RAD.

What is automatic collimation?

Automatic collimators alter the size of the X-ray beam to match the size of the cassette which has been inserted into the cassette holder. These are not necessary, because in practice all X-ray beams should be narrowed to cover only the part of the patient being examined,

regardless of the size of the cassette. Automatic collimation is expensive and complicated. It is not recommended anywhere, and particularly not in small hospitals.

Automatic collimation will not limit the beam properly with a digital receptor.

CHAPTER 5 – DIGITAL IMAGING

The technology of digital imaging is improving and changing rapidly: this chapter provides an introduction to the basic principles from which the choice of digital systems can be made. If it is decided to install a digital system, all the information about the system being considered and the exact details must be fully discussed with the vendor. It is wise to have this information in writing, with a clear description of any warranties (guaranties) and exclusions.

Is there any difference in the specifications of X-ray unit using films or using digital images?

No, the power requirements, radiation safety and every other specification of the X-ray unit are the same. The exposure from any X-ray unit can produce either film or digital images with film/screen cassettes or digital receptors. There may be slight adjustments to exposure settings when switching from film to digital detectors to produce the highest quality images while minimizing radiation exposure. Replacing an existing film system with digital (retrofitting) is easier with some digital systems than others.

What are the main differences between the currently available digital systems?

The main differences are in the detector and how the X-ray image is stored and displayed. The X-ray energy, instead of permanently imprinting film, is stored temporarily by a synthetic plate or detector. The image is transferred from the plate to a computer file which is then sent to an archive and to a computer workstation where the images can be interpreted. The plate is then reset automatically for the next patient, which reduces recurring costs because most plates or detectors are reusable thousands of times if properly handled.

- **Direct digital radiography (DR)** is an advanced technology usually installed in busy medical centres. Like a digital camera, exposed images immediately appear on a

computer screen and much of the settings are automated. Unfortunately, the complexity of the electronics makes the price very high and the glass components are fragile. Not all current DR systems will fit easily into existing cassettes or cassette holders. This makes the DR systems unsuitable for most small hospitals, especially when there are not many patients and there are no trained staff or service engineers.

However, DR technology is evolving rapidly and portable DR-receptors are becoming available (2011) which may make the system more suitable for small hospitals, depending, as always, on the price.

- **Computed Radiography (CR)** Has been in clinical use for over 25 years and is currently the best choice for small hospitals for new equipment or to retrofit any X-ray system, especially a WHIS-RAD. It is (2011) less expensive than DR. The detector system uses image plates (“phosphor plates”), which fit into a cassette. The cassette must then be manually removed and placed into a special plate reader. In a few seconds, the plate reader’s output appears on a computer screen as an X-ray image and the image plate is erased and ready for the next patient. CR plates are available in the standard X-ray film sizes and the cassettes fit in standard cassette holders.

What are the advantages and disadvantages in everyday use between digital images and digital systems and traditional film-based radiography?

Film systems are the gold standard and understood by most people using radiology. Film systems also require less power and may be more operable in areas with unreliable power mains. The X-ray unit can run on internal battery backups for days, allowing examinations to be made so long as a manual darkroom is available. However, film supplies and developer solutions must be constantly replenished and can be costly. Developer solutions can be messy and toxic. Film must be physically archived and hand-carried to the doctor or radiologist.

Digital images can be sent to anyone in the world with internet access and can be viewed in multiple locations at the same time, which assists in collaboration between medical staff. The process of sending images to another site to be viewed is known as 'Teleradiography'. A standard for digital X-ray images called the Digital Imaging and Communications in Medicine (DICOM) standard was developed to allow medical imaging devices to share computer files between institutions and vendors. A DICOM file typically contains the patient information, study information (chest X-ray, leg X-ray, etc) and the image. The radiologist's or other doctor's report can also be integrated with the image. Images in the form of computer files can be saved to removable disks or permanent archive disks located locally or remotely. The collection of networks, archives, and display workstations is called a **Picture Archiving and Communication System (PACS)**. Storage of digital images takes much less space than film. Previous images for a patient can also be quickly retrieved from the archive for comparison. If the PACS is well designed and managed, images will never be lost and can be viewed on demand by anyone who needs them. However, digital systems require constant and reliable power, computer networks, storage devices such as archives, and high-resolution computer monitors for viewing images. Currently, 2011, digital systems are much more expensive to buy than film systems. The annual costs in small hospitals over a period of years are not yet known (see below). However, costs are changing continuously and written quotations should always be obtained.

Is any digital system best for a small hospital?

Currently (2011), CR is best for most small hospitals especially for retrofitting an existing system. It has optimal usage up to 40 patients per day in a small hospital or clinic provided there are at least two operators. One CR reader can manage the output from several X-ray rooms if the work increases.

DR is more expensive (2011) than CR, but costs are decreasing and DR may be best for a new installation.

Written quotations should always be obtained.

What is the approximate additional capital cost of a digital system?

A digital system (CR or DR) in 2011 has an initial cost higher than a film-based system.

For a CR system, in addition to the X-ray equipment, a CR plate reader and computers are needed. Depending on the size of the clinic and number of doctors, two computers may be sufficient. The prices can vary widely depending on the clinic needs and geographical location. Packaged systems are available from several companies. DR systems usually cost more than CR systems and are designed to work in only one X-ray room where a CR reader can support the output from multiple X-ray rooms.

To compare costs, a film system with an X-ray unit and a darkroom will cost (2011) approximately \$35,000 to \$50,000. The ability to capture images with a digital system is only part of the cost. The digital images need to be stored on computer disks or some sort of storage media and must be retrievable when needed using database software. In addition, the images must be viewed on a high-resolution computer monitor. A small packaged CR system with monitors, computers, one X-ray unit, and archival storage may cost between \$80,000 and \$100,000.

A DR system with one X-ray unit may cost between \$160,000-\$180,000.

One complete WHIS-RAD with a film system may cost between \$35,000-\$50,000 and digital capability can be retrofitted when cost permits.

How are digital images processed, recorded and stored?

DR images transfer directly from the DR receptor to a computer where they can be stored and/or viewed.

CR images must be scanned into a computer system using the CR reader-hardware which also erases the images so the CR plate can be used again. In both DR and CR, computerized image processing optimizes the image, but this processing takes place in the "background". This usually takes less than one minute. Digital images are stored on a computer hard drive

or removable media. Images can be archived remotely if network access is available.

Is a dark room needed?

No dark room is needed for digital image processing, but darkening the room may improve contrast while viewing images on the computer screen.

It is advisable to have cassettes, films and manual development in a simple darkroom available for emergencies such as extended power outages.

How long does it take to process a digital image?

It takes about one minute to scan, digitize, and erase a CR plate. It might take the operator or radiographer a few more minutes to enhance the image on the computer (if necessary) before sending to the doctor. DR does not have an intermediate processing step. The images are automatically digitized immediately after exposure.

How much computer storage is required for digital images?

A typical X-ray image is around 8 megabytes. When calculating storage needs, remember that many examinations have more than one image. In fact a safe rule of thumb is to calculate three images per examination or 24 megabytes per examination. A typical CD-ROM disk can contain approximately 650 megabytes of data or about 80 images (26-27 examinations).

How is the patient's name, date, hospital number recorded on the images? Who does that?

If the hospital has an Information System (RIS) that stores patient and order information, the patient's personal and clinical information can be transferred to the CR or DR console. If no RIS exists, the operator will enter the information on the CR or DR console keyboard before processing the plate (CR) or exposing the DR detector. This information will automatically be integrated into the DICOM image header and can be displayed on the display workstations with the image. The scheduling can be done by the requesting

physician or the radiology department staff. The operator would check that the information is correct at the time of the examination.

Can the quality of the image be altered once it is taken or is a re-examination needed?

The images on any monitor can be altered by the viewer to give more information, and to be better seen, unlike radiographs. When there is improper positioning or patient motion, a re-examination is needed.

It is important that the exposure information for a new digital system be calibrated by trained staff when installed, because the exposure techniques may differ from those used with a film system. Ideally, the patient dose should be recorded, but this is not essential and is not always possible in a small department.

What is needed to see the images in the X-ray room and in other rooms in the hospital?

Although the technology differs, both CR and DR systems will display the images on a monitor: the monitor in the X-ray room does not need to be of diagnostic quality and is usually included in the cost of the system. All monitors in physician viewing areas must be high-resolution, LCD flat panel monitors. These vary in price but can be expensive because control stations will also be needed in each area. The number of monitors required, the price range and specifications must be discussed and agreed in writing before purchase. All must comply with the DICOM requirements and the cost of any software or connections needed to transmit the images around the hospital and elsewhere must be stated and included. Costs are varying all the time, so written quotations must be obtained.

How are the other viewing units connected to the X-ray room?

It is recommended that a local area network (LAN) be set up. This can be implemented with existing wiring; otherwise a simple wireless LAN is straightforward and low-cost. If all computers are already connected to the internet, images may be transmitted via e-mail or other virtual private networking (VPN). It is important to be aware of data security and

encryption standards for your location, as patient data should never be transmitted in an unsecure fashion.

How is an X-ray examination requested in a digital system?

Ideally the request is placed electronically so that it appears on the operators X-ray console as a work list or workflow list. This is more straightforward if the clinic has an electronic medical record system (EMR). A paper X-ray request may be written as well and hand-carried by the patient to the X-ray ward. The operator will then enter the request before the X-ray is taken.

How does the doctor see the previous images and compare them with the new one?

When the images are properly requested and stored with the patient's medical record number (MRN), previous images may be retrieved from a PACS archive and compared side-by-side on the computer screen. An RIS/PACS system with adequate training will make this process straightforward for your staff. Talk to your digital X-ray supplier for software guidance and get written quotations.

Where is the digital processor situated in the X-ray room? How big is it?

The CR plate readers vary in size, but a small hospital version is usually no larger than a desktop printer or fax machine. It is best to place the plate-reader on a flat surface away from the X-ray system. Some may be wall mounted. Readers should not be placed in a busy area. DR systems have built-in processors.

Must a plate reader always be protected from radiation? Does it give off radiation?

Most CR plate readers are shielded from radiation but should be positioned somewhere safe from scattered radiation, such as behind the screen around the control panel. CR plate readers do not give off radiation.

Does a digital system need a power supply, from the mains or from batteries? Will it produce images if the power fails?

CR plate readers and computers need constant power while in use. A constant power supply, solar battery or backup generator is essential if the usual power supply is unreliable. If no power is available, the digital system will not produce images.

Does a digital system need a light, for day and nighttime use if there is good light in the X-ray room?

No extra light is needed other than enough to see in the X-ray room. It is often advisable to keep the lights dim to allow better viewing on the monitor.

Does a digital system need a desk or other writing space?

All writing can be done on the computer so a writing desk is not critical. A flat surface makes computer and CR plate reader's placement simple. These items may also be mounted securely to the wall or a sturdy shelf or rack.

How long will digital equipment and monitors last?

A digital system and the monitors should last 5-years with moderate use, but the monitors may deteriorate and should be recalibrated and checked for quality and luminescence at least every 2-years. See below for the effects of climate.

Will a digital system work if the room temperature is over 22°C or under 10°C. Does high/low humidity affect it?

Most CR plate readers will work in these temperature extremes. CR is less sensitive to environment than DR.

It is important to check the humidity range specified for your system. Some are guaranteed in up to 95% relative humidity. In extremely humid environments it is important to regularly check for condensation so that water droplets do not damage components or affect image quality. **When environments are extremely dry**, take extra caution against building up static electricity because a static discharge can damage your equipment or startle a patient!

Discharge static by touching a non-painted metal surface.

How is the digital image of a patient transferred to another hospital?

The digital image can be e-mailed or transmitted by the internet, following internationally recognize protocols for the permitted compression of the images. Otherwise, the image can be stored on a CD-ROM, USB-drive or other portable media. The least preferable option is printing the image.

Can an X-ray unit be converted from films to digital? What is needed and what is the approximate cost?

Retrofitting an X-ray machine to digital is simple with CR. The film cassettes are replaced with specialized cassettes holding CR image plates (Check the inch-centimetre sizes before ordering). The CR cassettes fit in any cassette holder and modification of the X-ray equipment is not needed. The CR plate reader and computer are also needed. For estimated costs, see page 112.

Can a digital cassette be used to take films if the digital system is not working?

No.. The CR sensors are much thicker than film so the contact of screen to film would not be correct. With conventional screen/film radiography, the screen reacts to the X-ray and produces light which exposes the film. The screens in the CR cassette are different and will not expose the film.

The exposures and techniques for CR may be different from those for film. Taking CR plates out of the cassettes would subject them to moisture and scratching. It is necessary t keep some film and film cassettes and a darkroom for emergencies.

CHAPTER 6: THE LAYOUT OF EQUIPMENT AND ACCESSORIES: INSIDE THE X-RAY ROOM

It is very important to position the X-ray equipment correctly in the X-ray room because this helps to reduce the risk of radiation: it may reduce costs because additional radiation protection shielding may not be needed on the walls.

Where should X-ray equipment be placed in the X-ray room?

There are five basic principles in the layout of a diagnostic X-ray room: the first three: A, B, and C are not required for the WHIS-RAD, however they should be followed where possible.

- 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 doors or windows** if anyone can sit or stand outside. If unavoidable for some examination, e.g. for a cross table lateral projection, no one should be allowed to stand outside the door or window when such films are being taken, **Closing a window or an ordinary door does not offer radiation protection.**

For all X-ray units, including the WHIS-RAD:

- D The controls should be as far away as practical from the X-ray table and must be either in a specially designed control area for the operator or behind a protective screen.
- E The X-ray tube should always be at least 1.25 m (4 ft) away from any wall, door or window.

What is the main radiation hazard?

The main risk from radiation in any X-ray room is **from the primary X-ray beam and from stray radiation scattered off the patients** or equipment. The primary beam will be controlled if a WHIS-RAD is chosen. With ordinary equipment, additional shielding may be required. All X-radiation decreases inversely as the square of the distance: thus, distance is the most

important single factor in radiation protection. The actual position of each item of equipment is dictated by the room size and shape and the design of the equipment.

In what order should the X-ray equipment be installed?

A rough plan of the room will help installation (see figure 6). Most rooms will be rectangular, with the darkroom (if there is one) on a short wall.

Measure the room dimensions and draw in the components. **This is a non-WHIS-RAD room;** the basic layout can be reversed, left to right or top to bottom; the generator can be either side of the tube stand, depending on the cable-length.

