Chapter 5
Equipment and Physical Infrastructure

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Abstract In the planning of medical imaging services, it is important to consider the minimum requirements of equipment and facilities. In this chapter, ultrasound and X-ray units considered appropriate for rural health centers are considered in terms of image quality, cost and tele-imaging capabilities. Equipment procurement issues such as acquisition schemes, development/review of technical specifications, warranties, and obsolescence issues are discussed. The need for the availability of operation and service manuals as well as replacement parts, accessories and software upgrades throughout the life of the machine is emphasized. Guidance is given on the actual process of acquiring a unit and the site preparations involved, including the various permits needed. Examples of ultrasound equipment for low resource settings and the possibility of having ultrasound probes connected to a personal computer are explored. WHO's efforts in promoting the development of a versatile, high quality, low maintenance and inexpensive X-ray unit are reviewed.

Keywords Equipment procurement · Ultrasound units · X-Ray units · Radiation shielding

5.1 Equipment Procurement and Acquisition

5.1.1 Planning of Medical Imaging Services

Health care centers should be organized based on their technological complexity and should be incorporated within the general organization of health services depending on their stratification by levels of care. The criteria for the geographical

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and institutional placement of imaging services should be determined within each health services system in accordance with its parameters of accessibility and its definitions of levels of care. Prior to planning any service, it is essential to do a thorough analysis of morbidity and mortality in the community and to assess what impact the services may have in the overall patient management [1, 2]. The need for the services to be part of a patient-centered integrated health care system is further addressed in Chap. 9. There are three main considerations when establishing medical imaging services: equipment, facilities and staff. This chapter deals with equipment and facilities; Chap. 6 will discuss staff issues.

5.1.2 Equipment Procurement

5.1.2.1 Acquisition Schemes

Ideally, equipment should be acquired new. However, resource-limited countries should be discouraged to acquire prototype medical devices, which have not have been fully tested clinically and have not been approved either by the US Food and Drug Administration, carry the CE mark or been authorized for use by the country's own National Authority, if there is one.

One possibility is not buying but leasing the equipment. This option can be attractive when compared to the high capital cost of some items, and it gives the vendor an incentive to keep equipment operational [3].

Another acquisition possibility is what is called the "turn-key" solution, when the whole service is acquired "ready-to-use" and it even includes the staff. However, this option can be very complex, as it still requires "careful contract planning, progress monitoring and acceptance checks" [3], and unless some local personnel is hired to work in the facility, there is no transfer of technology from the donor to the recipient.

An easier possibility is to acquire used equipment. This may have two advantages. One, clearly, is reduced cost, but another one, often overlooked, is the potential familiarity with the equipment that the physician or technician—who is going to be responsible for its clinical use—may have. This second factor may be very important, since it may guarantee a more effective and safe utilization of the equipment.

Second-hand equipment may be acquired through purchase or through donations. Guidelines referring to health care equipment donations have been addressed extensively by the World Health Organization (WHO) [4, 5], which states that because of economic constraints, in some countries, nearly 80 % of health-care equipment is donated or funded by international donors or foreign governments. Donors include corporations acting directly or through other organizations, individuals, nongovernmental organizations, and governments providing aid to other governments.

WHO's [4] four core principles underlying the guidelines are:

(a) A health care equipment donation should benefit the recipient to the maximum extent possible;
(b) A donation should be given with full respect for the wishes and authority of the recipient, and be supportive of existing government policies and administrative arrangements;
(c) There should be no double standards in quality: if the quality of an item is unacceptable in the donor country, it is also unacceptable as a donation;
(d) There should be effective communication between the donor and the recipient 'donations should be based on an expressed need and should not be sent unannounced'.

Part of this communication involves responsibilities of the recipient health facility before agreeing to accept a donation. For example [5],

- Check that the equipment conforms to national policy, and is suitable for the facility and staff.
- Confirm that the equipment only requires spare parts and consumables that can be afforded using available budgets.
- Check whether the equipment will come with its relevant accessories, consumables, manuals and some spare parts, so that it can function and be used.
- Confirm whether the donor will be responsible for covering the costs of transport, freight, insurance, import duties, customs clearance, and installation and commissioning costs, if applicable. If not, has money been put set aside for this?