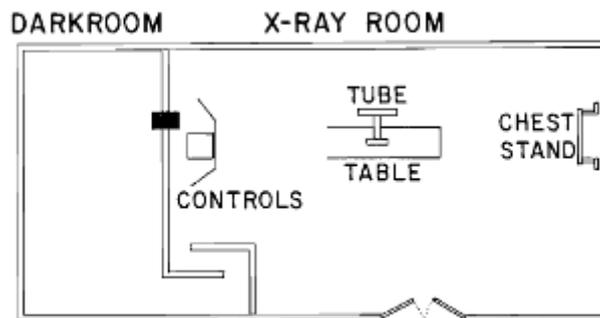


Figure 6: Suggested layout of X-ray room

With NON-WHIS-RAD X-ray units, the first item to be installed is the **chest cassette holder**. It must be positioned at least 30 cm (12 inches) away from the short wall furthest from the darkroom (or against an outside wall). It should be 1.5 m (47 inches) away from the long wall of the X-ray room which is furthest from the door (the window wall) When installed, it should be at least 30 cm (12 ins) from the wall so that patients can hold onto it.

Next, draw in the X-ray table. The centre of the table must be exactly aligned with the exact centre of the chest cassette holder. This should be 1.5 m from the long wall and 1.8 m from the position of the film in the chest cassette holder.

The X-ray tube stand is installed next, with any tube rails being located between the long wall of the room and the X-ray table. When the tube is exactly over the centre of the table it should be 1.8 m from the film in the chest cassette holder. If there is no Bucky or grid in the chest cassette holder, a shorter distance (1.4 m, 4.5 ft) is permissible. If the room is large, the distance can be increased, but the nearest end of the X-ray table should not normally be more than 2m from the film in the chest cassette holder. The tube rails must allow the tube to move beyond the end of the table. A movable platform to stand on, such as a box, may have to be provided for children and other short patients.

Normally there is a distance of about 60 cm (24 inches) between the X-ray tube column and the wall of the room. This is often the wall opposite the entrance door. In a standard size room this provides ample space to maneuver trolleys or wheelchairs or even beds alongside the X-ray table and under the X-ray tube. If there are tube rails on the floor, they must be on the far side of the table away from the door. There should be no rail or other obstruction on the floor between the door and the X-ray unit.

When locating any equipment but especially when it is not a WHIS-RAD, the generator and the control should be as far away from the table as possible. The generator is usually close to a wall or in a corner but can be outside in a separate small room if necessary. It must not obstruct the movement of trolleys, beds or wheelchairs in the room. The generator and all cables must not get wet.

The control should be close to the darkroom as is practical, as this is more convenient for the operator. It must always be behind a radiation protective barrier, with a lead glass or equivalent window so that the patient can be watched during the exposure. See figure 7 for an example of a radiation protective barrier. These layouts satisfy the basic principles. The X-ray tube is pointing away from the control area and the darkroom, and the distances are as large as possible.

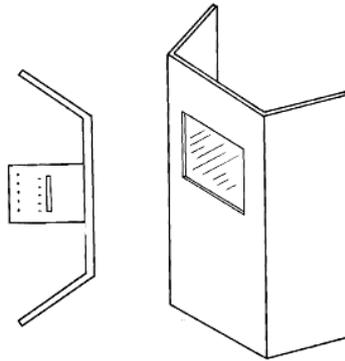


Figure 7: Design of a radiation protection barrier. The control panel is behind the barrier.

There are fewer problems with the WHIS-RAD design. The WHIS-RAD tube column is usually steadied by a bracket from a wall, preferably an outside wall, but the intervening space need not be as wide as with a standard type of column. Nevertheless, the distance from the wall to the centre of the tube column should not be less than 60cm (2ft) so that the trolley (patient support) can be positioned transversally to the horizontally positioned cassette/receptor to obtain a 'cross table' lateral projection as shown in figure 2.

The WHIS-RAD cassette holder is designed to absorb most of the primary X-ray beam so there is no significant radiation hazard behind the cassette holder. This makes equipment positioning less critical than for other designs. The WHIS-RAD can safely be in almost any position in the X-ray room, except alongside the control area. The patient support, a trolley on wheels, must be able to move freely away from the tube column.

Alternative layout

If the room is standard size or larger, has an outside wall and occupied space next to the short wall opposite the dark room, the chest cassette holder can be on the outside wall.

There are two requirements before this can be considered.

1. The X-ray tube must be able to turn so that it can point against the outside wall.
2. There must be room to maneuver a bed, trolley, a wheelchair next to the X-ray

table, without any intervening obstruction between the door and the table.

If these conditions are met, start the installation with the cassette holder 30cm (12in) away from the wall.

What other accessories are needed in an X-ray department?

There are many accessories which are essential in any X-ray room, even in a small hospital or clinic. Most can be supplied by the company which provides the X-ray equipment or can be purchased from an X-ray film supplier. To ensure familiarity and correct use, exactly the same items should be used wherever training takes place. Other than lead-protective aprons and gloves, (see page 38) the following are some of the more important:

1. At least **2 pieces of lead rubber** at least 0.25 mm lead equivalent and preferably more (0.5 mm-similar to the material used for the protective lead clothing) of dimensions 35.5 x 18 cm (17 x 7 inches). These are used for subdividing the films/receptor to take more than one projection on the same film.
2. **Foam pads**, of X-ray translucent and washable material to support the patient. They are used when it is necessary to lift the patient's head, position a hand accurately at a particular angle or hold limbs in the correct position. :
3. **A caliper** to measure the thickness of the part of the patient to be radiographed, which is the best way to find the correct exposure, particularly with frequency convertor, multipulse generators. Calipers are better than an anatomic exposure control in small hospitals and clinics. They must be large enough to measure the width between the hips of a large adult woman, at least 50cm (20inches). To correlate with the WHO Manual of Radiographic Technique, the calipers should measure in centimetres.
4. **Left and right markers**, (if not on a digital programme), It is important that the side of the patient is indicated on every X-ray image which is taken. For example, to locate the right kidney, it is important when looking at the image of the abdomen to know

which is the right side of the patient. If an arm is shown, it is important to know if it is the left or right arm; similarly, if both legs are fractured, it is necessary to know which films are taken of the right leg and which of the left. This is indicated on every X-ray image by small capital letters "R" or "L" (or equivalent in the local language).

There are many different types of "L" and "R" indicators, but at least two or three pairs should be purchased and kept in every X-ray room. If each pair of markers (L+R) is tied together with strings or tape, they are less likely to get lost.

Digital systems do not need these markers.

5. **Pillows and blankets** for patient comfort. If possible, sheets should be available to put on top of the X-ray table. Neither pillows nor sheets can have any painted or stamped name, pattern or number. These may show on the X-ray film and obscure an important detail or, on chest images, mimic a lung infection.

What drugs are needed in the X-ray room? Where should they be kept?

Emergency drugs may be needed in the X-ray room, particularly if contrast studies of the gallbladder or kidneys will be undertaken. The drugs should be kept in a LOCKED cupboard following all the usual hospital poison and drug-cabinet regulations. Local hospital regulations will decide which drugs are used for emergencies. There should also be:

1. Intravenous Saline with necessary connections for intravenous injection.
2. Sterile needles for the above.
3. Material for skin preparation, cleaning, adhesive tape etc.

Although the drugs may never be used, they should always be available in the department. The hospital pharmacist or chief nurse should check these every 3-months to make sure that they are all available and that they have not become out-dated. While not essential, it is helpful to have oral airways for adults and children available in the X-ray room for emergency

resuscitation, even if these can be obtained quickly from elsewhere in the hospital. If ever needed, they will be needed at once.

CHAPTER 7: THE DARKROOM: CASSETTES, SCREENS, FILM, PROCESSING EQUIPMENT

Care and attention to detail will yield better quality images and allow more patients to be examined each day. Many X-ray films are spoiled in the darkroom because the equipment has not been properly chosen, many accessories are missing or the layout of the X-ray room (and the darkroom) is not satisfactory. Money will be saved when films are not wasted.

What are cassettes?

Cassettes are light proof but X-ray translucent envelopes (cases) which hold X-ray films: they are made of plastic or metal such as aluminum (see figure 8). X-ray film can be spoiled (fogged) by ordinary light as well as by X-rays, so film can only be used in these lightproof cassettes (holders.) Within the cassette are two fluorescent screens and the film is put between them. When X-rays pass through these screens, they fluoresce (send out light) and the film is exposed by this light from the screens. There are 2 screens, because X-ray films have photosensitive emulsion on both sides, unlike ordinary photographic film which has emulsion on one side only. Cassettes are not used without screens and films are not used without cassettes.

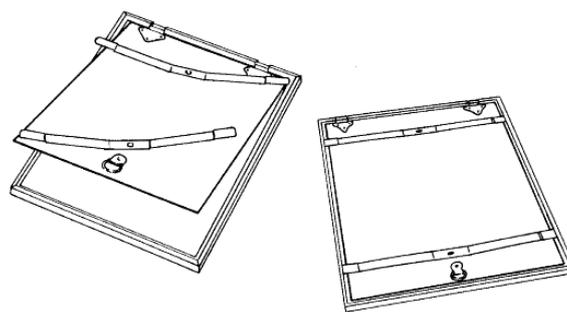


Figure 8: Film Cassettes

What are the specifications for cassettes?

X-ray cassettes and X-ray films can be supplied in centimetre or inch sizes. It is very important that the local suppliers of X-ray films be consulted before ordering any equipment because centimetre films will not fit properly into inch-size cassettes. Equally important, if manual processing is to be used, the hangers for the X-ray films must also be in centimetre or inch sizes, matching the films exactly. It is not possible to satisfactorily process X-ray films in the wrong hangers or to radiograph patients with the wrong cassette-screen-film combination.

Cassettes must be:

1. Strong and rigid, without warp (twist).
2. Lightproof.
3. Easily opened and closed in the dark.
4. Able to provide firm internal pressure, so that there is good and uniform contact between the film and both screens.
5. Durable.

Apart from keeping the X-ray film safe from exposure to light, the cassette keeps the fluorescent screens in close contact with both sides of the film. If there is poor contact, image detail will be missing on the resulting radiograph. To keep the pressure on the film, the best type of cassette has two spring steel straps across the width of the back, fastened centrally onto the back plate of each cassette and clipped under tension under two opposing edges. This pattern is the most durable, with the best pressure application. There is an alternative design of cassettes which have very slightly curved backs and these can provide satisfactory pressure.

The **back of the cassettes** should be radio-opaque metal and provide built-in protection against back-scattered radiation. Each screen should be fixed inside the cassette on a felt pad

to cushion the pressure. The best hinges are the long "piano hinge" design, running the full length of one side of the cassette. The alternative, small hinges and clip fasteners on one edge, may not be so durable, but with modern materials can be satisfactory. Cassettes should last five to seven years at least, perhaps longer, if kept carefully.

The only part of a cassette (other than the screens) that may require replacement is the felt under the screens, because it may become compressed or lose its elasticity: it may also be destroyed by a fungus or moths. The felt should last at least three years, often longer!

How many cassettes and screens and what sizes are required?

Every cassette must have a pair of intensifying screens (see next section). Each cassette size will have to have films of the same size: films are not usable in the wrong size cassette. The number of cassettes depends more on the number of patients to be radiographed every hour than on the total number per day. A small radiological facility examining 5-10 patients a day (1 or 2 every hour) needs two, or at the most, three of each of the following sizes:

Large	35 x 43cm or equivalent (14 x 17ins)
Medium	24 x 30cm or equivalent (10 x 12ins)
Small	17 x 24cm or equivalent (8 x 10ins).

An extra medium size cassette (24 x 30 cm) is useful because this is the most frequently used size, and will be worn out most quickly. Another useful size is 18 x 43cm, (7 x 17in) but it is not necessary to purchase more than 2 cassettes of this size. Additional cassettes will only be needed when there are more than 10-15 patients every day and there are two operators and automatic processing. Then the number of cassettes will have to be increased depending on the pattern of the X-ray examinations and on the number of patients per hour (for example, 20-patients from a busy chest clinic held 2 days a week).

Only consider specific cassettes for chest radiographs when there are a very large number of patients for chest radiography (30-40 per day). Matching film sizes, will be needed. These cassettes are really only useful for chest imaging, but before purchasing, make sure that the cassette holder can hold that size cassette. The choice between the two dedicated chest cassette sizes, 35 x 35 cm (14 x 14 ins) or 40 x 40 cm (16 x 16 ins), depends on the average size of the local patients: if in doubt, choose the larger. When used only for chest radiographs, the film-screen combination should have a speed of 200.

Before equipping any department with specific "chest" cassettes (4 are recommended) confirm that the matching films are available and that the cassette holder will accommodate the chosen size. Then mark each cassette "CHEST" to ensure that, apart from its size, the cassette will not be used for other examinations.

Summary of cassettes needed.

2 or 3 cassettes, size 35 x 43cm: 14 x 17in

3 or 4 cassettes, size 24 x 30cm: 10 x 12 in

2 cassettes: size 18 x 24cm: 8 x 10in

2 cassettes: size 18 x 43cm: 7 x 17in.

2 or 3 Specific 'chest' cassettes only if there is a busy chest clinic

What are intensifying screens?

Intensifying screens are thin, white, pink or cream boards with a smooth surface coated with chemicals which fluoresce (give out light) when X-rays go through them. They must be exactly the same size as the matching X-ray film and fit exactly into each matching cassette. The fluorescent light from the screen exposes the X-ray film. There is a "front" screen (the patient side) and a "back" screen in each pair and the X-ray film is put between the screens.

The screens are expensive but necessary because they reduce the amount of radiation required to obtain a good radiographic image. Although it is possible to radiograph a patient using an X-ray film without screens, the exposure will be at least 20-40 times higher.

Screens must be securely fastened inside the cassette. The front screen, which is the screen nearest to the patient, should be fixed on the inside of the front cover of the cassette without any intervening material. The back screen, always the one furthest from the patient, should be fixed on a felt pad on the inside of the back of the cassette. Some cassettes are supplied with plastic foam instead of felt. Most plastics will not last as long as felt. Glue must never be used for sticking screens to either felt or plastic, because chemical interaction may destroy the screen's fluorescent layer. Thin, double sided adhesive tape is satisfactory. Screens must never be loose. They must be carefully handled and the coated side of the screens should never be touched except when cleaning.

What is the coating on intensifying screens?

There are two different groups of chemical coatings which give either blue or green light. The films must be sensitive to the specific colour

'Blue' screens

- A. **Calcium tungstate**, gives off blue and ultraviolet light. High-speed" calcium tungstate screens have a speed of only 200 and a resolution that is a little less than 4 line pairs per millimeter.
- B. **Tantalum** has a much better resolution at the same speed.
- C. **Yttrium tantalite** also gives off blue light but is not recommended because it's combination of high resolution and high speed results in considerable background graininess due to the quantum noise.

'Green screens'

- A. **"Rare earth" metals**, such as **gadolinium oxysulphide**, give off a green light and are recommended for general radiography. They require green sensitive films.
- B. **Barium-sulphate**, has many disadvantages: the highest speed available is less than 200 and the screens age rapidly, especially in hot and humid climates. As these screens are repeatedly cleaned, the speed will decrease considerably. **Barium-sulphate screens are not recommended.**

What is meant by the "speed" of screens?

The screens and film together inside an X-ray cassette are a photographic system. The speed of a photographic system is related to the length of time needed to expose a photographic film to reach the correct amount of blackening. If the blackening can be done in a short time, the speed of the system is high. If it takes a long time, the speed is low. Anything that influences the time needed to produce a desired amount of film blackening is said to influence the speed of a photographic system. The X-ray film is exposed by light from the fluorescent intensifying screens. High-speed screens give off more light than slow screens allowing shorter exposure times.

Unfortunately, **the speed of intensifying screens is inversely proportional to their image quality.** If nothing else is changed in an imaging system, high-speed screens will give poor image detail compared with slow screens. Slow screens are often called 'detail screens' because they give the best image quality with smaller details.

High-speed screens require less radiation while detail screens require more radiation to give better image detail. There is one more aspect to consider. Detail screens may be so slow that the long exposure time needed may result in image blur due to patient motion. It is possible to find screens which give an acceptable image in most general radiographic

procedures, a compromise between loss in image detail (fast) and increase in exposure time (slow).

A screen combination used for universal purposes (general radiography) will have an intermediate speed and is usually known as "medium", or as "standard" or "universal".

Medium speed systems, have a relative speed of 200.

Using the same scale, a high speed system is 400 or more.

A "detailed" or high resolution system, has a speed of 100 or less.

Is the speed of screens the same for all exposures techniques?

Describing screens in terms of their speed is an over-simplification of a very complex phenomenon. **Most screens respond in different ways at different kV levels.** The screens which give off blue light (calcium tungstate or tantalum, the blue emitting screens) vary the least and respond at about the same speed at any kV level used in diagnostic radiography. The screens which give off green light (containing gadolinium oxysulphide)) respond best between 90 and 120kV, and are much slower at lower kV levels. For example, the speed of these screens at 50kV is approximately half the speed at 100kV. In practice, this is a great advantage because the thicker parts of patients require higher kV levels and, most important, the 120kV needed to radiograph the chest results in the shortest possible exposure time.

How is the resolution (imaging quality) of a screen judged?

Resolution is judged by the number of line pairs (pairs of lines) per millimetre which can be visually separated into a pattern of parallel lines which are the same width and separation. A medium speed system should have a resolution of 4-8 line pairs per millimetre. Because speed is associated with resolution, a high speed system will usually resolve less than 4 line

pairs whereas a detailed screen system will resolve more than eight line pairs. It should be noted that improvements in screens are being made all the time, and these are minimum definitions.

WARNING: Manufacturers do not always agree on terminology and one make of "fast" screens does not always match "fast" screens from another company.

Furthermore, if the screens emit green light the same 3 categories will all be about twice as fast as the blue emitting screens.

What are non-screen films?

It is possible to expose X-ray films without screens, using only X-radiation, and there are films specially made for this, called "non-screen" films. All X-ray films, including non-screen films, will be fogged by light, so they must be used in lightproof individual packets which do not contain screens. **Non-screen films should not be used because they require more than 10 times the patient dose** compared with ordinary screen-film combinations. They have a very high silver content and need individual packing, which makes them very expensive to buy and to process. The high silver content of non-screen films makes them more sensitive to background radiation, which makes their storage life much shorter.

There is no need to use non-screen films. They are not recommended and should not be supplied to small X-ray departments.

Can all films be used with all types of screens?

Incorrect matching of: blue films with green screens or green films with blue screens will halve the speed of the film-screen combination.

To get the BEST results, blue sensitive film should be used with blue emitting screens and green sensitive film used with green emitting screens

It is very important to know what type of films are available locally or, equally important, to be sure that, if requested, the type of film chosen can be supplied regularly. This information should be available before the type of screen is chosen. Screens are too expensive to change and will last several years. Films from one manufacturer can be used with screens made by a different company. However, films from different manufacturers may have different characteristics. The colour of the system, blue or green, is much more important than who makes it.

Wherever possible and if a constant supply is assured, choose green emitting screens and green sensitive films. Apart from other qualities, green sensitive film will last longer in storage.

Which screens should be chosen?

- A. **Fast or 'high' speed** screens are used mainly with a low-power generator. They are needed to image the spine or abdomen of very heavy patients.
- B. **High definition or 'detail'** screens are used when a great deal of information is needed. They require a relatively long exposure.
- C. **Universal or medium** screens are an acceptable compromise for all purposes, and **should be chosen for most small general departments.**

Before choosing the screens, it is essential to know what X-ray film is most easily locally available. What is the difference in cost between the two types of films (blue or green sensitive) and which type can be obtained consistently? If only blue sensitive films are

available, blue emitting screens must be chosen, but if this blue combination must be chosen, then either some extra high speed screens may be needed for spinal examinations of large patients or the generator must deliver at least 25 kW. Not all generators have this capability.

If green sensitive film is available, then green emitting screens must be chosen and the speed range of 250-320 is recommended as the standard screen. This will provide a resolution of 4-6 line pairs per millimetre. The maximum output of the generator need only be 16 kW with a green sensitive system. If green sensitive films and screens are used, but the generator has an output of 9-10 kW, choose the same 250-320 speed screens for general radiography but purchase one additional cassette with much faster screens. This should be 24cm x 30cm (10in x 12in) and approximately 500-600 speed which can be used when heavy exposures are needed, such as examinations of the lateral lumbo-sacral spine in large patients. The cassette fitted with these faster screens must be very clearly marked to avoid errors.

Recommendation:

CHOOSE Green sensitive film with matching green light emitting screens providing the 'green' film is always available.

Should screens in the department be the same speed?

If all the screens are of the same speed, many errors in exposure will be avoided. This will decrease the number of repeated films. If there are different speed screens in different cassettes, the exposures will have to be changed to match the chosen cassette, and it is inevitable that errors will occur. There are advantages to standardizing the screens not only in one X-ray department but throughout the whole region: this will probably reduce the purchase cost and will make quality control and training much easier. **It is very strongly recommended that all screens in any X-ray department be exactly the same speed and the**

speed should be shown on the back of each cassette.

There is only one exception; to meet the specific needs of lower powered generators, a large cassette with fast (high speed) screens should be available when they must examine the spine of large patients, or when ultrasound is not available for obstetrical examinations. The cassette fitted with these different speed screens must be clearly marked.

How long will screens last ? Can screens be damaged?

All screens, even those in cassettes can easily be damaged by dirt, moisture, chemicals, handling, scratching, etc. The manufacturer's instructions for cleaning, or those in the WHIS-RAD Manuals should be carefully followed. In small hospitals, screens should last at least three to four years, but they will eventually need replacement. Screens deteriorate over time, even if carefully maintained. This will slow their speed and alter the required exposures. If possible, all the screens in an X-ray room should be replaced at the same time, because the rate at which they deteriorate will vary.

When the surface of a screen is damaged, a significant mark appears on all the radiographs made with it, and this may then be misinterpreted or may obscure some abnormality in the patient.

In any X-ray department

- All screens (with one possible exception) should be the same speed, quality and age.
- Do not choose screens until you know the type of film available.
- Make sure that screens are of the correct metric or inch size.
- Mark the speed on the back of each cassette.
-

All the films in the department must be the same colour sensitivity, either blue or green.

All the screens must be of the same colour sensitivity as the films and all must be the same speed.

If films and screens do not match, there will be faulty exposures and costly repeat examinations.

How should X-ray films be tested for storage life?

The useful life of any X-ray film is dependent on storage conditions, particularly background (Natural) radiation, temperature and humidity. **Until films have been tested in the country where they will be used, the film life cannot be properly estimated.** Even under severe tropical conditions, **green sensitive film** should last for six months or more without appreciable deterioration. In less extreme climates, they may last a year or longer.

Blue sensitive films deteriorate a little more rapidly. If refrigerated storage is not available and if the climate is hot and humid, test the films before purchasing in large quantities, unless the storage life is already known locally from previous experience, or is guaranteed .

To test storage life, get several boxes of films of different sizes. Put a few films from each box in cassettes, place an approximately 4-5cm (2inches) thick book on the cassette and expose them using the normal exposure for an adult wrist. Process the exposed film in fresh chemicals, using standard temperature and time controls, or through an automatic processor. The unused films should then be resealed in their box and left on the shelf in the storage room. Other films from the same boxes should be exposed after three months, and again others after six months using the same exposures, the same book and the same X-ray equipment. The films should always be processed using the same techniques, with fresh chemicals. Comparison with the original set of films (taken when the box was new) should then be made to assess deterioration.

How are X-ray films supplied?

X-ray films are usually supplied in boxes containing 25, 50 or 100 films per box. Unless the X-ray department is very busy, the smaller boxes, containing 25-50 films are recommended for small hospitals. If there are a sufficient number of examinations per week to provide a rapid turnover of film, order larger boxes as soon as the pattern of work is known. Manufacturers can provide films in "tropical packs" with special interleaving and wrapping materials suitable for unusual heat and humidity, but this is seldom necessary.

How should unexposed (new, unused) X-ray film be stored?

When the X-ray film boxes are received in the X-ray department, **the delivery date and the expiry date of the film should be written on every box** (the manufacturers supply the expiry date.) To avoid damage, **boxes of unused films must be stored vertically** (like books in a library) and must **not be stacked flat, heaped upon each other**. The space between the shelves must be high enough for this vertical storage, at least 40cm (16inches). X-ray films are very heavy and shelves must be strong, with supporting brackets not more than ½m (18 inches) apart. The weight on the shelf will be as much as 200kg per metre (100kg per ½m) (136lbs per foot). This is many times heavier than most books! Shelving for unused film must

be built where there can be no risk of radiation, moisture, chemicals or fumes which may affect the unused films. Excess heat, e.g. from a hot water system or kitchen, must be avoided.

Are film sizes measured in centimetres or inches?

Film can be supplied in either centimetre or inch sizes and the cassettes and hangers must match them. They are not interchangeable. Only one system, either centimetre or inch, should be used in any department: centimetre sizes are probably the most common, but local inquiries must be made to find out what is consistently available locally.

Cassette sizes must match film sizes exactly. Centimetre size films will not fit into inch size cassettes (or hangers) and vice versa). Specify which system is to be used based on the advice of the most reliable local X-ray film supplier. This must be known BEFORE the X-ray equipment is ordered because the cassettes must fit into the cassette holder and the films must fit the cassettes and hangers. It will be expensive to change from inches to centimetres or from centimetres to inches at a later date and it may not be possible to alter the X-ray equipment satisfactorily.

What film sizes (and cassettes) are needed?

This is described fully in the section on "How many and what size cassettes are required?" (page 127) The correct film size for each examination is explained in the WHO Manual of Radiographic Technique, and is part of radiographer or operator training. Films can be divided by using lead-rubber sheets so that more than one image is on a film, for example, AP and Lateral views of a forearm.

If the unit has a light beam collimator and is being used by a trained radiographer, additional film sizes can be added and will depend on the most common type of X-ray examination

locally. This should be based on experience and additional sizes added as the workload becomes known. Most departments tend to have too many different sizes!

How are X-ray films developed / processed?

There are two ways to process X-ray films: manually (by hand) or with an automatic processor. Both need a "dry" work-bench in the darkroom, safe lights, storage for film and perhaps a film marker. The difference is that **an automatic processor needs a continuous electrical supply whereas manual processing can be continued when no electrical power is available.**

Both methods work best when there is running water, although both can work with water which is changed or refilled regularly. It is preferable to have hot and cold water, although water heaters can be supplied for either method.

Which should be chosen: manual or automatic processing?

Automatic processing is helpful when more than 12-15 patients are radiographed most days. One WHIS-RAD operator (or trained radiographer) working alone cannot examine more than 12-15 patients daily unless there is either an automatic processor or additional trained help in the darkroom. If the hospital or clinic needs more than 15 patients radiographed per day, has a good water supply and a constant electrical supply, then automatic processing is an advantage, but it will not process films without electricity.

The advantage of automatic processing is a finished and dry film in about three minutes so that more films can be produced per hour. **The disadvantages** are that automatic processors are expensive and if the electricity fluctuates or fails, no films can be processed. Much more routine cleaning and maintenance will be required. Unless there is an entirely reliable electrical supply in a small hospital, it is a wise precaution to have back-up manual processing and manual chemicals available to provide a continuous X-ray service, particularly if the X-ray generator is battery powered and can work without electricity.

Manual processing is simple and reliable although, unless done very carefully, films may suffer minor damage (scratches, etc.). For a small hospital, manual processing will work well and is less expensive.

Are there many different automatic processors?

Automatic processors vary in size, complexity and installation requirements. The largest are capable of processing several hundred films per hour, which is far more than are usually needed in a small hospital. Some automatic processors produce a lot of heat, and some may need to be installed partly through the wall of the darkroom. Big processors usually need regular servicing by specially trained technicians. **This type of equipment is not recommended in a small hospital.**

Some commercial automatic processors are quite small: they are usually called "table-top processors". They can be placed on a table in the darkroom, connected to the electrical supply and to a drain and provided with chemicals and water (as specified by the manufacturer of each unit). Running water is preferable, but not essential. The films will then be processed and dried within a few minutes. **[Make sure a film drier is incorporated.]**

All automatic processors, even small ones, are expensive and the larger units may equal about 25% of the cost of the whole X-ray installation. They are more complex than manual processing, water and electrical power needs are more critical and electricity must be continuous. More frequent maintenance is needed, including daily cleaning of some parts of the processor. A special mixture of chemicals is required for automatic processing which can, with proper dilution, be used for manual processing, but manual processing chemicals cannot be used with an automatic processor.

What is manual processing?