Some of these issues are discussed in the following sections.

If the used equipment is not to be acquired through a donation but through a purchase, it may make a difference whether it is bought from a medical facility or from a commercial vendor, and in the latter case, whether the equipment has been refurbished, and what warranties are offered. WHO [5] suggests that "consulting and involving local vendors, where they exist, will help to establish beneficial relationships between the users and the vendors of equipment and can prove to be less expensive than donations". Regardless, when acquiring second-hand equipment, previous service records should be obtained and the availability of replacement parts, assessed. Issues specifically regarding refurbished and/or second hand equipment were discussed by Borrás [6].

5.1.2.2 Development/Review of Technical Specifications

Equipment should comply with the original manufacturer's specifications, whether acquired new or used. For second-hand equipment, proof of compliance should be obtained before the equipment is acquired. If an original feature is no longer functional, but the equipment could still be used, this should be clearly indicated in the documentation provided by the donor/seller. The impact on the rest of the equipment of bypassing a particular feature should be carefully considered. Let's assume a rural health center is considering purchasing/accepting a conventional radiographic unit, where the automatic collimation (positive beam limitation) is no

longer functional, but where the collimator scale indication, the light field and the radiation field sizes coincide with each other within acceptable tolerances. The unit may be acquired. On the other hand, if the temperature display in an automatic film processor is no longer operational—the right temperature is critical for image quality purposes—the unit should not be acquired, as immersing a thermometer in the developer tank to read the temperature is cumbersome.

The main problems with older equipment are usually not caused by electrical components which can be easily replaced, but by mechanical parts. There is something called "material's fatigue" which will eventually make the equipment operate outside tolerance. A typical example is the motion of the collimators of an X-ray unit, which may get stuck or may open asymmetrically.

5.1.2.3 Warranties and Obsolescence

New equipment always comes with warranties, but refurbished equipment can be sold also with warranties, usually for one year of operation. Whenever possible, such a warranty should be obtained. It is important to establish exactly whether it includes parts (X-ray tubes are very costly for example) and when actually the warranty starts. Ideally, it should start after acceptance testing. Criteria for good refurbishment practices have been published [7].

Even if the equipment is in good operating condition, and even if it meets the manufacturer's specifications, its acquisition may be not be warranted if the equipment is obsolete. The concept of obsolescence needs to be understood clearly. Because a piece of equipment was manufactured long time ago, it does not have to be obsolete. The equipment may be obsolete if it has been replaced by a different type which allows to reach the diagnosis of some health condition with significantly greater accuracy. This is particularly true for ultrasound units, which have improved tremendously over the years.

Because obsolescence should be decided on a clinical basis, it may not be understood by the health authorities, which—on the basis of reduced cost—may accept purchasing or receiving equipment that is functional but obsolete, with its potential detrimental effects on the health care system. Worse, such an acquisition may delay the purchase of a better unit.

5.1.2.4 Operation and Service Manuals

No piece of equipment should be acquired without operation and service manuals. These should available, as required by the International Basic Safety Standards [8], in "appropriate language understandable to users". This may be difficult if the language of the original owner of the equipment was different from that of the intended recipient and the equipment is no longer being manufactured. The possibility of having the manuals translated should be explored and such a cost,

budgeted. If it is a donation, the donor may be asked to include the translation cost as part of the donation.

5.1.2.5 Accessories and Replacement Parts

Some equipment cannot function without accessories. When acquiring second-hand equipment, it is important to assess whether the original accessories come with the main unit. It is also essential that replacement parts be available from the original manufacturer or a reputable distributor for the length of the intended use of the equipment. WHO recommends that manufacturer's support—including spare parts and accessories—be available for a minimum of two years and preferably four [4].

The recipient institution should investigate from the original manufacturer their intended time length to support the equipment and whether local distributors and/or third party maintenance organizations have spare parts and accessories in stock, for how long and at what cost. Ideally a donated medical imaging equipment should come with a maintenance contract, preferably for 10 years. WHO suggests that the donation of a used X-ray system includes a new X-ray tube to ensure availability of a working replacement [5].