"Manual" or "hand" processing is the traditional way to develop films, particularly in small departments. In the darkroom, the films are attached to hangers and are moved by hand at timed intervals through a series of chemical and washing tanks. The chemical mixtures and

processing temperature are less critical than in automatic processing. Manual processing is easy to teach and requires little maintenance. The main disadvantage is that when films must be viewed quickly, they will still be wet. Another disadvantage is that films can be damaged during manual processing, as scratches or other marks may be made on the surface of the films. But, when there are less than 10 patients a day, automatic processing is not really necessary, and the additional expense is not justifiable. Manual processing will be entirely satisfactory. If the number of examinations increases, additional help in the darkroom (a darkroom technician) may be cheaper and more reliable than an automatic processor, and when not busy, that additional person can help with clerical work, record keeping and film filing. The technical details are given in "The WHO Manual of Darkroom Technique" (WHO, Geneva) and below.

What equipment is needed for manual processing?

The darkroom must have a large master processing tank fitted with two insert tanks for chemicals; one for developer and the other for fixer. (see figure 9).

Master tank: there are three alternative materials for the master tank:

1. Locally made concrete or waterproof plaster, tiles, etc.
2. Stainless steel of chemical resistant quality.
3. Plastic.

Although plastic tanks are cheap, many plastics do not last and they are not always easy to keep clean. Some plastic processing chemical tanks are supplied without a master tank, each standing freely in a row or on a wooden rack. These tanks tend to distort and crack, and there is always a problem of keeping the additional washing tank clean because running water is not normally used. Temperature control of the solutions is difficult. These individual tanks are heavy when full, they are not easy to move and the chemical solutions can damage clothing. As far as plastic tanks are concerned, there are two recommendations:

1. Do not buy any type of manual processing system which does not have a master tank surrounding the chemical tanks with water. (The master tank can be of another material and can be locally made, see below).
2. Large master tanks made of plastic, with plastic chemical insert tanks, do exist and if the material is sufficiently tough they can be satisfactory. They are not always readily available and, if such tanks are offered, the material should be carefully inspected. Unless it is very tough it will prove to be a poor investment.

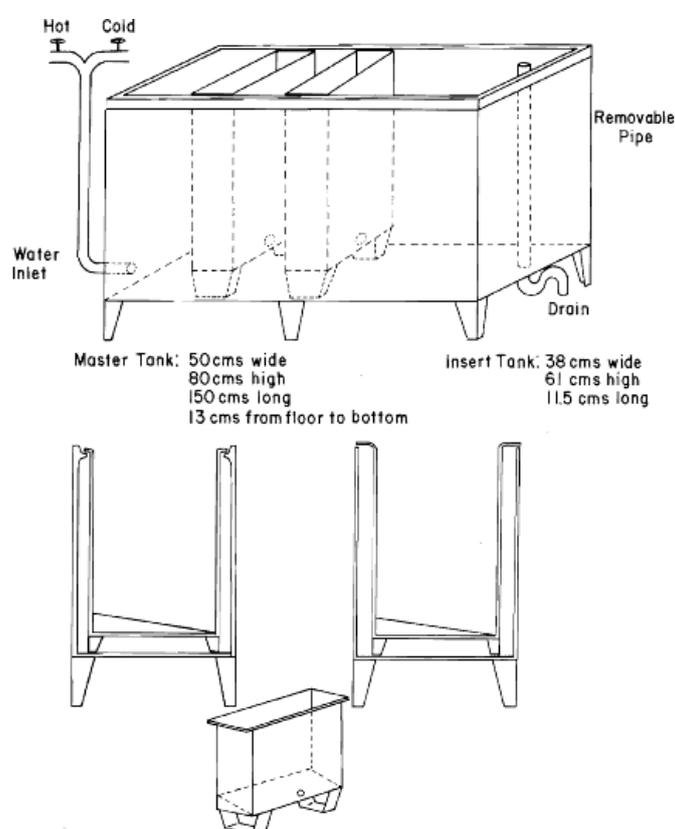


Figure 9: Tanks for the darkroom

A satisfactory master tank can be made locally from concrete or brick. The inside should be smooth and the edges and the long side nearest the operator should, if possible, be tiled or smoothed in some way. Tanks which are rough on the outside will damage clothing and may scratch skin. **Because of the chemicals, every effort should be made to avoid any possibility of skin injury** to those working in the darkroom.

Commercially made stainless steel tanks are preferable but they MUST be manufactured of special 18 gauge chemically resistant steel. Any other quality of 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. American Iron and Steel Institute (AISI) type 316 or 317]. When the tank is made, the steel must be welded with electrodes of the same type number. This is an essential requirement and must be guaranteed in writing by the supplier.

What is the size of the master processing tank for manual processing?

Figure 9 shows the dimensions of the master tank for any material. The water supply should come in at the bottom, preferably with the controlling inlet tap (faucet) close to 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. Preferably, the water should be allowed to run continuously while the tank is in use, draining through an overflow pipe at the opposite end as shown in the diagram. If running water is not available, the water must be changed every working day to prevent the expensive X-ray films from being spoiled. The controlling water taps (faucets) must be offset so that when films are lifted out of the tank the hangers do not catch on the pipes or handles. 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. The drain pipes from the master tanks must also be made of chemically resistant metal, heavy duty plastic or earthenware. Other materials will leak after a few months of use. Care must also be taken that the water draining from the tank does not damage any part of the main hospital drainage system or surroundings. There will be a lot of caustic chemicals in the drainage water from any X-ray film processing, manual or automatic.

What are the "chemical insert tanks"?

Separate tanks are required within the master tank to hold developer and fixer(fig:9) As recommended for the master tank (see above) stainless steel of the highest quality specified 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. Plastic tanks become deformed or cracked and have a much shorter life. They are cheaper in the beginning but definitely not so satisfactory and do not last so long. The size of the tanks is indicated on the diagram (fig:9): they must fit firmly into the master tank. Each should 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 a rim resting on the sides of the tank. They will be heavy when full of chemicals.

What is the size of the insert tanks for developer and fixer?

All insert tanks must be large enough to hold all sizes of X-ray film hangers. They must be suitable for holding the largest film size, 35 x 43cm, (14 x 17inches). The size of insert tank shown in the diagram will hold five or six films simultaneously. The X-ray films will be in the developing tank for 3-5minutes at standard temperatures, and 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 or larger insert tank for fixer should be purchased. The washing space shown in the diagram will accommodate 30 or more films in hangers and usually allows a washing time of at least one hour, preferably with slowly running water.

What are "combined" processing tanks? Are they satisfactory?

Small processing units are available which may seem to be an attractive compromise. They have a master tank which is much smaller than the size specified in figure 9: The insert tanks are situated at either end, and are often an integral part of the master tanks. Films are washed in the centre between the developing and fixing tanks: the same water is used to

rinse the films between the developer and fixing stages and also for washing films after they are fixed.

The smaller "combined" processing units can only process 2-5 films per hour (one or two patients) and may slow down the work in the whole X-ray department. The chemical tanks are small and only two or three films can be processed at any time. The washing space is small and will become rapidly filled with hangers and films if more than two or three patients are being examined or even if any one patient has multiple examinations. Films will then get scratched or even stuck together while washing. If the films are not properly washed after processing, some chemicals remain and the films will be spoiled after a short time in storage. Although they are cheaper, they are a false economy.

If more than two or three patients are radiographed in an hour, the small combined processing units will be unsatisfactory. They are not really a good investment even in a small clinic or hospital, because the number of X-ray examinations will always increase.

Is there any need for a "wetting" solution?

It is sometimes difficult to dry films in hangers, even when there is an electric dryer and films may be marked if they dry unevenly. It used to be recommended that a rinsing solution containing a wetting agent should be added for use before the films are hung to dry. This recommendation is very seldom followed today: it is an additional complication and it adds very little to the final result. It also needs an extra small insert tank, adds expense and time without equivalent benefit. **A wetting solution is not recommended for manual processing.**

What is a "stop bath"?

Some of the older processing manuals recommend the use of an additional acid 'stop bath' which will immediately stop further development of the film (by neutralizing the alkaline developer). It also has a positive result because it conserves the fixing solution. However, an

additional insert tank will be needed: the solution must be monitored so that it remains sufficiently acid and it will take up space in the master tank. **A "stop bath" is not recommended. It is an additional complication which is quite unnecessary in the normal practice of small hospitals and clinics.**

Do processing chemicals have to be kept at a certain temperature during use?

Processing chemicals should be kept as close as possible to 20°C (68°F.) In hot climates this can be difficult. It is expensive and seldom practical in a small department to cool the incoming water supply through a refrigerated water cooler which will require a good electrical supply and is costly to use and maintain. It is better to use special chemicals which will work in the local average ambient water temperature, even in hot climates.

What is the normal temperature range for processing chemicals?

Standard X-ray chemicals work between 15° and 24°C (59° and 78°F) but the optimum temperature is 20°C (68°F.) The developing time will then be 4½minutes. When the chemicals are too cold, they can be heated in three ways:

1. By hot water from the hospital supply running into the surrounding master tank. (not into the chemical tanks)
2. From an immersion heater specially designed for X-ray work (see next section).
3. In an emergency, by direct heating (see next page).

The easiest and safest way to heat chemicals is connect the master processing tank to a main hot water supply, so the tanks can be warm when necessary.

Are there immersion heaters suitable for X-ray chemicals?

Electric immersion heaters must be especially designed for X-ray chemicals, because X-ray chemicals will very rapidly destroy the outer casing of ordinary household immersion units. This can be very dangerous to personnel who may be electrocuted when they come into contact with the water in the tank or are lifting the films out of the insert tanks. All immersion heaters should be turned off whenever films are being processed.

An immersion heater needs a satisfactory electrical supply. Power cannot be supplied from batteries.

How can cold X-ray chemicals be heated in an emergency?

Hot water cannot be added to the chemical tanks because this will dilute the solution and the films will not be properly processed. It requires a considerable amount of hot water to heat up the surrounding master tank. In an emergency, when only a few films are needed, very hot water can be put in a suitable container, such as a large glass bottle or a "hot-water bottle", and directly submerged in the insert tank. The effect does not last long but the procedure can be useful. It will not be satisfactory for daytime use when a large number of patients are to be radiographed. Some chemical solution may be wasted as they can overflow!

If there is a large temperature variation at the hospital, some arrangement has to be made so that the chemicals can be kept at approximately the right temperature during working hours, and when there may be a night time emergency requiring radiography, at night.

It is not possible to process X-ray films properly if the chemicals are too cold or too hot.

How are X-ray chemicals cooled?

If the temperature in the darkroom is consistently too high, the developer will need cooling.

There are several alternatives:

1. Cool the incoming water supply. This can be done with electric water coolers. They are expensive, need a constant electrical supply and frequent maintenance. Water which has been used to wash processed X-ray films cannot circulate through the coils of a standard water cooler: the pipes will be destroyed by the chemical residues. The only way is to cool the water before it enters the wash tank (master tank). The water leaving the master tank cannot be used for any other purpose because of the chemicals in solution.
2. Air condition the darkroom. This is also expensive and needs a constant electrical supply. It does not always cool the chemicals sufficiently.
3. Use a special high temperature additive.
4. In an emergency, if ice is available, a container (plastic bag) of ice can be submerged in the developer for a few moments. This will be a short time method for a few films only. The ice must not be allowed to leak into the developer because it will dilute the chemicals.
5. In many countries, the nights are cooler and chemical temperatures are satisfactory each early morning for a few hours. Hospital-patients and routine X-ray examinations can be started early in the morning and continued until the temperatures rise again. The temperature of the chemicals will have to be monitored continuously.

Of these alternatives, **water cooling** (1st technique) is not usually practical. It is too expensive and not reliable. Diluting the chemicals, shortening the exposure or using "automatic" processing chemicals will not be satisfactory alternatives for high-temperature manual processing. Most processing manuals give a time temperature scale with a minimum processing time of 3 minutes at 23°C (73½°F). However, films can be processed at higher

temperatures for shorter periods; the minimum processing time is 1 minute, at temperatures of almost 27°C (85°F). Any processing at even shorter times will not be satisfactory.

How are X-ray chemicals supplied? Which is best?

Chemicals for processing X-ray films are supplied in powder or in concentrated solutions, both are supplied ready for mixing. The concentrated solutions are the easiest to use (see WHO Manual of Darkroom Technique) but may be a little more expensive. They keep better in storage. Dry chemicals in packets are usually cheaper, but they must be stored in a very dry place or else they will be altered and, if the packets leak or are damp, the chemicals will harm the shelves, clothing or staff.

The best alternative (powder or liquid) in each locality will depend on the local supplier and the cost. When properly mixed according to the instructions, both work equally well.

Whichever is chosen, **the instructions must be read very carefully, because manufacturers use different methods.**

It is important that chemicals be delivered in packages which exactly produce the correct strength for the size of the chemical (insert) tank being used, whether it be developer or fixer. This should be specified when ordering the chemicals. As far as possible, standardize and always supply the same chemicals in the same quantities to avoid mistakes. **Remember that USA Gallons are about 20% smaller than UK / Imperial gallons; it is better to use Litre tanks and matching solutions.**

How are X-ray chemicals mixed?

X-ray processing chemicals must be mixed whether they are purchased in solution or powder.

They are not mixed in the insert tanks. Two buckets are necessary, one must be clearly marked **developer** and the other **fixer**. Strong plastic buckets are preferable and will last longest, galvanized steel buckets rapidly develop leaks. **These buckets must never be used for any other purpose** because the X-ray processing chemicals are very poisonous and there will always be a small residue on the rods or in the buckets; **they should be kept in the X-ray department. The "developer" container/bucket must never be used for the "fixer" chemicals or vice versa.**

The chemicals will have to be stirred while they are mixed. If possible, provide long, thick industrial gloves. The stirring rods must have long handles so that the person mixing the chemicals does not get splashed by the solutions. Long plastic spoons or rods or, if necessary, long wooden rods can be used. Each should be marked "developer" or "fixer" and must never be used for anything else. Similarly, the X-ray buckets or mixing rods can never be used for anything else.

Supply industrial gloves, 2 buckets and 2 rods for mixing chemicals and label them.
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Can the same chemicals be used for automatic or manual processing?

The processing of X-ray films will always require both "developer" and "fixer." Unfortunately, automatic processors use a different strength and combination and **it is not satisfactory or practical to use chemicals meant for manual processing in any sort of automatic processor.** Chemicals designed for automatic processors can be used for manual processing but need to be diluted. The supplier will need to be consulted. This alternative should be avoided if possible, because the films will be more grainy if manually developed in chemicals supplied

for automatic processing. The chemicals for fixing are less of a problem, but automatic fixer chemicals will not be as satisfactory as the manual solution.