5.1.2.6 Software Upgrades

Nowadays software is as important as hardware. Equipment which uses some kind of software, especially if it is no longer manufactured, may have old software versions which may be out of date, or if nothing else, awkward to use. Computer programs have changed dramatically in the last years and their use is now easier than before. From a safety point of view, software should be "user-friendly" and their use, straightforward. Before acquiring any equipment, the availability of software upgrades should be explored from the original manufacturer and budgeted.

5.1.3 Equipment Acquisition Process

5.1.3.1 Obtaining Authorization from the Regulatory Authorities

The acquisition of medical imaging equipment needs to comply with national regulations. If the equipment emits ionizing radiation emitting, it should comply with radiation safety standards. Facilities of countries with radiation protection legislation/regulations need to seek approval of the Regulatory Authority before acquiring the equipment. The authorization process may require registering the equipment or licensing the installation [8]. Most manufacturers including refurbishing companies will not sell any piece of equipment to a foreign country until such documentation is produced. Regulatory authorities may require compliance

with safety standards for the equipment per se, the building which is to house it and in regards to the radiation protection, a list with the qualifications of the personnel who is to operate it. Requirements may be more stringent if the facility plans to introduce new radiological practices, in which case it may also need clearance from other governmental entities such as the Ministry of Health which regulates medical practices.

In facilities of countries that do not have any radiation safety legislation, the facility manager has to assume the responsibility to ensure that the equipment and its use comply with international safety standards such as those of Ref. [8]. The compliance should be documented in writing and made available to the staff and to the patients and public if so required.

5.1.3.2 Clearing Customs

If the equipment comes from a foreign country, importation permits are required and may have to comply with regulations other than radiation safety regulations. The facility manager should make sure of custom clearing processes well before the equipment arrives and have all the required documents ready.

5.1.3.3 Site Preparation

It is very important that there be good coordination between equipment acquisition and site preparation. The facility manager should ensure all the arrangements have been made so that the room in which the equipment is to be housed is ready before its arrival, so that its installation can proceed smoothly. Too often in developing countries one sees expensive X-ray units in the middle of hospital gardens waiting for the facility to complete construction. In the case of ceiling-mount units, it is important to consider the minimum ceiling height and the load bearing requirements for the ceiling [5].

5.1.3.4 Equipment Installation

Ultrasound units, even fixed ones, may be easy to move into their intended location within the health center, but the installation of X-ray machines may require cranes or other heavy machinery. The availability of all installation tools must be assured in advance of equipment arrival. Contractors and local staff must be properly protected and monitored if they can be exposed to ionizing radiation during their work. Accessories and supplies should be available at the time of installation to ensure that they are compatible and that the equipment can be operated in a safe manner.

5.1.4 Evaluation of Costs

The costs involved in the provision of radiological services have a significant impact on the type of medical imaging modality the health center plans to offer. Special attention should be given to the replacement of technologies, for example the change from conventional to digital radiography. When evaluating costs, it is insufficient to just consider the price of the equipment; it is necessary to assess the cost of the whole medical imaging service and the time it will take the facility to amortize the expenses. The costs can be categorized as capital costs, installation costs, siting costs, operational costs and humanpower costs.

5.1.4.1 Capital Costs

Capital cost is the price of acquiring the unit. WHO [4] cautions regarding new vs used equipment options. It states that:

> "Hospitals are typically paid 10 to 15 % of the original price for their used equipment by brokers and dealers. After the equipment is refurbished, it is typically sold for 45 to 60 % of its original cost. But new equipment can usually be purchased at discounts ranging from 95 % to 80 % of the list price. This means that buying equipment that is 5 to 15 years old and increasingly difficult to support usually costs one-third to two-thirds the cost of new equipment. In addition payment for used equipment usually becomes due in a lump sum on delivery, while leasing, rental, re-agent contracts, and other financial mechanisms for new equipment may often prove wiser than the purchase of used equipment. And new equipment often has safety and performance advantages, as well as better availability of spare parts and training".

In this chapter, Sect. 5.2 discusses specific issues related to ultrasound and X-ray units specifically designed for resource-limited health centers and the potential impact of cost on image quality.