In principle, order the correct chemicals (manual or automatic) for the method of processing. Check with the manufacturer of an automatic processor which chemicals are going to work most satisfactorily. However, it is not correct to claim that automatic processors only work with one manufacturer's products. If there is a big price difference, do some tests by trying different makes.

How often do X-ray processing chemicals have to be changed?

No X-ray chemicals will be satisfactory six weeks after the solutions were made, even if they have not been used at all. Six weeks should be the **maximum** interval between changes even if only a few examinations have been made. It is tempting to save money by hoping that the chemicals will last longer, but this will only spoil films and reduce the image quality, exposures will increase and patient care will suffer. It is also more expensive, because many films will have to be repeated and this costs much more than the new chemicals.

There is no difference in the average working life of chemicals supplied as liquid concentrates or as powders. With an average number of films required to examine five to ten patients per day, the chemicals will need to be changed every month. In the interval they must be "topped up" with both developer and fixer, and a stock of both should be kept ready mixed and available.

When fresh chemicals are mixed, extra quantities of full strength developer and fixer should be set aside in glass or plastic containers to maintain the levels of chemicals ("topping up"). These reserve mixtures should be standard processing chemicals in their normal correct dilution. It is important that they are kept in clearly marked and in well-closed bottles. The bottles are not interchangeable and developer should never be put in the fixer bottle or vice

versa. These chemicals for topping up the solutions are best kept in the darkroom, but in a place where they will not be kicked in the dark when films are being processed!

Always fill extra containers so that processing chemicals can be "topped up".

Why do both developer and fixer need to be topped up or replenished?

First, there is a difference between "topping up" (adding more of the original chemical) and replenishing (strengthening) the solution (see next Section). Developer slowly becomes less active, depending on the size and the number of films which are being processed. Some of the developer will be lifted out of the tank with each film as it goes to be washed. This is why the developing tank has to be topped up regularly.

Fixer also decreases in activity as films are processed. The fixing time will become progressively longer. Some of this is due to dilution by the water brought in with the film after rinsing. In the same way, the fixer is also lost when the film processing has been completed and the film is moved into the washing tank. The level can be kept by "topping up" with fixer solution, but the activity will slowly decline. It is possible to regenerate fixer but it is not very simple. It will require constant monitoring to keep the solutions chemically accurate. If the fixing time is becoming too long before the end of the month, change the chemicals more often. Trying to save on chemicals is a false economy.

Trying to save money on processing chemicals will waste money on X-ray films.

What is a "replenisher" for X-ray chemicals?

"Replenisher", is a solution which maintains a proper balance as the chemicals are used. It is not a strong solution of the standard chemicals, but different chemicals, formulated to maintain the correct balance needed to obtain good films. **In a small department a special replenisher is a luxury.** Most automatic processors will require replenisher-see next section.

Chemical tanks in small processing units can be kept filled by simply topping up with the same chemicals. **Replenisher adds yet another type of chemical and increases the possibility of errors. It is more reliable (and easier) to change chemicals more often as the work load increases.**

When are the chemicals changed in automatic processors?

Automatic processors cannot use manual processing chemicals: their chemicals are usually supplied in standard solutions. With automatic processing, the chemicals have to be carefully monitored and the instructions provided by the manufacturer must be very carefully followed. It is particularly important that the correct chemicals and the correct strength of solutions are used as instructed, otherwise the equipment may be damaged. The manufacturers will indicate how many films can be processed with their solutions. Experience alone will indicate the quantity to be ordered, but make sure that chemicals will be readily available locally before purchasing the processor.

Small automatic processors require cleaning; the rollers must be cleaned at regular intervals (depending on the work load, but perhaps every week) the plastic connecting tubes between the chemicals and the film bath must be cleaned. Otherwise they accumulate residue and eventually the processor will cease to function.

Automatic processors are expensive, excellent and work well if the instructions are followed exactly. If neglected, or if there is no electricity they become useless.

What is silver recovery? Is it necessary?

During the processing of X-ray films, silver will accumulate in the fixing solutions. **Silver recovery has no practical use other than saving money** but modern films (particularly the green sensitive emulsions) do not contain as much silver as those of a few years ago and the work load has to be significant before silver recovery becomes worthwhile. **In the average small hospital where a fixing solution is changed once a month, silver recovery is probably not practical because the quantities are too small.** If manual processing is used in busy departments, silver can be continuously extracted by means of a commercial electrolytic device, which usually clips onto the side of the fixer tank. It takes space, so one large single 45 litre (10gallon imperial) fixing tank is better than two 25 litre (5gallon imperial) tanks. Small automatic processors seldom incorporate silver recovery, but it may be an alternative option. If the department is examining 30 or 40 patients daily, then the possibility and economics of silver recover units should be discussed with the supplier of the equipment. Although the process is simple, it is not easy to devise a "home made" silver recovery unit. Any company that supplies a silver recovery unit should be willing to purchase the silver which is recovered.

What is "daylight processing"?

In a busy department with two or more X-ray rooms, it is possible to eliminate the darkroom by the use of daylight processing equipment, an automatic unit into which cassettes (with the films inside) are inserted. The special cassette is automatically opened, the film is removed, a new film is put in the cassette and the cassette is closed. The exposed film then passes through an automatic processor and is delivered a few minutes later fully processed and dry.

These units are much more expensive than manual processing or small automatic processors. Daylight systems also need much more careful maintenance and are not recommended other than in a fairly large town or city where a chemical supply company or service engineers are always available. They are too elaborate for use where there are only a

few patients and should probably not be considered unless more than 40 patients are examined daily in a department with fully trained radiographers and all the required support services immediately available.

If the above criteria are met, then consultation with the local agents is essential.

Remember that there are several entirely satisfactory makes of daylight processing equipment: they vary in price, capability and efficiency.

The single most important aspect which may influence the choice between different makes of daylight processors is the local availability of support services. Daylight processing is definitely not recommended for the isolated hospital or clinic or in any small department which cannot afford the regular technical support which will be required.

What is needed in a darkroom apart from processing tanks?

There must be a "dry" workbench, safelights, film hangers, storage for films, a film marker. See section on "How are X-ray chemicals mixed?" for details of mixing rods for chemicals and two tanks or buckets for mixing. Chemicals should not be mixed in the darkroom because of the fumes. If there is manual processing, it is helpful to have an electrical film dryer or a drying rack. If there is a small automatic processor, make sure that a film dryer is integrated within the unit.

What is a dry bench?

The dry bench is a firm smooth surface in the darkroom to support cassettes while films are changed. The dry workbench should be under or near the cassette hatch, (figure 10). It must be well away from the processing tanks.

There should be nothing on the dry bench except the films, cassettes and film marker

The dry bench should be about 85cm high (34inches), 120-130cm long (48-52inches), and 50-60cm (20-24inches) deep. The top must be smooth, either polished wood, vinyl (such as vinyl tiles), standard porcelain tiles or formica (or equivalent). The colour of the top should be deep red or deep blue (light colours can cause film fogging.) Beneath the work surface there should be one shelf with enough space to store one-weeks supply of X-ray film boxes standing vertically upright, side by side. This requires a 40cm (16inches) shelf space that is strong enough to support 100kg (202 lbs) for each ½m (2ft) of shelving.

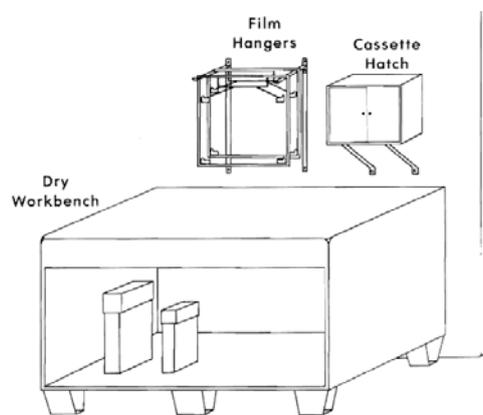


Figure10: Dry Bench in the darkroom with film hangers and cassette hatch

What lights are needed in the darkroom?

Every darkroom needs one or two lights with coloured safelight filters that will not fog X-ray films. Darkroom light filters are made of brown-red coloured glass if the film is blue sensitive, and ruby red glass if the film is green sensitive. The film manufacturers' requirements for the filters should usually be followed, but red X-ray darkroom filters are acceptable with almost any type of X-ray film.

The maximum recommended power (wattage) of the bulbs within the safelight should never be exceeded: this is usually 15 watts for a direct safelight and 25 watts if the light is reflected on the ceiling. It is a common fault to utilize too bright a bulb, which produces too much light, fogs (spoils) the film and overheats the safelight, frequently cracking the glass filter. A white light is also needed in the darkroom, but it must never be a fluorescent light. It must be controlled from inside the darkroom.

What are safelights?

There are two basic patterns of safelights (see figure 11)

1. Indirect beam, usually suspended but may be fastened on the wall;
2. Direct beam, fastened to the wall or to the ceiling

Usually the direct beam safelight is required directly above the dry bench and the central, indirect beam is required hanging from the ceiling shining upwards. If an additional safelight is required close to the processing unit, it should be positioned well above the chemical tanks but **not** in such a way that films can be held in front of it. In this position it will not be hit when films are lifted out of the tanks. **Films should never be visually checked in the darkroom at any stage of processing. This is a very common cause of poor quality radiographs.**

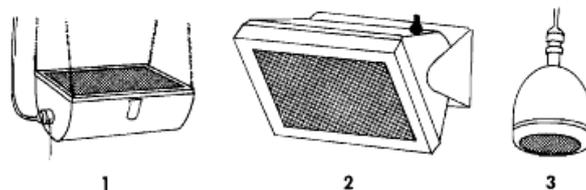


Figure 11: Different types of safelights. Number 3 safelight is used over the dry bench, number 1 is the central indirect beam and number 2 is an optional safelight. The safelight in the centre of the ceiling should shine upwards, never downwards.

NEVER put a viewing box (for looking at X-ray films) anywhere in the darkroom. Doctors or nurses or technicians should never be allowed to look at X-ray films in the darkroom; if there is no viewing-box, they will not even try! They must wait for them to be brought out of the darkroom when they have been properly fixed.

What are film hangers?

Film hangers are metal frames to hold the films while they are processed in the chemicals: they are only needed when there is manual processing. After films have been exposed in the X-ray room, the cassettes are taken to the darkroom and the films are removed from the cassette (on the dry bench) and fastened into stainless steel hangers. There are basically two types of hangers: (a) channel hangers and (b) clip hangers.

- a. The older channel design, with the film supported in a channel on either side, always leaves marks around the edge of the film and does not provide such good support. Films can fall out of the hanger when in the chemicals or when drying. **Channel hangers are NOT recommended.**
- b. The clip type hanger holds the films under tension. With a spring-clip at each corner. If it is made of high quality stainless steel it will last for many years.

There must be sufficient hangers for each size of film in the darkroom. Every film will be held in the hanger for at least one-hour before it is washed and dried, longer if there is no dryer.

It is important that the hanger sizes exactly match each of the film sizes. The films made in "inch" sizes will not fit into hangers designed for the "centimetre" sizes and vice versa. Small films cannot be processed satisfactorily in big hangers.

How many film hangers are needed?

Ten hangers (10) of each of the film sizes are recommended unless the hospital clinic is known to have exceptionally busy days, as for example when there is a routine "chest out-patient" clinic once a week, during which 10 or 15 patients may be radiographed from this clinic, as well as the other patients from other parts of the hospital. There may be a similar increase in patients if they come from nearby hospitals to be radiographed on certain days of the week. Then the number of hangers must be adjusted to the number of examinations per hour, so that patients and doctors are not kept waiting. This will also ensure films are properly fixed and washed and are not spoiled during drying. Hangers are relatively cheap and it is better to have too many than too few. Additional hangers can be purchased when experience shows how many are needed and will be a good investment.

Do automatic film processors need film hangers?

If there is automatic processing only, film hangers are not needed. If there is a back-up small hand processing tank, get a small supply (three or four of each size of hanger) because even the best automatic processors may break down or electricity may fail. Work will be stopped unless the films can be processed by hand. **Only if there is constant electricity, a good running water supply and technical maintenance readily available, will it be safe to do without a backup darkroom and a system of manual processing.**

How are X-ray films dried?

Manually processed films can be dried in the air or in electric dryers. Films from an automatic processor are dry when they come out of the processor (but when buying one, remember to specify that there must be a dryer incorporated.)

Electric dryers for films in hangers require considerable electrical supply, and are usually not required in a small department unless there are more than 10 patients a day or the climate is very damp. When the number of films per day increases so that an electrical dryer can be

justified (more than 10-15 patients per day), it may be to consider buying a complete automatic processor which includes a dryer as a standard item. Make sure that the particular model purchased does have a dryer in the system. Not all automatic processor include a dryer unless specified.

Be careful when choosing a separate film dryer because of the extra ventilation which will be needed. Electric film dryers generate quite a lot of heat and they are not practical within the darkroom or an X-ray room unless the heat can all be extracted or vented to the outside of the building. Some film driers which are shaped liked a rectangular box with a lid which must be opened to put the films in or take them out. The steel hangers may be quite hot and this design makes it very difficult to extract the heat from the room. This type of dryer will dry the films, but it will also heat everyone within the surroundings, which may be an added asset in some climates but a distinct disadvantage in others!

Is it easy to make an X-ray film drier?

If the films are processed manually on clip hangers it is not difficult to make a drier locally because it is really only a cupboard with wide doors, a heater and an extract fan. Wet X-ray films are kept in their hangers which hang from the racks inside the cupboard. It is very important to make sure that the water, which may still have residual chemicals from the films, **cannot drip either onto the heater or the fan**. With this type of drier, films are usually dried in about 15-20 minutes. Of course, the drier will only work when there is a good electrical supply.

There is a more complicated type of drier in which the wet films (without the hanger) are fed through rollers and comes out dry in a minute or two. This is the type which is incorporated in automatic film processors but it can also be purchased separately. It would be very difficult to make one locally and is not necessary for small hospitals.

How are films dried if there is no drier?

A simple drying rack can be made of wood, steel, brass or plastic and, if the darkroom is large enough, fixed on the wall opposite the dry workbench, next to the "wet" tanks (figure 12). If the dark-room is not large enough, the drying rack can be in the X-ray room (provided that room is large enough!) or anywhere suitable which is not too far from the darkroom and is not too dusty. **Wet films easily become coated with dust and insects before they are dry, and it is very difficult to clean films after this has happened.** The racks must always be fastened where no one will walk into them, especially in the darkroom. If the films and hangers fall on the floor, the films will be spoiled and the floor will be slippery and may be spoiled by the chemicals. **The darkroom floor must be kept dry.**

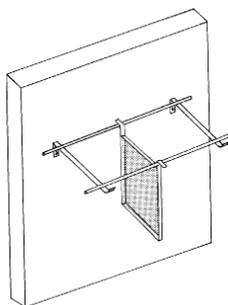


Figure 12: A film drying rack

The rack can be made from two parallel rods, which may be wood, bronze or stainless steel (figure 12). It must be at a height that will not cause any obstruction or injury in the dark. Below it on the floor there should be an additional shallow trough or tray to catch the drips. Alternatively, the floor beneath it should be of a material which is waterproof and easily drained. **X-ray films will drip chemical residues even after washing and the surface or the tray should be capable of accepting chemical contamination.** The trays can be made of plastic e.g. plastic baby baths obtained from local stores. These are often rectangular, usually cheap, and can be placed side-by-side beneath the drying rack. If made of galvanized metal the trays will need replacement quite frequently, so plastic is an ideal compromise. Special

quality chemically resistant stainless steel can also be used, but is expensive for a large floor tray; tiles or concrete are much less expensive.

How are wet films (after processing) carried so that the doctors can see them?

Immediately after the films have been fixed, they will be dripping chemicals even if quickly rinsed. If someone wishes to see them immediately, there will not be time to wash them properly (which may take an hour).

Films should NEVER be viewed by the doctor in a darkroom. It is also preferable that they are not reviewed in the X-ray room, where there may be patients, but are taken to the X-ray office or if necessary, sent to the outpatient clinic or ward.

The dripping chemicals from films that have just been processed make a considerable mess of any floor. Wet films should only be carried in a special "wet film carrier".

Wet film carriers.

Carriers for wet films should be made of chemically resistant stainless steel and must have a tray to catch all the drips. The tray can be plastic, but the frame usually has to be steel to be sufficiently rigid. Some film-carriers are made with metal rods which are coated in plastic; this type of protection does not usually survive and the carrier will rapidly become very rusty.

Most film carriers hold about five films in their hangers, so it is advisable that the small X-ray department have at least two. If many patients are seen in clinics after they have been radiographed, it may be advisable to have three or four film carriers. Wet films in hangers which are allowed to lean against the wall or even worse, piled one on top of the other will be scratched and may become useless. Wet films easily stick together and then cannot be

separated. The comparatively small investment in properly made film carriers is well worthwhile.

How are cassettes transferred from the X-ray room into the darkroom?

Cassettes can be carried from the X-ray room to the darkroom - the two rooms should adjoin. However, wherever possible, a simple "cassette hatch" is recommended, especially as work increases (figure13).

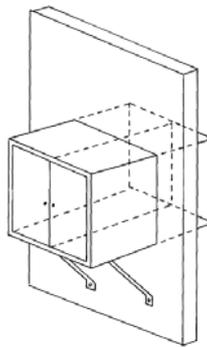


Figure 13: Design of a cassette hatch.

What is a cassette hatch?

A cassette hatch is an enclosed hole through the wall between the darkroom and the X-ray room large enough for the cassettes. It can also be used as radiation-safe storage for the cassettes. The door or doors of the cassette hatch on the X-ray room side may have to have additional lead (or equivalent) protection, depending on the size of the room and the type and position of the X-ray unit. If there is any doubt, leave a film (in a cassette) in the cassette hatch during a whole normal working week. Then process the film to see if it is fogged. Until this test has been made, keep all other cassettes in the darkroom.

Commercial cassette hatches are made of metal, may have single or 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 usually required on either side of the average wall. Some have a "darkroom side" and an "X-ray room side". Make sure that the hatch is installed the correct way when so marked, because one side will have radiation protection and the other may not. 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, there is a tube through which a brass rod can slide. Its movement is restricted to 3-4cm either way. When one door is down, the rod protrudes at one end over the top of the door but will allow the other door to be lifted vertically and opened. With one door open (up), the rod cannot be pushed back and the other door cannot be opened. Only when the first door is closed can the rod be pushed through again and the other door is allowed to open.

The doors of the hatch must be wide enough to overlap the divided box and must be lightproof. Counter-weighting can be simple weights on pulleys. Additional protection on the X-ray side can be provided, if necessary, with 2mm of lead. The counter-weighting will have to be adjusted to balance this.

How are each patient's film identified?

Films can be marked in pencil on the film in the darkroom before they are processed using the name, date, and, if available, the hospital number of the patient. When they have been finished and dried the information can be rewritten in white ink over the pencil marks.

A quicker and more reliable way is to mark the films photographically so that the name appears in the corner of the film. Commercial film markers are available; the cassettes must be adapted by shielding one corner to prevent X-ray exposure. (Some cassettes are supplied with this incorporated.) 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 easy to use; when there are more than four or five patients examined each day, a film marker becomes a useful item.

Some daylight film markers incorporate a clock with an automatic mechanism and the name, etc. can be photographed outside the darkroom. Special cassettes are needed. Such expensive markers are not needed in a small department.

What records should be kept in the X-ray department?

It should be possible to trace the name of every patient who has been radiographed, what examinations were done and on what day. A simple "daybook" utilizing one line per patient, recording the name, the date and the examination is essential. Where possible a hospital number should be included. It is helpful to record the number of films used, preferably by film sizes and also the age group of the patient (baby, child, adult, old), and the sex. The record book can be of any ordinary lined paper with a fairly hard cover and each pair of pages can be ruled to provide vertical columns. As the work increases an additional clerk to keep the records may allow the operator or radiographer to examine more patients. Apart from record keeping, there will be film storage envelopes to be prepared, films to be filed and previous films to be found whenever a patient returns to see the doctor. The darkroom technician can also help if a full-time clerk is not justified.

The daily X-ray records do not need to be complicated; they should be kept because they provide not only patient references but information indicating the number and types of examinations and the number of films used each year. It is also important to record the date on which processing chemicals were changed. This can be a separate chart on the wall of the darkroom.

How long should exposed X-ray films be kept?

Completed radiographs should be kept at least five years or longer, depending on the local or national regulations. They are best filed under the hospital number of the patient. The system used in the X-ray department should be exactly the same as that used for the patient's hospital records. There is no reason to use a separate numbering system in the X-ray department. Using separate numbers adds to the difficulty of finding the films when they are needed later. If films are transferred to another hospital, a card should be inserted in the file indicating where and when they went.

How are completed radiographs (films) stored?

Completed radiographs should be kept in film envelopes (packets). All the envelope need to be about 1-2cm larger than the largest film size. This will be approximately 38 x 45cm. No other envelope size is needed. If proper X-ray envelopes are too expensive to buy, cheap paper envelopes as used by local stores will work satisfactorily. If they are not large enough, slit open one side.

Shelves large enough to hold these X-ray film envelopes must be installed in the storage room, so that the completed films in their envelopes can be stored upright. X-ray films weigh a considerable amount and the shelves must be strong, with internal support between shelves and a division every 25cm (10in). The weight on the shelves may be as much as 200kg per meter of length or 136lbs per foot of length. It is recommended that shelves be supported every 60-80cm (24-32in). Such shelving will then support up to 160kg (350lbs) each. Shelves should not be more than 2m (80in) high: the space between shelves should not be less than 48cm (19in). If the shelves are deep enough, at least 40cm (16in), the envelopes can be filed with a small length extending beyond each shelf so that the file number can be easily read.

Strength is the deciding factor in the choice of the materials for shelves. Shelves do not need to be solid; squared timber or metal slats with spaces between them can be sufficient.

Strong metal shelves are ideal but wood is satisfactory provided there are enough intermediate supports. It is essential that the middle of the shelf does not bend downwards because of the weight. Additional upright supports resting down to the floor will eliminate the distortion. Shelves which bend will make filing and finding the films very difficult, and can be dangerous if they collapse.

How are unused (new) X-ray films stored?

Unused films are best stored in the office/store room but not where there is any direct sunlight. A weeks' supply may be stored in the darkroom under the dry bench. Wherever they are kept, the walls must be thick enough to prevent the new films from being fogged (spoiled) by radiation. They must be stored vertically above the floor level, and in the coolest, darkest, driest area. Avoid sunlight, dampness, heat and chemicals.

Each box must be dated with its delivery date and the expiration date of the film, written on one end of the box when they arrive. The manufactures will designate 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. In hot climates, the main (central) supply of films for any region should be kept in refrigerated storage.

How are X-ray chemicals stored?

Three months' supply of processing chemicals should be kept in the darkroom or office/storage space, with the plastic, glass or metal containers kept in the boxes in which they are delivered. Paper packets of chemicals should be avoided or must be kept absolutely dry. Containers of chemicals may stand directly on the floor beneath the shelving in the office/storage space, but they must be kept well away all moisture to avoid damage. The storage life of chemicals is excellent under good conditions provided the packages are completely sealed and kept dry.

Chemicals should not be stored on the same shelves as films and should preferably be as far away as possible, particularly from unused films. Remember that X-ray chemicals are very irritating to skin, the fumes can damage the lungs and solutions or powders can damage clothing, flooring, and unused X-ray films. Proper, careful storage is essential and will save money.

Darkroom layout

What is the best layout for the darkroom equipment?

The layout inside the darkroom is dependent on the position of the X-ray room and the entrance door. The position of the various items in the darkroom must follow a logical sequence, so that the operator starts at the dry bench, taking the film from the cassette, marking the patient's name and number on the film, and clipping it into a hanger. The film is then taken from the dry workbench to the developer, where it will be for 3-5 minutes. During that time a fresh film is put in the cassette on the dry bench. The film then goes from the developer to the intermediate rinse, then to the fixing tank (3-5 minutes at least), to the wash tank (20 minutes at least), and finally to the drying rack. If there is an electric film dryer, this must either be outside the darkroom or be well ventilated so that none of the hot air stays in the darkroom. Figure 14 is a suggested layout for a darkroom.

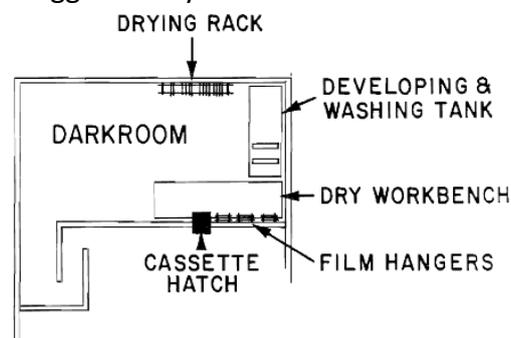


Figure 14: Suggested layout for a darkroom.

The processing tank must be located along an outside wall, because this will simplify drainage and the water supply. The master tank should stand about five cm (2 inches) away

from the wall. Liquids draining out of the master tank must run through pipes made of porcelain or earthenware, special quality plastic or corrosion-resistant stainless steel.

X-ray chemicals will cause standard metal pipes to leak after a few months.

Tiles behind the tanks and the drying rack are helpful, because the walls will almost certainly be splashed by chemicals. The floor below the drying rack may need protection. The **dry workbench** is best situated under the cassette hatch, against the X-ray room wall (see figures 10, 14). The **wet film drying rack** should be on the opposite side of the darkroom or outside the darkroom. **A heated drier** should be outside the darkroom.

The on/off **switch for the safelights should be OUTSIDE** the entrance to the darkroom, never inside, particularly if the darkroom is entered through a light-trap. There must be a white light in the darkroom, but the **switch for the white light MUST BE INSIDE** the darkroom so that it can never be turned on unexpectedly.

Alternatively, in some countries the regulations require that the switch for the white light in the darkroom is in a different position from switches in most ordinary rooms. This non standard position may be 1.8m (6 ft) above the floor so that it will never be turned on accidentally. The **white light in the darkroom must not be a fluorescent tube** because these often glow after they are turned off. There should be an ordinary incandescent bulb to provide white light.

If a **film marker** is used in the darkroom to mark the name of the patient on the films, this has to be in a convenient position on the dry bench. There must be a **timing clock** in the darkroom, which can be set to accurately indicate audibly any time from 2-10 minutes. There are special X-ray darkroom clocks; two should be purchased when the darkroom equipment is bought.

Electrical outlets and switches must be situated well away from the processing tanks.

An outlet must be above the dry bench if there is an **electric film marker**.

If an **immersion heater (designed for chemicals)** is used to warm the chemicals, waterproof connectors and cables are essential. It must have a dedicated power supply.

If there is an **automatic film processor**, the electrical outlet must provide sufficient power to maintain the processor at full load.

All taps (faucets) for water must be close to but not overhanging the processing tanks.

CHAPTER 8: TRAINING AND MAINTENANCE

Proper training for both the operators and the maintenance engineers will save a considerable amount of money and the cost of maintenance will be a very small compared with the cost of the equipment.

Many countries require recognized training for all those who use X-ray equipment. This may be fully qualified radiographers, assistant radiographers or, for the WHIS-RAD, properly trained WHIS-RAD operators.

Is a fully qualified radiographer/X-ray technician required?

It is not always necessary or even desirable to have a qualified radiographer in a small hospital examining only about 10 patients a day. He/she may become bored and their full talents will not be realized. The qualifications of the person who is to take the radiographs will depend entirely on the type of equipment and the number and complexity of the examinations to be undertaken in that particular hospital. There are three main categories of trained staff who can work X-ray equipment.

- a. A fully trained radiographer (an X-ray technologist).
- b. An assistant radiographer.
- c. A WHIS-RAD operator.

Fully trained radiographers will have an important additional role in supervising assistant radiographers and WHIS-RAD operators in small hospitals, making regular visits for advice and quality control.

How is a WHIS-RAD operator trained?

The WHO Manuals of Radiographic Technique (and Darkroom Technique, if not a digital system) should be used as the syllabus. This way it is possible to train someone who has no previous experience with X-ray work. However, it must be re-emphasized that **training IS required** and no one should be left to try and work from a book without instruction.

Although the training is not difficult, there are minimum requirements before anyone should

start. A WHIS-RAD trainee must be able to read and write and should preferably have some previous hospital experience, particularly in handling sick patients. They will be responsible for all the work in the X-ray department, not only for taking the radiographs. They must keep the records, file the films, use the digital system or mix the chemicals and do all the darkroom work, keep the equipment clean and above all be responsible for the patients who come to be X-rayed.