5.1.4.2 Installation and Siting Costs

Installation costs include all room modifications and equipment transportation. If the equipment comes from a clinical facility rather than from a refurbishing firm, there may also be costs involving the dismantling and packing of the equipment in the original site. The costs of transportation from there to the facility also need to be considered. Custom fees, when applicable, can also enter in this category. To contract a company that will take care of all the steps involved may be the best solution.

5.1.4.3 Operational Costs

Operational costs include registration and license fees, which normally are required on a periodic basis, as well as utility consumption such as electricity and water,

phone lines and internet connections. Supplies and consumables are also part of the operational costs. When considering acquiring second-hand equipment, the provision of consumables should be carefully budgeted. All too often, donated radiographic units lie idle because the recipient facility does not have money to buy X-ray film.

5.1.4.4 Humanpower Costs

Humanpower costs are incurred at all stages of the acquisition process, from the time the facility decides to acquire the unit until it is placed in clinical use, when the equipment is in operation, and when it needs to be discarded. It is essential that before the acquisition decision is taken, the facility management is sure that there is or will be adequate personnel for its operation and maintenance.

5.1.4.5 Hidden Costs

The health center should be aware that there are many hidden costs in the operation of a medical imaging practice. These are not only indirect costs such as facility and equipment depreciation, but unexpected fees arising from legal, accounting, clinical, architectural, engineering and medical physics consultations.

5.1.4.6 Sustainability Considerations

Prior to equipment acquisition, facilities should ensure through appropriate budgeting that there is adequate and properly trained staff for its operation and that the equipment can be maintained during its projected life time. If the equipment is second-hand, it may require more corrective maintenance than a new equipment and thus the maintenance budget should be increased. Discarding the equipment at the end of its life cycle should also be contemplated and disposal costs, budgeted. A significant consideration in the planning process is to estimate the future procurement needs and to include in the budget the replacement cost of the equipment. For this, it is essential to estimate the useful life of each piece of equipment. "Planned replacement of equipment helps to safeguard patient safety, ensure quality of results and reduce the cost of repairing old equipment that is no longer supported" [3].

Additional relevant issues to procurement of medical devices can be found in WHO's publication "Procurement process resource guide" [3].

5.2 Capital Costs Versus Quality of Medical Imaging Equipment in Low-Resource Settings

5.2.1 Ultrasound Equipment

High quality standard ultrasound scanners are very expensive, upwards from $50,000. Even refurbished units would be in the price range of $20,000. In the future, most of the low resource countries will need tens of thousands of remote centers in the rural areas to cover all of their population. For example, Bangladesh [9] with a population of about 160 million has around 450 semi-rural hospitals with an average of 50 beds each and all of these are equipped with X-ray and ultrasound equipment together with pathological facilities. This is beyond the district level hospitals and tertiary care hospitals in the towns and cities which together number around 80. At the bottom of the ladder, there are about 12,000 community clinics having rudimentary facilities taking care of an average of 6000 people each. It is estimated that more than 18,000 such clinics will be needed to cover the entire rural population. Ideally all the 18,000 community clinics would be target stations for telemedicine, and this shows the huge costs involved in equipment terms. Therefore, even if the quality is not as high as that of the machines operating in advanced hospitals, one needs to go for a minimum cost for any equipment including tele-ultrasound, discussed in Chap. 7. However, the equipment should have adequate quality to give a doctor enough details for primary diagnosis of common disorders and for pregnancy, at least for screening purposes.

Figure 5.1 shows an ultrasound unit from a well known manufacturer priced over $20,000 for refurbished units (all costs are 2015 values). Even some claimed

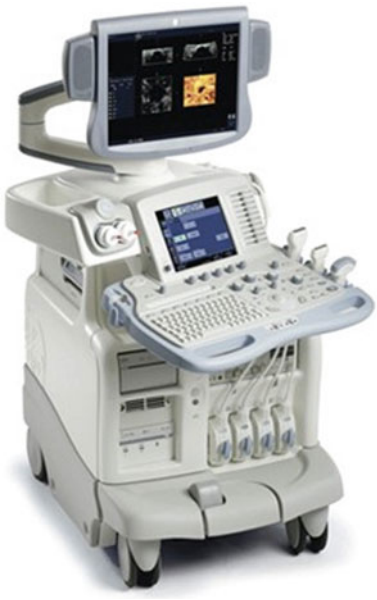

Fig. 5.1 GE Logiq 9 ultrasound equipment, general purpose [10]