WHIS-RAD trainees must receive all their instruction on WHIS-RAD equipment, similar to the X-ray unit that they will be using in their own small hospital or clinic. All the training of a WHIS-RAD operator should take place in the X-ray room and in the darkroom, not in a class room; it must be entirely practical. **Very little theoretical training is required.** Emphasis should be on practical radiation protection, learning each procedure step-by-step, on the importance of time-temperature manual processing or using a digital system and of a methodical approach to their work.

**The operators must be well aware of radiation hazards and
taught how to care for their patients.**

It is essential that standard procedures are followed exactly; the ideal way to do this is to use the WHO technique and darkroom manuals as the syllabus for the training course. Only when the operators can reliably make every examination in the WHO manual should they be considered ready to work on their own

WHIS-RAD operators cannot be trained on conventional equipment and then be expected to use a WHIS-RAD unit. They can learn darkroom technique, but must learn this with equipment which matches the processing unit which will be available in the small department

in which they are going to work. Training with an automatic processor will not result in good radiographs if the small hospital has manual processing only!

If there is no WHIS-RAD available in the large hospital, then a trained radiographer must go to a small department where there is a WHIS-RAD, and be prepared to spend several weeks training a group of WHIS-RAD operators there.

What happens after operator training?

With a few weeks of instruction by a qualified radiographer, trainees will be able to make more than 100 different standard X-ray projections, including all those which are likely to be required of the chest, abdomen and the skeleton (including the skull) as well as contrast examinations of the kidneys and gallbladder. This short training period is one of the major advantages of the WHIS-RAD (but does not qualify the operator to use any other sort of equipment).

After completion of basic training, an experienced radiographer must go to the specific radiological department to work with the trainee for two or three weeks, supervising every aspect of day-to-day work. Such a visit serves the double purpose of completing the training of the individual and checking that the equipment is working properly. It also allows the instructor to become familiar with any local variations, so that if difficulties arise and the inexperienced operator telephones or sends a written report asking for help, someone at the central department will know the arrangements at that local facility. This may eventually save a lengthy journey for a relatively minor problem. As the operator progresses, the visits by the trained staff can be at longer intervals so that there may be one per month, then one every two months. **However, they must never stop altogether.** Visits at least twice, preferably three times a year, are essential for quality control. **The operator in a small hospital should never feel abandoned.**

How much work can be done by a newly trained WHIS-RAD operator?

When trained, a WHIS-RAD operator can easily X-ray 5-10 patients per day perhaps even 15 if the majority are chest X-rays. He or she will also be able to look after the darkroom and all the patient records. In smaller hospitals where there are few examinations, the WHIS-RAD operator can be helpful elsewhere in the hospital for other duties.

Several operators should be trained, e.g. assistant nurses, so that between them they can provide a 24-hour, 7-day a week service. If anyone is not the regular operator, they should be allowed to X-ray patients occasionally so **they do not forget how to use the equipment** and the manual.

When the number of patients increases to 12-15 patients a day or more, the WHIS-RAD operator will be fully occupied in the X-ray department and may need extra help with the darkroom or clerical work. It is probably better to hire another WHIS-RAD operator before hiring a clerk. Alternatively, a small automatic processor should then be purchased. In all departments the staff must always have time so that records can be properly kept, films marked and filed, chemicals changed at least every month and screens cleaned on a regular basis. This work is as necessary as the X-ray examinations, and will be neglected if there is insufficient staff.

How long is the training to use ordinary X-ray equipment?

If either ordinary X-ray equipment or a mobile "ward" unit are to be used, training will have to be much longer than with a WHIS-RAD. **There are many more variable exposure factors, and there is much more radiation risk if ordinary equipment is not correctly used.**

Therefore such equipment should only be used by an individual who has at least completed training as an assistant X-ray technician; this will need not less than a year. During training, an assistant technician must have a lot of practical radiographic experience under close supervision, preferably in a large busy X-ray department supervised and taught by fully

trained radiographers. Even if only a few patients per day (3-7) are expected at the small hospital, it will still be necessary to carry out training in a large department if ordinary equipment is used and preferably with the same type of equipment which they will use.

There should be no shortcuts: good technique, good radiographs, good patient care are essential: that means good training.

How many staff are needed in the X-ray department?

The number of staff depends on the number of patients to be examined, and the type of examinations which will be most frequently requested. There are some recognized standards and this question is better answered in the next section.

How many patients can be X-ray each day?

There are many variable factors: much depends on the type of work. For example, many patients who can walk and need chest X-rays will take much less time than many elderly patients who are in wheelchairs or trolleys, or children who have been injured. The following guidelines are reasonable for general radiography in small hospitals, with different types of examinations and patients:

With a WHIS-RAD.

- (1.) 10-12 patients per day. One WHIS-RAD operator working alone (and doing X-ray work only) can examine 10-12 patients per day, do all the film processing and maintain the records. With some clerical help to keep the records or with a small automatic processor, the work can be increased to 12-15 patients daily.
- (2.) 15-20 patients per day. An assistant X-ray technician or a fully trained radiographer using a WHIS-RAD with a small automatic processor can

X-ray 20 patients a day but will need full-time clerical help with the record keeping and patient organization.

(3.) 20-25 patients per day. Two WHIS-RAD operators can X-ray 20-25 patients per day with manual processing (provided the tank is large enough). The numbers can be increased to 30 per day with an automatic processor, and by extending the hours of work. Part-time ($\frac{1}{2}$ day) clerical help will be needed.

(4.) 35-40 patients per day. Two assistant X-ray technicians or a qualified radiographer with a trained assistant have been able to examine as many as 35-40 patients per day using a WHIS-RAD with a small automatic processor and clerical help.

Standard equipment (NOT A WHIS-RAD).

(1.) 10-12 patients per day. An assistant X-ray technician with standard X-ray equipment can X-ray 10-12 patients a day with manual processing, or a larger number of patients if a small automatic processor and clerical help are available.

(2.) 20-30 patients per day. Two assistant X-ray technicians can X-ray 20-30 patients per day with standard X-ray equipment and a small automatic processor. They will need clerical help.

All the above estimates refer to the usual variety of routine work required in a small hospital. This would include all the projections shown in the WHO Manual of Radiographic Technique. As the department becomes busier it may be less expensive to provide clerical help to keep the records and films in order so that the operators or assistant technicians can concentrate on radiography.

A digital system will allow more examinations per day in each of the above categories.

When is a fully qualified radiographer needed in a small hospital or clinic?

The standard and scope of work which can be performed with any of the types of equipment described will depend entirely on the skill of the user. If there is a WHIS-RAD unit available, the work is routine and there are less than 15-20 patients per day, the salary of the fully trained radiographer is probably not justified. It is also probable that a fully trained radiographer may not feel satisfied with this level of work.

If there is non-WHIS-RAD X-ray equipment, there will have to be an assistant technician or trained radiographer to do the same amount of work. There can be no doubt that as the work increases, it is an advantage to add a fully qualified radiographer to the staff. However, even well-qualified radiographers may need reorientation if they are to work in a small hospital. They must be prepared to accept all the responsibilities, which will include film processing and all darkroom/digital work, clerical work, cleaning, care and elementary maintenance for the equipment. Some radiographers from larger hospitals may not like to do many of these duties; the work involved should be made clear before they are appointed.

How can a satisfactory standard of radiography be maintained?

When all the training has been completed, and the X-ray equipment and the operator are working satisfactorily, it is very important that a fully trained supervisor visit each department at least every six months. Preferably, this should be every three or four months. This will encourage the isolated operator to maintain satisfactory standards, allow work and equipment to be checked and continue the education and assessment of each individual. Experience shows that these regular visits are very necessary to maintain a continually good imaging service, and are very cost-efficient.

What do physicians need to know about their imaging equipment?

Every physician who works in a small hospital or clinic should have some radiological experience, either when a medical student or after qualification, to learn the capabilities and limitations of the small X-ray department. He or she should generally know how the equipment works, what it can and what it cannot do and be aware of radiation safety requirements. If working with a WHIS-RAD operator, the physician must be aware that the operator can only do the examinations in the WHO manual. They are not trained to do any additional views, but the manual contains all those likely to be needed in a small hospital.

Equally important, all physicians should be trained to interpret and should become familiar with the standard radiographs that are taught to the WHIS-RAD operators or assistant technicians. (The WHO Manual of Interpretation for General Practitioners will help.) Similarly, any physician (other than a radiologist) or a radiographer working with ultrasound must have specific training. Guidelines for training are in the WHO Manual of Ultrasound (see page 186). Routine follow-up visits by the nearest radiologist, preferably every six months or more often to each local radiological department are most valuable, even if a digital system allows frequent consultation. Ideally these visits should be at the same time as the visiting supervising radiographer, so that images can be reviewed for technique with the operators and the diagnosis can be discussed with the local practitioner. If ultrasound is being used, the techniques and scan quality should be reviewed. Such continuing education and encouragement is a valuable investment. Isolation for either operator/technician or physician perpetuates errors and bad habits (quite involuntarily). Regular visits stimulate interest and renew expertise.

When digital tele-consultation is not available, X-ray films should be sent regularly to the nearest radiologist for interpretation, even if they take a few days to arrive. It is very helpful for the physician to have a written comment, however brief, from a specialist radiologist. It helps if the radiologist has brief clinical details and the physician's interpretation.

A single room X-ray department in a small hospital or clinic should not be isolated but should be regarded as part of the main, central X-ray department. It should be considered just another X-ray room in the same service, somewhat further away but still the responsibility of the radiological staff.

Staff in a small X-ray department SHOULD NEVER BE LEFT ALONE AND FEEL FORGOTTEN.

What maintenance is needed?

Regular equipment maintenance is essential. How much maintenance depends very much on the type of equipment and whether it is battery-operated or directly powered from a main power source. The daily number and type of examinations will also influence the maintenance schedule. Many small installations need a service visit only once yearly.

Apart from minor technical faults, the main sources of breakdowns are the X-ray tube and the batteries. Indicator lights, and occasionally meters, may need attention or replacement.

After some years of operation, contact-breakers may become faulty, especially in tropical areas. Well made equipment should continue to produce X-ray films without much care or attention for many years. The WHIS-RAD operator or assistant technician can be taught simple mechanical maintenance, such as lubrication of wheels and moving parts, tightening screws, etc. This can be checked at each six monthly routine radiographer's supervisory visit. The alignment of the light beam collimator should be checked every six months.

How should a maintenance service be organized?

Maintenance can be contracted from the equipment supplier on the basis of a visit at least twice a year and additional cost only if any spare parts are required. However, it is better if the Ministry of Health (or its equivalent) can standardize the type of equipment and provide their own service engineer. These engineers must be made familiar with the equipment,

have a complete set of diagrams available and have the same standard of knowledge and competence as those who could be obtained on contract from the supplier. This means that they must be offered pay equal to that in the commercial world: it may seem expensive but it will be money well spent.

What happens when equipment breaks down?

Any equipment breakdown should lead to a phone call/ e-mail 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! Communication with someone familiar with the particular department before sending an engineer is essential.

Where should the service engineer and spares be located?

The location of the service engineer and the stock of spare-parts will depend entirely on the regional terrain and transport difficulties. There should be a central maintenance department stock of spare parts. This is a good reason to standardize the equipment as far as possible. It is not necessary to keep a stock of spare parts in a small department.

What is the growth potential of a small X-ray department?

One complete X-ray facility (the X-ray room, digital system or darkroom and office) can be used 12 or more hours daily: its output is limited more by staff than by equipment. The WHIS-RAD can perform at least 95 percent (or more) of all the radiographic procedures ever required in a community hospital or clinic. It does not provide fluoroscopy and therefore very few gastrointestinal and vascular examinations are possible. If ultrasound is not available, the kidneys and the gallbladder can be imaged with appropriate contrast drugs. One 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 15-20 patients per day, additional help in the dark-room or, alternatively, two X-ray operators, will be necessary. A darkroom technician may also help with the clerical work. Clerical help becomes necessary in a non-digital department as the number of examinations increases.

As the work increases, what about radiation risks?

As the number of examinations increases, the radiation protection should be checked. The primary care radiological facility will provide a firm foundation on which the whole service of that hospital can expand. If there are more than 3,000 examinations per year with standard equipment, or 6,000 per year with a WHIS-RAD, the radiation protection provided in the walls of the X-ray room needs to be surveyed and reassessed, preferably by a radiation physicist. There may not be any problem, but it is important to be sure no one is harmed.

If one X-ray room cannot manage the work, what next?

The easiest solution is to duplicate the existing equipment and have two identical X-ray rooms, with 50% more staff supported by an automatic processor. The operators will not need further training and some of the accessory equipment can be shared between the rooms. However, if the work of the hospital is becoming more complex, the next important expenditure is the appointment of a trained radiographer. A careful assessment must be made to see if the character of the X-ray work or the type of patients seen in the hospital or

clinic will also change as the work increases. Often it does not, but this will depend on the skills of the doctors and on what other support they have. Will the amount of surgery increase, are there any specialists who will be visiting, etc? Will a radiologist be coming to the hospital on a regular basis and would fluoroscopy be desirable?

These questions must be asked before a final decision can be made. Advice from an experienced consulting radiologist may save money. WHO, Geneva; the Pan American Health Organization, and the other regional offices of WHO can advise on suitable consultants if there are none available in the region.

X-ray equipment is so expensive that its choice should not be left to a general duty medical officer or a hospital administrator. The clinicians should state what examinations need to be done and the radiologist can then advise how this need can best be met.

The choice must certainly not be left to or made on the advice of the X-ray company representative. That will be expensive!

CHAPTER 9: ULTRASOUND

Ultrasound is quite different from radiography (pictures taken with X-rays). The only thing in common between them is that both produce images of the human body but even the images are different. Ultrasound does not use ionizing radiation and as far as is known (2011) is safe when used properly. The equipment is much smaller, less expensive and does not need special installation. There are no radiation risks and no radiation protection is necessary in the room. However, the range of imaging with ultrasound is much less and basically different from X-ray examinations. Ultrasound is best used to image soft tissues, such as the liver, pancreas and other abdominal contents. It is excellent for all obstetrical imaging. Ultrasound cannot image the lung or most common skeletal lesions. It is helpful in localizing osteomyelitis in small children, is unreliable in the recognition of fractures, and cannot help with the diagnosis of pulmonary tuberculosis or pneumonia.