'low cost' units developed by certain research groups in the industrially developed countries, aiming at the low resource countries, are not low enough. Some of them are priced at about $10,000, which is still very high. Some portable PC units are available from Chinese manufacturers costing about $1200–$2500. The price is still high, but so far, these are the lowest commercial devices available. Figure 5.2 shows a wireless probe that may be useful as it connects directly to a tablet PC or a smartphone which have the required software. The quality of the images is not as high as that of the high priced units, but for many primary diagnoses this may be adequate.

A recent (2015) innovation from Newcastle University of UK gives a very attractive proposition. It has developed a simple ultrasound probe that would cost around $50 and would require software to go into any PC. Produced in volumes, it offers a great potential in obtaining a low cost ultrasound equipment. Figure 5.3

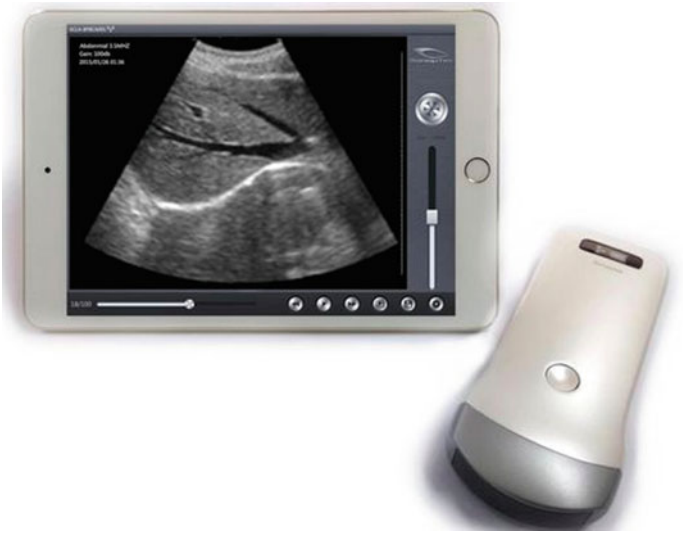

Fig. 5.2 Hand held wireless probe—connects to a tablet PC or a Smartphone with software [11]

Fig. 5.3 The $50 ultrasound probe developed by Newcastle University, UK [12]

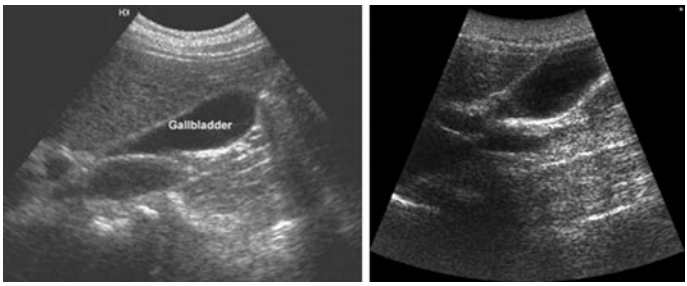

Fig. 5.4 Image of a Gall bladder from a high-end scanner (*left*) and that using the low cost probe (*right*) [12]

shows a picture of the probe and Fig. 5.4 shows an example of a gall stone image, compared with the same image using a high end machine. The main approach taken for this astounding cost reduction is in the choice of the transducer and in the minimization of the hardware external to a PC. It has opted for a single fixed focus ultrasound transducer that rocks within a certain angular aperture, replacing the expensive multiarray ones used in the current commercial models. All the signal processing is done in the PC, using software. This gives a low speed, giving about 4 frames per second, and therefore would not be suitable for heart scanning. However, for most other applications including obstetrics, gynecology and abdominal scanning, this may be adequate.