In a general hospital or clinic, X-ray equipment is needed first because it will serve the needs of the most patients.

Ultrasound should be the second choice, provided that there is someone trained to use it and who has time to spend with patients. This is another difference; X-rays can be taken by a non-physician and examined later by the doctor. Ultrasound nearly always needs the physician who has been trained in ultrasonography; and has the time to personally make the images. Interpretation of the images is very dependent on the actual scanning of the patient. All ultrasound scans are important as a health record.

What is ultrasound? How does it work?

Ultrasound uses high frequency sound waves which are not audible or visible. The waves are transmitted through the body tissues from which they are reflected, to be seen as an image on a video screen. Because body tissues are of different density, the reflected waves form a

pattern which demonstrates the anatomy of the region being scanned. The ultrasound beams come from a small hand-held unit called a transducer and can either fan out or form a linear pattern. The visual image is seen on a video monitor and must be watched as the transducer is moved over the patient by the examiner. The image is then recorded on a film or print or as a digital record.

There are different types of transducers working at different frequencies. Some have specific applications but all the transducers have to be kept in close contact with the patient's skin, usually moving with the tip (which is not sharp but rounded), gliding over a coupling agent such as an oil or a gel which has been smoothed onto the part of the patient to be examined. Ultrasound does not pass easily through air or gas, such as in the lungs or bowel, nor does it move freely through bone. Ultrasound therefore is of the most use in the examination of soft tissues, provided they are not obscured by any overlying air or gas (see page 188)

Is ultrasound safe?

Ultrasound does not ionize gas or tissues and in ordinary use there is no known danger. X-rays may be dangerous because they use ionizing radiation. If a very high power ultrasound unit is used continuously, the beam can generate heat within the patient and this must be avoided. Apart from this, there is so far (2011) no proof that in normal clinical use there is any deleterious effect on a fetus or on the gonads.

Ultrasound is safe provided it is not used excessively and it should only be used when there is a good clinical indication. Because it is safe and without harmful radiation, it does not mean that it can be used without proper training (see page 187). It is very easy to make mistakes in the interpretation of ultrasound images and proper training is essential.

What room is required for ultrasonography?

Ultrasound units are available in many different sizes, from small portable equipment which can easily be carried, to larger units which can be pushed around but can be heavy and are far from portable. Although WHO has specified a general purpose ultrasound unit and requires it to be portable over short distances, equipment is developing all the time and up-to-date advice should be obtained.

No special room or radiation protection is needed when using ultrasound. The patient must be able to lie comfortably on a couch and there must be an electrical supply, unless the unit is battery operated. The room should provide privacy, and it is desirable to have a toilet nearby and facilities for washing hands. However, ultrasound can be carried out in almost any ordinary room. Subdued lighting is an advantage.

Who can use ultrasound?

The images of ultrasound, the static picture obtained from the monitor, are not always easy to interpret unless you have personally made or watched the examination. The beam starts from a narrow source and, because it can be angled, the image of any tissue (for example, the kidney), can be distorted. While doing a scan, it is not difficult to recognize the anatomy and any abnormal change in shape or density, but viewing an image taken by another examiner may not be so easy. If the images are taken in the standardized way, reliable interpretation is possible, but this requires careful training and a sound knowledge of anatomy, as well as understanding of ultrasound. (see page 187)

Ultrasound is therefore much more operator-dependent than radiography and in most small hospitals and clinics; ultrasound will involve a great deal of physician time. In large and busy imaging departments it is possible to train technicians to examine the patients and then review the resulting images with the physician. Unlike X-rays, in most primary care hospitals the ultrasound examination will have to be done personally by the physician and this may take 20-30 minutes for each patient.

What are the names given to those who practice ultrasound?

A physician who is trained in the use of ultrasound, often but not always a radiologist, is **an ultrasonologist**. **A technician** who has been trained in ultrasound is **an ultrasonographer**.

How long does it take to train an ultrasonologist?

For those who are already used to interpreting images, such as radiologists, WHO and the International Society of Ultrasound recommend at least six months full time training in a busy ultrasound department to become fully competent. For those with less imaging experience, it will take 12 months to reach a similar standard.

How long is needed to train a general medical practitioner to use ultrasound?

The family practitioner who wishes to interpret obstetrical ultrasound will need one month of full-time training in a busy obstetrical department to obtain sufficient competence to interpret the most obvious (but not the subtle) findings. This will mean carrying out 400 ultrasound examinations under supervision. For those wishing to acquire general competence in abdominal ultrasound, which is the most common requirement, at least two months experience in a very busy general ultrasound department is recommended, three months is preferable.

How long does it take to train an ultrasonographer?

Training a technician in ultrasound requires at least one year's experience working under close supervision in a busy ultrasound department. It is preferable that the trainee should already have knowledge of anatomy and physiology, such as a radiographer or nurse. An obstetrical nurse (midwife) could learn to interpret the routine major antenatal ultrasound findings after working for two months in a busy obstetrical department.

Why does training in ultrasound take so long?

Ultrasound can produce a great deal of information and can reliably demonstrate the difference between normal and abnormal tissues. However, there are many normal variations and there are many sources of error. The shorter periods of training, the one or two months recommended above, provide only minimal experience and less obvious, but still significant, findings may be overlooked. In spite of those limitations and the likely errors which will occur, ultrasound is a very useful diagnostic examination for primary care, **PROVIDED the physician is prepared to get proper training** and then spend time making all the routine examination personally. Most errors of misinterpretation will be those which arise from failure to recognize some abnormality: Over-interpretation, or mistaking a normal variant for an abnormal finding, is less common.

What are the main clinical uses of ultrasound?

Ultrasound is much more limited in its scope than routine radiography. Where there is a shortage of money, X-ray equipment should be the first purchase because fractures and chest X-rays account for about 90% of the imaging needs of patients in small hospitals and clinics. Ultrasound cannot help with skeletal or pulmonary diseases.

Ultrasound **cannot** demonstrate:

1. Fractures (with the possible exception of fractures in small limbs).
2. The majority of chest diseases.
3. Renal function.
4. Most gastrointestinal diseases (e.g. intestinal obstruction, ulcers).
5. Any abnormality of the adult skull.

Ultrasound can demonstrate:

1. The obstetrical progress of mother and fetus.
2. Abdominal diseases, including:
 - a. Ascites.
 - b. Liver tumours.
 - c. Liver abscesses.
 - d. Gall stones (calculi)
 - e. Pancreatic cysts and some pancreatic tumours.
 - f. Splenic cysts and splenic trauma.
 - g. Ovarian cysts.
 - h. Uterine abnormalities.
 - i. Abdominal hydatid disease.
 - j. Para-aortic masses.
 - k. Abdominal aortic aneurisms.
 - l. Renal anatomy: Renal tumours.
 - m. Hydronephrosis of the kidney.
 - n. Renal stones (calculi)
 - o. Thickened ureters (schistosomiasis).
 - p. Tumours of the bladder wall.
3. Intracerebral conditions in the neonate while the fontanelles remain open.
4. Some thyroid diseases.
5. Soft tissue masses in the neck.
6. Pericardial effusions.
7. Pleural effusions (some).
8. Early peripheral osteomyelitis.
9. Congenital dislocation of the hip.
10. Testicular tumours, infections and injury.

With more complex ultrasound equipment and further training, it is possible to demonstrate abnormalities in the prostate, the eye and, if special equipment is available, the heart and cardiac valves and blood flow can be examined. However, these are not normally within the scope of the average primary care physician, or general practitioner. These ultrasound lists are incomplete but describe the main conditions for which ultrasound is useful. Provided the special accessories are available, ultrasound is also useful for guided needle biopsy.

What are the indications for obstetrical ultrasound?

Ultrasound is the preferred method of imaging pregnancy. WHO recommends that a normal pregnancy be monitored by two routine ultrasound examinations, the first during the 17th-18th weeks and the second during the 36th-37th weeks. Further examinations may be necessary if there is a clinical indication or ultrasound evidence of an abnormality.

Ultrasound is particularly helpful in the diagnosis of:

1. Early pregnancy.
2. Hydatidiform mole: Chorionic epithelioma.
3. Abnormal fetal development.
4. Abnormal fetal position.
5. Multiple pregnancy.
6. The position of the placenta.

With particular training, ultrasound can demonstrate fetal neural abnormalities, renal, cardiac and other developmental anomalies. It can be used to guide amniocentesis.

What are the indications for neonatal ultrasound?

The infant's liver, kidneys and other abdominal organs can be examined: ultrasound is very useful in making the diagnosis of infantile pyloric obstruction. While the fontanelles remain open, ultrasound can help with the diagnosis of intracranial haemorrhage, hydrocephalus and

monitoring the progress of cerebral abscess and meningitis. With special training, it is very useful in neonatal cardiology.

What is the best imaging combination for a small hospital?

Physicians at a 1st referral hospital, the small hospital or clinic looking after a wide range of general patients, will need to image patients for:

1. Trauma and skeletal disease.
2. Infectious diseases, including tuberculosis.
3. Obstetrics.
4. Abdominal diseases and injury, urinary tract, gallbladder, gastrointestinal tract, liver, spleen, pancreas.
5. Female pelvic diseases. Uterus, ovaries, tubes.
6. Miscellaneous problems. Thyroid, testicles, neck, etc.
7. Cardiac diseases (imaging is not always necessary).

The WHIS-RAD is ideal for 1 and 2 on the above list and can help in many cases in 4, 5, 6 and 7. It should not be used for 3-Obstetrics. A general purpose ultrasound unit is ideal for 3, and for many aspects of 4, 5, and 6. It is less or little assistance with 1 and 2.

Therefore, a WHIS-RAD is the best choice for imaging in any small hospital or clinic. When it can be afforded, ultrasound should be added. There will then be less than 3% of common illnesses which will need referral to a larger hospital imaging department, and most of those will be for illnesses which cannot be managed at the first referral level, but need more advanced, specialist treatment.

WHO recommends that all small, 1st referral hospitals have an X-ray unit and general purpose ultrasound.

A WHO group designed the WHIS-RAD for radiography in these hospitals.

Equally important, WHO recommends that all those who take or interpret the images MUST be properly trained. It is a waste of money and time to install equipment unless it can be used to its best potential: it is often dangerous for the patients and staff.

Trained personnel must be available to maintain and repair all imaging equipment; it is an expensive and important investment for health care.

ABOUT THE AUTHORS

Dr. Philip Palmer, M.D., F.R.C.P., F.R.C.R., was born and educated in England. He received his Medical Degree from London University and he is Board Certified in Diagnostic Imaging, (DI), Internal Medicine, Radiation Therapy-Oncology (RTh). He also worked for eight years in the Rural family practice and Diagnostic Imaging in the UK. He then went to Africa and for ten years was in charge of Radiology in Matabeleland, Southern Rhodesia (now Zimbabwe), practicing all genres of DI and RTh in two large central/referral hospitals with a UK-recognized radiographer training school. He was also installing X-ray equipment in and making regular visits to 30+ small rural hospitals. Then for four years he was Chair and Professor of Radiology in the University of Cape Town, where he also was responsible for Radiology resident training and Radiographer training. Dr. Palmer served as an examiner at 3 different universities and guided/visited multiple small and large hospitals/clinics in the Cape Province.

USA: Dr. Palmer completed his National Boards (MD). He was a professor of radiology at the University of Pennsylvania, where he helped develop the prototype of the WHIS-RAD.

Subsequently, he became inaugural Professor, and later Chair of Radiology, at University of California, Davis Medical Center.

WHO/HQ Geneva, PAHO, and other WHO Regional Offices: Dr. Palmer was a WHO advisor for DI for more than 25 years. He also served as a member of a small international group designing the WHO-Imaging system and he authored, co-authored and edited four WHO

Manuals that were later translated in 14-languages. Dr. Palmer was the Chair and member of several WHO-International DI-committees. While in those roles, Dr. Palmer, after extensive advisory visits, authored many reports for WHO on updating radiological services at the request of various Ministries of Health in many different parts of the world. Dr. Palmer has taken two sabbatical years, within which, with WHO's support, he set-up university radiology teaching programmes and also imaging departments in mission hospitals in Kenya.

Dr. Gerald P. Hanson, Dr. PH, is an engineer and health physicist (BSE, MSE, MPH; radiological health: University of Michigan) and a medical physicist and public health specialist (Dr.PH: UCLA). After graduation from the University of Michigan, he was appointed as radiation control director for the State of Kansas. In 1962, he went to Washington D.C. to be the first radiation safety officer at a Department of Defense research and development laboratory. In 1964, he joined the Pan American Health Organization (PAHO) and was sent to Lima, Peru, to organize radiation protection services throughout Latin America and the Caribbean.

In 1969, he was granted leave of absence from PAHO to obtain his doctorate at UCLA and returned to PAHO in 1971, working in the central office to expand the programme to include diagnostic imaging, nuclear medicine and radiation therapy. In 1971, he was certified as a health physicist by the American Board of Health Physics and in 1974, as a medical physicist by the American Board of Radiology in Roentgen-ray and Gamma-ray Physics.

In 1987, he was invited to join the staff of the Headquarters of the World Health Organization in Geneva, and became Chief of Radiation Medicine, responsible for diagnostic

imaging, nuclear medicine, radiation therapy and radiation protection. He retired from WHO at the end of 1995.

While at WHO Headquarters, he was responsible for the Organization's contribution to the ***International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources***, jointly sponsored by the FAO, IAEA, ILO, OECD/NEA, PAHO, and WHO; and published by the IAEA.

Dr. Janice Honeyman-Buck, PhD, FSIM--Editor –Currently serves as Editor in Chief of the *Journal of Digital Imaging*, the official peer reviewed publication of the Society for Imaging Informatics in Medicine. She earned a Doctorate in Computer Information and Science from Kansas State University. She provides consulting services in Imaging Informatics to VA Hospitals and hospital systems and has served as Deputy Director of Electronic Publishing for the Radiological Society of North America (RSNA) and in teaching and professorial assignments at the University of Florida, Kansas State University, Drexel University and the University of Virginia. Trained as a Radiology Technologist at the Lancaster General Hospital, Lancaster, PA, she was employed as a Radiology Technologist at the Aga Khan Hospital in Nairobi, Kenya, and taught basic science courses to secondary school students in Tanzania.

Michael Hoaglin-Contributor. Authored elements of the Digital Imaging section. He is a Graduate of Northwestern University, Biomedical Engineering Program; and is currently (2011) attending medical school at the University of Pennsylvania.