5.2.2 The World Health Imaging System—Radiography

During the period 1975–1985, the Pan American Health Organization (PAHO) and WHO focused their efforts on the development of what they denominated the Basic Radiological System (BRS) in a concerted effort to provide developing countries with the much needed access to diagnostic imaging services [13]. The BRS consisted of a high frequency multipulse X-ray generator—a great novelty at the time—an X-ray tube with fixed aperture collimators that matched typical X-ray film sizes and a bucky with an antiscatter grid, rigidly joined to the X-ray tube in a U shape stand to ensure X-ray beam alignment. The source-detector distance was fixed at 1.4 m and a movable patient table, which could be substituted with a patient trolley, was part of the system. Aware of the electrical power limitations in most of the resource-limited regions for which the machine was developed, the generator consisted of battery-charged electrical storage units, capable of operating even if there was no power at the time of needing to take the radiograph. A critical requirement was that the unit could be easy to operate and to maintain.

To facilitate the work of obtaining, processing and interpreting the radiographs with such a system, WHO produced—in several languages—three training manuals: the Manual on Radiographic Interpretation for General Practitioners [14] the

Manual on Radiographic Technique [15] and the Manual on Dark-Room Techniques [16]. In addition, the manufacturer was expected to prepare and deliver with every machine a manual on maintenance and identification of failures. Trial tests were conducted in the America's Region, since PAHO had been the promoter of such a system, with very good results [13].

In 1993, WHO convened a consultation meeting at the University of Lund, Sweden, where it had a WHO Collaborating Center for General and Radiological Education which had served as the focal point for the development of the WHO-BRS since 1980. At the meeting, attended by radiologists, radiological technologists, radiological physicists and engineers, and representatives of the industry, enhanced specifications—based on actual field experiences in the use of the units—were proposed, mainly adding light field indication. The system was renamed *The World Health Imaging System—Radiography* [17], name that it has been retained until today. A typical system is shown in Fig. 5.5.

In spite of the modifications, and even though the system is very easy to use, its adoption by health services has fallen short of expectations. In 1997 there were only 39 of these units in nine countries of the Americas [1]. And in 2002, Vanden Brinken estimated that since 1975 only 1200 WHIS-RAD units had been installed worldwide [18]. One of the main reasons for its lack of acceptability in developing countries is that the machine was neither FDA nor CE certified. Thus, it was seen as an "inferior" product. The high cost was also a major barrier.

Fig. 5.5 WHIS-RAD unit installed in a rural health center in Haiti, mid 1990s

In addition, some units had design flaws. In the mid 1990's Borrás evaluated the problems associated with the installation in Haiti of 10 WHIS-RAD units, manufactured by two different X-ray companies. In one brand, it was found out that the generator failed to comply with the ease of use and maintenance required by the unit design, and repairs were conducted. The manufacturer in question actually exchanged the X-ray generators for others of more robust design and modular access for ease of maintenance. Still, by 1997, none of the units were working. The other manufacturer's units fared a little better, mainly because of the efforts of a local X-ray company representing the manufacturer. The main problems stemmed from the technology design itself. The electrical supply units consist of batteries which—like car batteries—need to run to keep their charge. After a period of non-usage, the batteries become unchargeable. As Borrás reported "The problem that occurs most often is a blown fuse due to a power surge, so common in Haiti, which the poorly trained X-ray technicians do not know how to replace! As a result, the unit becomes inoperable, and after a certain time, the battery is discharged to a level that it can no longer be recharged!" [19].

Another problem common in all developing countries, is film processing [1]. So, as soon as computed radiography (CR) image receptors became available, efforts were made to use these detectors obviating the need for darkrooms and film processing. Rotary International facilitated and supported the deployment of WHIS-RAD/CR systems in Africa and Latin America. They even supported the publication of a 2011 on-line manual on diagnostic imaging for clinics and small hospitals in collaboration with PAHO [20]. This publication was followed with another one, "Radiation Shielding for Clinics and Small Hospitals with a WHIS-RAD 2013", also available on the PAHO website [21].

Work on upgrading the WHIS-RAD design continues at WHO headquarters in Geneva. They are promoting a project led by an alliance, GlobalDiagnostiX, that has developed the protype of an inexpensive digital radiography machine adapted to the context of developing countries "without compromising on performance and quality" and "compliant with applicable international standards and regulatory directives". The imaging system consists of a digital detector with a DICOM viewer that can be connected to a PACS system for teleradiology and telemaintenance access [22]. Compared to currently commercially available equipment, the prices of which are listed in Table 5.1, the product claims "to match the performance of standard digital X-ray machines on the market and is ten times less expensive than comparable designs when factoring in related equipment maintenance costs". (The 2014 target was $50,000 including 10 years of maintenance.) Furthermore, part of the project includes training tutorials [22].

Table 5.1 Imaging equipment prices (USD)—2015

General purpose X-ray unit (non-digital)	Basic system 100–150 k
General purpose X-ray unit—CR	Add 40–75 k to above
General purpose X-ray unit—DR	Add 60–110 k to the basic system
Ultrasound unit—fixed	80–115 k
Ultrasound unit—portable	30–60 k

The latter is essential, especially in rural health centers where any imaging workstation will be challenged by the limited knowledge of the X-ray operators and by adverse environmental conditions such as unreliable power supply, extreme temperatures and high humidity. No matter how well designed the integrated system might be, no radiography system in the world will perform adequately, unless the X-ray technician fully understands the operation of the X-ray unit and the workstation; knows how to position the patient; what image acquisition parameters to select, and how to produce, store and transfer the diagnostic images. In addition he/she should be capable of diagnosing functioning issues and perform simple maintenance tasks. The key for the success of any X-ray system, including the WHIS-RAD, is operator training.

5.3 Building Space Requirements

Once it has been decided where the health center is to be located, what services is to provide and what equipment is to be installed, consideration should be given for what kind of facility is to be built, the construction materials and its size. The types of medical imaging services to be provided at a rural health center may be limited to ultrasound and diagnostic radiology. They should both be located on the ground floor of the building, near the Emergency Room, if there is one, accessible to casualty patients that may come by ambulance or by car. Adequate means of access into the room and to the patient couch should be provided. It should be possible to maneuver a patient trolley through the imaging room door to a position beside the patient examination table.

Ultrasound equipment may not need a dedicated room—an examination room may be adequate, but such a room should have a clearly labeled area where image accessories, such as probes, and consumables such as gel and print paper, are stored and, thus, can be easily found. On the other hand, X-ray services will need at least two rooms: one for the study to be performed, and another one for image processing. A third room for viewing and interpretation is desirable. If the facility is to use film/screens as image receptors, such a viewing area will have the viewboxes for film display and image interpretation. To process the films, a darkroom will be needed. If the volume of films is low or the processor is only used for a few days per week, manual processing may be preferable. Otherwise an automatic film processor is desirable. Darkrooms should be adequately illuminated using a color filter that should be compatible with the film/screen spectral response and must be installed with air ducts that permit ventilation to the outside to prevent the toxicity of the processing chemicals to affect health center workers. The dimension of the darkroom should be such that it allows to store small amounts of film in open packages; larger number of film packages should be stored in a dedicated storage area with humidity between 40 and 60 % and low temperature. Film should not be stored in areas where it may be exposed to ionizing radiation or chemical fumes. Additional considerations regarding the darkroom can be found in Chap. 4, Sect. 4.2.

Both the X-ray room and the dark room may need additional structural shielding to attenuate the radiation both for radiation safety purposes and to prevent film fogging. If the patient radiological workload is low, the conventional building materials used in ceilings, floors and walls may provide adequate shielding against both the primary X-ray beam and stray radiation. When existing structural material does not provide adequate protection, additional shielding will be required. This can be accomplished by using greater thickness of the building material or by adding lead to the walls, floor and ceiling of the existing facility. The shielding thickness and lead equivalence depends on patient workload, X-ray techniques used for patient examinations, room dimensions and occupancy factors. Particular attention must be given to the position of the X-ray technologist, who must stand behind a protective barrier from where he/she can energize the X-ray tube and at the same time observe the patient to be radiographed. Radiation shielding designs require calculations by radiation experts, usually medical physicists. Typical shielding design calculations are available from the literature [21, 23]. The adequacy of the shielding—taking into account patient, staff and public dose constraints—should be tested ideally during construction, or, at least, before the X-ray unit is put in clinical use, preferably by a medical physicist or by a radiation protection specialist.

If the image receptors are digital, there is no need to have a darkroom; the images may be processed at the image acquisition workstation which can be located within the control area of the X-ray room behind a protective barrier or just outside it. The latter requires a leaded window for patient observation. Although the acquisition workstation has software for image display that would allow the physician to interpret the images right there, the process is inconvenient, since it interferes with further examinations. It is best to have another workstation, the interpretation workstation, located in a viewing area for the physician to evaluate the images. The size of the rooms depends on patient workload and available resources; Hanson estimates that a 16 m^2 room is adequate to house a WHIS-RAD unit. A simple layout, adapted from Hanson's publication [21] is shown in Fig. 5.6.

In all cases, the facility needs to comply with local building codes regarding space, accessibility, floor loading capacity, electrical power (voltage, frequency, phase and heat dissipation), water volume, pressure and drainage, etc. Floor loading capacity may be a critical issue if an X-ray machine is to be installed in an already existing rural health center designed without structural shielding present. In that case the addition of such shielding in walls, windows and perhaps even ceilings and floors, may be more costly as the room dimensions are already fixed. The placement of the X-ray machine in an existing room within the health center will have to be optimized to take advantage of space and X-ray tube orientation. For example chest X-ray projections, which need the X-ray beam to be horizontal, may be aimed at an exterior wall, where instead of adding lead, one could plant thick shrubs that will impede human and/or animal access. The problem with these "cheap" solutions is that unless the facility has the radiation considerations properly documented, with time, the facility may build an adjacent room in that location and by then the fact that the wall is unshielded may no longer be remembered. In the long run, it may be better to put shielding everywhere to take into account future expansions.

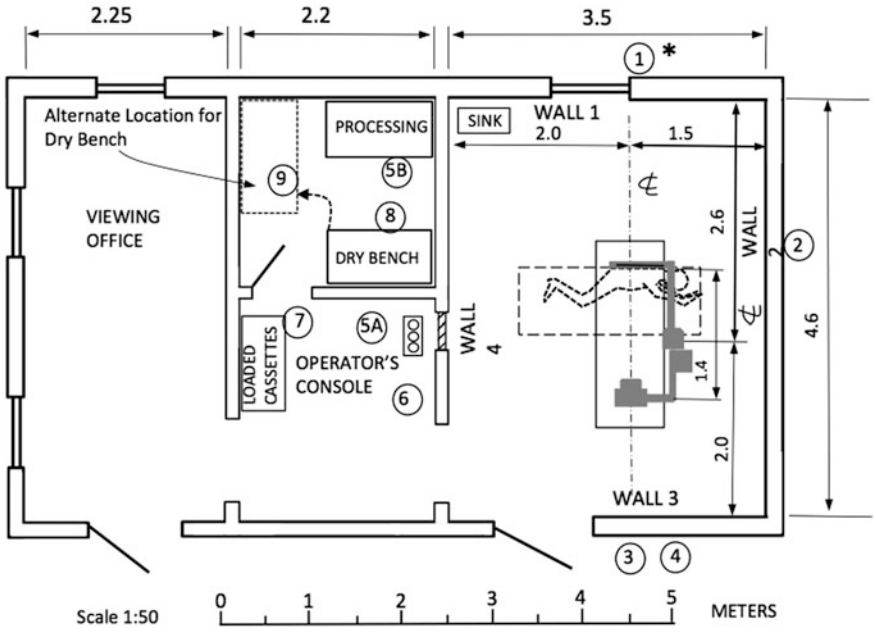

Fig. 5.6 Simple layout for an X-ray installation in a rural health center. Adapted from [21]

In addition to shielding and ergonomics considerations, additional space may be needed depending on specific equipment needs. For example, most types of medical imaging equipment can only function well with a stable power supply. The need to purchase additional generators and/or UPS units should be addressed and budgeted. The location of these generators within the building is a consideration to be done at the planning stage. Another problem is the need of many units to have air-conditioning.

The biggest problem, however, especially in tropical countries, is the humidity. This will affect ultrasound units and X-ray machines. Electrical equipment just does not work well without proper humidity control. The requirements for both temperature and humidity should be known before the equipment is acquired. Room modifications should be implemented and plans for daily monitoring of the temperature and the humidity should be established before the equipment is put in clinical use.

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